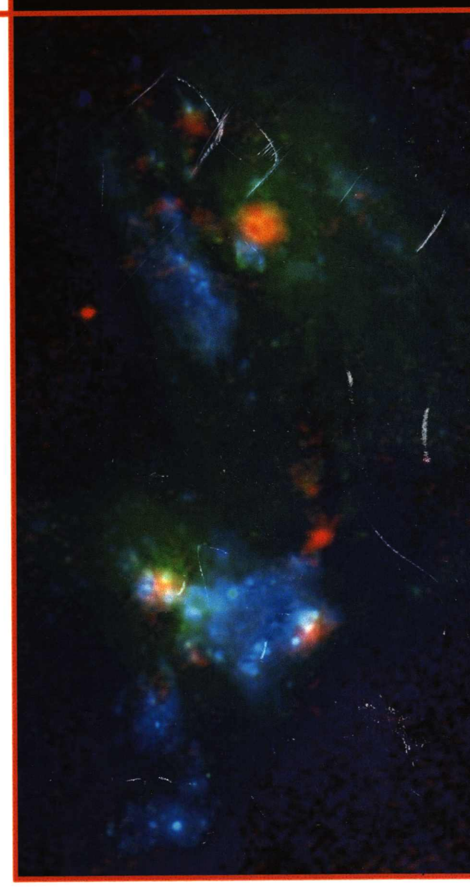
Program Plan

Fiscal Year - 2004

National Radio Astronomy Observatory



NATIONAL RADIO ASTRONOMY OBSERVATORY

Preliminary Program Plan
FY2004

October 2003

Revised 11/10/2003

The National Radio Astronomy Observatory is a facility of the National Science Foundation operated by Associated Universities, Inc.

Table of Contents

Table of Contents

I. Mission Statement

The mission of the National Radio Astronomy Observatory (NRAO) is to design, build, and operate large radio telescope facilities for use by the scientific community; to develop the electronics, software, and other technology systems that enable new astronomical science; to support the reduction, analysis, and dissemination of the results of observations made by the telescope users; to support the development of a society that is both scientifically and technically literate through educational programs and public outreach; and to support a program of staff scientific research that enables leadership and quality in all these areas.

II. Introduction

In 2004, the National Radio Astronomy Observatory (NRAO) will continue to provide users with outstanding radio astronomical facilities for scientific discovery, via the unique unblocked aperture 100 m telescope – the Robert C. Byrd Green Bank Telescope (GBT), the most powerful, versatile and productive radio telescope array – the Very Large Array (VLA), and the dedicated astronomical facility with submilliarcsecond imaging capability – the Very Long Baseline Array (VLBA). At the same time, the NRAO will continue to build the next generation facilities for future students and scholars, by implementing the first phase of the VLA Expansion Project and by executing the North American half of the ALMA project. To inform and enlighten the public, Education and Public Outreach (EPO) efforts will continue to increase the public awareness of the advances and excitement in radio astronomy enabled by the NRAO.

Specific initiatives in 2004 described in this Program Plan and supported by the Missions Requirement budget include the following:

New Capabilities for Scientific Discovery

- The GBT will achieve routine scientific operation at frequencies as high as 50 GHz. The 26-40 GHz receiver and the new continuum back-end will be completed. A simple but powerful user interface for observing setup will be completed to improve the ease of use of the complex GBT system.

- The VLA will be scheduled in a way that allows rapid response to time critical astronomical phenomena. In this era of multi-wavelength astronomical research, the demand on the powerful VLA for coordinated observations with new space missions is steadily increasing. The VLA will reserve some time in 2004 for a pilot program with the Chandra Observatory. Online access to the VLA archive will also be operational, which will facilitate and optimize the exploitation of past but valuable VLA data.

- To achieve better sensitivity and higher operational efficiency, the current VLBA tape-based recording and playback system will have to be replaced by hard-disk systems in the near future. To prepare for such a transition, upgrades will be made to the software and hardware of the VLBA correlator. Efforts to improve the high frequency performance of the VLBA antennas will continue.

Next Generation Observing Facilities

- The Expanded Very Large Array (EVLA) Project will complete the installation of the fiber optic cables along the arms of the array, finish testing of new electronics and monitor and control software on the EVLA test antenna, start the production of new electronics systems, start outfitting of new EVLA electronics on the VLA antennas, and construct a prototype subset of the EVLA correlator.

II. Introduction

In FY 2004, the major focus of the ALMA Project will be the completion of the prototype antenna evaluation and the procurement of 64 production antennas. The other key goals include the start of the construction of civil infrastructure at the Chilean site, the integration and testing of the electronics sub-systems, detailed designs of the front-ends, and planning for receiver integration.

The scientific programs conducted on NRAO instruments by visiting scientists, students, and NRAO staff is described in Section III. It presents the forefront astronomical research made possible by the facilities operated by the NRAO. It includes the discovery and mapping of new structure of the Galactic halo, mega-masers that are exceptional probes of AGN, new supernovae in distant starburst galaxies, molecular gas in high-z galaxies and quasars in the Epoch of Re-ionization; precise astrometric measurements of proper motions of pulsars and of Local Group galaxies; studies of micro-quasars and gamma-ray bursters, as well as objects of the solar system. More details of the research by the NRAO staff are given in Appendix A.

The FY 2004 initiatives for the GBT, VLA, VLBA, and EVLA are described in Section IV of this Program Plan. As described in Section V, the Central Development Laboratory (CDL) provides design and fabrication support for the electronics instrumentation on all the NRAO telescopes, including ALMA–this will soon be support for a total of 103 antennas! The new Division of Science and Academic Affairs (DSAA), formed in mid 2003 to provide a more coherent framework for the scientific and academic activities of the NRAO, is described in Section VI. Computing and Information Services (CIS), previously a part of Data Management, is described in Section VII. The mission of CIS is to provide for an optimum computing and network environment for the users of NRAO telescopes, for the operation of those instruments, and for the development of new facilities. The telescope-oriented tasks previously included in Data Management have been assigned to local site managers, and the Interferometry Software Division and Single Dish Software Division have been created. Education and Public Outreach plans for improving public awareness and understanding of astronomy and the NRAO are found in Section VIII. The ALMA Project is described in Section IX. To plan for the future, the NRAO efforts devoted to New Initiatives are described in Section X.

The NRAO Program Plan for FY2004 is based on the management of the Observatory according to a comprehensive Work Breakdown Structure (WBS) for every Observatory activity. Section XII shows the distribution of personnel and funding according to WBS activity. Management by the WBS allows the full scope of Observatory activities to be assessed, the costs to be properly established, and the interrelations between activities to be readily visualized. It also has the advantage of correctly presenting the Observatory organization as a single, centralized, management structure. Full implementation of this approach will continue in 2004.

Finally, a major goal for 2004 is the establishment of better communications with the astronomical community, increased involvement of the community in strategic planning, and increased support for university-based radio astronomy groups. Following the recommendation of the Astronomy and Astrophysics Survey Committee that recommends that awards of observing time be accompanied by funding grants, the NRAO is continuing such a program for all observing programs on the Green Bank Telescope that involve students. In addition, to attract the best young scientists to radio astronomy, the Jansky Fellowship will be made largely equivalent to other prestigious fellowships, with a few set aside for residence in university groups. Visitor programs to facilitate university faculty members to spend sabbaticals at the NRAO will be implemented.

The funding needed in FY 2004 to support the initiatives in FY2004 as outlined in the Program Plan constitute a funding level referred to as the "Mission Requirements" level. Unfortunately, the President's FY 2004 budget request for NRAO operations is $7.8M less than that required for the mission. Because the request budget is such a large departure from what is required for the NRAO mission, the text of this FY 2004 Program Plan is written to the Mission Requirements budget, and the ramifications of a reduction to the President's budget, should that be required, are summarized in Section XI. Both budgets are presented in Section XII.

As described here, the opportunity to realize the benefits of the investment made in planning, design, and program development at the NRAO over the past 5-10 years is achievable only at the Mission Requirements level; we eagerly anticipate the enhanced ability of the NRAO to serve its users and community that the successful execution of the Mission Requirements program will bring in FY2004.

III. Science Programs in FY 2004

Green Bank Telescope

The Robert C. Byrd Green Bank Telescope (GBT) began routine scientific operations in 2003. By midyear, more than 50 percent of the total telescope time was being scheduled for refereed scientific observations, and this percentage is expected to rise to 60-70 percent by the year's end. The astronomical community responded enthusiastically to the initial calls for proposals indicating their keen interest in the scientific capabilities of the GBT. Research programs in a variety of areas including spectroscopy, continuum imaging, pulsar physics, Very Long Baseline Interferometry (VLBI), and planetary radar studies are now in progress. An example of continuum imaging is given in Figure III.1, which shows the radio emission in the neighborhood of the ultracompact HII region W3, a location where massive stars are being formed.

The unique capabilities of the GBT include almost 8000 m^2 of fully steerable collecting area, a sky coverage of all declinations north of -46 degrees, an unblocked aperture for high fidelity imaging, the telescope's location in the National Radio Quiet Zone, and a precision structure that will ultimately allow observations over three decades of frequency from ~100 MHz to more than 100 GHz. Observations at frequencies up to 26.5 GHz are now routine and initial tests of the 40-50 GHz receiver were conducted successfully in spring 2003. Full telescope operation to 50 GHz is expected by the year's end. The following is a sample of the scientific programs and research areas that will occupy the GBT in 2004.

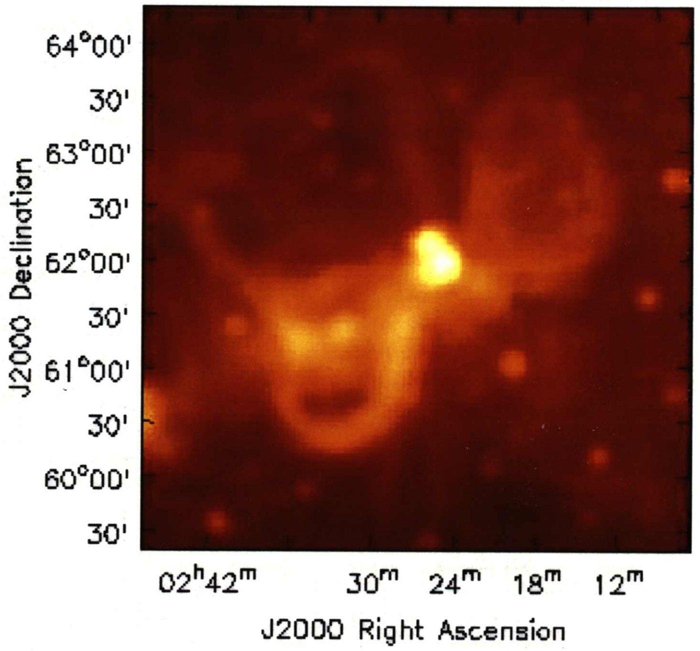


Figure III.1 1420 MHz continuum image of W3 (Minter 2003).

High Redshift Galaxies and the Early Universe

A number of galaxies at very high redshift have been detected in their dust continuum and CO line emission. The look-back time for some of these galaxies is as much as 90 percent of the age of the universe. Virtually all of the galaxies detected so far have had their emission amplified by intervening lensing galaxies along the line of sight. With the sensitivity of the GBT, many unlensed systems can be detected. This will allow a much more thorough study of the early universe. Observers will exploit the unique sensitivity of the GBT to study J=1-0 CO redshifted to K-band

III. Science Programs in FY 2004

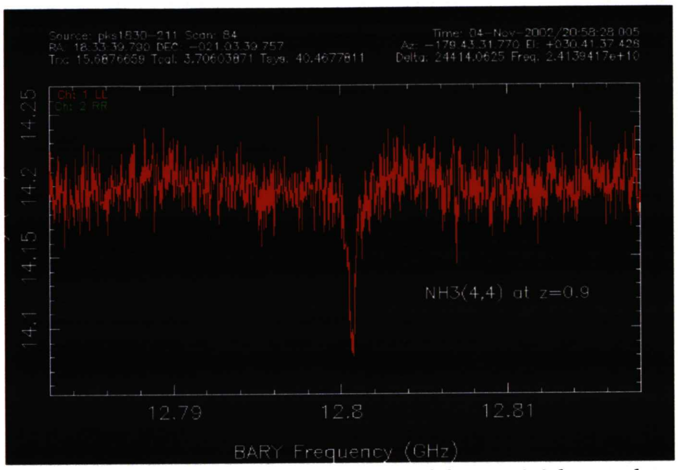


Figure III.2 Redshifted ammonia line of the z = 0.9 lens galaxy of PKS 1830-211 (Henkel & Braatz 2003).

(18-26 GHz), which corresponds to a redshift of ~4. In the coming year, the Q-band (40-50 GHz) receiver will be fully commissioned and in regular use, and the Ka-band (26-40 GHz) receiver will be completed. This will give the GBT sensitive redshift coverage to z > 10 in various CO transitions. The GBT will also be used to detect high redshift emission or absorption in other molecules of astrophysical interest. The ammonia molecule NH_3, for example, is a sensitive tracer of the density in molecular clouds and has been detected with the GBT at its largest redshift ever (see Figure III.2). The flexible frequency coverage and protected radio environment of Green Bank also allows the GBT to be used at lower frequencies to study highly redshifted HI lines and OH megamasers. Observations of this sort are often precluded at other sites by radio interference.

Cosmology

The high sensitivity, accurate absolute calibration, and low sidelobes of the GBT make it uniquely capable for studies of cosmology. The GBT will have excellent performance at 1 cm (30 GHz), a preferred window for studies of the cosmic background radiation. The Ka-band receiver and a complementary continuum back-end built by Caltech as part of the university-built instrumentation program will be completed in 2004. This receiver and back-end combination will have extraordinary sensitivity to point sources. It will be used to remove the point source contamination in fields measured by cosmic background survey instruments and thus significantly refine the cosmic background characterization. The system should also be a powerful tool to search for distant galaxy clusters by means of the Sunyaev-Zel'dovich (SZ) effect.

The GBT will also have unique capabilities in the 3 mm band, where wide field observations of the SZ effect will reveal concentrations of dark matter. The Penn Array Bolometer Camera, another university-built instrumentation project, will address this area of research among many others. It is scheduled for delivery in 2005.

III. Science Programs in FY 2004

HI Spectroscopy

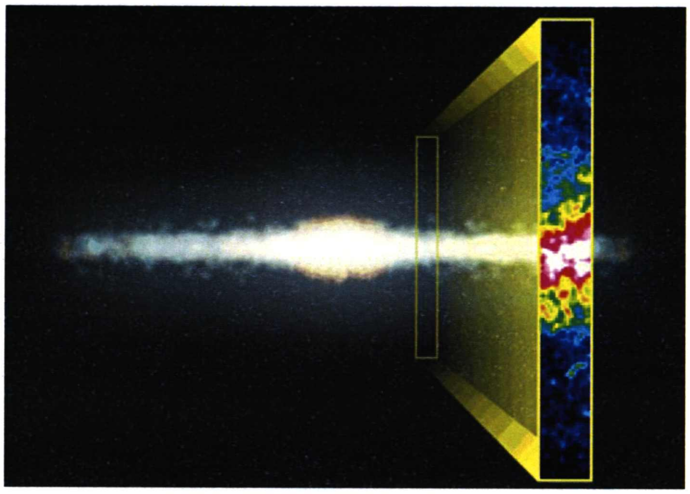


Figure III.3 Artists conception of the Galaxy and halo with actual GBT HI data in the inset (Lockman 2003).

The high fidelity and comparatively small beam size of the GBT are already leading to significant new discoveries in Galactic structure. For example, GBT observations of the Galactic HI halo in the inner Galaxy show that in many directions the halo consists of previously-unresolved clouds, some of which are found more than 1 kpc from the Galactic plane, co-rotating with the disk below (see Figure III.3). In previous, lower-resolution 21 cm observations the cloud ensemble appeared nearly continuous, suggesting, incorrectly, that the HI halo was diffuse.

Researchers have also used the GBT to determine that a well-known high-velocity cloud, Complex H, is clearly associated with the Galaxy, and is probably in retrograde motion about the Galaxy. The tidal stripping of material is evident, as shown in Figure III.4 below. Work on related Galactic HI imaging projects will continue in 2004.

Continuum Imaging

The high fidelity imaging capability of the GBT is also proving of great value in continuum observations. Faint, extended structures are often resolved by interferometers and obscured by the distorted beam response of conventional, blocked aperture telescopes. The high dynamic range of GBT data is illustrated in the image of the Rosette Nebula at 8 GHz (Figure III.5). For the first time, some of the faint, diffuse gas apparent in optical images of the nebula can be measured in the radio. Observers have also obtained images of the Galactic Center with unprecedented fidelity in several frequency bands. Continuum imaging projects to study supernovae and other radio sources will be carried out in 2004.

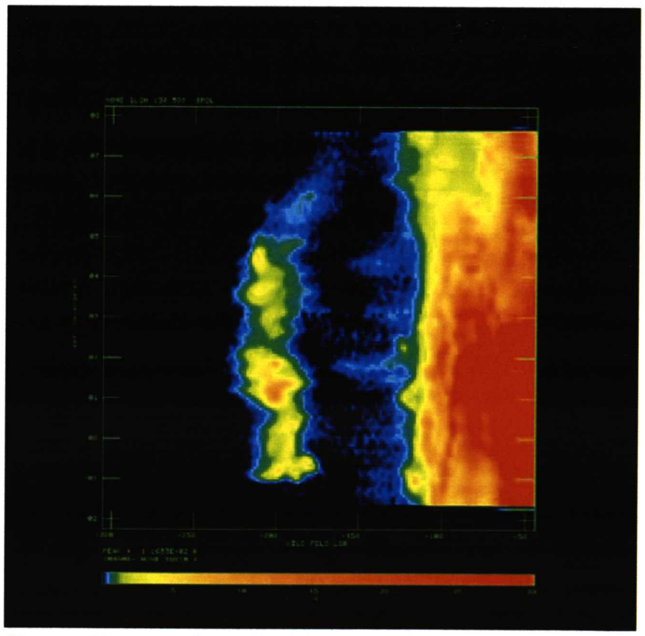


Figure III.4 HI latitude-velocity diagram of Complex H showing velocity streamers between the cloud and Galactic disk (Lockman 2003).

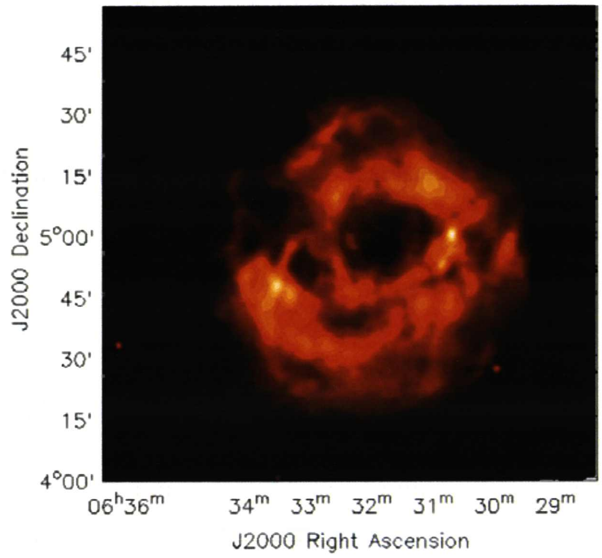


Figure III.5 (Left) 8 GHz continuum image of the Rosette Nebula (Ghigo & Maddalena 2002); (Right) Optical image of the Rosette (Seitzer). The low surface-brightness and large angular size of this nebula makes radio observations difficult, but as can be seen by the correspondence between the GBT radio image and the optical image, the diffuse radio flux has all been recovered.

Pulsars

From its first day of operation, the GBT has contributed important insights in the physics of pulsars. Significant results include the detection of new millisecond pulsars in globular clusters and the long-sought detection of the youngest-known (820 years old) radio pulsar, located in the SNR 3C 58 (Figure III.6). Discovery of this object more tightly constrains the variation of pulsar luminosity with age. In 2004, new pulsar capabilities will be available, including the pulsar "spigot" mode for the Spectrometer, developed in collaboration with a group from Caltech. This mode will take advantage of the 800 MHz bandwidth of the GBT for unprecedented sensitivity. Pulsar projects in 2004 will include searches in Crab-like supernova remnants and globular clusters, and studies of pulsars associated with gamma ray sources.

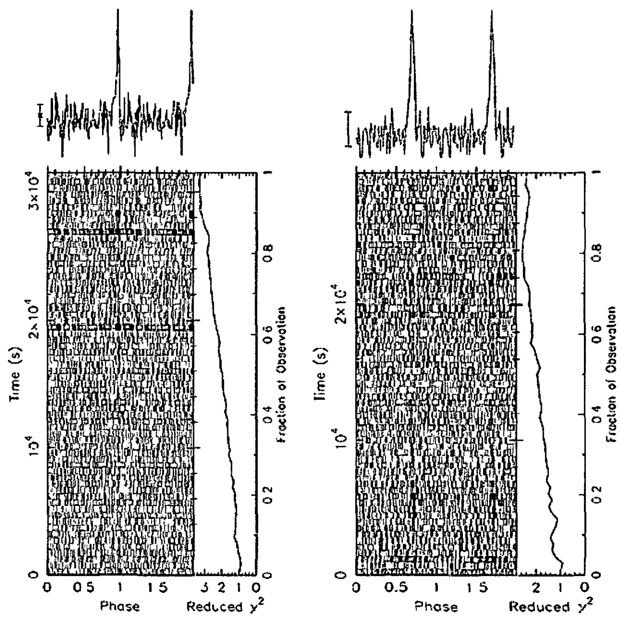


Figure III.6 GBT detection of the youngest known pulsar, the pulsar in the supernova remnant 3C58 from Camilo et al. (2002 ApJ 571: L41). Left: data at 1375 MHz. Right data at 820 MHz.

Planetary Radar

Planetary radar observations in collaboration with the transmitting facilities at Arecibo and Goldstone are a very active and productive area of scientific work. The GBT can receive radar transmitted from Arecibo and reflected off distant objects whose return echo is outside the Arecibo tracking range. The GBT can also receive echoes from nearby solar system objects for which the return is too fast for Arecibo to switch between transmit and receive modes. For Goldstone, the GBT can participate in X-band projects along a nearly East-West baseline which is ideal for many studies. Bi-static observations for increased angular resolution are possible with both facilities. Margot et al. have recently used the Goldstone antenna and the GBT to constrain the instantaneous spin rate and orientation of Mercury, which in turn can be used to constrain the size and state of that planet's core. Further observations of Mercury and other solar system objects are anticipated in 2004.

Astrochemistry

The capabilities of the GBT will make it a powerful instrument for studies of the chemistry in interstellar and circumstellar clouds. The GBT will be used in the search for and study of very heavy molecules such as those containing long carbon chains or those of biological interest, such as amino acids and sugars. The enormous sensitivity of the GBT provides an order of magnitude improvement over previous studies in detectability of simple amino acids and other molecules in the

40-50 GHz frequency range. A number of searches for molecules which are biological precursors and other complex molecules in the K-band (26-40 GHz) and Q-band (40-50GHz) ranges are planned for 2004.

Very Long Baseline Interferometry

Progress in many of the most interesting astrophysical areas, such as the study of the energetics of active galactic nuclei, requires observations with ultra-high angular resolution and very high sensitivity. The large effective collecting area of the GBT is of enormous benefit to Very Long Baseline Array (VLBA) studies of such objects. In particular, the GBT and the Very Large Array (VLA) form a very high sensitivity, east-west baseline for inclusion in the VLBA and global VLBI networks. Such projects have already led to significant results. For example, the GBT recently participated with the VLBA to detect the radio counterpart of the closest and brightest gamma-ray

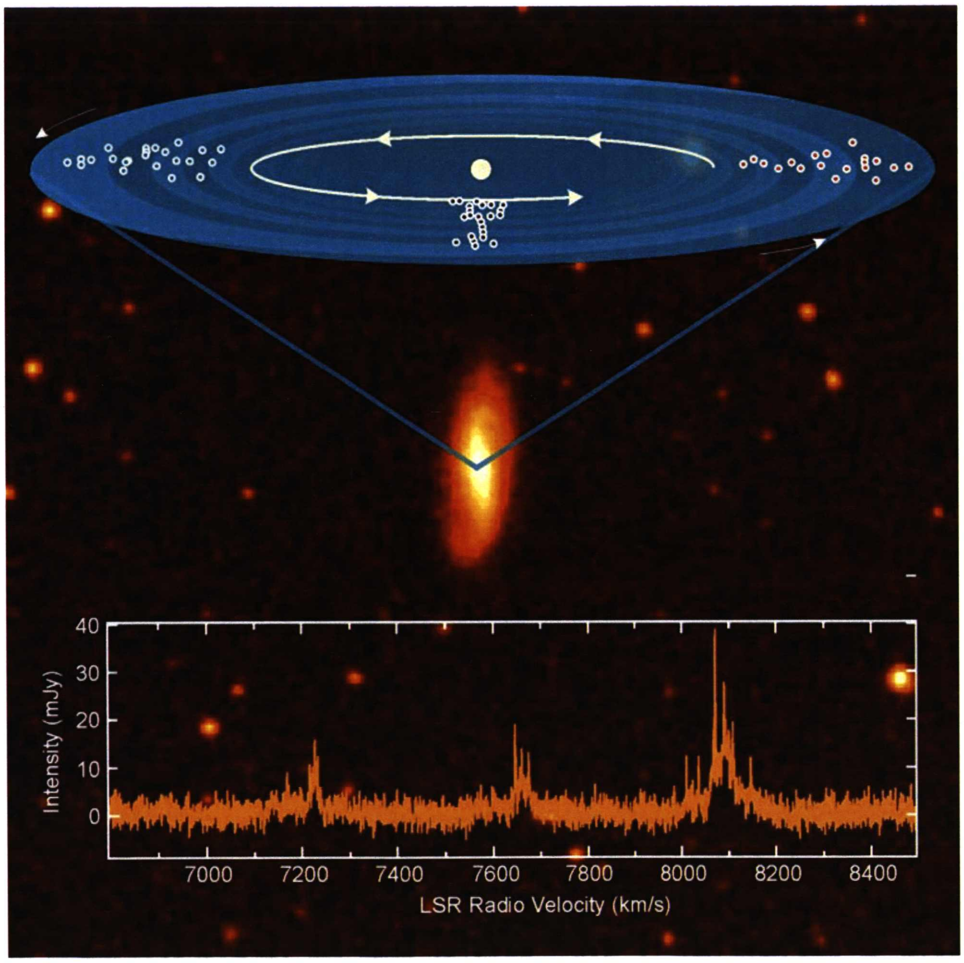


Figure III.7 Water maser emission was discovered toward the nucleus of the active galaxy NGC 6323, shown in this image from the Digital Sky Survey. The maser spectrum, shown in the bottom panel, consists of three distinct groups of narrow maser features. Each group of maser features is interpreted to arise from a well defined locus within a thin disk, as represented by the red, blue, and black spots in the artist's drawing. (Braatz et al. 2003) burst object. Because of the GBT, the observations had the sensitivity to provide constraints on physical models for these objects. VLBI observations are regularly scheduled on the GBT, which can participate seamlessly as an 11th element of the VLBA.

Water Masers in Active Galactic Nuclei

One of the most interesting results in all of radio astronomy in recent years has been the measurement of the water masers that are apparently in Keplerian rotation about a central black hole in the galaxy NGC 4258. Precise VLBI astrometry gives a simple and accurate trigonometric determination of the distance to this galaxy, which then fixes the cosmological distance scale. At present, detailed studies of the water masers in extragalactic sources can be carried out only for relatively nearby galaxies because of the faintness of the maser lines. The GBT, with its wide-band spectrometer and a sensitivity 10-100 times greater than anything available heretofore, provides a major advance in capabilities for this area of research. GBT observations by themselves can determine which maser systems are likely to originate in nuclear disks (Figure III.7). They can also limit the rotational velocity of the disk and, by measuring changes in spectra with time, yield a mass for the central black hole. VLBI arrays which include the GBT can then determine the exact angular size of the disk and hence its distance. The discovery and study of additional distant water masers like the one in NGC 4258 will allow for a direct and precise determination of the size and age of the universe. Further searches for extragalactic water masers are planned for the coming year.

Very Large Array

In 2003, the Very Large Array is completing long-awaited upgrades to its high-frequency receiving systems. Specifically, 43 GHz receivers have now been installed on all the antennas, and new, lower noise 22 GHz receivers on all except the first two Expanded Very Large Array (EVLA) prototype antennas. Together with the pointing, scheduling and efficiency improvements discussed later in this Program Plan, these new systems will make the VLA a much more powerful instrument for scientific programs which use the highest frequencies. The discussion below includes several programs that will make important use of the new systems in FY 2004.

Solar System

The proximity of Mars, which in August 2003 makes its closest approach to Earth in about 60,000 years, has excited worldwide interest. The VLA will be used to observe the 22 GHz water line in the Martian atmosphere in early FY 2004 with a nearly ideal combination of array configuration, planetary angular size, and likelihood of good weather. These observations will be used to make accurate measurements of pressure-broadened lines and retrieve the water vapor profiles along the Martian limb. At the same time, the Mars Global Surveyor spacecraft will be making in situ measurements that can be compared to the VLA results. All of these measurements will be used to improve modeling of the release of water vapor from the polar ice caps, which is of particular importance in Mars climate studies.

III. Science Programs in FY 2004

The Galactic Center, Pulsars, Novae, Supernovae, X-ray Binaries, and Other Radio Stars

The VLA has a long history of rapid response to newly-discovered supernovae and outbursts of X-ray binaries. The VLA has contributed multifrequency, long-term radio light curves of both types of objects, providing information vital to deciphering their physics. In addition, VLA observations have revealed the presence of expanding jets in X-ray binary star systems, many of which are thought to include black holes as their compact component. Weekly monitoring of transient sources in black-hole X-ray binaries will continue throughout FY 2004. If fluxes reach a given level, these observations will trigger a program to image the transient events using the VLBA. The data will constrain models for the correlation of X-ray with radio emission, though to be associated with events in which the inner accretion disk of the binary system is tidally disrupted and falls into the black hole. This is one of a number of synergistic research programs which involve both the VLA and the VLBA.

Several programs are under way to search for radio emission from so-called "Ultraluminous X-ray Sources" (ULXs). These objects, having X-ray luminosities well above 10^{39} ergs/s, are too luminous to be normal X-ray binaries with neutron-star constituents radiating at their Eddington limits. They are thought to be either beamed X-ray binaries or black holes containing hundreds of solar masses. Only one Ultraluminous X-ray Source has been identified clearly as a compact radio emitter outside a galaxy nucleus, and it will be monitored with new VLA observations to help determine its origin. Others will be observed on at least one occasion with the VLA, since the radio/X-ray ratio is an important characteristic that distinguishes among different models for the ULXs.

Long-term supernova-monitoring programs will continue on the VLA in FY 2004. Of particular interest is a program to search for radio emission from newly discovered Type Ib and Ic supernovae in relatively nearby galaxies. Recent evidence has shown that in some cases such supernovae may be found underlying gamma-ray burst sources. The details of the supernova explosions, and why such a wide variety of energy goes into the gamma-ray component, are still elusive. More such supernovae must be observed in order to perform the calorimetry of the explosions, and gather enough statistics to say how the gamma-ray fraction might be related to relativistic beaming.

The Interstellar Medium, Molecular Clouds, Cosmic Masers, Star Formation, and Stellar Evolution

A number of programs will be carried out to study the accretion processes around massive young stars. At 43 GHz, dust disks may be detected and even imaged using the VLA; so emission from both ionized accretion disks and dust disks is being sought. Dust emission has a spectrum which rises steeply with frequency and some programs will observe quasi-simultaneously at 22 and 43 GHz in order to separate the ionized component from the dust component. In addition, these high frequencies are important in the study of "ultracompact" and "hypercompact" HII regions, which may be gravitationally bound to the massive protostars and mediate their accretion flow.

III. Science Programs in FY 2004

The bulk of the known main sequence stars in our galaxy exists in binary or multiple systems, yet theories of how such systems form and evolve are poorly constrained by observations. The classical low-mass star-forming system, T Tauri, has been observed astrometrically with the VLA over a period of 20 years. The most recent observations appear to show an ejection of one component of a triple star system due to a close encounter with another component. This may be our first view of such a common, but short-lived event in the lifetime of a young stellar system. However, two groups have analyzed the same data and come to different conclusions, using different assumptions about the relative locations of radio and infrared sources. Over the next year or two, the VLA will continue to monitor the astrometric evolution of the T Tauri system, and will determine whether the star that may have been ejected continues to escape at a rate of tens of milliarcsecs per year, or has a motion that can be characterized by a closed orbit around the system center of mass.

A 300 MHz survey of a portion of the inner Galactic Plane is being carried out in multiple VLA configurations at longitudes between 5 and 19 degrees. This will be combined with a similar data set at 74 MHz in order to make spatially resolved studies of supernova remnants and HII regions. The survey will be used to constrain models of shock acceleration and to disentangle superpositions of thermal and nonthermal sources. Since the survey covers the last remaining region of the inner Galaxy not yet surveyed at sub-arcminute resolution, it is anticipated that many previously unknown sources will be found.

Normal and Starburst Galaxies

The VLA has a special category of "Large Proposals" which typically request several hundred hours of observing time. Anticipating the launch of the Space Infrared Telescope Facility (SIRTF) in August 2003, a number of these large proposals have focused on projects which may complement the SIRTF results. Two such large programs will be carried out in FY 2004 and beyond, using the neutral hydrogen (HI) line at 1420 MHz. In one program, the VLA C configuration will be used to image the HI in 28 spiral galaxies in the Virgo cluster at 15 arcsec resolution; combined with archival data, this will bring to 40 the number of galaxies observed in HI at such high resolution. The galaxies are located throughout the cluster volume and span a range in star-formation properties. The sample will be used to study in detail the physical mechanisms that may drive the evolution of galaxies in clusters at high redshifts. The second program will use multiple VLA configurations, focusing on the B configuration at 6 arcsec resolution, to investigate the HI structure of a sample of 39 galaxies all at distances of less than 10 Mpc. As in the Virgo survey, the galaxies span a range of properties and will be studied to find the importance of galaxy environment on the small-scale structure of their interstellar medium, their dark matter distribution, and the processes leading to star formation on 100 parsec scales.

A multi-configuration VLA study of the nearby spiral galaxy M51 will be combined with archival data to complete a large imaging data set on this galaxy. Combined with observations of its infrared emission to be taken as part of a SIRTF Legacy program, the radio imaging can be used to examine the radio-infrared correlation on relatively small scales. This relationship is used universally to compute star-formation rates in distant galaxies. In M51, the study will provide a test of whether the radio emission is a true indicator of the local star formation rate over the wide range of physical conditions found across the galaxy.

Radio Galaxies, Quasars, Active Galaxies, and Gamma-ray Bursts

Old and fossil radio galaxies will be the subjects of several investigations in FY 2004. Fossil radio galaxies have been selected based on their very steep broad-band radio spectra, which seem to indicate that they are dominated by old populations of electrons and are dying out as synchrotron radio emitters. Multi-configuration spectral-index images will be used to put limits on the presence of radio cores and jets, testing whether the active nuclei of the galaxies are completely inactive at present. An active core found in association with the fossil large-scale emission would indicate that these objects undergo multiple cycles of activity during which the extended lobes replenished by recurrent activity in the core. In a similar spirit, one of the largest radio galaxies in the universe will be studied at low frequencies to see if "relic" regions indicative of old sources can be found, and to determine whether energy transport from the nucleus is ongoing.

After many years of study, the nature of radio-quiet quasars, and how they differ from their radio-loud cousins, is still elusive. It is not clear why these objects have a much smaller fraction of their total luminosity in radio emission than normal quasars, but this may be related to a strong interaction between jets and the interstellar medium of the host galaxies as suggested by Hubble Space Telescope images of several radio-quiet quasars. With the VLA, several PG quasars will be imaged on kiloparsec scales in order to determine whether they contain extended emission indicative of interaction with the interstellar medium. This determination will indicate whether Seyfert galaxies and radio-quiet quasars can be encompassed in a single physical model which spans at least three orders of magnitude in luminosity.

One of the key activities of the VLA over the last few years has been the monitoring of gamma-ray bursts, providing important calorimetry of the energy in the bursts, and support for the relativistic fireball model of the emission. The VLA is uniquely suited for this work, because it can follow the afterglows for hundreds of days, monitoring key transitions from highly relativistic bulk motion to transversely expanding jets. NASA soon will launch the *Swift* satellite, probably delayed into the early part of calendar year 2004; *Swift* is expected to detect and localize as many as several hundred gamma-ray bursts per year. By mid-to-late FY 2004, we expect the satellite to be fully operational. The VLA should play a major role in the follow-up observations of the new gamma-ray bursts; currently we are exploring ways of participating in the large multi-wavelength campaigns in a way that provides the maximum scientific return to the large number of astronomers interested in the physics of gamma-ray bursts.

Cosmology, Large Scale Structure, Galaxy Formation, and Gravitational Lensing

One of the key results from the VLA over the last few years has been the detection of CO at fairly large distances, redshifted into the VLA observing bands. In FY 2003, the CO(3-2) emission line which has a rest frequency of 345 GHz, was detected in the highest redshift quasar, (J1148+5251 at

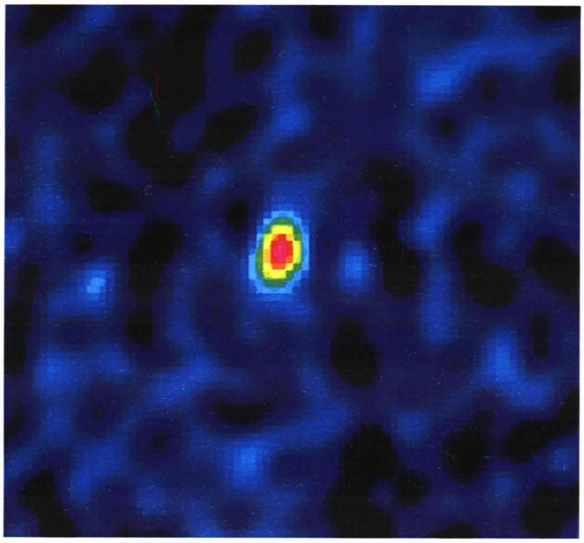


Figure III.8 Detection line of CO(3-2) emission at a rest frequency of 345 GHz in the highest redshift quasar, (J1148+5251 at z=6.42), redshifted to an observed frequency of 46 GHz.

z=6.42), redshifted to an observed frequency of 46 GHz. Figure III.8 is an image showing the detection of this line. Although the source is unresolved, it illustrates the remarkable result that massive stars had already been formed in this earliest quasar, and that star-formation was concurrent with the formation of the massive black hole that powers the quasar. In FY 2004, significant additional observations will be devoted to this source at higher resolution in an attempt to resolve the molecular gas disk of the underlying host galaxy on kiloparsec scales. Both spatial and spectroscopic resolution will be used to model dust heating by either the active galaxy or by star formation, and to obtain direct constraints on the dynamical mass of the earliest galaxies.

The program which has been allocated the largest amount of observing time for FY 2004 is a 74 MHz survey at a resolution of 80 arcsec of the entire sky visible from the VLA. This survey is expected to take several years to complete, with a few percent of the total VLA observing time allocated in FY 2004. The sky has never been surveyed at such a low frequency with the high sensitivity and resolution of the VLA, so the planned program is expected to produce a catalog of approximately 100,000 sources. Statistically useful samples of a variety of objects, including high-redshift radio galaxies and supernova remnants, will be assembled from the survey. It is possible that the 74 MHz survey will discover a sample of very high redshift radio galaxies, enabling observational constraints to be placed on hierarchical models for structure formation in the early universe. One of the key scientific goals of the proposed *LOFAR* telescope is the imaging of HI from before the epoch of reionization; that HI would be seen in absorption against high-redshift radio galaxies that might be bright at fairly low frequencies. The VLA 74 MHz survey will play a key role in determining whether radio galaxies exist beyond z=7, and whether the *LOFAR* science goal may be achievable.

Very Long Baseline Array

The VLBA is a valuable and popular instrument for a wide range of astrophysical inquiries. It can routinely produce images with an angular resolution of a milliarcsec: 10 to 100 times better than the Hubble Space Telescope. Newer capabilities such as pulsar gating and the growing suite of 86 GHz (3 mm) receivers are expanding the value of the VLBA as a scientific tool. An important capability of the VLBA is the ability to make repeated observations of the same objects over periods ranging from days to many years. This enables a wide variety of studies of evolution of different sorts of radio sources, ranging from galactic objects to very distant quasars. It is a key component of a number of long-term astrometric programs. Sub-milliarcsec astrometry with the VLBA, both relative and absolute, enables investigation of a number of fundamental questions in astrophysics, a few of which are described below.

The Galactic Center, Pulsars, Novae, X-ray Binaries, and Other Radio Stars

The resolving power of the VLBA enables observers to measure parallaxes and proper motions of strong pulsars. We now have approved a major expansion of a large program to measure velocities and distances of pulsars out to distances of several kiloparsecs. The VLBA is measuring pulsar distances factors of several larger than was possible previously, increasing the volume accessible by a factor of 30-50. In the early stages of this program, for example, a precise distance was determined for the pulsar PSR B0656+14. This pulsar lies near the center of the Monogem Ring, a circular supernova remnant straddling the constellations of Monoceros and Gemini. Measurement of the pulsar distance has resolved a long-standing controversy, placing it at the same distance as the supernova remnant, implying that the pulsar is the remnant of the exploding star that generated the remnant. This pulsar and the associated supernova remnant may well be the origin of an excess of cosmic rays found in the same direction. During FY 2004, approximately 30 different pulsars will be observed as part of the pulsar-parallax program, typically for several hours each at intervals of about three months.

High-precision VLBA astrometry, sometimes including the GBT, will be carried out on both

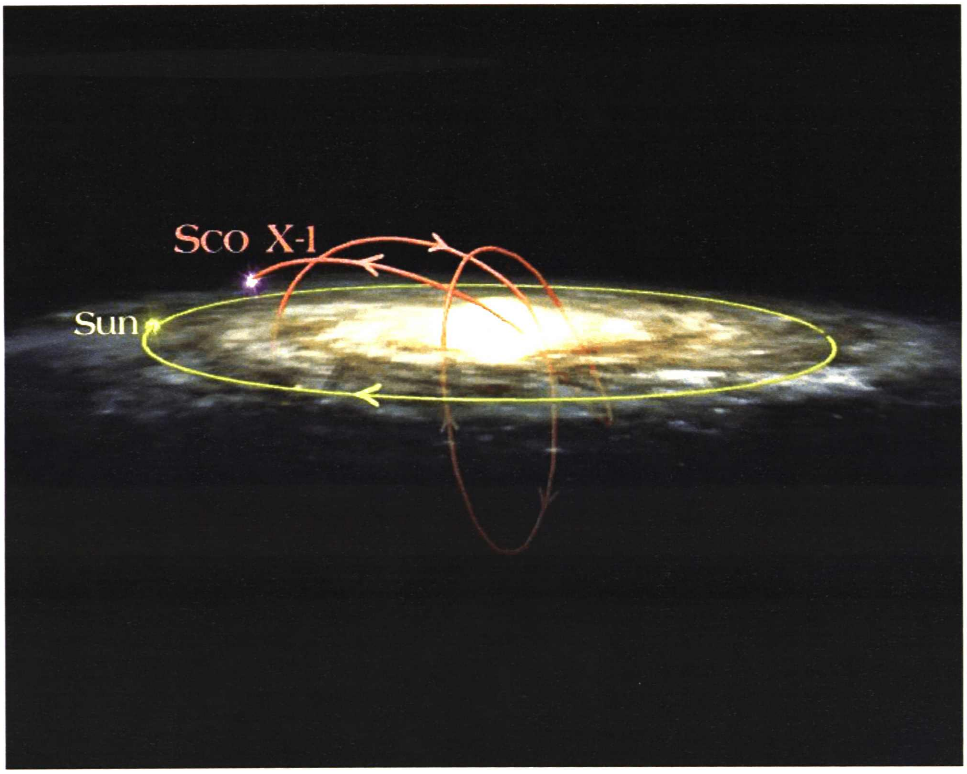


Figure III.9 Path of X-ray binary Scorpius X-1 (red) and Sun (yellow) through the Milky Way Galaxy for the past 230 million years.

persistent and flaring X-ray binaries. These observations will be used to determine the trigonometric distances to the binaries as well as their space velocities. Over the last several years, similar astrometric observations have been used to trace motions of two X-ray binaries backward in time, improving the understanding of their origins within our Galaxy, and hence the stellar population in which they originate. For example, Figure III.9 shows the apparent path of the X-ray binary Scorpius X-1 over the past 230 million years, illustrating the fact that this binary star originated in a stellar population with substantial orbital motions out of the Galaxy plane. The distance measurements are essential in order to measure the apparent linear speeds of relativistic jets, and hence constrain the physics of the jet generation and propagation. The space velocities can be used to determine the birthplaces of more black hole binaries, as well as exploring whether they are born in supernova explosions and receive a substantial velocity kick at the time. In a few favorable cases, the astrometric wobble due to a companion star may be measurable, providing important new information on the mass functions of individual binary systems.

The Interstellar Medium, Molecular Clouds, Cosmic Masers, Star Formation, Stellar Evolution, and Supernova Remnants

Planetary nebulae evolve from intermediate-mass stars following a period of intensive mass loss; their shapes differ dramatically from the expected spherical symmetry. It may be that high-velocity jet-like outflows early in the protoplanetary nebula phase play a crucial role in shaping these asymmetric nebulae. Some of these objects show hydroxyl and/or water maser emission, whose spectral lines can be used to measure velocities within the circumstellar material. The "water-fountain" sources show water maser emission with velocities as high as 100-200 km/s, perhaps representing the jet-like outflows that sculpt the nebulae. The VLBA will be used to map the distribution of water masers in water-fountain objects to determine the time scale of the fast outflow, critical for understanding the hydrodynamic shaping of the stellar envelopes. If the protoplanetary nature of these water fountain sources is confirmed, multi-epoch imaging will be carried out to measure proper motions, providing the third dimension in the velocity structure of the maser sources. These VLBA observations may play a crucial role in uncovering the origin of the beautiful asymmetric structures of planetary nebulae imaged with the Hubble Space Telescope.

Spectral-index measurements are being used to study a number of low-mass young stellar objects (YSOs) which contain water maser emission, and also may have structures largely determined by radio "jets." A sample of six YSOs in three distinct evolutionary stages is being observed at four epochs each, in order to determine the three-dimensional velocity structure of the protostellar jets. The structure will be used to perform a comparative study of the velocities as a function of protostellar ages. For example, it is expected that the velocity structure will change progressively due to evolution in the accretion activity.

The VLBA will continue to participate in the global VLBI network program to image over many epochs the expansion of Supernova 1993J in the nearby galaxy M81. This time sequence will allow the study of the evolution of the supernova remnant and its interaction with the surrounding interstellar medium. Spectral-index measurements are being used to study particle acceleration at the reverse shock in the supernova remnant and to seek signs of a pulsar wind nebula at the center, which could indicate the presence of a pulsar whose radio emission is not beamed toward us.

Normal and Starburst Galaxies

The distribution and total mass of the Local Group of galaxies are important properties that can help characterize the amount and location of dark matter in the Group and in the individual galaxies. A three-dimensional velocity model is needed, which requires measurements of the proper motions of the Local Group members. Phase-referencing observations of IC10 and M33 will be carried out relative to background quasars; initial epochs separated by nine months show errors of less than 20 microarcsecs in position relative to the phase calibrators, compared to expected motions of 10-20 microarcsecs. Therefore, three additional epochs will be obtained over the next two years, providing a total time baseline of approximately three years, and providing the first real measure of angular motions within the Local Group, at distances of up to 800 kpc.

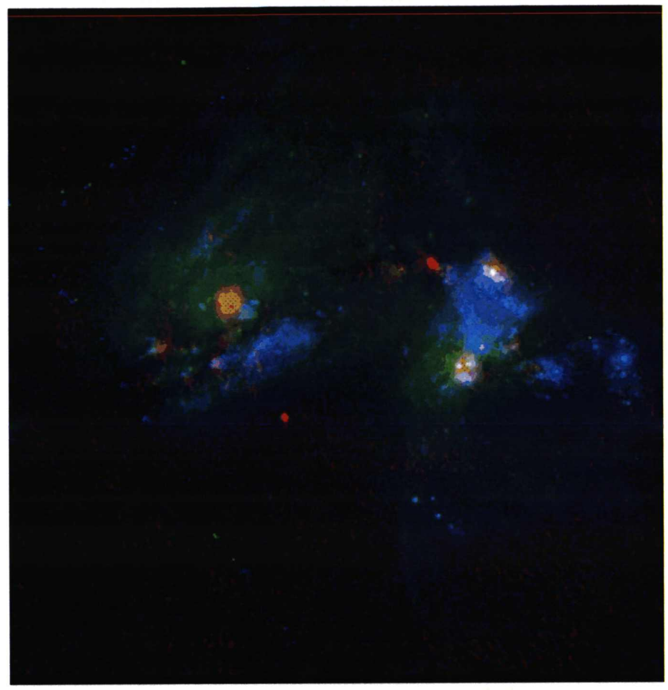


Figure III.10 Multiwavelength image of the colliding-galaxy pair Arp 299 using data from the VLA and Hubble Space Telescope. Here, radio emission is shown as red, infrared as green, and ultraviolet as blue.

Two merger galaxies, Arp 220 and Arp 299, recently have been found to have multiple compact radio sources in the merger nuclei, using imaging with the VLBA and/or the European VLBI Network. At respective distances of roughly 75 and 40 Mpc, the faint radio sources still are hundreds of times the luminosity of Cassiopeia A, the remnant of the most recent supernova in our own Galaxy. Figure III.10 shows the Arp 299 merger, while Figure III.11 compares maps made with the VLBA at two different epochs. It is thought that the new source which has appeared in the last year (Figure III.11, right) is a young supernova. This and the other compact radio sources may arise from the evolution of massive stars created in starbursts within the galaxy nuclei. In fact, optical telescopes cannot see through the dust to detect these objects, and the VLA does not have sufficient angular resolution, so only VLBI techniques can be used to study the individual supernovae. The merger nuclei will be monitored with the VLBA and other telescopes over the next several years, in order to determine the rate of evolution of the young supernovae as well as to search for new supernovae. The nature of the supernova progenitors will be determined from the radio light curves, while the supernova rate in the obscured nuclei can be measured or limited by searching for new radio sources to faint levels.

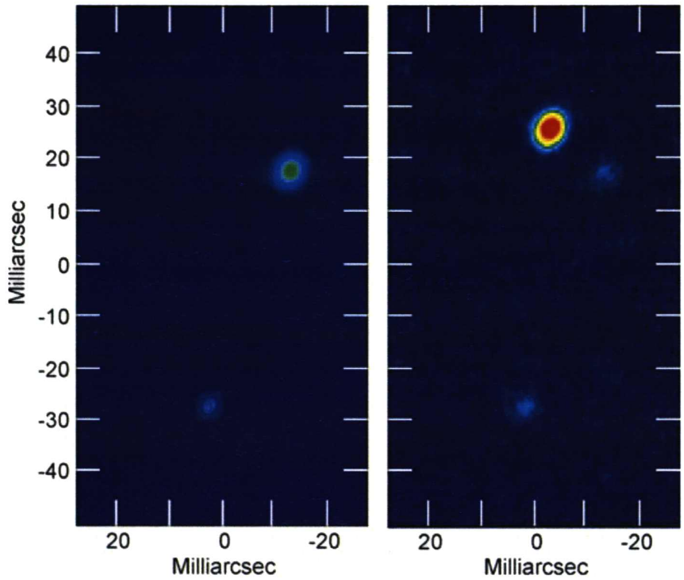


Figure III.11. Left panel image made in 2002 shows two prominent objects in the field of view. A 2003 image, right, shows a new supernova. These sources are all located within the most luminous radio-emitting region shown in Figure III.10.

Active Galaxies, Radio Galaxies, and Quasars

"Blazars" are optically violently variable sources that are located at the nuclei of active galaxies and appear to have relativistic jets that are aimed nearly along our line of sight. High energy TeV gamma rays have been detected from a few of the more nearby blazars, such as the elliptical galaxy Markarian 421. During a TeV flare, this object will be observed in a coordinated program along with approved Target of Opportunity observing on the *INTEGRAL* satellite. These coordinated multi-wavelength observations will be used to compare the spectrum of the VLBI core component with that predicted from high-energy emission models, constrain the size of the high-energy emitting region from limits on the VLBI core size, and determine the speed of radio components emitted in response to any nuclear flare.

A new class of flat-spectrum radio quasars has been found to have a synchrotron peak in the ultraviolet/X-ray band, compared to the previously observed peaks in the optical/infrared band. Such objects have never been imaged previously with the VLBA, but eight will be imaged in FY 2004. At present, it is not clear how these new objects fit into the unified schemes for active galactic nuclei, used to explain an abundance of effects in various types of active galaxy. The new objects will be imaged to explore their parsec-scale morphologies and to measure such quantities as the core dominance and the jet/counterjet ratio, critical parameters in placing the high-frequency-peaked objects in the unified schemes.

Two active blazars will be monitored at multiple epochs and multiple radio frequencies using the radio/optical Whole Earth Blazar Telescope. One such object, AO 0235+164, has shown radio and optical outbursts quasi-periodically, with a period of slightly less than six years. Its next outburst is predicted to occur in February/March 2004, so the VLBA should be able to observe it in all stages of the rising and falling flare. This will enable imaging of multiple synchrotron components throughout the history of the flare, providing better modeling of the spectrum. It also will provide information about the location of the radio flare, specifically about whether the flare flux is found primarily in a new radio component. Alternatively, the flare may be due to shocks passing through the radio core, which actually is located in front of the active galactic nucleus and its massive black hole, where the initial energy release takes place.

The Compton Gamma Ray Observatory, operational in the 1990s, performed the first sensitive all-sky gamma-ray survey, detecting approximately 300 new sources. Most of the identified extragalactic objects are blazars, including several of those mentioned above. However, to date, fewer than half of the 300 sources (which have poorly determined positions) have been identified with objects observed in other wavebands. Recently, the optical Hobby-Eberly Telescope has been used to investigate flat-spectrum radio sources from the VLA gravitational lens surveys, and identified a number of possible optical counterparts to some of the unidentified gamma-ray emitters. Beginning in FY 2004, about 30 of these candidates will be observed in three epochs at one year intervals, in order to determine their structures and evolution on milliarcsec scales. A primary goal is to identify characteristics that are most likely to be associated with the weaker gamma-ray sources, which will improve identification of gamma-ray emitters that will be detected by the Gamma ray Large Area Space Telescope (*GLAST*), due for launch in 2007. GLAST is expected to detect 5000 or more sources, compared with the 300 CGRO, so identification of the *GLAST* sources will be critical for carrying out quantitative astrophysical investigations and making full use of the satellite data.

A large VLBA program is being carried out to image more than 150 strong compact radio sources at multiple epochs, using an observing frequency of 15 GHz. Observing sessions of approximately 24 hours in length are carried out every 6-8 weeks, and will continue in FY 2004. The primary aim is to create a statistically complete data set of radio source motions that can be used to characterize the kinematics of AGN jets and determine how these relate to other source properties. In FY 2003 and FY 2004, full polarization imaging is being added to this monitoring program in order to investigate the changing magnetic field structures that have been seen in observations of individual sources.

Surveys, Fundamental Physics and Reference Frames

A VLBA+GBT investigation is being carried out in two NOAO Deep Wide Fields, in Bootes and Cetus. Approximately 200 radio sources stronger than 10 mJy in the FIRST (Faint Images of the Radio Sky at Twenty centimeters) survey are being imaged using new wide-field techniques, and roughly one source in three has been detected. This survey, unbiased by spectral index selection, is a new way of identifying active galaxies with compact cores, and differentiating them from starburst galaxies in the NOAO fields. During FY 2004, it is expected that the remaining portion of the Cetus field will be observed. As VLBI data rates are increased over the next several years, it is anticipated that the wide-field imaging technique will prove to be an important means of detecting weaker and weaker active galaxies, perhaps including some at quite high redshifts.

Monitoring of the position of the radio star HR 8703 (IM Peg) will continue in FY 2004, using the VLBA and some of the world's largest radio telescopes. The goal is to determine the mean proper motion, acceleration, parallax, and binary orbit of this star to better than 0.1 milliarcsecs, using data when HR 8703 is as faint as 1 mJy. HR 8703 is the single critical reference star for the half-billion dollar *Gravity Probe-B* (*GP-B*) mission scheduled for a NASA launch in early FY 2004. *GP-B* is to be used to test two of the fundamental precepts of General Relativity, the curvature of space-time in the Earth's gravitational field, and the frame-dragging due to the Earth's rotation. Accurate knowledge of the reference star position is required to measure the precession of the onboard gyroscopes, which provides the fundamental observable for the General Relativity tests.

The VLBA will continue its regular schedule of bimonthly 24-hour astrometric VLBI observations, to maintain and improve the fundamental reference frame for geodesy and astronomy. This frame is used to study a variety of geophysical phenomena including tectonic plate motion, Earth rotation rate and orientation, and the interaction between the Earth and its atmosphere. In addition to the regular observations at 2.3 and 8.4 GHz, a series of geodetic-style observing sessions is being carried out at frequencies of 22 and 43 GHz. These sessions are being used to assess the ability of the VLBA to generate the data for a higher frequency VLBI catalog that is less affected by the ionosphere than are observations at 2.3 and 8.4 GHz, and may reduce the errors caused by source structure in extended jets. During FY 2004, the high-frequency program will attempt to observe weaker sources than in FY 2003, in order to assess the likelihood that the weaker sources are compact, and ultimately to determine the density of compact sources at the high radio frequencies. This program is the precursor to an effort to build a VLBI source catalog at 32 GHz, which will be critical for the navigation of future NASA interplanetary spacecraft using VLBI.

IV. Facilities

Green Bank Telescope

The GBT is the most advanced and versatile single dish telescope in the world. It features an unblocked aperture design, an active surface, a laser metrology system for surface and pointing control, a rotating receiver turret for fast selection of receivers, and a wide bandwidth spectrometer with up to 256k spectral channels. The frequency coverage of the telescope will be ~100 MHz to ~115 GHz. The combination of all these features in a 100 m diameter telescope gives the GBT unprecedented sensitivity and performance, and the capability to address projects from low frequency phenomena to high frequency molecular line and dust emission. The plan for operating and developing the GBT is described below.

Figure IV.1. Aerial photo of the Green Bank Telescope (GBT).

GBT Strategic Plan

The GBT has several key instrumental assets that give it unique scientific capabilities. The strategic plan for the GBT seeks to maximize returns from these unique features listed below:

High fidelity imaging - The unblocked aperture of the GBT significantly reduces its sidelobes, producing an exceptionally undistorted main beam. At the frequency of the HI line, for example, the first sidelobes of the GBT are ~30 dB below peak response, compared to the ~20 dB typical of symmetric antennas with blockage. In addition, the GBT's active surface reduces the aberrations and misalignments which produce coma and astigmatism compromising observations at high frequencies. The high quality optics of the GBT is one of its unique and powerful assets and gives it a major step forward in capabilities. As demonstrated in the preceding science discussion, the GBT has already revealed properties of Galactic HI that significantly change our view of Galactic structure, a remarkable achievement considering that there have been half a century of HI studies in this area.

Comparatively high angular resolution with sensitivity to total emitted flux and extended emission - The 100 m aperture of the GBT affords the comparatively high angular resolution of 720[arcsec]/ν [GHz]. Thus, at 100 GHz the GBT resolution is ~7". Furthermore, as a single dish, the GBT is sensitive to total flux from all angular scales. This is a key difference from interferometers, which can provide very high resolution, but may be insensitive to extended emission. Sensitivity to total flux is a powerful asset for stand-alone science, and it is also exploited when data from a single dish and a synthesis array such as the VLA are combined to produce an image rich in the details of the radio source at all angular scales.

Wide field of view - The Gregorian optics of the GBT afford a wide field of view that is relatively free of aberrations. At 3 mm wavelengths, the useable field of view is about 10 arcmin and could contain up to 10,000 beams or pixels in a fully sampled array. The focal plane can thus accommodate large format imaging cameras. When coupled with the high fidelity, the comparatively high angular resolution, and the sensitivity to extended, low-brightness emission, it is evident that the GBT has unique potential as an imaging instrument. This is clearly a capability that we wish to foster through instrumentation and software initiatives.

High point source gain at all frequencies from ~300 MHz to 115 Ghz - The GBT has a physical collecting area of 7854 m^2. This aperture, the unblocked optics design, and the active surface, and precision control system combine to provide extraordinary gain and point source sensitivity from low frequencies to, ultimately, 115 GHz. This gives the GBT high sensitivity to point sources such as pulsars, stars, and external galaxies. Because the GBT has high gain over three decades of frequency, it can be used to study cosmic phenomena that occur, or vary in nature, over a range of frequencies. For example, redshifted CO line emission may have lines that fall throughout the frequency range of the GBT, depending on the rotational transition and the redshift. Extragalactic continuum sources may emit in thermal free-free, synchrotron, or dust emission over ranges accessible to the GBT, which might then be used to separate the contributions of these phenomena to the continuum spectra.

Comparatively low RFI contamination - The GBT is located in the National Radio Quiet Zone, a unique, national resource. Although Green Bank is certainly not RFI free, the natural topography of the area around the site in combination with Quiet Zone regulations continue to make it one of the best locations for radio astronomy in the world. For example, observations near the 1420 MHz HI line are largely free of contamination in Green Bank, whereas in certain parts of the world they have become almost impossible to carry out. We can exploit the Quiet Zone for numerous low frequency projects and will continue to protect it vigorously.

As is evident from the description above, the information present in the focal plane of the GBT is extensive and unique in both the spatial and frequency domains. In overview, the strategic plan for the GBT is to develop the scientific capabilities to capture this information as fully as possible. The specific strategic objectives and projects or programs that address them are listed in the table below.

Table IV.1

Strategic Objective	Projects addressing it	Status
Develop the high frequency capability and performance of the GBT to 115 GHz.	▸ Precision Telescope Control System ▸ 3 mm (68-92 GHz) Receiver ▸ Ka-band (26-40 GHz) Receiver ▸ Penn Array Bolometer Camera ▸ Caltech Continuum Back-ends	In progress In progress In progress In progress In progress
Develop imaging cameras with increasingly large pixel formats at key bands, including 21 cm, 1.3 cm, 1 cm, and 3 mm.	▸ Penn Array Bolometer Camera ▸ Beam Forming Array ▸ 3 mm MMIC Array ▸ 3CAM large format bolometer camera	In progress Future Future Future
Develop ultra-wideband frequency analyzers for redshift searches.	▸ Wideband Spectrometer	Future
Mitigate the effects of RFI, enhance the available spectrum in Green Bank, and increase protection in the National Radio Quiet Zone.	▸ Interference Protection Work ▸ Quiet Zone administration	In progress In progress
Develop observing strategies such as dynamic and queue-based scheduling that will allow observing programs to take best advantage of the prevailing weather and RFI environment.	▸ Dynamic and Queue-based scheduling development.	Future
Work to sustain and enhance the single dish radio astronomy user community through NRAO sponsored programs	▸ Student Financial Support Program ▸ University-built Instrumentation Program ▸ Single Dish Summer School	In progress In progress In progress

GBT Strategic Objectives

Although our strategic emphasis will be on these areas, the list is not inclusive of all activities, either developmental or operational. For example, we may work with university groups to develop next-generation pulsar observing back-ends. We will also devote resources toward upgrading existing instrumentation and data analysis, enhancing observer services, etc.

The projects underway in FY 2004 and those planned in future years are described in more detail in the next two sections. As the GBT has just completed initial commissioning, we have found a number of areas where improvements to first-generation instruments or systems are needed. Many of these are required for smooth and productive operation of the facility, and a substantial fraction of our effort in FY 2004 will go toward these operational enhancements and improvements. Projects in this category include enhancements to the Spectrometer, improvements in spectral baseline quality, ease of configuration of the observing system, and improved data analysis software.

IV. Facilities

Although the GBT is meeting or exceeding expectations in nearly every scientific category, a problem area has been the azimuth track, which is exhibiting serious, premature wear. An aggressive program is underway to analyze the causes of this failure. Short-term mitigation of the wear has been implemented, but it is clear that the steel portions of the azimuth track will require replacement or significant retrofitting within the next one or two years. Substantial staff effort and funds are being applied to this program, which have had an impact on other programs. We are nonetheless confident that a good solution will be forthcoming soon and that this problem can be solved once and for all.

Operations and Development Programs for FY 2004

The plan for 2004 will take major steps toward the strategic vision described above, while also providing a number of short-term operational enhancements.

Operational Initiatives and Enhancements

The list of operational initiatives and enhancements for 2004 includes (*descriptions below*):

- Increasing the fraction of time for science
- Azimuth track work
- Data export and analysis
- GBT configuration and ease-of-use
- Spectral baseline improvements
- Spectrometer reliability upgrades
- Spectrometer pulsar timing and spigot modes
- Spectrometer polarization/cross-correlation mode
- RFI mitigation

Increasing the fraction of time for science. The GBT should reach full efficiency of observing time during FY 2004. Owing to the complexity of the structure, electronic, and mechanical systems, the GBT will always require maintenance time of ~2-3 workdays per week, and more extensive time in the summer for heavy engineering and inspection activities. In all cases, we will make maintenance activities as efficient as possible, and will seek to minimize maintenance time during the winter months when atmospheric transparency is best. During the winter of 2003/2004, the fraction of time available to science should be in the range of 65-70 percent.

The GBT superstructure consists of over 13,000 steel members, all of which must undergo a structural inspection and be painted on a prescribed schedule. We have developed a 6-year painting plan over which the entire structure will be painted during the summer months. For the past two summers, we have utilized crews of temporary painters, supervised by the NRAO Telescope Operations staff. The crews typically work four, 10-hour days per week, and stow their gear each night so that observations can resume.

Last year, we let a study contract to a qualified engineering firm to develop a comprehensive structural inspection plan for the GBT. Their plan was delivered and adopted in early 2003, and the first structural inspections are occurring in the summer of 2003. The structural inspections will be completed in summer 2004, and will then be repeated every second year thereafter. The annual painting and structural inspection activities represent a significant expense for Green Bank Operations.

Azimuth track - As has been described in Quarterly Reports and other documents over the past year, the GBT azimuth track is experiencing serious, premature wear and will require significant modification or replacement in the near term. Over the past year, Observatory engineers and external consultants have been engaged in an intensive program to analyze and model the behavior of the track, to try a possible retrofit solution, and to examine the options for a new track. This work will continue until the end of calendar year 2003. At that time, we should have good understanding of the retrofit option, and whether it represents a viable solution. Depending on the findings, the need for any further studies, the time required to let contracts and procure materials, and the condition of the present track, the track work would be done either in the summer of 2004 or 2005. This program has and will continue to require a major commitment of resources from Green Bank telescope operations and mechanical engineering staff, as well as Observatory central engineering resources.

Data export and analysis - Single dish data analysis software is now the responsibility of Green Bank Operations. A new Single Dish Software Integrated Product Team(IPT) has been formed that is addressing all aspects of GBT software, including both the real-time and analysis needs. During FY 2004, the group expects to deliver a consolidated FITS data format that will be exportable into a number of existing data reduction packages, including IDL and CLASS. The group will also develop plans for the future direction of single dish data analysis software at the GBT, and expects to deliver some initial prototypes. The major initiatives will be presented for Observatory review, and the work will be done in close collaboration with the Synthesis IPT under the direction of Socorro Operations.

GBT configuration and ease of use - The GBT is presently configured for observations by a combination of GUI screens and Glish scripts. We are working to consolidate these programs into a unified system that allows system configuration and observation execution. This system should be sufficiently straightforward to use so that the telescope operator and visiting observer can set up observations without the assistance of a local expert. In the longer term, GBT requires a system that allows observer scripting and automated queue execution. Some promising systems for this purpose have already been developed at other observatories and we will examine these closely to determine if they can be adopted for use at the GBT.

Spectral baseline improvements - When GBT spectroscopy began in earnest in 2002, we found that instrumental baseline curvature was present in most bands. This was made evident by the much wider spectral bandwidths available at the GBT compared to the previous generation facilities. We expect the spectral baselines to be quite good owing to the unblocked optics design which eliminates many sources of standing waves. In fact, the challenging projects observers wish to pursue with the GBT, such as the detection of high redshift CO lines, demand extremely flat and stable baselines. Over the past year, an engineering and science team has made a very detailed study of baseline problems and has successfully associated most of the features to specific parts of the signal path. These include reflections and resonances in the feedhorn and the feed to waveguide thermal transition, standing waves in the fiber optic modulators, and numerous sources of temperature-sensitive standing waves in the IF conversion system. These studies are continuing, and are now isolating the baseline features to the component level. Over the next year, receiver feed and IF modifications will be made to mitigate the problems. This effort remains a priority and requires a significant commitment of senior staff and capital resources for electronic modifications.

Spectrometer reliability upgrades - The GBT Spectrometer is a powerful instrument that provides the backbone of GBT spectroscopic capability. It has up to 256,000 total spectral channels and 6.4 GHz of total bandwidth. Over the past year, enormous progress has been made in commissioning and debugging the instrument; it is now in daily, routine use, and is generally performing well. Nevertheless, it still experiences some crashes and other anomalies, and requires a high level of expert maintenance. The staff has identified several hardware improvements that will give the instrument better reliability and performance, and would reduce the level of the maintenance requirements. The engineering plan is presently being developed and we expect to carry it out in FY 2004.

Spectrometer pulsar timing and spigot modes - The GBT Spectrometer has a pulsar timing mode that has not yet been implemented. Because of the wide (up to 800 MHz) bandwidth of the Spectrometer, this mode should offer substantially improved pulsar sensitivities. The Spectrometer also has a "Spigot Card" mode that allows very rapid, wide bandwidth dumps into an external data recording back-end for detection projects. This project is being done in collaboration with a group from Caltech. NRAO provided the spigot card, the firmware, and extensive hardware support and development. Caltech has provided the external data recording system and is contributing to overall debugging and observing mode development. This system is nearly available for "expert mode" astronomy use, but will need further software development before it can be available to the general community. Some of the timing and spigot modes involve common development, and we hope to address both of these projects in FY 2004.

Spectrometer polarization/cross-correlation mode - Another mode of the Spectrometer awaiting release is the cross correlation mode used for polarization studies. Astronomers are presently using the polarization mode of the older Spectral Processor, but may have more options available with the Spectrometer. This Spectrometer mode has undergone some preliminary engineering checks with apparent good results, but more detailed work is required. We expect to complete this work in the coming year.

RFI mitigation - When observations first began with the GBT in 2001 and 2002, there was a considerable amount of RFI at frequencies of 1.5 GHz and below. The site RFI team conducted extensive investigations and found that in a number of cases, the interference could be traced to sources on site. In the past year, the group has made excellent progress in mitigating this RFI. For example, the GBT feed arm servo system has been substantially modified with filtering. Leakage from the shielded rooms in the Jansky Lab has been successfully eliminated through rework of the windows. Other sources of RFI such as the LO1 frequency standard and the HVAC controllers on the GBT have been isolated and are undergoing modifications. This is an ongoing program – when a strong source of RFI is eliminated, the next weaker source is often revealed. The group has a considerable list of projects to investigate and address, both for local RFI mitigation and Quiet Zone administration. This will continue to be an active area in FY 2004.

Strategic Development Projects in FY 2004

A number of development projects that are part of the strategic, long-term plan will be underway in FY 2004, and are listed and described below:

- Precision Telescope Control System
- Ka-band (26-40 GHz) receiver
- 3 mm (68-92 GHz) receiver
- Common millimeter-wave down-converter
- Caltech continuum back-ends
- Penn array camera
- Wide bandwidth spectrometer preliminary studies.

Precision Telescope Control System (PTCS) Development - PTCS is our highest priority development project. It is the combination of metrology systems, servos and control software which will allow the GBT to achieve the specifications for pointing, collimation and surface accuracy required to operate at 115 GHz. More details of the current performance of the GBT, and the plans for PTCS development work may be found from the project web pages: http://www.gb.nrao.edu/ptcs.

Work on the PTCS project in the first half of 2002 proceeded more slowly than we had hoped, primarily as a result of the continued requirement for scientific, engineering and software staff effort for general commissioning of the GBT. As a result, by October 2002 we were significantly behind the schedule laid out in the 2002 Program Plan. In November 2002, NRAO conducted a one day Commissioning and Development Review of the GBT; a clear outcome of this review was that the GBT must consider the PTCS to be a top priority project. As a result of this, the PTCS project team was reconstituted with a formally assigned Project Manager (Richard Prestage), Project Engineer (Kim Constantikes) and Project Scientist (Jim Condon) and significantly enhanced personnel resources. The first task for this new project team was to prepare for and execute a Conceptual Design Review; this was successfully passed in April 2003.

Since April 2003, we have been executing the items outlined at the conceptual design review, largely according to schedule. The most ambitious single item was to equip the antenna structure with a set of eighteen high-precision temperature sensors. The initial prototype was installed in early June, and has fully met all performance specifications; the remainder of the installation will be complete by mid-August, well ahead of schedule. These sensors will initially be used along with astronomical pointing and focus measurements to make simple, empirical corrections for diurnal temperature variations.

The second major development activity is to complete the Engineering Measurement System (EMS) by October 2003. As described in the 2003 program plan, the EMS is a production system which will process ground rangefinder data in near real-time to produce absolute (xyz) target positions in a routine way, but which will not be used to provide pointing corrections to the antenna control system. EMS survey data will however be used to improve existing model accuracies (e.g., feed-arm tip deflection as a function of gravity) or to construct other models that will be used to improve GBT performance (e.g., feed-arm tip deflection as a function of temperature and wind). Software development of the EMS has been proceeding extremely smoothly; the main limitation at this stage has been difficulty in keeping at least eight rangefinder units in reliable, correct operation.

Other activities in the first half of 2003 included initial experiments to commission the "out-of-focus" holography technique, continued traditional holography, various improvements to the antenna trajectory control software, and upgrades to the Quadrant Detector, which will be reinstalled in August 2003.

The precise work to be executed in FY 2004 depends in large part on the outcome of initial commissioning experiments utilizing the new antenna temperature sensor system, and initial results from production use of the EMS. Both of these activities are scheduled for August-September 2003 and so the outcomes are not known at the time of writing; an In-Progress Review is planned for October 2003 to review the results. However, based on the plans presented at the Conceptual Design Review, and some initial results, we anticipate the following three main activities for FY 2004.

First, we will support effective Q-band(40-50 GHz) science observations through the winter of 2003/04. After the Conceptual Design Review, the review committee noted that improving the pointing performance of the GBT was the most important task. In fact, some preliminary half-power tracking experiments suggest that the tracking stability on half-hour timescales is already extremely good, and easily acceptable for Q-band observing provided some long-term trends can be removed. We anticipate that these trends are due to a combination of diurnal temperature effects and/or residual systematic errors in the pointing model, perhaps due to limitations in the focus-tracking algorithms. We expect that both of these can easily be accommodated through improvements to the traditional pointing model, and simple corrections based on the antenna temperature sensors. In addition to pointing improvements, we expect to make some modest improvements to the antenna efficiency on the basis of our two holography techniques.

Secondly, we will continue to perform commissioning experiments through the winter of 2003/04 to assess the capability of the antenna to achieve 3 mm operation under benign conditions. Half-power tracking and other experiments performed under excellent conditions will demonstrate the ultimate performance capability of the GBT. Correlations with other engineering quantities (e.g., quadrant detector, accelerometer outputs, etc.), may reveal rather straightforward techniques which can be used to achieve this performance under less than benign conditions.

Finally, starting in early spring 2004, we will review our strategy and begin implementation of techniques to allow prototype 3 mm operation to commence as scheduled at the start of FY2005 (the schedule set out in the 2003 Program Plan). By necessity, this is likely to be a "trimmed down" version of the PTCS as discussed in the FY 2003 program plan and April 2003, PTCS Conceptual Design Review. We will need to be both innovative and pragmatic to achieve the goal of 3 mm operation on this timescale.

Ka-Band (26-40 GHz) receiver - The Ka-band receiver will be completed and see first astronomical use in FY 2004. This is a dual-polarization, dual-beam, pseudo-correlation receiver optimized for point-source sensitivity and capable of high bandwidth continuum or spectral line observations. Receiver design is presently well along and most of the components have been procured. The receiver will be particularly valuable for continuum point-source detection and also for high redshift CO observations.

3 mm (68-92 GHz) receiver - Work on the 3 mm receiver will resume in FY 2004. The work had been suspended to pursue the spectral baseline investigation and to perform a number of other pressing operational tasks. The target for completion is early 2005 for initial use with the PTCS system. The 3 mm Receiver is also a dual beam, pseudo-correlation receiver and will be sensitive to both continuum and wideband spectral observations. Most of the capital expenditures for the project have already been made.

Common millimeter wave down-converter - The Common down-converter serves both the Ka-band and 3 mm receivers. It down-converts for use with the GBT Spectrometer and also has a port for future use with a wideband spectrometer. Most of the components for the down-converter have been acquired and construction will be concluded in FY 2004.

Caltech continuum back-ends - The Caltech continuum back-ends are rapid sampling back-ends for use with the Ka-Band and 3 mm receivers. Two back-ends are being built by Caltech as part of the NRAO sponsored university instrumentation program. The back-ends can analyze ~20 GHz of bandwidth divided into three frequency bands for limited spectral information. The project is proceeding well and the back-ends are expected to be completed by April 2004. NRAO has considerable involvement in the project: our mm-wave project scientist works closely with the project and provides management coordination; the Green Bank software group is writing the real-time control manager, and the Electronics Division is providing the filtered input to the back-ends and is consulting closely on the digital electronics.

Penn Array - The Penn Array is a 64-pixel bolometer camera for 3 mm continuum imaging on the GBT. The camera is funded by NRAO through the university instrumentation program and is being built primarily by the University of Pennsylvania, but in collaboration with NASA-Goddard, NIST, University of Cardiff, and NRAO. The camera uses transition edge superconducting bolometer elements in a fully-sampled array. This is a three-year project that is about half way through. A Critical Design Review is scheduled for early October 2003. The group has built a cryogenic prototype that is performing to specification, and has also completed the optics design. Design of the detector array at NASA is underway. NRAO also has significant involvement in this project, including project scientist coordination, overall project review, cryostat construction, mechanical interface specifications, control software, and analysis software.

Wide bandwidth spectrometer preliminary studies - One of the strategic objectives of the GBT is ultra-wideband spectral analysis for redshift searches at ~20 GHz through ~100 GHz. Because of its point source gain and frequency coverage into the millimeter wavelength region, the GBT is potentially an extremely powerful instrument for the detection of high redshift CO emission from distant galaxies. Since extragalactic objects may not have known redshifts, e.g., millimeter or submillimeter continuum emission, a spectrometer with a wide search bandwidth would be very valuable. One could then conduct blind redshift searches of targeted objects or open fields. We have been working with Prof. A. Harris (University of Maryland) and others to determine scientific and instrumental specifications for such an instrument. It is likely that a call for proposals to build such an instrument will be issued to university labs in the coming year. If the budget allows, this project would be funded through the university instrumentation program. This would provide a needed instrument and would also encourage university development groups.

Future Strategic Initiatives

Key strategic initiatives include:

- Continued PTCS development
- 7 mm tertiary chopper
- Adaptive optics studies
- Wideband spectrometer construction
- 3 mm MMIC spectroscopic array
- Next generation spectrometer
- Beam-forming array
- 3CAM bolometer array
- Advanced data reduction
- Dynamic scheduling
- Turret rotator

Continued PTCS development - The PTCS project has as its goal effective performance of the telescope at 3 mm by early 2005. Almost certainly, further performance enhancements beyond those achieved initially will be possible. Thus, we can anticipate that the PTCS project will continue for several years.

7 mm tertiary chopper - It is likely that the performance of the 7 mm (Q-band) Receiver could be significantly improved by adding a tertiary chopper in the optical path. Fast chopping would give better atmospheric compensation, would help to switch out any gain instabilities in the first amplifiers of the receiver, and give flatter spectral baselines. This would be initially constructed as a single-axis chopper switching between the two cross-elevation horns of the receiver.

Adaptive optics studies - Even more sophisticated optical elements such as tip-tilt mirrors may improve the imaging performance of the GBT. Such a mirror could be served to the feedarm quadrant detector and could be used to compensate for feedarm oscillation. Using atmospheric water vapor sensors, such a system might also be used to remove anomalous refraction effects on telescope pointing. Substantial design studies as part of the overall PTCS project will be required to assess the applicability of adaptive optics techniques to the GBT.

Wideband spectrometer construction. As described above, a wideband spectrometer would be a powerful scientific instrument for redshift searches on the GBT. Analog correlators with up to 20-30 GHz of total bandwidth have been developed. They have relatively low spectral resolution, but are optimized for detection purposes. These wideband spectrometers could be used in conjunction with the 26-40 GHz and 68-92 GHz receivers, which are optimized for point source detection. This front-end / back-end combination coupled with the gain of the GBT would give an extraordinary high redshift detection capability. Furthermore, one could use the Penn Array camera for the detection of dusty, extremely distant galaxies, then determine their redshift with the wideband spectrometer.

3 mm MMIC spectroscopic array. The Penn Array will give excellent 3 mm continuum imaging performance and serve as a pathfinder for a large format bolometer camera. We also wish to construct the complementary spectroscopic array for 3 mm molecular line studies of star forming regions, Galactic, and extra-galactic structures. As is well known, the 3 mm band is particularly rich in molecular lines (CO, HCN, HCO^+, SiO, CN, CS, CH_3OH, and a host of others). Each of these molecules samples different density and temperature regimes and are, collectively, powerful diagnostics of the structure and physical conditions of molecular clouds and star forming regions. At 90 GHz, the GBT has 8 arcsec resolution, which is much higher than provided by most other millimeter-wave single dishes; this will allow very detailed imaging of a variety of sources, particularly nearby galaxies. Nevertheless, imaging one pixel at a time with such a small beam will be time-consuming and inefficient. A large format array for 3 mm imaging on the GBT would be a uniquely powerful scientific instrument. Technology is also evolving in this area, and it is now possible to build MMIC arrays of HEMT amplifiers in fairly large format arrays. We will begin investigating the possibilities of such an array on the GBT with the expectation of starting a project in 2-3 years.

Next generation spectrometer. The GBT spectrometer is a quite powerful instrument with 256 k spectral channels and up to 16 independent inputs. Nevertheless, the technology employed is now more than 10 years old, which is quite a long time in the fast-moving world of digital electronics. More modern, and probably easier-to-maintain technologies are now available, including the use of off-the-shelf computers rather than custom devices. Furthermore, the present spectrometer will not be able to service a large-format array such as that described above. Spectrometer development will be coupled with spectroscopic array development.

Beam-Forming Array. Beam-forming array technology is a very promising approach for wide-field imaging. The concept utilizes a number of planar feeds that sample the electric field of the telescope, and through appropriate signal processing, form an image of the sky over an area proportionate to the number of sampling elements. The signal processing offers the option of full sampling of the sky and for the correction of optical aberrations and sidelobes. However, the technology is challenging, in areas of noise performance of the feed/amplifier elements, in cryogenics, and in digital signal processing. If these hurdles can be overcome, and if adequate computational power is available cheaply enough, this approach may offer an important breakthrough in large format array technology.

For the past few years, we have had a group doing prototyping and design studies on beam forming arrays. Owing to the research and development requirements, and the fact that staffing resources are presently assigned to other projects, the group is recommending the technical development problems be worked on in the context of incremental improvements to existing GBT systems. Specifically, they propose to build an integrated OMT/LNA assembly in the end of a receiver waveguide, move to digital signal transmission of IF information, and begin developing parallel signal processing using commodity equipment. The experience would then be collected in a few years to construct a production beam-forming array for astronomical use.

3CAM - a large format bolometer array - As described above, the Penn Array is our first 3 mm continuum imaging camera. It will have a 64-pixel, 0.5 arc minute, fully-sampled field, with outstanding sensitivity (~350μJy/√s). The technology for bolometer cameras is perhaps the most rapidly advancing of all technologies in the radio / mm wavelength region. Just about six years ago, the first 91-pixel bolometer camera, SCUBA, was put into operation at the James Clerk Maxwell Telescope with ground-breaking astronomical results. The group that built SCUBA is now building SCUBA-2, which has ~10,000 total pixels, using essentially the same technology as employed in the Penn Array. Preliminary investigations indicate that a 3 mm array of 6400 pixels would be possible for the GBT. This would be a revolutionary advance in wide-field imaging speed, would provide unique scientific results, and also complement the information obtained at shorter wavelengths. Since the Penn Array employs much of the same technology needed for a much larger array, it is an excellent pathfinder project for both the technology and the science. If results from the Penn Array are as significant as we expect them to be, we will begin proposal and preliminary design studies for a large format camera for 3 mm wavelengths.

Advanced data reduction - As noted above, Green Bank Operations is now responsible for data analysis software for the GBT. Although we expect that basic data reduction systems will be provided in the near term, advanced reduction software for imaging cameras and other techniques and instruments will be required. Discussions on software for the Penn Array are already underway. We anticipate that this will be a continuing area of activity for several years.

Dynamic scheduling - For efficient high frequency operation of the GBT, we must also develop a dynamic or flexible scheduling system. Atmospheric monitoring data indicate that about 100 days a year should be suitable for 3 mm observing. Most of these occur between October and late April, but cannot be predicted more than a few days in advance. In order to complete high frequency programs, and not to waste time that could be used profitably for lower frequency projects, we will need a system for dynamically scheduling the telescope. This system should be coupled with a good remote observing capability so that observers can still interact with their projects from their home institution, even if scheduled on short notice. There is considerable experience with dynamic scheduling being acquired with the VLBA, and there is an effort now in progress to develop a pilot dynamic scheduling system for the VLA, as is described at the end of Section IV. We intend to examine these efforts closely to determine if they could be adopted or modified for use on the GBT.

Turret Rotator. Many observing projects, including pulsar and VLBI projects, need to change observing bands rather quickly for reasons of observing efficiency or for recording time-variable phenomena. The GBT Gregorian receivers are mounted, on a rotating turret in the Receiver Room on the feedarm. The present turret drive mechanism requires that we drive the telescope to the "access" position in which the feedarm is vertical. The actual rotation is fairly quick, but the entire process including the move can take 10 minutes or more. This is slower than desired by many projects, and can be a scheduling problem for VLBI projects in which the other antennas can change frequencies more quickly. An upgrade is possible that would allow the turret to be rotated at any elevation angle, thus circumventing the move back to vertical. The mechanical requirements for this upgrade are fairly straightforward, but require detailed design and funding. Our mechanical engineering staff is presently occupied with azimuth track work and other projects, but would hope to proceed with this project as soon as time is available.

Development Budget

Budget and staffing estimates for the development program described above are presented in the following table. The estimates for future initiatives are very rough and are based on experience with previous, similar projects, but not on any detailed project studies. They are included for planning the general scale of the program. Detailed studies will be carried out before projects are formally started. Proposed funding and staffing levels may exceed those actually available, including those in FY 2004.

Table IV.2

GBT Development Program Estimated Costs[1]

Requested Levels

Fiscal Year / Project	FY2004 Cost k$	FY2004 FTEs	FY2005 Cost k$	FY2005 FTEs	FY2006 Cost k$	FY2006 FTEs	FY2007 Cost k$	FY2007 FTEs	FY2008 Cost k$	FY2008 FTEs	Total Cost *2004-08(k$)*	Total FTEs 2004-08
GBT Development Plan - Active												
Azimuth Track Study / Trials	535	3 0									535	3 0
Precision Telescope Control System[2]	100	8 0	100	8 0	30	4 0	15	3 0			245	23 0
Spectral Baseline Improvements	10	2 0		0 5							10	2 5
Data Handling Improvements[2]		3 5		3 5		2 0		1 0		1 0	0	11 0
Ease of Configuration & Use		2 5		1 0							0	3 5
1 cm Rx (26-40 GHz)	20	1 0									20	1 0
3 mm Rx Module 1 (68-92 GHz)	15	2 0		0 5							15	2 5
RFI Suppression Program	12	5 0	15	5 0	15	4 0	15	3 0	15	3 0	72	20 0
Common mm down-converter system	5	0 5									5	0 5
Spectrometer Upgrades	34	2 5		0 5							34	3 0
Rx and System Upgrades	10	1 0	50	1 0	50	1 0	50	1 0	50	1 0	210	5 0
Future Program												
Dynamic & Queue-based Scheduling				2 0		1 0					0	3 0
3 mm Rx Module 2 (90-116 GHz)			50	2 5	25	1 5					75	4 0
7 mm (Q-Band) Tertiary Mirror			50	1 0		0 5					50	1 5
Active Tertiary Optics System					50	3 0	50	2 0		1 0	100	6 0
Receiver Turret Rotator Upgrade			75	1 0							75	1 0
Beam Forming Array			50	4 0	250	6 0	250	6 0	50	3 0	600	19 0
Digital IF Preliminary Studies			20	0 5							20	0 5
3CAM Bolometer Array					250	6 0	1500	8 0	1500	8 0	3250	22 0
3 mm Focal Plane Array					100	3 0	400	6 0	50	6 0	550	15 0
Multibeam Spectrometer					50	4 0	250	5 0	200	5 0	500	14 0
Prime Focus HI Receiver			25	1 0	75	1 0					100	2 0
Total NRAO Internal Development	741	31 0	435	32 0	895	37 0	2530	35 0	1865	28 0	6466	163 0
University-built Instrumentation												
Penn Array Bolometer Camera	187	0 25		0 25							187	0 5
Caltech continuum backend	83	0 25		0 25							83	0 5
Future Projects											0	0 0
Wideband Spectrometer			125	1 0	200	1 0					325	2 0
Total University-built Instrumentation	270	0 5	125	1 5	200	1 0	0 0	0 0	0 0	0 0	595	3 0
Totals	1011	31 5	560	33 5	1095	38 0	2530	35 0	1865	28 0	7061	166 0

Footnotes

[1]Capital and FTE values for future projects are very rough estimates for planning projections only.

[2]Includes staff contributions from other Observatory units (Charlottesville & Data Management).

Very Large Array

The VLA is the most scientifically productive centimeter radio telescope in the world today. Figure IV.2 shows the number of refereed astronomical publications using the VLA and VLBA for the last decade. In a typical year such as 2003, about 700 scientists use the VLA for their research work. Roughly 10 percent of these scientists are students, making the VLA one of the world's premier tools not only for research, but also for educating and training the next generation of researchers.

Demand for the VLA arises both from the multiwavelength nature of contemporary astronomical research and from the flexibility of the telescope. Indeed, in recent studies of publication rates from various astronomical instruments, the VLA is second only to the *Hubble Space Telescope* in the number of refereed papers produced per year. It is widely recognized that radio observations provide unique insight into a variety of astronomical objects that may be used to complement the information gained with telescopes operating at visible, infrared, gamma-ray, or X-ray wavelengths; conversely, radio observations often provide a research focus which is complemented by data obtained at other wavelengths. The angular resolution, sensitivity and field of view of the VLA are generally similar or superior to those achievable with modern detectors at other wavelengths, allowing multi-wavelength observations to be merged with little ambiguity. For example, during 2004, we expect the VLA to play a major role in the identification and followup of new gamma-ray burst sources detected with NASA's *Swift* telescope.

Present Instrumentation

The VLA consists of twenty-seven, 25 meter antennas arranged in a wye configuration, with nine antennas on each 20 km arm of the wye. The antennas are transportable along a double rail track and may be positioned at any of 72 possible stations. In practice, the antennas are rotated among four standard configurations, which provide maximum baselines of 1, 3, 11, and 36 km. Additional "hybrid" configurations with a long northern arm are used to provide optimal sampling of sources in the south. Reconfigurability provides the VLA with variable resolution at fixed frequency or fixed resolution at variable frequency.

The VLA supports eight frequency bands which, generally, can be remotely changed by means of subreflector rotation. (The 74 MHz system consists of dipoles that are mounted periodically for short campaigns, then removed, due to minor impact on the aperture efficiency at some of the other frequencies.) The following table summarizes the current parameters of the VLA receiving systems. The VLA has full polarization capability in all continuum and spectroscopic bandwidths ranging from 50 MHz to 195 kHz. Within certain total bandwidth limitations, 512-channel spectroscopy is supported in all bands.

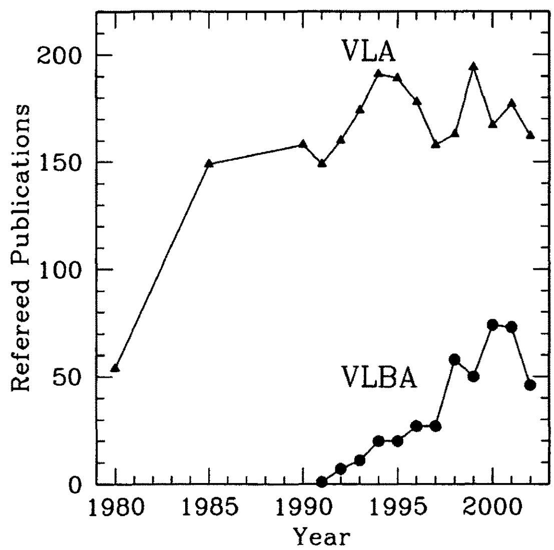


Figure IV.2 Refereed publications per year for the VLA and VLBA, for selected years since 1980.

Table IV.3 VLA Receiving Systems

Frequency (GHz)			T_{sys} (K)	Amplifier
0.070	to	0.075	1000[1]	Bi-Polar Transistors
0.308	to	0.343	150	GaAsFET
1.34	to	1.73	33	Cryogenic HFET
4.5	to	5.0	45	Cryogenic HFET
8.0	to	8.8	31	Cryogenic HFET
14.4	to	15.4	108	Cryogenic GaAsFET
22.0	to	24.0	55[2]	Cryogenic HFET
40.0	to	50.0	95	Cryogenic HFET

[1] T_{sys} includes galactic background.
[2] Two antennas still have systems with T_{sys}(K) = 160K as of August 2003.

Ongoing Operations

Over a number of years, the amount of scientific observing time used on the VLA has remained very stable at 76 percent or 77 percent of the number of hours in a year. The amount of lost time during these scientific observations also has remained quite constant, at about 4 percent of the number of scheduled antenna-hours. During 2004, we expect a slight reduction in the availability for scientific observing due to the demands of the VLA Expansion (EVLA) Project. In particular, two antennas will be used for prototyping EVLA equipment, and will mean that the VLA may be restricted to only 26 observing antennas rather than 27 for a substantial part of the year. In addition, since VLA/VLBA Operations is contributing a significant number of personnel resources (more than 30 FTE personnel) to the EVLA project, the balance between development and maintenance is likely to change such that the antenna downtime increases slightly. We expect that the number of hours available for scientific observations still will be well above 70 percent of the hours in the year, and the downtime will be no more than 5 percent of the scheduled antenna-hours (in addition to the scheduled downtime of the EVLA prototype antennas).

In a steady state, the number of refereed papers published for VLA observations is about 175 per year, with only modest changes in this number since 1985. Indeed, the decade between 1993 and 2002 has seen 1,756 refereed papers published based in whole or in part on observations made with the VLA. The oversubscription rate for the VLA is expected to remain at a factor of 2-2.5, with larger oversubscriptions in particular parts of the sky in specific configurations. Three "large projects" have been recommended by an external committee reviewing proposals requesting more than 300 hours of observing, and all three will be started during FY 2004. We expect to allocate approximately 500 hours of observing to these projects during the year, about 7-8 percent of the total observing hours available. In particular configurations at some sidereal times, this will raise the oversubscription rate to a factor of 4-5, making it fairly difficult for the standard "small" proposals to be awarded observing time on the VLA.

The NRAO is implementing a new set of policies for "Rapid Response Science," which incorporates observations of known transients, exploratory science that does not fit normal proposal deadlines, and true targets of opportunity. These policies are intended to provide better response to rapidly moving developments in modern astrophysics, including instruments that are designed specifically to investigate the time domain (e.g., gamma-ray burst telescopes and optical-transient searches). In FY 2003, a committee of VLA and external scientists made a set of recommendations for changes in how NRAO handles this Rapid Response Science; the changes then were discussed by internal NRAO staff and the NRAO Users Committee, with only minor modifications to the initial recommendations. The new policies include an allocation of up to 5 percent of the VLA observing time for Rapid Response Science, with uniform procedures for proposals and more open summaries of observing time granted under this category. Implementation of the new procedures will take place as of the October 1, 2003, proposal deadline, at the beginning of FY 2004.

Ongoing Initiatives

Most of the initiatives being undertaken to improve the VLA actually are part of the EVLA Project, and will be conducted as such in 2004. Therefore, we comment only briefly on a number of the past initiatives that have been completed or are nearing completion.

High Frequency Systems

All 28 VLA antennas now have been instrumented at 43 GHz, completing a nearly decade-long project. As of August 2003, only two antennas remain to be equipped with new, lower-noise 22 GHz receiving systems. These remaining antennas are the two scheduled to be equipped as EVLA prototypes, and the new receivers will be part of the EVLA outfitting. We have nearly completed the program of 43 GHz holography, and subsequent panel-resetting, that provides aperture efficiencies above 30 percent at 43 GHz. However, the resetting of the panels on the primary reflector actually takes out errors in both the primary surface and the subreflector. Since the locations of the receivers around the feed ring are being moved as part of the EVLA Project, it will be necessary to redo the holography after the receivers are moved. For the sake of efficiency, we plan to wait until a number of antennas have been changed before restarting the holography program. Therefore, the efforts in FY 2004 largely will be confined to "clean-up" and confirmation of the results on the last few antennas to be equipped at 43 GHz.

IV. Facilities

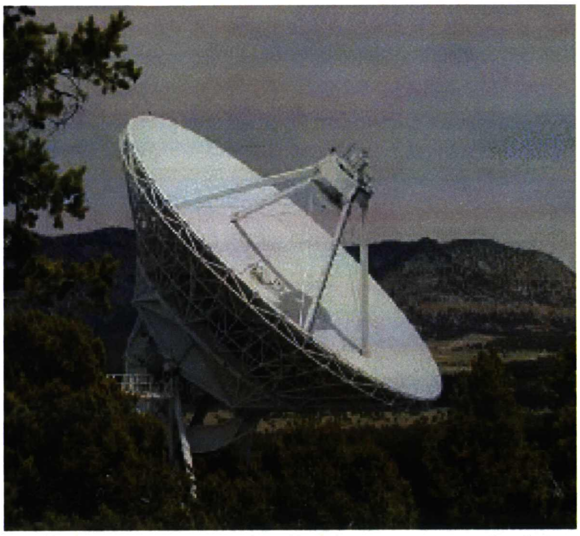


Figure IV.3 The Pie Town VLBA antenna, which has been connected to the VLA by means of wideband fiber optics.

Water Vapor Radiometry

In 2003, NRAO has completed the revamping of two prototype water vapor radiometers, installing them on two of the VLA antennas. Tests are under way to determine the benefits of using these radiometers to correct the phase of high-frequency interferometric data and extend the coherence time of VLA observations. We anticipate continuing with these tests only at a low level in FY 2004, which may result in enough data to make a decision about how to proceed. In general, this activity has been personnel-limited, and will continue to receive a lower priority than maintaining our operational status and EVLA development.

Contingency/Dynamic Scheduling

We will continue contingency scheduling of 22 and 43 GHz observations as possible during the early part of FY 2004. By midyear, we anticipate the availability of a prototype for dynamic scheduling on the VLA, which will be used on a test basis for the remainder of the year. This prototype is expected to evolve toward fully dynamic scheduling of observing blocks for the EVLA.

Low Frequency Systems

A program to upgrade the low-frequency documentation was begun in 2002, and scheduled to be completed in 2003. However, this upgrade depended on contributions from postdoctoral researchers with other career priorities, and has fallen somewhat behind schedule. New web-based documentation for the 1.4-GHz band was made available in 2003, but the documentation for the 74 MHz and 330 MHz bands has not been completed. We anticipate that little work will be carried out in this area during FY 2004.

Pie Town Link

The VLBA Pie Town antenna (Figure IV.3) has been connected as a real-time active element of the VLA under funding through a Major Research Instrumentation proposal to NSF, with matching funds from Associated Universities, Inc., and incorporating a fiber optic connection completed by the Western New Mexico Telephone Company. This link doubles the effective resolution of the VLA; Figure IV.4 below shows the aperture-plane coverage achieved by adding Pie Town to the VLA for a complete synthesis of the galactic supernova remnant Cassiopeia A. During 2003, the Pie Town link was offered again in the May-September time period. It will not be offered in FY 2004, because the 16-month VLA configuration cycle means that the largest VLA configuration, the A configuration, will not be available during the year; the Pie Town link is useful only with the largest VLA configuration. We anticipate offering the Pie Town link again early in FY 2005, with subsequent use dependent on the progress and requirements of the EVLA Project.

VLA Data Archive

Over the course of the late 1990s, we completed a project to transfer all raw archival astronomical data ever taken with the VLA onto 8 mm data cartridges. An on-line search capability was implemented to permit astronomers to find data that they might want as a function of a wide variety of observing parameters, such as frequency band, configuration, and sky position. Access to non-proprietary data has not been immediate, but has required NRAO personnel to copy the data from the archive tapes to another tape or disk file for export. Because of demands on staff time some requests for particularly large data sets could not be fulfilled. Despite these difficulties, there were at least 25 refereed papers published in 2002 that made use of the VLA archive.

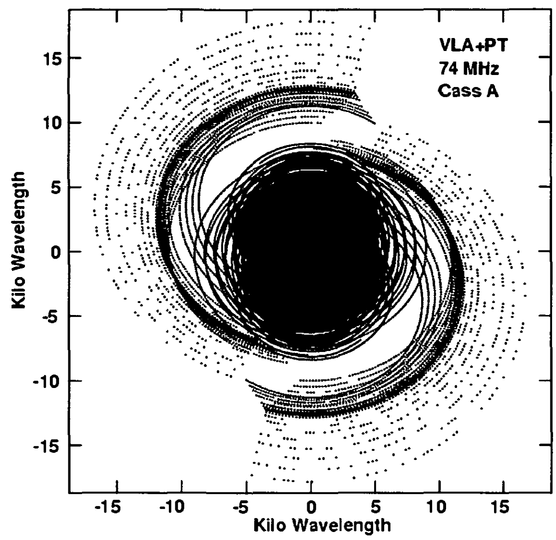


Figure IV.4 Aperture plane coverage for the VLA with the Pie Town link in operation, for a 12-hour synthesis of Cassiopeia A, using the 74 MHz receiving systems at the VLA and at Pie Town. The inner dark region shows the synthesized aperture of the VLA alone, while the outer, more sparsely covered region shows the benefits of adding a single additional antenna at Pie Town. The maximum baseline lengths and imaging resolution are approximately doubled in both the north-south and east-west directions.

During FY 2003, we are coming to the close of a project in which all the VLA archive data have been copied to a Storage Area Network, and will be available electronically via the Web. Access to this on-line archive will be turned on early in FY 2004, making more than a quarter century of VLA data available immediately by electronic means. We anticipate that this will result in a dramatic increase in the use of the VLA archive as a resource for many different astronomical purposes. Given the large amount of data and the uncertainties in interpreting the intentions of the original observers, there are no plans to calibrate the data retroactively. Still, the raw data alone will be a major resource, and the availability of this archive may well be the most significant new VLA capability for users in FY 2004.

Software

A number of new capabilities were added to the Astronomical Image Processing System (AIPS) software in 2003; this is the software used by virtually all astronomers to calibrate their VLA data, and by more than 95 percent for any subsequent imaging and self-calibration cycles. Examples of the new capabilities include the filling of data from disk files, necessary to make use of the on-line

VLA archive, and a number of improvements in wide-field imaging capabilities. In addition, AIPS was ported to the MacIntosh OS X operating system, as requested by a number of our users. In FY 2004, the small AIPS group will concentrate predominantly on supporting users with installation and bug fixes. The annual frozen release of the software will take place at the end of December 2003, and frequent upgrades and bug fixes will be made available via the standard "midnight job." As resources permit, code will be overhauled to improve its overall structure and longevity, and a few new applications will be added (e.g., new troposphere correction algorithms are scheduled for completion).

The AIPS++ software continues to be developed, primarily for the EVLA and ALMA. However, existing VLA data are used for much of the testing and debugging of the AIPS++ package, which also enables some new capabilities such as combination of VLA data with single-dish (GBT) data sets for mosaicing. Performance metrics for AIPS++ will continue to be improved, using comparisons to the processing time for the same data sets in the existing AIPS package. Critical milestones for the international ALMA project in FY 2004 will be dependent on the continuation of a robust development and testing program making use of a suite of VLA data sets obtained in a wide variety of observing modes.

JObserve— a new program for scheduling VLA observations—is a Java-based replacement for the OBSERVE program that has been used at the VLA for many years. It incorporates a more modern user interface, as well as the features necessary to schedule the VLA-Pie Town link; JObserve has been used to schedule all the Pie Town link observations in the first three operational link sessions. A web-based JObserve Cookbook was made available in FY 2003, and a few remaining bugs were corrected. In view of the efforts to produce new end-to-end software for the EVLA, which would include experiment scheduling, we expect only limited improvements to JObserve in FY 2004 and subsequent years.

VLA monitor and control was turned over to a set of newer on-line computers in 2002. Current work on the monitor and control system, including replacement by a modern monitor and control system, is under control of the EVLA Project. Included in this effort is the requirement that both "old" antennas and those with "new" EVLA electronics be able to work together with each other and with the old correlator. During FY 2004, we expect that the prototyping of EVLA electronics will be complete, and the conversion of VLA antennas to the new electronics will begin. Therefore, it will be essential that the EVLA monitor and control effort continue on schedule in FY 2004, in order to maintain the ongoing operability of the VLA for its scientific users.

Infrastructure

A number of infrastructure projects were completed or nearly completed in 2002 and 2003. At the mission requirements budget, routine infrastructure maintenance will be carried out in 2004. Some of the more visible efforts are mentioned below:

- In FY 2003, the survey to increase the density of VLA calibrator sources at 43 GHz moved forward; the number of calibrators now totals 1,860, most of which are usable at 43 GHz. This increase in calibrator density is aimed at a goal of having a mean calibrator separation of 3 degrees on the sky, in order to permit adequate capabilities for imaging target sources in almost all directions. This program to increase the calibrator density was completed in FY 2003.
- During FY 2003, we completed a project to install filters that permit observation in the OH band at 1610.6-1613.8 MHz, in the presence of the adjacent strong signals from the Iridium satellite constellation. Documentation was provided for the use of the filters. No further effort is planned for FY 2004.
- In 2001, a program was begun to install new encoder systems to improve the pointing performance of the VLA antennas, specifically reducing errors that are periodic as a function of angle. In 2002, a technique was developed to retrofit antennas in the field, rather than waiting for them to cycle through the Antenna Assembly Building. As of this writing in August 2003, 22 antennas had been completed, and tests show that the cyclical pointing errors have been reduced well below the overall goal of 6 arcsecs for blind pointing accuracy.

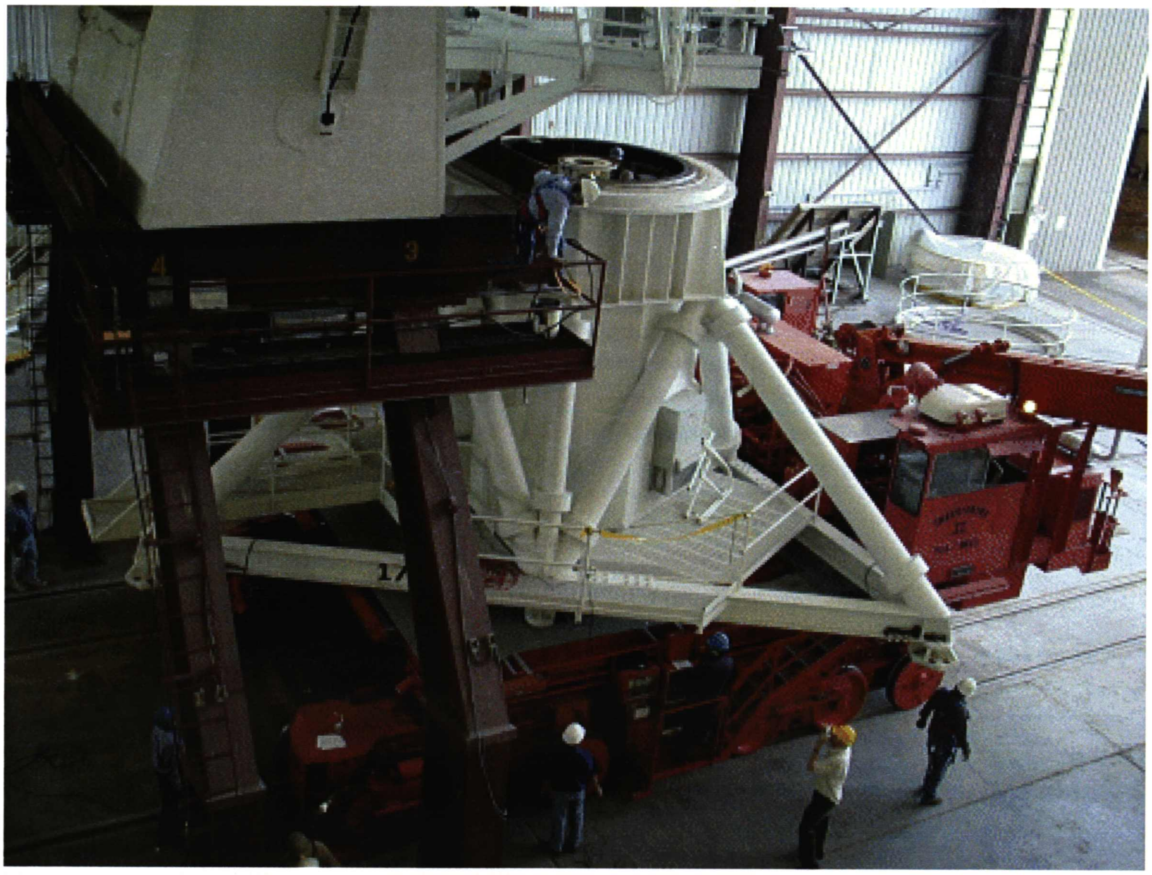


Figure IV.5 Antenna transporter removes the lower half of a VLA antenna, containing the azimuth bearing to be replaced, from underneath the support structure holding the top half of the antenna.

- The bad azimuth bearing on Antenna 15 is scheduled for replacement in August 2003, making this the seventh VLA azimuth bearing to be replaced. (Last year's Program Plan erroneously reported that seven, rather than six, bearings had been replaced previously.) Figure IV.5 shows part of the delicate procedure used for replacing an azimuth bearing. There are at least four additional antennas which show significant metal flakes in their grease, necessitating bearing replacement. We anticipate that one or two of these bearings will be replaced in FY 2004, depending on budget level. If bearings are replaced before they have deteriorated too badly, they can be re-worked at a cost of less than $25,000 and reused in the array. If the deterioration is too great, then new bearings must be obtained at a unit cost of approximately $45,000.
- In 1998, an internal inspection of the VLA track system found one-third of the railroad ties to be past their service life; an external consultant has recommended a 20-year program of 5000 tie replacements per year. Infrastructure funding in 2001 enabled the purchase of a three-year supply of ties and ballast (approximately one ton of ballast is required for every tie replaced).
- During FY 2003, the program was slowed somewhat due to lack of personnel resources (temporary laborers were not hired for a six-month summer stint, as a cost-saving measure). This means that the current supply of ballast and ties will suffice for FY 2004, although the average rate of tie replacement over the four years from 2001 through 2004 will amount to only 4,000-4,500 ties per year, lower than the rate recommended by the consultant. Thereafter, an annual infusion of $300,000 for materials, plus more than $100,000 for labor, would be required in order to maintain a rate of 5,000 tie replacements per year. Over the long term, failure to maintain the track could require discontinuing the use of the **A** (largest) configuration, as a safety measure.
- Repainting of the 28th (and last!) VLA antenna was completed in FY 2003. Only spot painting repairs are anticipated for FY 2004.
- Due to EVLA retrofits, we likely will slow the rate at which antennas are cycled into the Antenna Assembly Building for routine maintenance. We expect that the major maintenance rate will be reduced from about eight antennas per year to about four per year, since the nominal EVLA budget will support modification of only four antennas per year.
- The beginning of the EVLA and ALMA projects, and the consequent large increase in NRAO personnel in New Mexico, has resulted in a situation in which the work space at both the Array Operations Center and the VLA site are filled to capacity. The AOC has already accommodated more than thirty additional people since early 2002, and the total increases from 2001 through 2006 may be as many as seventy people. In FY 2004 it is essential that we acquire additional temporary office space, which must be available by April 2004 to accommodate the summer student program. We have budgeted funds for acquiring office space for 10-15 additional employees in Socorro. The VLA site needs an additional 5,000 square feet of covered work space which is not now in the budget for FY 2004.

Expanded Very Large Array

The Very Large Array is the most productive radio telescope ever built. Because of its combination of sensitivity and flexibility, it has been used by thousands of astronomers from every continent for research that spans the entire breadth of modern astronomy. Yet the VLA is limited in its ability to address the key questions of twenty-first century astrophysics. The antennas, site, array layout, and infrastructure—the most expensive components of any array—are fundamentally sound, and will remain so for as long as the array is maintained. But the electronics on which the data transmission and processing are based, the heart of the instrument, has not been changed since the array's commissioning 25 years ago. The modern data transmission and signal processing technologies that are key elements of the EVLA Project will increase the observational capabilities of the telescope by an order of magnitude or more, providing the power demanded by the scientific requirements.

The VLA Expansion Project's principal technical requirement is to improve the array's observational capabilities by an order of magnitude or more. This will be done by: (I) adding new frequency bands, (ii) upgrading or replacing current receivers, (iii) replacing the data transmission system and correlator, and, (iv) connecting two VLBA antennas into the array and incorporating new antennas at locations between the VLA and the VLBA. In addition to these, new and more powerful on-line computing will enable better access to the array's data products, and will give a much improved interface with users.

The effect of these planned improvements and enhancements on the array's capabilities are comprehensive, as listed below:

- The continuum sensitivity will increase by an order of magnitude or more in several bands.
- Continuous frequency coverage from 240 MHz to 50 GHz will be obtained.
- The bandwidth that is transmitted from the antennas, and processed by the correlator, will increase by a factor of 80, from 200 MHz to 16 GHz.
- The maximum number of spectral channels available, and the maximum frequency resolution, will increase by a factor of over 500.
- The resolving power will increase tenfold.
- The new instrument, when cross-linked with the VLBA and with new antennas located about 50-300 km from the VLA, will greatly enhance the VLBA's dynamic range, field of view, and frequency scalability.

The impact on astrophysics of returning the VLA to the state-of-the-art will be profound. Many severe limitations now constraining VLA observations will be removed or greatly relaxed.

A short selection of unique experiments made possible includes:

- Measuring the three-dimensional structure of the magnetic field of the Sun.
- Using the scattering of radio waves to map the changing structure of the dynamic heliosphere.
- Measuring the rotation speeds of asteroids.
- Observing ambipolar diffusion and thermal jet motions in young stellar objects.
- Measuring three-dimensional motions of ionized gas and stars in the center of the Galaxy.
- Mapping out the magnetic fields in individual galaxy clusters.
- Conducting unbiased searches for redshifted atomic and molecular absorption lines.
- Looking through the enshrouding dust to image the formation of high-redshift galaxies.
- Disentangling starburst from black hole activity in the early universe.
- Providing direct size and expansion estimates for up to 100 gamma-ray bursts every year.

- Measuring the parallaxes of pulsars as far away as the Galactic Center.
- Imaging thermal objects such as stars and novae with milliarcsec resolution.

The expanded VLA will open a vast area of "discovery space," which is currently inaccessible to any instrument. We can expect that, as with the original VLA, it is likely that the most important discoveries to be made will be those that cannot now be foreseen.

The VLA Expansion Project comprises two major components, Phase I - an upgrade of the existing VLA and Phase II - the New Mexico array and other enhancements.

Phase I

This phase of the project concentrates on improvements to sensitivity, frequency availability, spectral capabilities, and improved on-line computing. The major components are:

- A new correlator, able to support 32 antennas, to process broadband signals and to provide vastly improved resolution and flexibility for spectral line work.
- A fiber optic data transmission system to transmit the broadband signals and monitor data from the antennas to the control building, replacing the original waveguide.
- New on-line computers, operating software, archiving and end-to-end data management software, to enable more powerful and flexible interaction between the telescope and the operators and observers.
- Improved receivers with lower noise temperatures and much wider bandwidth performance (up to 8 GHz in each polarization channel) in existing bands; addition of 2.4 GHz and 33 GHz bands at the Cassegrain focus. The goal is to provide continuous frequency coverage from 1 GHz to 50 GHz in eight frequency bands from the Cassegrain focus.

In May 2000, the NRAO submitted to the NSF a proposal to fund Phase I of the VLA Expansion Project. The proposed plan was for a project which would last nine years, at a total cost of $76M. Of this, $50M would be new funding from the NSF, and the remainder would come from expected operations funds redirected to support the project, and from contributions from foreign partners. After review, the EVLA Management Plan was submitted to the NSF in September 2001, and the National Science Board approved the project for construction on 14 November, 2001. The funding profile approved by the NSB spanned 11 years, which will result in work being completed in 12 years.

Progress in FY 2003 continued to be good. A major update of the WBS and Schedule was completed in the third quarter of FY 2003. The overall budget plan shows that the remaining contingency funds are 15 percent of the remaining expenditures. The EVLA baseline cost and FY 2003 earned value predictions, required for GPRA reporting, were submitted to the NSF.

VLA Antenna No.13 was taken out of service in April 2003 to be the EVLA Test Antenna. It has now been modified and brought out of the Assembly Building to be seated on the master pad. The work of outfitting is proceeding and the first feed has been inserted into the new feed cone structure. Installation of the optical fiber cables on the antenna has been done, and some of the new electronics racks will be installed soon. A functioning receiver will be installed by the end of FY 2003. Astronomical source tracking and first fringes are expected in the second quarter of FY 2004.

Installation of the fiber optic cable along the arms of the VLA is now more than 50 percent complete. The initial installation was along the west arm. With the completion of that section the effort moved to the east arm, and after passing through the rocky terrain near the station AE8, the work is nearing completion.

A scaled model of the large L-band feed was constructed and tested successfully, demonstrating that good feed performance over the wide 2:1 bandwidth required by the project is attainable. The machine for making the L-, S-, and C-band feed rings was completed, a necessary step in the preparation of the many feeds required for the full array. Bench prototypes of most of the LO modules were completed, and tests of the prototype Down Converter continued. Construction of an integrated version of the Down Converter, using MMICs and surface mount components, was begun.

With Canadian funding for the correlator secured, work continued by the Canadian Partners on the detailed design of the correlator. One important focus of the work was on the issue of whether to build the prototype correlator using Field Programmable Gate Arrays, as originally planned, or to bypass the FPGA step and develop the final Application Specific Integrated Circuit for the prototype correlator. The final decision on this issue will be made early in FY 2004.

Planned Activities for FY 2004

The budget approved by the National Science Board for FY 2004 for the EVLA is $ 5434 k. These funds will support the following activities:

- Continued installation of the fiber optic cables along the arms of the array.
- Testing of the new EVLA electronics and monitor and control (M/C) software system on the EVLA Test Antenna (VLA Antenna No. 13) to determine the adequacy of the design of the new system.
- Start of the production of the new EVLA electronics systems.
- Start of the routine installation of the new EVLA electronic systems onto VLA antennas.
- Construction of a prototype subset of the EVLA correlator in preparation for testing on the VLA in 2005 (this work will be done by the Canadian partner and is not contingent on NSF funding).

Phase II - the "New Mexico Array"

This phase of the project will expand the resolution of the array by a factor of 10 by:

- Adding eight new antenna stations at distances of up to 300 km from the array center, to provide now unavailable baselines between those in the VLA and those in the VLBA.
- Adding fiber optic links between the VLA and the inner VLBA antennas, and between the VLA and the additional new stations.

In addition, other enhancements will include:

- Implementation of an improved low frequency capability, which will provide frequency coverage from ~240 MHz to 1 GHz.
- Addition of stations for a compact E-configuration with baselines less than ~300 meters, to be used for imaging extended low-surface-brightness objects.

A proposal is now nearly completed for submission to the NSF. It is expected that activities in FY 2004 will focus on providing such information as the NSF requires to complete its review and assessment of the proposal.

Very Long Baseline Array

Present Instrumentation

The VLBA is an instrument devoted to very long baseline interferometry (VLBI), with ten antennas distributed throughout the United States in a configuration which optimizes the distribution of baseline lengths and orientations. It is the only such dedicated VLBI instrument in the world. The VLBA has baselines between 200 and 9000 km, which provide angular resolution as fine as 0.1 milliarcseconds at 86 GHz. The shorter baselines, and hence the highest concentration of antennas, are near the VLA for optimal joint observations. The antennas are 25 meters in diameter and of an advanced design which allows good performance at 43 GHz and useful performance at 86 GHz. Table IV.4 summarizes the performance of the instrument at its ten frequency bands. The antennas are operated remotely from the Socorro Array Operations Center; local intervention is required only for tape changes, routine maintenance, and troubleshooting. In 2003 we celebrated the tenth anniversary of operations with the VLBA.

The VLBA correlator is located at the Array Operations center (AOC), and is able to correlate as many as eight input data channels from each of 20 antennas simultaneously. For most modes, the correlator can provide 1,024 spectral points per baseband channel, and up to a maximum of 2,048 spectral channels per station or baseline can be provided for each recorded signal. In order to join its long baselines with the shorter baselines of the VLA and perform high-sensitivity imaging over a wide range of scales, increased bandwidth is critical for the VLBA. This will require a substantially increased capability for VLBA correlation, which can probably be done most cost-effectively by an expansion of the EVLA correlator hardware now under development.

Table IV.4 VLBA Receiving Systems

Frequency Range (GHz)			Typical Zenith SEFD[1] (Jy)	Typical Zenith Gain (K Jy^{-1})
0.312	to	0.342	2217	0.097
0.596	to	0.626	2218	0.090
1.35	to	1.75	295	0.093
2.15	to	2.35	325	0.094
2.15	to	2.35[2]	344	0.089
4.60	to	5.1	289	0.132
8.0	to	8.8	299	0.118
8.0	to	8.8[2]	391	0.111
12.0	to	15.4	543	0.112
21.7	to	24.1	976	0.104
41.0	to	45.0	1526	0.078
80.0	to	96.0[3]	3500	0.030

[1] System Equivalent Flux Density: The source flux density which doubles the system temperature.
[2] With dichroic.
[3] All except Brewster and St. Croix installed. Two antennas only cover the frequency range up to 90 GHz.

Ongoing Operations

For several years the amount of scientific observing time used on the VLBA has remained fairly stable at about 55 percent of the number of hours in a year. In part this is because of the tape-limited data transfer to the correlator. For those observing programs which require the highest continuum sensitivity the current tape technology is not able to support observations twenty-four hours per day at the largest bandwidth, so that when such an observation is run the array is shut down for part of each day. The other limitation arises because of the small number of antennas. Losing one antenna from the VLBA reduces the number of baselines by 20 percent, whereas losing one antenna from the VLA reduces the number of baselines by only 8 percent. The VLBA is scheduled dynamically, and the observations sometimes are canceled if the weather or hardware conditions preclude the use of one or two antennas. Such canceled observations are not counted as lost time, but are subtracted from the number of hours that are scheduled for scientific observations.

Issues of cost and capability to maintain the VLBA recording and playback systems remain critical, due to the increased obsolescence of the magnetic tape technology and the lack of commercial vendors who produce or repair the required equipment. Figure IV.6 shows one of 24 playback drives

Figure IV.6 A VLBA tape drive, showing one of the many magnetic recording tapes currently in use at the VLBA. One tape holds approximately 590 Gb of data, corresponding to just over 10 hours of recording at 128 Mbits/sec. The original cost of each tape, together with its glass reel, was about $1,300, while the headstack assembly costs roughly $12,000.

attached to the VLBA correlator; an additional 24 recording drives are present at the ten VLBA sites, the VLA, and the GBT. Each of these drives relies on a headstack assembly which has only a single supplier and costs approximately $12K; between 8 and 12 of these assemblies need replacement each year. Pending funding, we have a goal of changing over to more modern disk-based recording technologies over the next three years, and eliminating the dependence on tapes. This would result in increased reliability, reduced maintenance costs, and the ability to observe for a larger fraction of the hours in a year. More details are discussed below, as part of the "Ongoing Initiatives."

The observations for two large VLBA proposals which were recommended by the Skeptical Review Committee began in FY 2003. One program involves measurement of pulsar parallaxes, while the other is a long-term monitoring program of the structure of active galaxies at 15 GHz. Both programs will receive a considerable amount of observing time during FY 2004.

As usual, the VLBA will continue to participate in the Global VLBI observing sessions that are carried out three times per year. By using antennas in the U.S. and Europe together, the opportunity arises for increased sensitivity and twice the resolution that could be achieved with either the U.S. or Europe alone. Proposals for Global VLBI observations are submitted separately to NRAO and to the European VLBI Network (EVN), refereed separately by the VLBA and EVN referees, with time allocated by joint decision between the VLBA and EVN program committees. During FY 2004, the three Global VLBI sessions will take place in October/November 2003, February 2004, and May/June 2004.

In FY 2003, we instituted a program of running a set of weekly monitoring observations of all VLBA frequency bands, exercising the most commonly used observing modes, as a way of performing regular end-to-end systems tests. This enabled us to begin a program of automated release of most observations to the scientific investigators, without the previous time-consuming process of validation of each specific experiment. Results of this program will be evaluated in FY 2004, and an assessment will be made of whether increased reliability and operational efficiency have resulted.

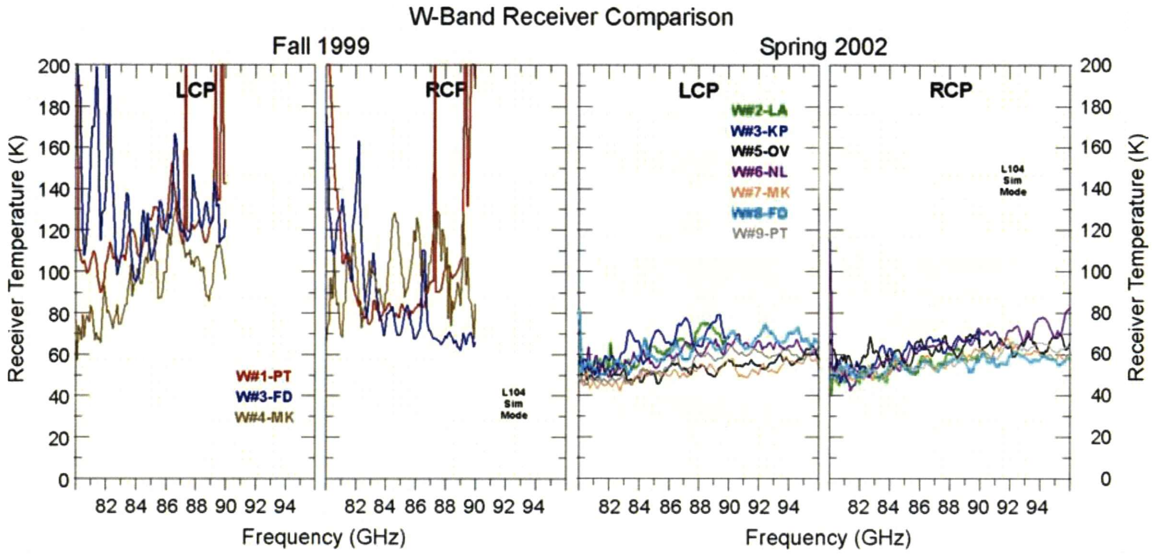


Figure IV.7 A comparison of the performance of an 86 GHz receiver before (Fall 1999) and after upgrading (Spring 2002).

Ongoing Initiatives

High Frequency Systems

The major new frequency capability being developed for the VLBA over the last several years has been the addition of 80-96 GHz receivers (usually referred to as "86 GHz") to most of the antennas. This has been funded partly out of the NRAO operating budget and partly by the Max Planck Institut fur Radioastronomie (MPIfR). Presently, only eight antennas are equipped; the wet weather at St. Croix and the poor subreflector at Brewster mean that it is not worth spending the money to equip either antenna at present. Significant efforts have been made to improve the 86 GHz receiving systems over the last several years; the improvement is shown in Figure IV.7.

During 2001, the NRAO began an effort on a local holographic system to improve the antenna surfaces with the goal of increasing the 86 GHz aperture efficiency to 25-30 percent. The first measurements were done on the Pie Town antenna, but measurement of the other antennas, as was planned for FY 2002, could not be completed because of resource limitations. It is likely that the different VLBA antennas, in fact, have different relative contributions to surface error due to the alignment of the primary panels and the shape of the subreflector. In 2002, a precision device was purchased to measure subreflector shapes mechanically in the lab. During 2003, this machine was used to assess the shape of the "spare" subreflector, which then was resurfaced manually (Figure IV.8) and installed on the Pie Town antenna. To date, tests have not shown the improvement in high-frequency aperture efficiency that was expected based on the "before and after" measurements of the subreflector, possibly due to alignment problems on the antenna. In the latter half of 2003, we will rework the subreflector that came off the Pie Town antenna, with an aim of replacing the subreflector at Brewster in FY 2004. However, this change will be made only if we are able to achieve the expected improvements with the subreflector presently on Pie Town. Since the key scientist working on the alignment and holography initiatives is likely to be needed on the pilot program for spacecraft navigation, we expect slow progress (at best) in this area during FY 2004.

Figure IV.8 An antenna mechanic manually re-surfaces the spare VLBA subreflector to improve its high-frequency performance.

An effort is under way to resurrect "global" 86 GHz VLBI experiments, which previously were carried out under the auspices of the Coordinated Mm VLBI Array (CMVA). Provided that an agreement is reached in late 2003, we expect to schedule two global sessions of 4-7 days in length, one in April 2004 and the other late in FY 2004 or early in FY 2005. Coordination will be carried out jointly by NRAO and MPIfR.

All highly rated, pending, observations at 86 GHz were allocated telescope time over the winter of 2002/2003. We are now considering several new programs that were rated quite highly by NRAO's external referees, and we plan to allot them considerable observing time over the winter during FY 2004.

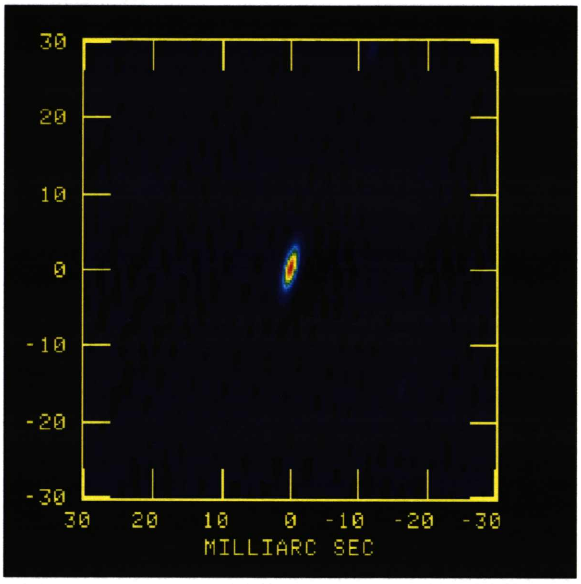
Dynamic Scheduling

The fraction of VLBA observations scheduled dynamically has continued to increase, particularly since NRAO participation in the VSOP Space VLBI mission has ended. In FY 2004, the VLBA will participate in the "Rapid Response Science" program that was described in the section on VLA operations, with up to 5 percent of VLBA observing time dedicated to such science. This will actually require little perturbation on current VLBA operations, since the large percentage of time which is now dynamically scheduled means that there are many open slots in the nominal schedule that can be used to insert observations under the new Rapid Response program.

IV. Facilities

Spacecraft Navigation Pilot Program

The NRAO has negotiated an agreement to carry out a pilot program to assess the feasibility of angular navigation of NASA's interplanetary spacecraft using the VLBA in a phase-referencing mode. A few preliminary experiments were carried out in FY 2003 (Figure IV.9), and demonstrated enough potential that a full-scale pilot program (funded by NASA) now is planned, to be carried out primarily in FY 2004. This pilot program will involve observations of several NASA spacecraft at 8.4 GHz (the standard spacecraft downlink frequency). Determination of the accuracy that can be achieved, the elimination of any biases in positional measurements, and the development of a scheme for possible operational support of the NASA spacecraft all need to be done. In addition, plans will be developed for implementation of a 33 GHz receiving capability on the VLBA to support the future spacecraft communication frequency. Finally, there will be a study of implementation of a disk-based recording system that would enable rapid data return and correlation, in order to support the short turnaround time required by NASA.



VLBA image at 3.6cm of STARDUST spacecraft at 2.2 AU

Figure IV.9 VLBA image of NASA's Stardust spacecraft, obtained as part of a preliminary demonstration of a VLBA spacecraft tracking capability.

If the pilot program is successful, NRAO, NSF, and NASA may decide to move forward with the project in the years following FY 2004. This likely would include installation of 33-GHz receiving systems and Mark 5 disk-based recording systems on the VLBA, as well as a commitment of observing time to the NASA projects.

VLBI Recording Systems

All VLBA stations (as well as the VLA and the Green Bank Telescope) were equipped with a 512 Mbits-per-second observing capability by mid-2001. This feature is used fairly rarely due to the limitations of the present magnetic tape system, discussed above in the section on "Ongoing Operations." During 2002, the NRAO has invested in a "Mostly Off The Shelf" (Mark 5) disk-based recording system under development at Haystack Observatory, and interferometric fringes were obtained in 2003, using a prototype system at the Pie Town VLBA station. The rest of the VLBI world, including the European VLBI Network and the geodetic community, is moving rapidly into implementation of the Mark 5 systems.

The cost for hardware to move to a complete disk-based recording system, including units at the VLBA stations and correlator, the VLA, and Green Bank, is now estimated at about $600K, down from an estimated $800K one year ago. This estimate does not include the cost of recording media,

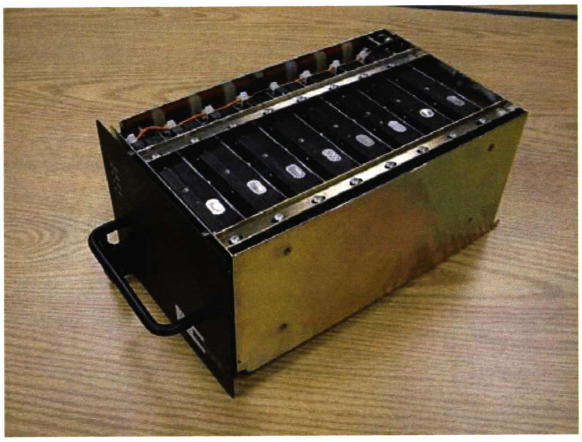


Figure IV.10 Mark 5 disk pack, which could replace magnetic tapes for recording of data from the VLBA. A disk pack similar to the one displayed here, containing currently available 160 Gbyte disks, would contain more than twice the data of a standard VLBA tape. Two such packs containing 800 Gbyte disks would permit continuous recording for more than 24 hours at a rate of 1 gigabit per second.

which has decreased quite significantly in the last several years. The current cost of disk is about $1 per gigabyte, comparable to the tapes presently used on the VLBA. If the cost per gigabyte of the disk systems drops to 30 cents, as is projected by 2005 or 2006, with an average recording rate of 1 Gb per second (increasing the VLBA continuum sensitivity by a factor of 2-3), and the current observing efficiency and turnaround, the cost of the disk supply would be between $1.5M and $2.0M. One of the goals is to operate the VLBA at 1 gigabit per second for 24 hours, with no tape changes required at the stations. This would require individual disks within the Mark 5 systems with capacities that approach 800 gigabytes; such disks are not yet available commercially. Figure IV.10 shows a Mark 5 disk pack, containing eight disks that would be used and shipped as a unit in the disk-based recording system.

The complete cost of moving to a Mark 5 system is estimated to be more than $3.0M. It does not appear that funds for this will be available from NRAO's operating budget in the next two years. However, it is possible that the Mark 5 system will be required for navigational support of NASA spacecraft, as described above, and therefore might be funded from NASA through this program.

Software and User Support

A new version of the Sched software was released; this software is used for planning and scheduling VLBA observations. In FY 2004, we anticipate changes in Sched that will enable improved scheduling of spacecraft observations and handling of disk-based recording systems.

We have continued the practice of calibrating data from selected VLBA continuum observations in an AIPS pipeline, distributing these data to the observers, and archiving the calibrated data. Due to the effort on automated release of VLBA monitoring observations, progress to expand the service to a broader spectrum of observations was not as fast as expected in FY 2003. The pipeline should handle observations incorporating a single VLA antenna in late 2003, and expansion to some spectral-line data sets now is expected to occur in FY 2004.

Operational software that controls the correlator and its playback drives will be modified in FY 2004 in support of the spacecraft navigation pilot project. As part of this effort, it is also possible that the software used for keeping track of the VLBI data-recording tapes will be upgraded to support tracking of Mark 5 disk packs and ancillary hardware as well.

VLBA Data Archive

VLBA correlator output data are being loaded into an on-line archive similar to that described for the VLA. At present, only data from observations in 2002 and later is present. In general, VLBA data sets are much larger than VLA data sets, due to the inherently larger number of spectral channels output by the VLBA correlator. We expect that the current observations and calibrated data (see above) will be filled into the archive as data are correlated, but the larger requirements for storage space imply that older data will be added to the archive only rather slowly during FY 2004. In total, the archive of VLBA data since its 1993 dedication amounts to about 12 Terabytes, while the increment of new data plus pipeline products now is about 4 Terabytes per year.

Infrastructure

Significant infrastructure developments during FY 2003 and planned for FY 2004 are discussed below. At the level of the NSF budget request, most of the hardware activities such as regular antenna maintenance visits will be put on hold. This ultimately will lead to serious failures, and will change the philosophy from the normal "proactive" maintenance stance to one of being "reactive" to serious failures. Major infrastructure activities, and the ability to carry them out within the level of the NSF budget request, are discussed below:

- Observations of additional VLBA calibration sources near the galactic plane were carried out in 2001 and 2002. During 2003, the final astrometric analysis of these observations took place, and the new sources were added to the VLBA calibrator list. No significant effort is expected in this area in FY 2004.
- The VLA program to monitor potential VLBA polarization position angle calibrators has continued, and now is used routinely to provide regular feedback on VLA antenna performance along with the primary use of enabling better VLBA polarization calibration. It was expected that these scripts would be translated into AIPS++ in FY 2003, but that translation has been put on hold in order to concentrate on specific EVLA and ALMA deliverables within AIPS++.
- Management of Los Alamos National Laboratory (LANL) has requested that the VLBA antenna be moved from its present location in LANL Technical Area 33, due to increased classified activities in the vicinity. During FY 2003, possible alternatives were considered, and a cost estimate of $3.5-4.0M was derived for moving and re-erecting the antenna. The preferred option for NRAO is to move the antenna to the Corona/Vaughn area, southeast of Albuquerque; in fact, this antenna location is now an important part of the planning for the New Mexico Array of EVLA Phase II. In FY 2004, an effort will be made to identify funding for this move, and planning will begin. We anticipate that no move will take place before FY 2006. However, any move of the antenna will put one VLBA station out of commission for 6-12 months, and eliminate 40 percent of the baselines shorter than 1000 km during that period. This will have a huge impact on the imaging and scientific capability of the VLBA during the antenna downtime.
- In 2002, a project was initiated to replace VLBA tape drive headstack assemblies with a new flexible circuit card, in order to reduce the high failure rate experienced with the current head assemblies. That failure rate leads to significant hardware and personnel costs for frequent repairs. This project has been deferred, and is likely to be cancelled completely if prospects are good for replacing the current tape drives with disk-based recording systems.

IV. Facilities

- NRAO staff typically make major maintenance visits to three or four VLBA antennas each year. During FY 2003 we are visiting St. Croix, Kitt Peak, and North Liberty. Major maintenance visits should continue at the usual level in FY 2004, with visits to three or four other VLBA sites.
- The first St. Croix visit in FY 2003 revealed significant metal fragments in the grease samples extracted from an elevation bearing of the VLBA antenna. Given the non-zero possibility of catastrophic failure, a second visit was scheduled to the St. Croix site, and the bearing was replaced in late July. Upon inspection, the failure mode of the bearing proved to be virtually identical to a failed elevation bearing at Los Alamos, which was replaced in FY 2001. As this report is being written, the possibility of a preventive maintenance program to replace the elevation bearings at the other VLBA antennas is under discussion. Such a program would cost roughly $40K per antenna, including personnel costs, and also requires jacking each antenna up for several days to replace the bearing, which carries its own risks. A decision will be made in late 2003 about how aggressively to pursue a program of preventive replacements.
- The second axle on the Los Alamos azimuth drive assembly failed in mid-2002 and was replaced (the other axle was replaced in 2001). The ultimate cause is unclear, although there is speculation that the axles are nearing the end of a projected 20-year lifetime. We consider it prudent to investigate all the axles more carefully in order to determine whether there is a design or construction flaw, or a finite lifetime. We have developed a plan for inspection and ultrasonic testing of these axles, which would require an investment of $10K in hardware, and trips to all VLBA sites. Replacement of the 16 axles not previously replaced would cost $160K for hardware, plus personnel and travel costs. This program is on hold due to insufficient funding.
- Fall arrest and apex guardrail protection is being added to VLBA antennas to protect our workers while performing maintenance tasks on subreflector focus/rotation mounts. Three VLBA telescopes were retrofitted in 2003, leaving only Fort Davis remaining to be done in FY 2004.
- The grout that distributes the weight of each antenna from its azimuth rail to the concrete foundation is deteriorating at several VLBA sites. Sections of the azimuth track showing poor rail support can be repaired in a labor-intensive process of replacing the existing, crumbling grout with a higher quality material. Rail grout repairs were completed at the Los Alamos and North Liberty sites in 2002. The azimuth rails at Mauna Kea and Pie Town are in immediate need of repair; given the mission requirements budget used in this plan, we expect at least to repair the Pie Town grout in FY 2004.
- The azimuth track at St. Croix has been deteriorating significantly due to rust caused by the high ambient humidity that is always present at that site. In FY 2003, the previous rail coating and large quantities of rust were scraped off this track, and the track was coated with a rust inhibitor commonly available on St. Croix. This appears to have restored the track and arrested the rust problem; the state of this repair will continue to be monitored during FY 2004.

IV. Facilities

Facility Software Development

A new software group, the EVLA Computing Division, has been created. This division will be responsible for all aspects of EVLA software development, including those EVLA-specific activities formerly housed in the end-to-end project within Data Management. The Interferometry Software Division, formed earlier in FY 2003, incorporates Integrated Product Teams in areas such as post-processing software, data pipelines, data archives, and proposal handling. In order to ensure that the more specific focus on the EVLA Project is well coordinated with other NRAO telescopes, and enhances the long-term developments that are important for all of NRAO's telescopes, a chief architect for the Interferometry Software Division has been appointed, reporting directly to the co-leads of the Interferometry Software Division. His duties will include guiding the efforts of Integrated Product Teams in data flow and data management areas as well as in the development of the Virtual Observatory. An immediate goal in FY 2004 is to develop a common proposal handling facility for EVLA and GBT. Eventually the coordination of this effort with ALMA should be explored to ascertain if it is feasible to present a common interface to the user.

Some of the software development has been described in the previous sections dealing with the individual telescopes. The focus here is on the software with a broader application.

The end-to-end (e2e) development originally was envisioned to address issues in proposal submission and handling; dynamic scheduling of the telescopes; pipeline processing, especially of data from interferometric arrays; data archive; and virtual observatories. The end-to-end project no longer exists as a separate entity. However, the unifying philosophy of the individual components is being actively addressed within different groups. A key part of the e2e strategy has been to capitalize on the similarities between the different telescope systems and to coordinate development where possible.

Proposal Submission and Handling

It is desirable to have a unified process to handle scientific proposals for all telescopes from submission, refereeing, evaluation, and scheduling through to association of proposals with corresponding observational data in an archive. There are specialized processes for initial proposal handling for the present instruments (VLA, VLBA, GBT). However, with the development of new instruments (ALMA, EVLA), there is an opportunity to coordinate the development of a standard set of utilities to help streamline and complete the process of proposal handling. Two prototypes (one for VLA/EVLA/GBT and one for ALMA) are currently being developed. The ALMA proposal-handling tool is a responsibility of the European part of the ALMA Project, making common initial development somewhat difficult. However, it would be advantageous to unify proposal handling across NRAO by the time EVLA and ALMA come online.

Dynamic Scheduling

In the future, all instruments will need to be able to respond more quickly to changing observational environments (e.g., to respond to changing climatic conditions or to avoid radio frequency interference). There is an opportunity to coordinate the development of strategies to adapt to prevailing conditions and to allow for insertion of important targets of opportunity. We have considerable experience with dynamic scheduling of the VLBA over the last several years, and are applying that experience to the development of a pilot system for use on the VLA.

Pipeline Processing

Although radio astronomy instruments have not traditionally applied automatic data quality and data processing algorithms to observed data, the production of reasonable quality standard data products (spectra, reference images, or combinations thereof) will be a requirement for the operation of all new telescopes. Such a capability would also help observers with our existing instruments. Development of an automated pipeline processing capability is in progress now on the ALMA project, and we plan to make the modifications and additions to this capability necessary to enable support of the EVLA. Initial testing of the pipeline facility will be done using data from the existing VLA.

Data Archive

Although observed telescope data has been readily available for years, the NRAO has had no unified science data archive for all of its instruments. As was described in a previous section, such an archive is now almost complete, and it is scheduled to be released in the first quarter of FY 2004. It will provide access to all data ever observed by the VLA, plus the last few years of VLBA data. All data from the GBT since early in 2003 except those from some very high data rate observations (e.g., certain pulsar observations) are also being archived. As new data are observed, they will be automatically ingested into the archive and, after a proprietary period, made universally available. It is important that this effort be continued and expanded in scope to support the higher data rates expected from the more modern instruments, and to enable the archive to eventually become a significant resource for multi-wavelength research via the Virtual Observatories initiative.

Virtual Observatories

Scientifically, it is becoming increasingly important to compare observations made with different instruments and at different wavelengths and energies. The virtual observatory projects are mandated to provide such access. The NRAO is a partner in both the domestic National Virtual Observatory (NVO) project and the International Virtual Observatory Alliance (IVOA). Present activities are mainly on standards development, especially concentrating on those needed for radio astronomy data storage formats and access methods.

V. Central Development Laboratory

Cooled HFET Development

The NRAO has worked on the development of HFET (heterostructure field-effect transistor) amplifiers for many years and is the recognized leader of cooled HFET amplifiers for radio astronomy use. The highest frequency amplifiers cover the band 68-116 GHz with noise performance comparable to SIS mixers and much wider instantaneous bandwidth.

The NRAO has produced hundreds of advanced HFET amplifiers for use on NRAO telescopes and for others in the radio astronomy community and other research areas. These range from low-frequency amplifiers (for <1 GHz) used in fundamental particle physics and magnetic resonance imaging development to the highest attainable frequencies for cosmic microwave background experiments. At the lowest frequencies, special balanced amplifiers have been developed which largely eliminate the need for bulky isolators and have better immunity to the effects of interference.

The current total production rate for all amplifiers of all types is approximately 90 per year; this rate may drop by 20 percent in 2004 due to a technician's retirement, but it will still be adequate to provide for the needs of all NRAO instruments, including the EVLA. We will continue to produce amplifiers for these needs and a few selected non-NRAO institutions as time permits.

InP amplifiers incorporating in their first stage devices from the so-called Cryo3 wafer are now in regular production. These achieve world record noise temperatures, as given in Table V.1. For most bands, amplifier noise is now a minor contributor to system noise temperature.

In 2003, SIS mixers developed for ALMA Band 3 (84-116 GHz) and Band 6 (211-275 GHz) were interfaced to refined versions of the InP low-noise IF amplifiers, resulting in world-record bandwidth and noise performance (see details below).

Continued production of InP 18-26 and 40-50 GHz amplifiers has enabled completion of the upgrade of the VLA at K-band and Q-band. InP amplifiers for 18-26 GHz have been produced for use in upgrading the original K-band receiver for the GBT, and will go into use in Fall 2003. InP amplifiers for 26-40 GHz have been produced for the Ka-band receiver for the GBT. Additional such amplifiers will be produced as time permits for eventual use on the EVLA.

A major effort was expended to implement the existing device models and designs into a modern, commercial CAD environment, Microwave Office. This implementation will facilitate the future design, modification, and presentation format of amplifier designs and simulations. Work continues on the evaluation of Cryo3 devices and their application in designs covering the 1-2, 2-4, 4-8, 12-18, 40-50, and 75-118 GHz frequency ranges.

V. Central Development Laboratory

Table V.1. Current NRAO Production Amplifiers

Band (GHz)	Name	Noise (K)	Comment
0.3-0.4		2.0	Balanced
0.4-0.5		2.0	Balanced
0.5-0.7		2.0	Balanced
0.7-0.9		3.0	Balanced
0.9-1.2		3.0	Balanced
1.2-1.7	L	3.0	
1.7-2.6	L/S	4.5	
2.6-4.0	S/C	5.2	
3-13	X	2.5	InP
8-18	Ku	4	InP
18-26.5	K	7	InP
26.5-40	Ka	8	InP
36-50	Q	10	InP
65-90	V	45	InP
68-116	W	31-50	InP (3 variations)

Millimeter-Wave Receiver Development

The design and fabrication of SIS (Superconductor-Insulator-Superconductor) mixers covering parts of the frequency range 68-720 GHz are done by CDL engineers in collaboration with the Semiconductor Device Laboratory at the University of Virginia, whose ability to provide rapid turnaround of new designs is crucial to the development effort. Mixers have been produced not only for ALMA applications, but for other radio astronomy organizations as well. The noise temperatures now being attained in laboratory receivers are only 3 to 6 times the photon temperature *hf/k*, so in many cases the dominant noise sources are external to the mixers.

A new elemental mixer optimized for ALMA Band 6 (211-275 GHz) and for use in an integrated mixer-preamp was designed and fabricated at the University of Virginia foundry. Initial tests of this design were performed in February 2003. The prototype mixer shows the lowest noise temperature yet achieved with a wideband IF for ALMA band 6.

This mixer chip has been incorporated into a sideband-separating design which is expected to be the final configuration for the ALMA Band 6 receivers. The Band 6 mixer is shown in Figure V.1. The first production mixers will be extensively tested in 2004.

A new SIS mixer for ALMA Band 3, 84-116 GHz, has been designed and tested. This is expected to be the elemental mixer used by the Herzberg Institute in Canada for the Band 3 receivers. We have achieved 8 GHz bandwidth with good noise temperature with a 4-12 GHz IF over 84-116 GHz RF, using the InP discrete transistor amplifier described earlier (see Figure V.2). In 2004, we will continue to work closely with HIA, rendering assistance in meeting the ALMA performance goals for Band 3.

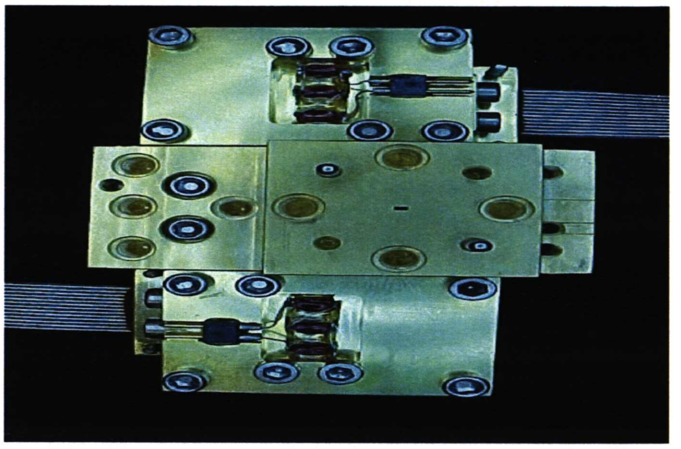


Figure V.1 The new ALMA band 6 sideband-separating mixer, shown above at approximately true size. The ALMA performance specification is 78K over 80 percent of the band 211-275 GHz, and this unit meets that specification.

Emphasis on developments for ALMA strongly brings to attention the need to improve the speed at which SIS mixers can be built and tested. At present, it is possible to produce one fully tested SIS mixer in approximately two months, given all the workloads of existing personnel. For ALMA, we must achieve about two SIS mixers *per week* during the construction phase. For this reason, new techniques for assembling and automating the testing of SIS mixers must be developed, and this process which began seriously in 1998 continued throughout 2003. Good progress toward this goal has been achieved and will be further improved during 2004, including placing performance optimization under computer control. A new test dewar dedicated to ALMA Band 6 production mixers is nearly completed and will be used throughout 2004.

The ALMA receivers must meet a difficult goal of achieving excellent performance in single-dish total-power observing mode, as well as working well in interferometer mode. Work has begun on evaluation of the total power stability of SIS receivers with wide IF bandwidth, and this will be carefully pursued in 2004 in order to characterize performance.

Another area of receiver development is the ALMA Band 6 cartridge, a plug-in assembly which is a complete dual-polarization SIS mixer receiver including optics, SIS mixer-preamps, local oscillator, and IF outputs. These semi-autonomous cartridges will plug into the dewar and be integrated with the rest of the receiver assembly to constitute a complete front end package. Detailed design of the cartridge has now been completed (see Figure V.3), and prototype components have been fabricated for the skeleton, mirrors, etc. In 2004, a prototype cartridge (see Figure V.4) will be completely assembled and tested in a dedicated cartridge test dewar.

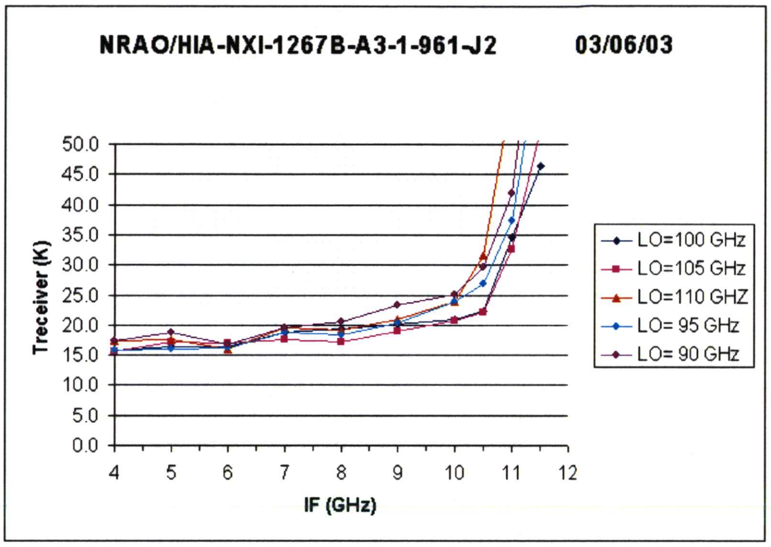


Figure V.2 Performance of the elemental 84-116 GHz SIS mixer-preamp. Double-sideband noise temperature as a function of IF frequency for several LO frequencies is shown. The increase in noise at the upper end is due to decreasing gain above 10 GHz of the preamp used and can be decreased. With a 4-8 GHz IF band (proposed by HIA), the ALMA LO range will be 92-108 GHz.

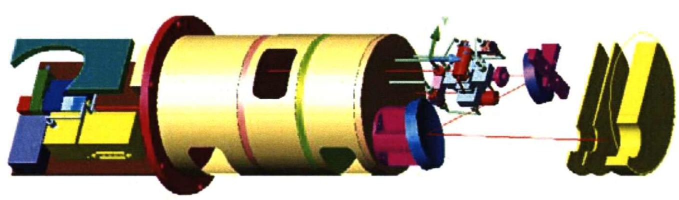


Figure V.3. Band 6 cartridge layout. The beam enters the dewar from the left, is reflected by two mirrors, and enters the feed, which is followed by an orthomode transducer and two SIS mixer-preamps. The local oscillator source is at the left (outside the dewar) and drives high frequency multipliers hidden within the cartridge body. Supporting brackets have been omitted for clarity.

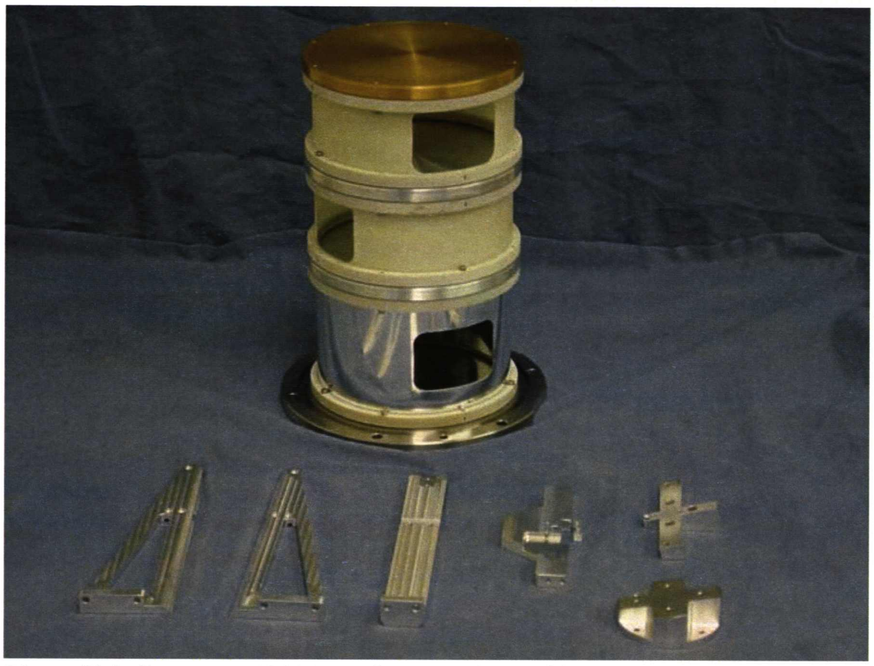


Figure V.4. Prototype ALMA Band 6 cartridge and brackets.

Electromagnetics

Wider band amplifiers and mixers require wider band supporting elements. The CDL has designed and tested several new components with the goal of having receiver performance limited only by the bandwidth of single-mode waveguide. A new orthomode transducer (OMT) and phase shifter to convert between dual linear and dual circular polarization were produced in quantity over the last few years for the VLA K-band receivers, now completed. A phase shifter for the 26-40 GHz band has been designed and tested which will be used on the GBT and EVLA, and is also suitable for adding this band to the VLBA.

New feeds are required for the EVLA bands below 18 GHz and for 26-40 GHz, and design and optimization work is in progress. A prototype of the L-band feed, scaled to C-band (4-8 GHz), was built and tested. It was measured to have cross-polarization levels in the range of -18 dB to -23 dB above 7.2 GHz. This is not quite as good as is desired, and the excess cross-polarization may be due to the oversized rectangular waveguide attached to the feed that is used only for measurement. The cross-polarization levels in this type of feed should be below -25 dB. Further work is planned before fabrication of the first real L-band feed. A 26-40 GHz feed has been designed and will be tested in 2004.

For the GBT, in order to reduce the leakage through the thermal gap in the Ku-band (15 GHz) receiver, a photonic crystal structure was designed using Finite Difference Time Domain software. The return loss of the gap with this structure is predicted to be better than -30 dB, and the leakage into the gap is lower than -25 dB. However, the illumination beam of the main reflector, derived from far-field maps at 12 GHz and 22 GHz, showed asymmetry in the pattern. Theoretical calculations are being conducted to study this effect and will be completed in 2004.

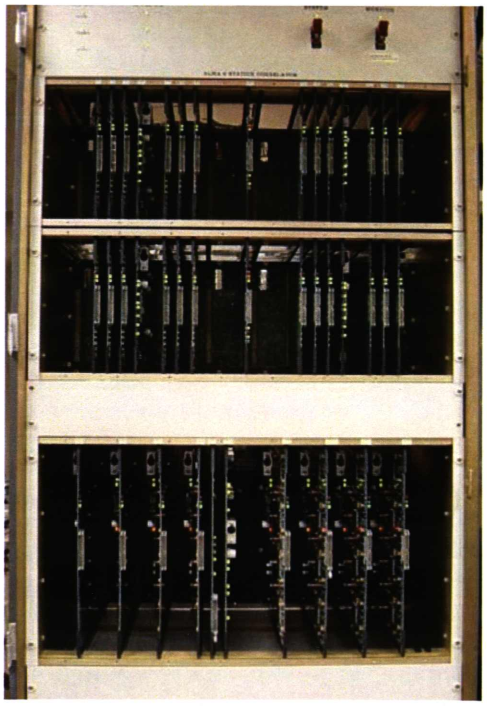
Digital Correlators

Design work on the ALMA correlator is nearly complete, and a prototype two-antenna correlator has been built and tested (Figure V.5). The correlator schedule is not expected to be a limiting factor in getting first operational use of ALMA.

An enhanced-performance digital filter card has been designed as an alternative to the original design used in the 2-antenna prototype correlator. This new filter uses a polyphase filter algorithm to provide multiple frequency band outputs rather than just a single filter. This permits more efficient use of the cross-correlation resources with no other changes in the hardware architecture. The net result is that the frequency resolution for the widest bandwidth operation can be increased by a factor of up to 32, greatly improving the speed at which wide bandwidth survey-type observations can be performed. Table V.2 shows the improvements with the new filter. The performance of the original filter for each bandwidth is the same as the entry with number of filters equal to 1.

The enhanced performance, of course, comes at the expense of an increased output data rate, which must be accommodated by the data processing system. However, it appears that the new filter can be built for about the same cost as the original design, and it is anticipated that the new filter may be selected if further studies show that it is feasible to implement this new design.

In 2004, the first quadrant of the correlator, capable of handling up to 16 antennas, will be built and tested, with delivery to Chile scheduled in mid-2005.



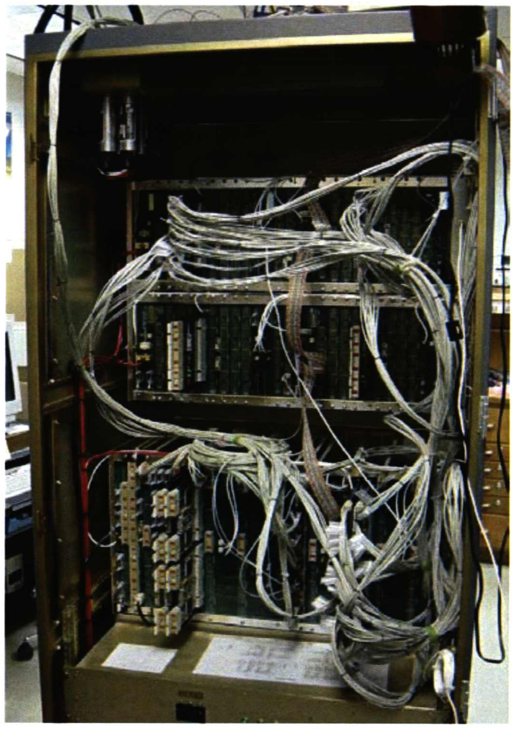


Figure V.5. Two-antenna ALMA prototype correlator rack front and rear views. Only half the interconnecting cables are installed in the rear view, for clarity.

CORRELATOR PERFORMANCE WITH ONE QUADRANT, TWO BASEBANDS, NO CROSS PRODUCTS

BANDWIDTH PER BB	FILTER BANDWIDTH	NUMBER FILTERS	SPECTRAL POINTS PER FILTER (1 BB)	FREQUENCY RESOLUTION	ONE SECOND DUMP RATE
2 GHz	2 GHz *	1	128	15.6 MHz	4.2 MBYTE/SEC
2 GHz	1 GHz	2	128	7.8 MHz	8.4 MBYTE/SEC
2 GHz	500 MHz	4	128	3.9 MHz	17 MBYTE/SEC
2 GHz	250 MHz	8	128	1.9 MHz	34 MBYTE/SEC
2 GHz	125 MHz	16	128	976 KHz	67 MBYTE/SEC
2 GHz	62.5 MHz	32	128	488 KHz	134 MBYTE/SEC
1 GHz	1 GHz	1	256	3.9 MHz	8.4 MBYTE/SEC
1 GHz	500 MHz	2	256	1.9 MHz	17 MBYTE/SEC
1 GHz	250 MHz	4	256	976 KHz	34 MBYTE/SEC
1 GHz	125 MHz	8	256	488 KHz	67 MBYTE/SEC
1 GHz	62.5 MHz	16	256	244 KHz	134 MBYTE/SEC
500 MHz	500 MHz	1	512	976 KHz	17 MBYTE/SEC
500 MHz	250 MHz	2	512	488 KHz	34 MBYTE/SEC
500 MHz	125 MHz	4	512	244 KHz	67 MBYTE/SEC
500 MHz	62.5 MHz	8	512	122 KHz	134 MBYTE/SEC
250 MHz	250 MHz	1	1024	244 KHz	34 MBYTE/SEC
250 MHz	125 MHz	2	1024	122 KHz	67 MBYTE/SEC
250 MHz	62.5 MHz	4	1024	61 KHz	134 MBYTE/SEC
125 MHz	125 MHz	1	2048	61 KHz	67 MBYTE/SEC
125 MHz	62.5 MHz	2	2048	30 KHz	134 MBYTE/SEC
62.5 MHz	62.5 MHz	1	4096	15 KHz	134 MBYTE/SEC

* ANALOG FILTER

Table V.2. Performance of the correlator with the enhanced digital filter.

V. Central Development Laboratory

Millimeter-Wave Local Oscillators

The LO requirements for the ALMA receivers include all-electronic wideband tunability, low amplitude and phase noise, sufficient power to drive SIS mixers, high reliability, and low cost. This precludes the use of the traditional second-harmonic Gunn diode oscillators followed by frequency multipliers employing whisker-contacted diodes which are used in most millimeter receivers. ALMA has decided on a baseline plan of LO multiplier chains using YIG-tuned oscillators (YTO), amplifiers, and frequency multipliers, with a photonic reference for phase-locking the YTOs using two phase-locked lasers. We have demonstrated that the phase noise, amplitude noise, and harmonic content of such driver chains, using high-power MMIC amplifiers developed by JPL and by the NRAO, are satisfactory for use in an interferometer.

In order to provide enough power to drive the final frequency multipliers for some bands, large amounts of power near 100 GHz are required. A series of MMIC power amplifier chips using both GaAs and InP technologies has been designed and delivered by the UMS and HRL foundries. Large cost savings are possible using a combination of commercially available and custom amplifier and frequency multiplier MMIC chips for producing the driver signal to the final power amplifier stages. Such integrated driver blocks (warm multiplier assemblies) have been prototyped and tested, and pre-production versions will be built and incorporated into the prototype receiver cartridges in 2004.

In order to filter out unwanted harmonics of the YTO, it was necessary to design special filters for each stage of multiplication; an example is shown in Figure V.6 below.

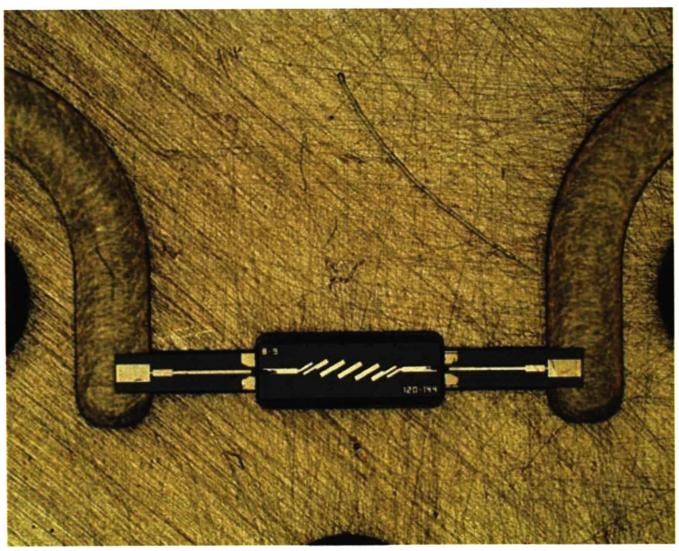


Figure V.6. Detail of a 120-144 GHz Waveguide harmonic filter. The filter section consists of the multiple diagonal strips in the center. The distance from tip to tip of the waveguide probes is 6.5 mm.

V. Central Development Laboratory

New frequency multipliers have been developed in collaboration with the University of Virginia. Design suggestions from NRAO personnel have resulted in a series of varistor-mode high-frequency multipliers by a commercial company, Virginia Diodes Inc. These multipliers appear to have adequate power output for use in ALMA Bands 6 and 7 (no final multiplier is needed for Band 3). Pre-production units for use by ALMA cartridge designers will be delivered in 2004.

For ALMA Band 9 (602-720 GHz), the GaAs-on-quartz technology of Virginia Diodes, Inc. has so far produced marginal LO power unless the driver power is increased by at least a factor of two above what we have planned. This could, in principle, be done by power combining the outputs of two or more MMIC power amplifier chips (which we have already demonstrated); however, this would result in increased cost and heat dissipation on the back of the cartridge. Therefore, as a backup to the Virginia Diodes designs, and in case there are problems with reproducibility or lifetime in a cryogenic environment, we are continuing to work on MMIC frequency multiplier designs for critical higher frequencies, in collaboration with JPL. JPL has produced for the Herschel instrument several narrower-band high frequency multiplier designs with high power output, and we are investigating a collaboration to produce wider-band designs for ALMA bands 8, 9, and 10. This work will continue throughout 2004.

Other Electronic Developments

In addition to use in power amplifiers for the ALMA local oscillator chains, other electronic designs may benefit in performance or cost by using integrated MMIC designs tailored to specific requirements. These include ultra-wideband low noise amplifiers for receiver front ends, second-stage IF amplifiers, high frequency mixers, and amplifiers for down conversion of IF signals to baseband prior to digitization. Some such special designs have been undertaken for the EVLA project, and in 2004 we will undertake design studies (and possibly fabrication in collaboration with JPL) of various such components.

There are also a number of performance issues for radio astronomy receivers, such as gain stability, radiometer performance, and bandwidth, which may be treated by use of novel approaches and devices. In 2004, we will study a number of these issues, such as possible use of heterostructure bipolar transistors (HBT's) to improve 1/f gain fluctuations, use of novel materials for SIS mixers, and relatively inexpensive array receiver configurations using HFET or SIS mixer front ends.

Future Directions

The year 2004 will be one of partial transition from development focused closely on ALMA to longer-term research and development. ALMA SIS mixer-preamp and local oscillator work at the CDL has resulted in laboratory performance which meets specifications. The ALMA effort is now concentrated on moving from an R&D phase to production prototyping, and in the following year a further transition to volume production will occur. As ALMA enters that phase, its need for research personnel will diminish, and time will be available for new projects. In the analog domain, a primary thrust will be planning and early development of superconducting materials with higher critical temperatures and band gap energies for SIS mixers, which in theory should lead to receivers with significantly better noise temperatures, particularly above ~700 GHz. Other exciting possibilities include SIS fabrication techniques which may result in much easier and more reliable assembly (meaning lower cost), high frequency array receivers for the GBT, and the incorporation of MMIC devices into front end electronics for new capabilities and reduced production costs. In the digital domain, possible new projects include extremely wideband spectrometers suitable for use with multi-pixel spectral line front ends. Other R & D activities which have been in progress will continue, including development and initial production of new wideband InP amplifiers for the new EVLA observing bands and further work on the optics for EVLA and GBT receivers.

VI. Division of Science and Academic Affairs

Introduction

In mid 2003, the Division of Science and Academic Affairs (DSAA) was created at NRAO. The purpose of this new division is to provide a more coherent framework for the scientific and academic activities of the Observatory and especially to facilitate interactions with the U.S. university astronomy community. Special emphasis will also be placed on the stimulation of scientific research at NRAO sites. A number of existing activities (see below) will be incorporated within the DSAA.

A number of existing committees will be coordinated by the DSAA, including the Observatory Science Council, a committee to advise the director of NRAO on scientific issues, and the Observatory Committee on Tenure and Appointments (OCTA).

New activities will include the coordination of NRAO-sponsored conferences and the planning of joint university-NRAO meetings, the coordination of external proposals originating from the NRAO scientific staff, and the introduction of NRAO-wide colloquia. The Division will assist in the assignment of telescope time, a responsibility which the NRAO takes very seriously. It will ensure the NRAO facilities are used in the best possible way to advance science and astronomy. An advisory committee for the DSAA was established during the course of 2003; this group will continue to evaluate the status of the DSAA activities throughout 2004.

The Scientific Staff of the NRAO

The scientific staff comprises scientists with experience in different aspects of astronomy and astrophysics, in computer sciences, and in electronic instrumentation. A fraction of the time of each of the scientific staff is spent on personal research. By maintaining an active research interest, the scientist keeps abreast of the developments in her or his field of specialty, and is better able to maintain contacts with the broader user community. A fraction of the scientists' time is spent in direct support of Observatory programs. In addition a fraction of the time is devoted to service to the broader astronomical community, coordinating planning for new instrumentation, serving on review panels, and providing referee evaluations for publications and grant proposals. This division of effort is analogous to that of university faculty who devote time to research, teaching, university affairs and external service.

The scientific programs which are planned by the staff for FY 2004 are summarized in Appendix A. The members of the staff are listed in Appendix B. The major fields of astronomical and astrophysical research are well represented; many of the staff have strong backgrounds in radio astronomical techniques.

Science Support

The support needed by the Observatory spans a wide range of functions. One of the more demanding activities is the commissioning of a new telescope such as the GBT. The scientific staff work with the technical staff to debug the monitor and control system, to establish the calibration of the radiometers and to develop a model of the pointing corrections which must be applied in order that the telescope properly acquire and track radio sources at many frequencies. An essential project is measurement and alignment of the primary mirror in order that the telescope operate with maximum possible efficiency. The scientific staff also work very closely with outside observers in the early stages of testing new systems.

Operating telescopes require scientific support throughout their effective life. Each system needs continuing assessment of its performance, and scientific involvement is important as upgrades are designed, developed, and implemented. A recent example is the development of a real-time data transmission link between the Pie Town VLBA antenna and the VLA which doubled the effective angular resolution of the VLA in the A array. Another example is the improvement in the figure of the secondary mirror on one of the VLBA antennas, enabling a higher level of performance at 86 GHz.

The scientific staff also provides assistance to visiting observers, since the latter frequently have experience at other wavelengths and need an introduction to radio astronomy instrumentation. One component of this endeavor is assistance to visiting observers in the planning of new observations and in the analysis of the telescope data. In addition, the NRAO conducts orientation workshops in interferometry, and, with the Arecibo Observatory, in "single-dish" radio techniques. In each case the scientific staff serve as the faculty of the school.

New Initiatives

One of the roles fulfilled by the staff is to guide the Observatory in the design and development of new instrumentation. Often this instrumentation takes the form of an upgrade to instrumentation on an operating telescope. Examples of this might be a new spectrometer for the GBT, or an improved set of radiometers in the 22 GHz band for the VLA. However, a critical aspect of this role is in the specification and development of entirely new systems which are needed to meet the changing needs of the science. The recent examples of this are the EVLA Project and ALMA.

In the case of a major new initiative such as ALMA the process has taken many years. The first concept of a new mm array arose in discussions within the radio astronomy community in the early 1980's. The concept became more focused as the requirements for imaging at millimeter wavelengths emerged, and the NRAO, in collaboration with the user community, proposed to the NSF the Millimeter Array (MMA). The concept gained support in the decadal review for the 1990's. During this period the NSF realized that it would be appropriate for such a costly and major instrument to be organized and funded as an international project. The MMA project evolved into ALMA, and the ALMA project was approved for funding in 2002. During all of this period, members of the NRAO scientific staff contributed a portion of their time to developing the concept, and eventually the design. Studies were made of the configuration of the antenna elements, and searches and evaluations were made of prospective sites. The diameter of the antenna was critically evaluated, because of the impact on the cost of the antenna, the ability to make rapid changes in the antenna attitude, and the precision with which the surface and the pointing could be maintained.

VI. Division of Science and Academic Affairs

Working with the community, getting advice from selected advisory committees, and convening workshops on both technical and scientific issues were all an important function of the NRAO staff.

During the coming year the staff will continue to be heavily involved with the EVLA Project, and will work with the ALMA project staff. In the latter case one of the principal tasks will be to advise on the nature of the initial operations of ALMA.

The staff is currently involved in the early stages of four possible new initiatives. These are described in more detail in Section X. Two of them, RadioAstron and LOFAR, have a limited involvement of NRAO staff. A number of the staff will be working on the Square Kilometer Array (SKA), and a pilot broadband spectrometer for solar studies will be developed at NRAO on behalf of FASR in FY 2004.

Maintaining Association with the Scientific Community

The NRAO staff serve as a conduit by which the scientific community can maintain its connection to the NRAO. Staff personnel serve on advisory committees and review panels, give colloquia and invited talks, and attend meetings and workshops on a variety of topics. In these activities there is an opportunity for the external scientists to discuss with their NRAO colleagues the state of current instrumentation, the direction of current research, and the need for new techniques and instrumentation.

Library and Archives

Library

The primary mission of the National Radio Astronomy Observatory Library is to provide research support for the explorations of the scientists, engineers and students, to support the information needs of all NRAO staff, and, as the library of a national facility, to serve the wider astronomical community. This support is provided through collection development and document delivery. Collection development consists of identifying, purchasing and processing appropriate materials in a range of formats including paper, electronic, CDs, videos, DVDs, sky survey plates and observatory and institute publications from around the world. Ordering, billing, license negotiating and cataloging of materials are library activities; core items may be duplicated in several locations for immediate access by NRAO staff. Document delivery networks have been formed with other astronomy libraries to provide materials not in the NRAO holdings. The NRAO Library also supplies materials to other libraries under national and international interlibrary lending agreements.

The NRAO Library has collections and staff at several sites: Charlottesville (astronomy at Edgemont Road and engineering at Ivy Road), Green Bank, Tucson, and Socorro (main collection at the Array Operations Center and a small reference collection at the VLA site).

VI. Division of Science and Academic Affairs

Plans for 2004

The NRAO Library uses the InMagic integrated library management software for database and web provision. The new WebPublisher PRO release will be purchased and loaded. Existing databases will be made accessible via the new interface. The library web pages will be reviewed and upgraded as appropriate, to take advantage of the new interface capabilities.

The Edgemont Road building in Charlottesville is undergoing an expansion. Parts of the collection will be moved out of the main library area while that space is being upgraded. The Central Development Laboratory (CDL), currently located on Ivy Road, will be moving to new quarters in the building formerly occupied by the Institute of Textile Technology (ITT). The CDL engineering collection, now housed in two small basement rooms, will be reassembled and occupy one, larger, space. During 2004, library staff will work to supply books, journal articles, etc. requested by researchers, both from the in-house collections and from other libraries, when local collections are obstructed by moving and construction activities. The staff will manage the construction and moving disruptions so as to minimize delays in access, and will plan and oversee the reorganization and moving of library materials into the upgraded and expanded spaces.

The Library's large collection of publications from observatories and institutes is being processed and added to the online catalog. This project is about 50 percent complete and will continue into and possibly finish in FY 2004.

The Tucson facility will be phased out by 2006. During 2004, library staff will undertake an inventory of the collection which will form the basis for developing the plans for the future disposition of the library materials. Tucson holdings will be compared to CDL and other NRAO collections to identify unique items for redistribution. Dispersion of Tucson library materials will be phased to parallel the relocation of the ALMA staff to Charlottesville.

NRAO Archives

The intent of the NRAO Archives is to actively seek out, collect, organize, and preserve institutional records and personal papers of enduring value which document NRAO's historical development, institutional history, instrument construction, and ongoing activities, including its participation in multi-institutional collaborations. As the national facility for radio astronomy, it also is appropriate for the Archives to include materials on history and development of radio astronomy in the United States, particularly if such materials are in danger of being lost or discarded by other institutions or individuals. The Archives Office is new for NRAO, and significant time in the first year will therefore be spent in organization of the Office and in development of procedures, as well as in designing the Archives space in the Edgemont Road building addition. During the coming year, we plan to continue work on the web page of Nan Dieter Conklin's chronicle of her career as the first woman in US radio astronomy, to begin work on the cataloging of Grote Reber's papers, donated by him to NRAO, and to begin an inventory of the materials at the various NRAO sites which should eventually be included in the Archives.

VI. Division of Science and Academic Affairs

Educational Programs

Undergraduate Research Program

The NRAO has received a five-year continuation of the Research Experiences for Undergraduates (REU) program with the intention of having 18 NSF-sponsored students each summer. These students will be placed at one of the four NRAO sites in New Mexico, West Virginia, Virginia, and Arizona for a period of 10-12 weeks. While other activities take place during the summer, the main thrust of the summer program is the participant's research project. These projects are suggested by NRAO staff members in their area of expertise, and include all areas of astronomy as well as astronomical engineering and computing. Projects are entirely research oriented, including those of an engineering nature. The students are expected to contribute materially to the research they are assigned, and these contributions are often reflected in co-authorship on resulting papers. The NRAO is perhaps unique among the astronomy REU sites in the mix of students of various ranks and of teachers that participate in our summer program. This mix of graduate and undergraduate student interns working on research together, with additional help from NRAO pre-doctoral students, and oversight by Jansky post-doctoral fellows and staff advisers, gives students full exposure to life as an astronomer. Though much of the funding for this program has come from the NSF Research Experience for Undergraduates (REU) program, additional students are funded out of the NRAO operations.

The NRAO has also established a co-op program wherein undergraduate engineering students from participating institutions work at one of the NRAO sites for two (non-consecutive) semesters. The program allows students to acquire important technical skill sets by working under the supervision of the NRAO technical staff on problems at the technological forefront. The program is presently funded through the NSF Cooperative Agreement.

Graduate Education

Professional astrophysics is a multi-wavelength, problem-oriented discipline. Students entering the field need a wider range of skills than most college courses provide. To rectify this situation, and to train students in the techniques of radio astronomy specifically required for the individual student's research, two programs are available at the NRAO. First, summer student positions for graduating seniors, and first and second year graduate students are available. This allows students to gain experience in radio astronomical research early in their graduate careers, and to establish important skills as they embark on their thesis research. Second, NRAO staff scientists collaborate with university astronomers in the supervision of Ph.D. thesis projects. Awards are made to graduate students for residence at the appropriate NRAO site, taking data, reducing it and writing their thesis, all under NRAO guidance. This program is highly valued by faculty in universities unable to support this kind of position otherwise, and by NRAO staff for the excellent student interaction it generates.

In addition to graduate summer students, and to resident graduate students, more than 100 Ph.D. students make observations with NRAO telescopes each year. Short stays of one to three weeks at the site, travel reimbursement, and computing facilities are provided to assist any students using NRAO facilities.

Postdoctoral Education

Postdoctoral appointments are given Jansky Research Associate positions with a term of two years that may be extended for a third year. In the selection process recent graduates are given preference over those applying for a second postdoctoral position. Jansky research associate appointments are available not only to radio astronomy students but also to recent Ph.D. recipients in engineering and computer science.

Jansky fellows formulate and carry out investigations either independently, or in collaboration with others within the wide framework of interests of the Observatory. Two types of appointments are made (I) in-residence Jansky fellows and (ii) traveling fellows. Both types receive a discretionary research budget. The in-house fellows are located at any of the NRAO sites, and traveling fellows are located at U.S. research institutions. An annual Jansky symposium is held at the NRAO to foster interaction among the fellows and with the NRAO staff. The Jansky program has been designed to prepare the fellows to assume leadership positions in the U.S. astronomical community, and to promote the health of radio astronomy in the U.S.

The selection of Jansky fellows is by a committee made up of scientists both from the NRAO and from other U.S. research institutions. An annual review is held to evaluate the progress of the fellows.

VII. Computing and Information Services

Overview

The mission of Computing and Information Services (CIS) is to provide for an optimum computing and network environment for the users of NRAO telescopes, for the operation of those instruments, and for the development of new facilities. CIS sets policies and standards in this area, and coordinates relevant activities across the Observatory. CIS supervises the maintenance of all computer equipment and software observatory-wide, and maintains a budget to provide these services.

The sites and projects (Green Bank, Socorro, Tucson, ALMA) each have a computing division which is charged with providing local support and which reports to the local site director or project manager, as appropriate. Operational funding for them is through the sites and projects. The Observatory Computing Council comprised of senior staff drawn from the projects and from the scientific staff sets the priorities for the major development projects, and coordinates the activities of the computing divisions.

CIS activities are divided into five major areas:

Computing Security

Observatory-wide Coordination
- Computing Standards and Policies
- Common Computing Environment
- Contracts
- Digital infrastructure
- Recurring costs
- Coordinated activities

Information Infrastructure
- Web services
- Other services

Networking and Telecommunications

Headquarters Computing

Computing Security

In the modern world where direct connectivity to the Internet is an essential part of daily operation, the NRAO, like all other similar organizations, must take electronic security very seriously. However, the needs of high security must be balanced against the NRAO's mission to be readily accessible to the radio astronomy community and to the general public. In 1999, the NRAO adopted a formal security policy which provides a framework to balance these requirements.

VII. Computing and Information Services

All of the NRAO operational sites are networked together. It is therefore essential that security be maintained at all sites; lack of diligence at one site could otherwise compromise the security at all sites. The vehicle stipulated by the security policy to achieve this is a Computing Security Committee (CSC) composed of two representatives chosen by each site, the chief NRAO network engineer, and the Computing Security Manager, who is a member of the CIS staff and chairs the committee.

The CSC has specified and implemented detailed practices to minimize the security exposure. Since the implementation of these practices, there have been no serious computer security incidents. However, this is not sufficient. Intrusion attempts and attacks from the Internet continue to increase in frequency, scope, and sophistication. We will continue to improve education and documentation for NRAO computer users. We will maintain and enhance the security measures already in place. In addition, we will fully implement Virtual Private Networking to allow travelers and telecommuters to become part of the NRAO internal network securely.

Observatory-wide Coordination

Computing Standards and Policy

In order to provide a uniform structure in which to do business, CIS will continue to develop and enforce standards, policies, and conventions originally formulated and adopted by its predecessors. Policies include Computer Use, Major Software Procurements, Computer Hardware Purchasing, etc. Standards include computer hardware configurations and recommended software.

Common Computing Environment

For various historical reasons, the computing environments differ between sites, sometimes significantly. This results in incompatibilities, duplication of effort, and confusion for users who work on systems at multiple sites. Considerable efficiency can be gained by creating standards for computing environments and inter-site infrastructure, based on discussion and consensus among the four major sites. A major initiative toward this end, the Common Computing Environment (CCE), was started in 2000, was refocused at the end of calendar year 2002, and will continue until the end of calendar year 2003. However, computer environments are never static: new versions of operating systems are released, new capabilities become widespread in the industry. As a result, this coordination will need to continue indefinitely.

Contracts

It is clearly advantageous that widely-used software, such as office suites, computer-aided design software, and operating systems are kept at the same revision throughout the observatory. This greatly simplifies document interchange and package support. A major activity of the CIS is to maintain these software contracts. Further, CIS is responsible for maintaining contracts for key hardware components—computers, printers, routers, etc.—and for the frame relay intranet service.

By consolidating licenses or equipment from multiple sites under a single budget, we reduce the overhead of managing these contracts, simplify the process of obtaining software upgrades, and can often negotiate better discounts with vendors. This amounts to a total of roughly sixty contracts annually.

Digital Infrastructure

There have often been cases where the computer needs of a local computer divisions are in excess of their local budget. Traditionally, we have tried to make note of large new initiatives and to attempt to fund them from a separate budget that is centrally administered. No funds have been allocated to this endeavor, but we will continue to coordinate such interests with a view to seeking funding for them should the opportunities arise.

Recurring Costs

Outside the construction projects, the NRAO has computer and associated equipment that are valued at roughly $1.6M. This equipment has a lifetime of no more than five years. It makes sense to continue the practice of maintaining a central budget for new equipment to replace the old. This includes the whole spectrum of equipment from powerful systems for scientific visitors down to desktop personal computers. At the desktop, when new equipment is acquired, it has traditionally been given to those who need the highest performance. The less capable systems are then trickled down to less demanding users so that the oldest, slowest computers can be discarded.

Observations continue with the VLA, VLBA, and the GBT; data is written into the on-line archive as it is observed. This means that we have the additional recurring cost of adding disk space to the archive regularly.

Coordinated Activities

In addition to the activities mentioned previously, we intend to continue the practice of maintaining support for other computing activities. We will provide a central budget to cover training fees for any computer professional at any site. In order to foster communication and collaboration between computing staff at the various NRAO sites, we will provide funding for their inter-site travel. This budget will be available to cover the travel expenses involved in bringing together a large number of NRAO computing staff involved in specialized computing fields such as real-time development or system administration.

Information Infrastructure

Web Services

In the last two years, the NRAO has made huge improvements in its web infrastructure by deploying identical servers running identical web server software (Apache) at the four major sites (Tucson, Socorro, Green Bank, and Charlottesville). The content of these servers is regularly mirrored so that each site's server has the same content for their local users. For a user from outside, the servers now employ a load-balancing scheme, providing service from the three sites that are directly connected to the Internet (Tucson, Socorro, and Charlottesville).

In collaboration with Education and Public Outreach (EPO), a new style for the top tier of NRAO web pages has been adopted. Technically, we provide templates and tools ("server-side includes") which allow web authors to create pages with the NRAO standard "look and feel." Although many authors have adapted their webpages to conform with this new standard, much work remains to be done to standardize the information presentation.

Also in collaboration with EPO, we designed and deployed an Image Gallery for the NRAO website. This Gallery contains a collection of astronomical images taken with NRAO instruments, as well as photographs of NRAO telescopes and facilities. The information is completely annotated with detailed descriptions and literature references. Much work on this is still needed to maintain it and to enhance the information content.

With EPO, we propose adding a full-time Webmaster position to provide the necessary technical leadership to keep the NRAO's web presence at a high professional level by following new technology and providing tools to web authors.

Other Services

The NRAO now has a unified calendaring system for scheduling internal meetings, colloquia, and other significant events. Other uses for this system will be pursued. We are also actively developing a common directory access protocol to provide accurate, up-to-date staff information, including a phone book, for the entire observatory.

Networking and Telecommunications

In the last two years, we have consolidated many of our long distance phone services under a single contract through the General Services Administration (GSA) Federal Telecommunication Service (FTS2001) initiative. In addition, we provide audio conferencing, international and domestic toll-free service, and calling cards to our employees under this program. This provides the most cost-effective service available. However, prices and available features are changing constantly, so continuous monitoring of service contract options is necessary.

The Local Area Network (LAN) in Green Bank has been greatly enhanced in the past two years and a major upgrade is in progress in Socorro. However, with the ongoing additions to Stone Hall and the relocation of the other groups in Charlottesville, there will be a major effort to re-engineer the connectivity of the local site.

Since 1996, the NRAO has had an intranet connecting most of its locations using a frame relay network provided by AT&T. This provides a reliable and secure backbone for all internal electronic communications between the locations. Increasing the bandwidth is, in many cases, merely a matter of cost. Since the requirements of the operations have grown since 1996, in the coming year we will re-evaluate the bandwidth provided at the various locations.

Through a special grant in 1999, we were able to deploy a small video communication network between the major sites using the intranet infrastructure. In 2001, we procured equipment to increase the number of systems to ten and we now routinely support concurrent video conferences. The video system is also widely used to relay scientific and technical colloquia throughout the observatory. However, the biggest remaining deficiency for interactive multi-site video between the auditoria is the auditorium sound systems. These will be upgraded in the next year. We will also investigate a more sophisticated video hub to give us better diagnostic capabilities and to allow us to run conferences from a studio if needed.

Although the NRAO is a full partner in a connection to the Abilene network in New Mexico, the other locations are not. There are also many network connectivity requirements for future operations: the need to serve data from the archives for the presently operating instruments (VLA, VLBA, and GBT), the full deployment of the GBT spectrometer, the opening of the Science Center in Green Bank, the development of the North America ALMA Science Center in Charlottesville, the connectivity from Charlottesville to the operational sites in Chile, and the EVLA deployment. A study is underway to integrate these needs into a coherent whole for future network connectivity.

Headquarters Computing

The NRAO Charlottesville Computing Division's mission is to provide the computing services to the local NRAO staff and scientific visitors to Charlottesville. The local groups served by the computing division include the Director's office, Education and Public Outreach, scientific services, the Central Development Lab (CDL), the Human Resources office, the business office, Charlottesville ALMA staff, and the Charlottesville-based software development staff. The services provided include electronic mail, printers, central servers, centralized data storage, data backup services, software installation and support, computer configuration and procurement, remote access capabilities (dial-up modems, etc.), web services, directory services, network management, and phone service.

In the coming year, this support will be in the context of the general relocation of personnel due to new office locations and renovation of Stone Hall. It will take significant effort to minimize the disruption caused by the personnel and equipment relocation. It is our responsibility to ensure that all staff has appropriate availability of computers, servers, printers, phones, and networking before, during, and after relocation.

VIII. Education and Public Outreach

Overview

The National Radio Astronomy Observatory is an internationally recognized world-class leader in radio astronomy research and development. Augmenting the mission of the NRAO is a comprehensive Education and Public Outreach (EPO) program that strives to improve public awareness and understanding of astronomy and the NRAO. The fascinating challenge of exploring the early stages of galaxy, star, and extrasolar planet formation, the tracking of complex molecules which may be precursors to life, and other intriguing discoveries of radio astronomy, which are hidden to optical telescopes, draw the attention and imagination of the public. These outreach efforts demonstrate the value of the NRAO to the wider community that supports us. They also serve to attract, motivate, and train students at early stages in their careers to the possibilities of radio astronomy. Furthermore we endeavor to educate and promote the capabilities of NRAO facilities to the astronomical and scientific community. A change this year is the relocation of most direct undergraduate and graduate education efforts to the NRAO's new Division of Science and Academic Affairs. Research Experience for Teachers and college class use of student telescopes as well as K-12 and general public education efforts continue to reside with EPO.

The EPO division has long term goals and objectives in Observatory publications, web publishing, science/visitor center operations, museum/planetarium collaboration, and expansion of its education efforts directed at teachers and students. The Research Experience for Teachers had its inception at the NRAO in 2000 and has been renewed for a full 5-year period, with the intent to expand the program from two sites to three. Aside from increased visitation time at each of our centers, it is our specific goal to increase the number of class observing runs in New Mexico and West Virginia.

Formal Education

Courses for College Teachers/College Support

In the coming year, both Green Bank and Socorro will continue to offer their very successful workshop programs, including Chautauqua short courses (see Figure VIII.1). Over 500 college teachers have participated in these in the past. Less formal continuing programs allow college professors teaching astronomy to schedule observing time at either site using the VLA in New Mexico and the 40-foot antenna in West Virginia. Agnes Scott College, Concord College, Gettysburg College, Harvard University, Marshall University, Morehead University, Mt. Union College, Ohio State University, Towson University, Haverford/Bryn Mawr, Ohio University, Pennsylvania State University, University of Chicago, University of Kentucky, Villanova University, West Virginia University, and others have availed themselves of this opportunity to provide hands-on exercises with real observational data. In addition to learning about NRAO operations in Green Bank, students in these visiting classes learn to operate the 40-foot telescope, collect data, and analyze that data. The intent is to establish a similar opportunity with the N^2I^2 interferometer, an NRAO/New Mexico Tech project, located on the New Mexico Tech campus in Socorro near the NRAO Array Operations Center (AOC). Expansion of that array to four elements funded by a grant to New Mexico Tech is planned for the coming year and when completed, it will provide a means whereby teachers and classes will come to learn to operate the interferometer, gather data, and analyze that data. We are considering whether to seek funding for converting the 20-meter telescope at Green Bank to similar use.

Figure VIII.1 Participants of the 2003 Chautaugua.

Programs for Secondary Teachers

In concert with a renewed REU program, the NRAO's Research Experiences for Teachers (RET) program has been renewed by the National Science foundation (NSF) for five years. The award calls for four teachers to participate in the program each summer for eight weeks. The program will be held in West Virginia and New Mexico. The intent is to maintain the program in Green Bank, strengthen the program in Socorro, and we are exploring the possibility of expanding the program to Charlottesville. In addition to working with a staff adviser on a project in the staff adviser's area of expertise, teachers will take part in a summer lecture series introducing them to the fundamentals of radio astronomy and to current topics in astronomical research. They will participate in weekly educational sessions to develop classroom activities that make use of their research experience at the NRAO. RET teachers from this past summer are expected to present posters at the January AAS meeting.

Programs for K-12 Teachers

At Green Bank, the NRAO has operated a series of programs where K-12 teachers visit the site for a one or two-week intensive course in astronomy and the scientific method. The cornerstone of the experience is a set of open-ended research projects that groups of teachers must perform with the 40-foot telescope. Working closely with observatory scientists, teachers gain concrete experience in science research. They then develop research projects for their classroom students. Participants also train other teachers to develop inquiry-based projects for their students. Through participant reporting, it is estimated that the program has impacted more than 5,000 teachers. What once was the Science Teachers Institute evolved into the Rarecats program. Although the program was scheduled and expected to end in 2003, cost savings from within the program will enable one additional round of training to be offered. Furthermore, we have also spun off an NRAO/NASA Astronomy Institute. The program also trains teachers in the use of astronomy data reduction software, specifically the *Hands-on Universe (HOU)* image-processing program. Nationally recognized, HOU gives teachers software tools to use in creating astronomy research projects with their students. Teacher-graduates of these programs are encouraged to bring groups of their students to Green Bank to use the 40-foot telescope, and many do so each year. NRAO staff collaborate with those interested teachers to tailor an extended visit to the specific group of students.

For 2004, the NRAO again will offer a program to link professional and amateur astronomers with elementary and middle schoolteachers to bring astronomy into the classroom through Project ASTRO. The NRAO is a member of the Southern New Mexico Project ASTRO coalition, serving schools in the southern half of the state. Staff members serve as team members with local schoolteachers, and the NRAO further supports Project ASTRO by providing educational materials, information, and class tours for teachers in this program.

Programs for K-12 Students

The new Science Center at Green Bank is now open. It will expand the experience that school groups have in visiting the NRAO on a field trip. Previously they would come for the traditional presentation about radio astronomy and the NRAO, and then go on the bus tour of the telescopes. The new array of exhibits, many of them hands-on, will offer them the chance to do all of the above and also tackle, in an interactive mode, topics such as *What are radio waves?*, *How do we detect radio waves?*, *What can radio astronomy tell us about the Universe?*, *What is currently being observed with NRAO telescopes?*, and *What is the role of technology in Science?* There is even an interactive model of the Robert C. Byrd Green Bank Telescope for student use. The NRAO has formed a partnership with the West Virginia Education Alliance, whereby they will provide for a limited number of mini-grants to assist West Virginia schools with the travel costs of visits to the Science Center at Green Bank.

The NRAO will continue to provide financial support and prizes for science fairs in Socorro County, the state Science Fair, and the New Mexico Science Olympiad. Numerous NRAO staff members volunteer as judges and officials. Both the New Mexico State Science Fair and the state Science Olympiad are held every year in Socorro, and the NRAO schedules a special, guided VLA tour for the participants. Though the NRAO operates no telescopes in Charlottesville, there are possibilities of collaborating with efforts at the University of Virginia's McCormick Observatory and we are beginning to make informal efforts to reach teachers and students of Charlottesville, Albemarle County and surrounding counties.

The NRAO anticipates hosting extended tours for the West Virginia Governor's Honors Academy and Upward Bound science camps. The Regional Science Bowl for high school students will continue to be held at the NRAO-Green Bank and the site is also a "Business Partner" to the local elementary and middle schools, and the county high school. In FY 2004, there will again be a mentor program for area high school students who spend time weekly on the site working on scientific and engineering projects for their senior theses. The NRAO-Green Bank facility offers career awareness tours for the Pocahontas County High School freshman class. In Charlottesville, we anticipate participating again in Career Fairs for 7th grade middle school students and 10th grader high school students from Charlottesville, Albemarle, and Fluvanna school districts at Piedmont Virginia Community College.

Informal Education

Visitor Science Centers

Figure VIII.3 July 2003 photo of the Science Center at Green Bank.

Across the nation, it is estimated that more people visit museums every year than attend professional sporting events. The visual impact of our telescopes and the educational value of self-directed exploration around our sites make visiting NRAO telescopes an enjoyable and enriching experience. Over the past year both NRAO centers (Science Center at Green Bank and the VLA Visitor Center) have expanded. With those expansions, focus will be on efforts within those centers, on the programs and exhibits they offer, and also on the educational outreach efforts visitors will take away both from those centers and from the NRAO web site. With major renovations in Charlottesville, an increase in lobby entrance space will provide the means to display effectively what the NRAO does. Although the focus for our efforts is radio astronomy, we must draw upon all of astronomy and create effective, interactive experiences that will lure a student's mind into the means, the method, and as well as the results of the experience.

VIII. Education and Public Outreach

Science Center at Green Bank

In Green Bank, the NRAO opened its new Science Center in late spring (Figure VIII.3). This center will provide year-round educational programs for the general public and students. The science visitor center contains 25,000 square feet of exhibit space, classrooms, auditorium, gift shop, offices and astronomical telescopes. Funds of $7.65 million were secured through a NASA appropriation for construction.

In concert with the construction of the Science Center, a dormitory for student visitors with separate wings for girls and boys is under construction with expected completion in autumn 2003. The new dorm, or bunkhouse, will provide inexpensive overnight quarters for school groups visiting the center (Figure VIII.4).

Figure VIII.4 Construction photo of the Green Bank bunkhouse. Completion is expected in the fall of 2003.

The NSF-funded exhibit project, entitled *Catching the Wave*, conducted outside evaluation of exhibit prototypes in 2001. Exhibit design and construction commenced in 2002, with installation ensuing after the center's completion in late spring 2003. The NRAO also received a grant from the State of West Virginia and Pocahontas County of $128,000 for an interactive model of the Robert C. Byrd Green Bank Telescope (GBT) shown below in Figure VIII.5. The opening of the Center has necessitated an increase in staff including a museum exhibit technician, science shop and admission clerks, more tour guides, food service, custodial and infrastructure support.

VIII. Education and Public Outreach

The goal of the Green Bank public tour program is to give visitors a better understanding of, and appreciation for, astronomy and the work done at the NRAO in Green Bank. The public is encouraged to visit the site and see the telescopes and they may often see the GBT turning in azimuth and altitude as it goes to its next target. The availability of the Science Center will greatly enhance any visit. Hourly guided tours, directed by local college students, are given daily from Memorial Day Weekend through Labor Day, with a Wednesday through Sunday schedule planned

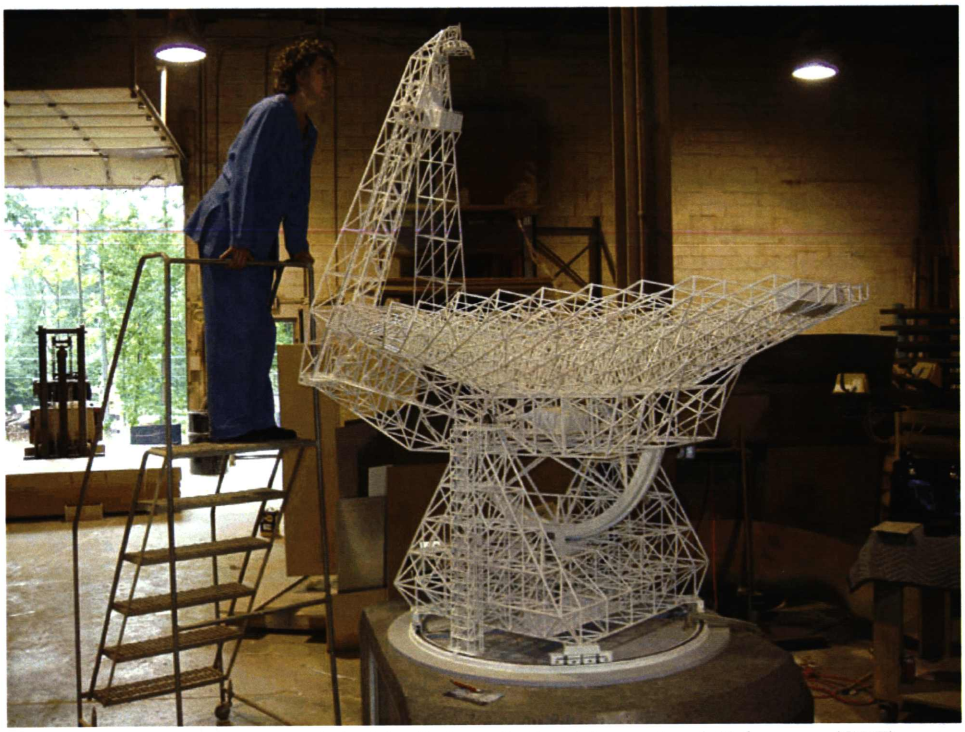


Figure VIII.5 Interactive model of the Robert C. Byrd Green Bank Telescope (GBT).

for the rest of the year. Prescheduled group tours can be arranged at any time of the year. The GBT continues to be a powerful attraction. Another factor is increased media relations and outreach to tourism outlets around the state and county. As mentioned elsewhere, NRAO-GB is promoted at numerous sites within the county and on both the county and state tourism websites. Special programs are offered to give smaller groups a more in-depth experience at the Observatory. These programs ranged from star parties, to in-depth technical tours, to image processing sessions. A portable planetarium, Starlab, is being used in the special program series this year. Teachers are trained in the use of the Starlab and the NRAO makes it available to schools at no charge.

As the completed Science Center moves into normal operations we will focus on increasing the number of visits by regional students, with the goal that every West Virginia K-12 student visit the Green Bank facility at least once during their school career. Another goal is to increase use of the 40-foot telescope by school groups, and the addition of the dorm/bunkhouse should provide needed lodging for students during such observing sessions. The NRAO will promote the distribution of copies of new exhibits created for the Center, which prove themselves by actual experience in the Center, to other science centers and planetariums across the nation. The Center is also working toward providing real-time internet links for remote involvement from museums, science centers, planetariums, and schools in activities occurring at the Center and at the Observatory.

VLA Visitor Center

The VLA Visitor Center continues to be a popular destination for tourists. Annually more than 20,000 visitors sign an unattended guest book, and tourism experts contend that the actual numbers of visits may be as much as three times higher. In a typical year, these tourists come from all 50 states and some 40 foreign countries. With the opening of the gift shop in early June, the Visitor Center is now staffed for the majority of its open hours, providing a more suitable environment for visitors as many of their questions can now be answered.

Figure VIII.6 VLA Visitors Center gift shop May 2003.

The visitor center features an automated video presentation, displays on the history of radio astronomy, the operation of the VLA and VLBA, and information on scientific results from both instruments. It is the starting point for a self-guided walking tour that provides visitors a close-up look at a VLA antenna and, from an observation deck, views of the electronic equipment, the control room, and the array itself. The free walking tour brochure, given to visitors, has been updated. It will guide them along the path where informational signs at strategic points on the tour explain the workings of the telescope.

In addition to the self-guided tours, the NRAO also provides a limited number of guided tours. In the summer, the NRAO will continue to offer regular weekend tours, often involving REU summer students as guides. Throughout the year, the NRAO conducts guided tours for educational and scientific groups by appointment. These include school and university classes (some out of state), amateur astronomy clubs, engineering societies, youth science camps, and others. Quarterly public tours (except during summer) will continue to be offered, based on successful efforts this past year. Special prearranged tours are again expected to occur for science groups, school groups, university groups and for special programs being held at Socorro, New Mexico Tech, and the VLA. On the web *Bringing Your Class to the VLA*, provides teachers with background information and tips on maximizing a visit's educational value through pre-visit and follow-up activities.

VIII. Education and Public Outreach

A new ten-minute informational DVD has been successfully installed and is in daily use on a wide screen TV display. A small radio telescope that can be manipulated for visitors is a popular attraction. The new gift shop addition enlarges the undersized (1,500 square feet) Visitor Center and provides access to souvenirs, the sale of which then pays the salary of a clerk/guide who is on hand seven days a week. To bring the VLA to the state of the art in public outreach, the NRAO plans to build a new VLA Visitor Center that will serve as a far more effective tool for attracting and educating tourists about astronomy and NRAO research. This center, similar to the one just opened at Green Bank, will become the centerpiece for a wide range of new educational outreach programs. Although both sites will include information about ALMA, the new telescope is likely to play a larger role at the VLA site due to the ALMA antenna prototype testing occurring there. The display lobby in Charlottesville will also emphasize ALMA, as Charlottesville will be the site of the North American Science Center.

World Wide Web

The NRAO is working to keep pace with the ever-growing public and consumer demand for Internet content and services. The NRAO homepage on the Internet, www.nrao.edu, is the primary point of contact with both the scientific community and the general public. The NRAO web system provides information about our facilities and recent scientific results. It is also used as an integral part of the operation of our instruments. The NRAO website is a rich source of information about radio astronomy, our instruments, press releases, data products, and general contact information. Implementation of a mirroring system around the four main NRAO sites last year enables rapid access to our site internally and from anywhere in the United States.

In 2002, the NRAO developed a highly functional Image Gallery. This gallery now has nearly three times the number of images with which it started and offers a number of useful features:

- Thumbnail-based views of scientific categories and subcategories.
- Useful cross-links (e.g., to NED/SIMBAD, to ADS articles, and to suitable NRAO publications).
- Basic and advanced search functions.
- Option to display search results as thumbnails or tables.
- Fields for both general captions (suitable for the general public) and more specific captions (more detailed image information, such as contour levels and resolution). Links to high, medium, and low print-resolution images, when available.
- An on-line image submission tool, to facilitate addition of new images on a timely basis.

The gallery is constructed by a database that automatically generates the HTML pages, so as new images are entered, they are instantly available in the gallery. This helps to ensure that the gallery is kept current and minimizes future maintenance.

The web site also includes a growing archive of power point presentations that can be viewed or downloaded for information or for presentations related to radio astronomy. Other potential projects for our website include real-time displays of our telescopes. Updated construction photos of site work for ALMA is a likely project similar to what was done for the construction stages of the Science Center at Green Bank last year.

The NRAO web site underwent a major restructuring this year and the intent is to continue improvement and create oversight of the web site as standard part of the NRAO's operations. Four prime groups—students/teachers, general public, outside observers, and NRAO staff—were established as part of the design and with the objective that they should be rapidly directed to the information vital to them. Another challenge for this year will be to properly establish and update ALMA information and to work cooperatively with ESO (European Southern Observatory) and the JAO (Joint ALMA Office). The continuing aim is to enable teachers, students, and the general public to readily find the astronomical information they seek, while still guiding researchers and staff to the operational aspects they require. Perhaps more than any other aspect of the NRAO, the web site can serve as a reliable national resource for astronomy education and insight. The position of EPO web master will be filled as a regular full-time position this year to ensure that the EPO aspects of the site are created and maintained on an ongoing basis. An ongoing goal will be to continue the renovation of the pages intended for the public, students, and teachers so that we will have a uniform look to the pages and enhance the ease with which visitors navigate those pages. The challenge for this year will be to establish and update the resources available to such groups on our web pages.

In addition to the overall structure and goals discussed above, there will also be ongoing addition, modification, and updating of individual pages. The inclusion of General Public and Education pages at both the VLA and VLBA websites has increased our visibility globally. Virtual tours of antennas and antenna sites, visual explorations of how radio astronomy works, and descriptions of current projects being observed at the VLA and VLBA telescopes are the bases of these websites. Real-time web cam images of the telescopes and descriptions of work performed on site (job and career information) are being considered for the future.

Astronomical Community

Science Conferences

The NRAO continues to maintain and enhance its high visibility at scientific and professional meetings. This is an important way for the Observatory to advertise the capabilities of our organization and instruments, and to maintain our credentials as a world-leading scientific organization with a history of serving the astronomy community. The NRAO traditionally operates booths at the winter and summer meetings of the AAS and is planning to do again at Atlanta Jan. 4-8, 2004 and at Denver, May 30-June 3, 2004. The NRAO display was restructured for the last AAS meeting and highlights the NRAO telescopes (ALMA, VLBA, VLA, EVLA, and the GBT) and presents a summary of the user services. NRAO scientists are on-hand at these displays to answer questions from current and potential users. The display area will be stocked with the complete unified set of scientific brochures outlining the capabilities of each NRAO instrument.

An NRAO presence at the annual AAAS conference was successful last year and we are considering a repeat visit FY 2004.

Astronomical Consortium Efforts

The NRAO will continue to participate in the Southwest Consortium of Observatories for Public Education (SCOPE), which also includes Kitt Peak National Observatory, Whipple Observatory, McDonald Observatory, Apache Point Observatory, and the National Solar Observatory. SCOPE is an effective vehicle for cooperation and information exchange about public-education programs among the participating observatories. This organization has raised funds from both public and private sources to produce astronomy education materials. These materials are distributed at no charge to tourists at the VLA Visitor Center, to visitors at other regional tourist attractions, and to area schools. The Consortium is investigating cooperative efforts with tour agencies to produce a tour package that would include the member observatories.

The NRAO also continues to participate in STARTEC -- State of the Art Telescope Educational Consortium, which began in 2001. STARTEC is a global version of SCOPE. By sharing resources and expertise, the members of STARTEC enhance individual education and public outreach activities and convey the excitement of astronomy to a wider audience throughout the world.

A conference on Communicating Astronomy to the Public is scheduled for October 2003 in the Washington, D.C. area organized by the NRAO in cooperation with the National Research Council. The conference goal is to include national observatories, universities, planetariums, government agencies, and science museums in a practical examination of the problems and possible solutions. This is a follow-up conference to the first international conference on this subject held in February of 2002. Additionally, the NRAO will participate in the NSF-sponsored symposium, the Universe From the Ground Up, also scheduled to be held in October 2003 in Washington, D.C. The NRAO will be exhibiting and the Director, Fred Lo, will be one of the panelists discussing the astronomical tools of the future.

Amateur Astronomers

Amateur astronomers are a proven resource for public education, many of them showing great enthusiasm for bringing astronomical information to the public and to schools. The NRAO has forged close ties with New Mexico's extensive amateur astronomy community. Lectures and tours are regularly provided for amateur groups. The NRAO will again provide staff assistance, VLA tours, and lecturers for the tenth annual Enchanted Skies Star Party, an event that draws amateur astronomers to Socorro from across the United States and several foreign countries. Event participants comment that the VLA tour and interacting with professional astronomers are the highlight of their visit. This year for the first time, the NRAO will provide NRAO-labeled giveaways for the Mid-Atlantic Star Party in North Carolina, now in its ninth year and likely to attract several hundred avid amateur astronomers. We are expanding distribution of NRAO posters to other regional star parties.

VIII. Education and Public Outreach

The NRAO is ideally positioned to use the amateur radio community, with more than 600,000 licensed operators in the United States, as a force multiplier for public education efforts. Not surprisingly, many staff members are licensed radio amateurs and are involved in local and national radio organizations. Staff also present lectures to amateur radio organizations, and the NRAO provides displays and information about radio astronomy at amateur radio events.

The Society of Amateur Radio Astronomy (SARA) has their annual conference at NRAO-Green Bank. SARA members are active supporters of radio astronomy outreach. Using castoff satellite dishes and electronics, they have developed low-cost demonstration radio telescopes. These demo telescopes, capable of detecting the Moon, Sun, and thermal emission from people, have been donated to museums and classrooms around the country. The Green Bank site was the recipient of one of these systems in 2002, which was labeled "the Little GBT" with an off-axis feed arm. This telescope was quickly put to use during summer in the tour center and will be used in the new Science Center.

Publications

The Observatory has an array of publications which includes telescope brochures to encourage use of those instruments by astronomers, quarterly newsletters for observers and other interested parties, quarterly reports, and a number of administrative publications for either internal and external needs. There are also a number of publications directed to public external groups described in the next section. A campaign to achieve cohesiveness and added professionalism among those publications is anticipated to reach a plateau of maturity within the coming year. Among the new publications planned are an annual report and a brochure outlining the Student/Teacher internships, workshops, and summer programs offered.

Community Relations

Local Community Programs

The NRAO serves as a good neighbor in the communities where its sites operate. Activities, in addition to those already mentioned under education, which meet that criterion and are expected to continue include:

- After-school "Science-for-Fun" program for local Green Bank elementary school children.
- A monthly radio show in West Virginia featuring astronomy and the Observatory.
- A business partner of local schools in West Virginia.
- Presentations at State and National Education and Tourism Conferences.
- AUI sponsored Jansky public lectures at all four NRAO sites
- Girl Scout and Boy Scout Astronomy badge days where scouts complete activities and earn astronomy badges.
- Extended visits, half-day to overnight stays, to use the 40 Foot Telescope by organizations ranging from the National Youth Science Camp to college astronomy clubs.

VIII. Education and Public Outreach

Conference Displays

In New Mexico, the NRAO provides a display and staffing for career days at area schools, a particularly important function in a region where large numbers of minority and disadvantaged children need to be made aware of the possibility of scientific or technical careers. The NRAO also provides a display and staffing for the Albuquerque Astronomical Society's annual Astronomy Day event at New Mexico's largest shopping mall, at which more than 40,000 people typically visit. This year the NRAO will have a display at the SACNAS (Society for Advancement of Chicanos and Native Americans in Science) meeting in Albuquerque.

Public Awareness

The NRAO continues to work to implement a suite of promotional literature. These documents represent an overarching image for the Observatory, and the use of consistent imagery in all of our outreach materials has been found to be very important. Each of the NRAO telescopes has a general public brochure. The coming year will see new brochures for ALMA and for the NRAO as a whole. There are also updated tour brochures for both the VLA and Green Bank. These brochures are intended for distribution through visitor centers, tourism promotion outlets, and professional meetings. For each of the NRAO telescopes, there exists a general public brochure. The coming year will see new brochures for ALMA and for the NRAO as a whole. There are also updated tour brochures for both the VLA and Green Bank. These brochures are intended for distribution through visitor centers, tourism promotion outlets, to educators, and at professional meetings.

In 2002, the NRAO also published a CD Business Card, which featured a 2-minute video on the NRAO, background information on the telescopes, and links to important NRAO web pages. Nearly 2,000 were distributed to students, educators, the general public, and the astronomical community. This CD was so popular that it was "reprinted" in a more software friendly format and all of the second printing have been distributed. It will be reprinted again, perhaps with some updates. For 2004, we will once again print an NRAO calendar illustrated with research results and photographs of NRAO sites.

Outside Promotion

Emulating the NRAO CD Business Card, West Virginia's Pocahontas County produced their own CD business card and NRAO-Green Bank was featured prominently. That business card is scheduled to be reproduced again this coming year. NRAO Science Center brochures are on display at many Pocahontas County tourist attractions including the Pocahontas County Visitor Center, Snowshoe, Durbin & Greenbrier Valley Railroad, and Seneca Rocks Discovery Center in adjacent Pendleton County. The NRAO is listed on the Pocahontas County and State of West Virginia web sites. In addition, NRAO tourism brochures are placed in all of the highway welcome centers around the state and at Convention and Visitors Bureaus. The NRAO has a prominent educational display at the Charlottesville airport and we are planning similar displays at well-visited interstate visitor centers serving West Virginia. The NRAO has also joined the Albuquerque Convention and Visitors

Bureau which allows us to place our brochures at their airport welcome center and lists the NRAO at their visitor kiosks.

Media Relations

The NRAO's public-education efforts, through visitor centers, teacher workshops, class tours and other programs, reach tens of thousands of people annually. However, news stories about the NRAO and the research done on NRAO telescopes can reach many millions of readers and viewers in a single day. Wide dissemination of NRAO research results through the mass media contributes significantly to fulfilling the Observatory's mission of building a scientifically literate society. In addition, by thus allowing the taxpayers to share in the excitement of new astronomical discoveries, we help ensure continued public support for astronomy.

Press Releases and Media Inquiries

The public information officers (PIOs) write and issue press releases, working closely with the researchers involved, NRAO management and the NSF Office of Legislative and Public Affairs. Releases routinely generate news coverage in major newspapers such as *The New York Times* and *The Washington Post*, as well cable, broadcast outlet, and network coverage. Wire-service stories resulting from NRAO press releases appear in hundreds of subscribing news outlets.

Press releases feature the work of any who use NRAO telescopes, both staff scientists and investigators from other institutions. When the investigators are from other institutions, NRAO PIOs will work collaboratively with press officers of those institutions to produce either a release that is issued jointly or simultaneous individual releases focusing on the aspects most pertinent to each institution. In the process of preparing to issue a release, the PIOs provide assistance and guidance to the researchers with respect to the news-embargo policies of journals such as *Nature* and *Science*.

Press releases are distributed by electronic mail directly to major news organizations, and, via the AAS, to more than 1,400 science journalists worldwide. Releases and associated images also are available on the NRAO website. Frequently, web-based news organizations, such as Space.com, will link directly from their news stories to NRAO press release and images. Hubble and other NASA sites will often have links to NRAO images and information. The NRAO must take full advantage of the opportunities that ALMA will provide for highlighting the vital role of the NRAO. It will continue to be crucial for NRAO PIOs to be up-to-date about any breaking stories, hopefully exciting research results, so that the NRAO can respond in an informed and competent manner to any media inquires.

Throughout the year, the PIOs receive countless inquiries about the NRAO and radio astronomy from journalists, book authors and screenwriters. Inquiries range from general questions about astronomical phenomena such as eclipses and meteor showers to detailed questions aimed at providing background for a book. Authors of works not only on science and engineering but also business, art, and history call for information. Inquiries come from authors of fiction as well as of non-fiction, all looking to the NRAO to help ensure a level of technical accuracy. The PIOs routinely provide tours of NRAO facilities to journalists and authors.

In addition to stories about research results, state and regional publications often run stories about NRAO activities such as workshops, seminars, public lectures and student accomplishments. NRAO facilities in both Green Bank and the VLA are widely cited in tourist publications and as tourist destinations.

AAS Press Room

The AAS meetings receive some of the best news coverage of any scientific organization and the AAS pressroom operation is frequently cited as an example for other scientific societies. This operation, while organized by the AAS Press Officer and his deputies, relies on staffing and assistance by PIOs of observatories and other research institutions. The NRAO has supported this effort for nearly a decade, providing PIOs to staff the AAS pressroom. AAS meetings draw a corps of science reporters that account for the majority of astronomical stories in the U.S. media and a significant fraction of astronomical news coverage worldwide. Pressroom service by NRAO PIOs allows the NRAO to build long-term working relationships with many of those reporters, resulting in enhanced media visibility for the Observatory.

Research results from NRAO instruments presented at AAS meetings will be frequently featured in press releases we distribute there. In addition, many such research results have been the topics of AAS-sponsored meeting press conferences. A result highlighted in a press conference at an AAS meeting is virtually guaranteed to receive significant media coverage. For example, at the June 2003, Nashville AAS meeting there were two press conferences featuring results obtained with NRAO telescopes and both stories were covered by the New York Times and other national media.

For the first time this past year an NRAO PIO served in this role at the AAAS conference and based on that success, we will consider a repeat.

Filming Coordination

Radio telescopes have a constant appeal to filmmakers, commercial photographers and producers of commercials, musical videos and advertisements. Such interest often runs in spurts, and at times can become quite time-consuming. NRAO policies seek to ensure reasonable access to commercial filmmakers and photographers while at the same time protecting the operation and reputation of the Observatory. Implementing industry-standard access fees and reimbursement policies has ensured that taxpayer funds are not expended for commercial uses and also has generated funds earmarked for the Observatory's EPO activities. Based on this past year's activity, interest in using the VLA and the GBT for such filming purposes shows no sign of waning.

IX. ALMA

Project Overview

The Atacama Large Millimeter/Submillimeter Array (ALMA) is a collaborative venture of the U.S. National Science Foundation and a coalition of European institutes represented by the European Southern Observatory (ESO). The NSF, as the U.S. partner in ALMA, also represents minority participation by the National Research Council of Canada (NRC) so that the NSF is properly the *North American* partner in ALMA. The ALMA partners are working toward a project that embraces equality of effort and contribution from, and benefit to, the partners. The construction phase in the U.S. began in 2002 while ESO formally began construction in January 2003. A bilateral agreement between North America and Europe was signed earlier this year.

The North American participation in ALMA is executed by AUI/NRAO, funded by the NSF through a Cooperative Agreement with AUI. The U.S. participation in ALMA grew out of the Millimeter Array (MMA) Project, which was proposed to the NSF in 1990 by AUI and funded for a three-year Design and Development phase that began in 1998. In 1999, the NSF agreed with the European coalition to merge the MMA with the European Large Southern Array (LSA) project to create the *bilateral* ALMA Project. Subsequently, the NRAO ALMA project management, and the ESO ALMA project management worked cooperatively on a common design and prototyping effort. This work led to a jointly agreed work breakdown structure (WBS) for the construction phase of the bilateral project that includes a thorough cost estimate and project schedule.

Thus, an overview of ALMA is this:

- ALMA is a joint project carried out by the NSF and ESO, each of these entities representing other participating parties;
- Following a successful design and development phase, ALMA has initiated a construction program managed cooperatively by the NSF, acting through AUI/NRAO, and by ESO;
- A common ALMA construction program WBS, cost, schedule, and division of effort has been developed jointly by AUI/NRAO and ESO for the bilateral project;
- A Joint ALMA Office (JAO), lead by the ALMA Director, provides a unifying management layer that brings together the efforts of the two Executives.

Science Objectives

The ALMA Project will provide scientists with an instrument uniquely capable of producing detailed images of the formation of galaxies, stars, planets and the chemical precursors necessary for life itself.

ALMA is designed to operate at wavelengths of 0.4 to 9 millimeters where the Earth's atmosphere above a high, dry site is partially transparent and where clouds of cold gas as close as the nearest stars and as distant as the observable bounds of the universe all have their characteristic spectral signatures. It will image stars and planets being formed in gas clouds near the sun, and it will observe galaxies in their formative stages at the edge of the universe, which we see as they were nearly ten billion years ago. ALMA provides a window on celestial origins that encompasses fully both space and time.

ALMA will provide an unprecedented combination of sensitivity, angular resolution, and imaging fidelity at the shortest radio wavelengths for which the Earth's atmosphere is transparent. It will provide a wealth of new scientific opportunities. In particular, the scientific specifications for ALMA were chosen to allow astronomers to:

1. Image the redshifted dust continuum emission from evolving galaxies at epochs of formation as early as z=10;
2. Trace through molecular and atomic spectroscopic observations the chemical composition of star-forming gas in galaxies throughout the history of the universe;
3. Reveal the kinematics of obscured galactic nuclei and quasi-stellar objects on spatial scales smaller than 300 light-years;
4. Assess the influence that chemical and isotopic gradients in galactic disks have on the formation of spiral structure;
5. Image gas-rich heavily obscured regions that are spawning protostars, protoplanets and pre-planetary disks;
6. Determine the temperature of the photosphere of thousands of nearby stars in every part of the Hertzsprung-Russell diagram;
7. Reveal the crucial isotopic and chemical gradients within circumstellar shells that reflect the chronology of invisible stellar nuclear processing;
8. Obtain unobscured, sub-arcsecond images of cometary nuclei, hundreds of asteroids, *Centaurs,* and Kuiper-belt objects in the solar system along with images of the planets and their satellites—observations that can be done for astrometric or astronomical purposes during daylight or nighttime hours;
9. Image solar active regions and investigate the physics of particle acceleration on the surface of the sun.

This list of specific science capabilities leads to a definition of common science requirements that can in turn be used to establish requirements on the technical performance of ALMA. Foremost among those science requirements are precision imaging and sensitivity. Precision imaging and sensitivity enable the entire spectrum of science to be done with ALMA, irrespective of whether the scientist wishes to study solar system objects or galaxies twelve billion light-years away. Quantitatively, the *level 1 Science Requirements* for ALMA are the following:

ALMA Level-1 Science Requirements

- The ability to provide precise images at an angular resolution comparable with that expected from the James Webb Space Telescope (JWST). Resolution better than 0.1 arcsec. The term "precise imaging" means images not limited by imaging artifacts at a dynamic range less than 1000:1 over the entire sky visible from the ALMA site;
- The ability to detect CO emission in a normal galaxy like the Milky Way at a redshift z=3 in less than 24 hours of observation. The scientifically related requirement is this: the ability

to image the kinematics of such a galaxy using the NII or CII emission line in a single source transit;
The ability to image the gas kinematics in a solar mass protostar with a protoplanetary disk at the distance of the star-forming clouds in Ophiuchus or Corona Australis.

Technical Objectives

The technical challenge to the ALMA designers is to build a telescope that extends the high-resolution imaging techniques of radio astronomy to millimeter and submillimeter wavelengths.

High Resolution Imaging

High resolution imaging is achieved by making use of the technique of aperture synthesis, which uses many individual antennas to synthesize the imaging performance of a single antenna significantly larger than the individual antennas. Aperture synthesis is the technique used, for instance, by the Very Large Array to image at centimeter and meter wavelengths. ALMA will use 64 individual precision antennas all operating in concert to extend the aperture synthesis technique to observations at millimeter and submillimeter wavelengths. The signals received by the superconducting receivers on each antenna will be digitized and processed in a special purpose computer or signal correlator. Images of astronomical objects and cosmic phenomena will be made using computer algorithms designed to correct for atmospheric propagation effects, and for the fact that the synthesized telescope is in fact made up of individual, separated antenna elements. The image-forming optics of ALMA is a computer.

The objects that a scientist wishes to study often are embedded in larger structures that are physically or causally related to the objects of interest. Examples would include a protoplanetary disk found within the molecular envelope of a protostar, or the active nucleus of a spiral galaxy. In many cases, perhaps most, the physical context in which an object is found illuminates its origin or evolution. For this reason, the scientist will need to image both very small structures (the protoplanetary disk or galactic nucleus) and the much larger embedding structure (the molecular cloud or spiral galaxy). ALMA realizes this capability by means of rearranging the physical layout of the antennas on the site. Such reconfigurability provides ALMA with a zoom-lens capability.

In Figure IX.1, ALMA's 64 antennas are shown arranged close together for observations of large regions of the sky at low resolution. The antennas may also be arranged in progressively larger oval configurations for higher resolution observations of smaller regions of the sky. In the lower right of this image one of the antennas can be seen being moved from one location to another. Also, illustrated in this image are the ALMA control building, maintenance shops and the tall antenna assembly building.

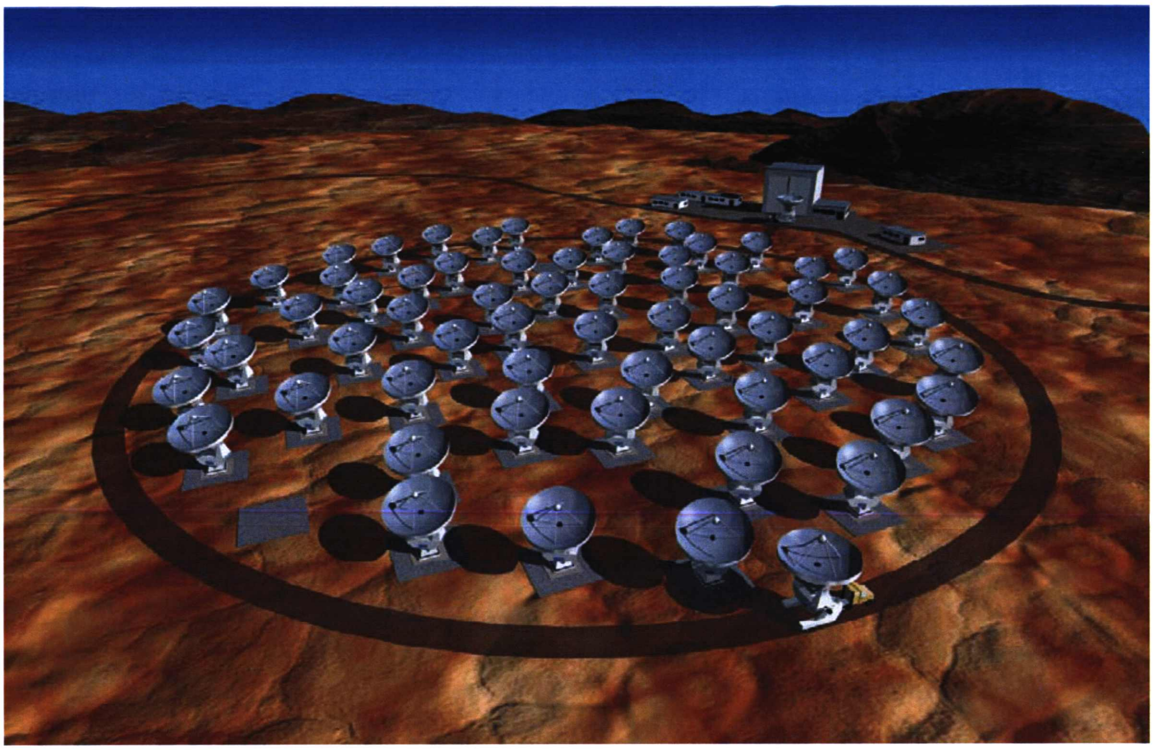


Figure IX.1 An artist's rendition of the ALMA compact array.

The antennas can be moved into larger configurations using a special forklift-type vehicle, but they must be attached to prepared concrete foundations. ALMA has 217 antenna foundations or "stations" for the five array configurations. Each station is connected to the site electrical power and communication network. An antenna moved from one station to another can be simply connected and it will be ready to resume observations.

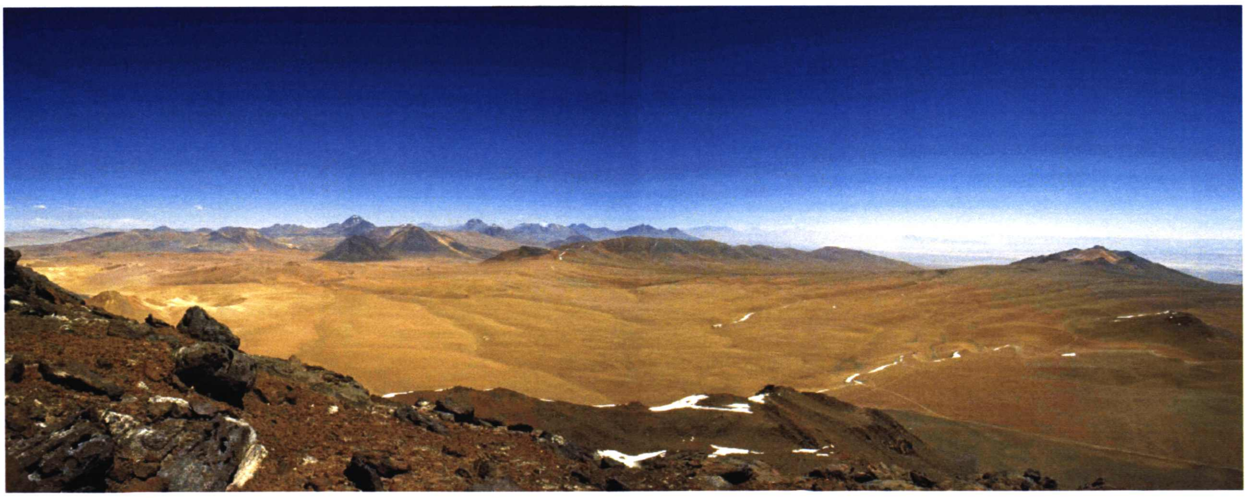


Figure IX.2 The ALMA site in the Altiplano of northern Chile.

The largest array configuration is a wye configuration nearly 14 km in diameter. This large configuration will give images with the highest angular resolution, a resolution as high as 7 milli-arcseconds.

Operation at Millimeter and Submillimeter Wavelengths

The challenge of engineering the unique ALMA telescope to operate at millimeter and submillimeter wavelengths begins with the telescope site. Water vapor in the Earth's atmosphere strongly absorbs light from cosmic sources at millimeter and submillimeter wavelengths; little of that light may reach the surface of the Earth. The solution is to locate ALMA in the thin, dry air found only at elevations high in the atmosphere. For this reason, ALMA will be sited in the Altiplano of northern Chile at an elevation of 5,000 meters (16, 500 feet) above sea level; this area known as the Llano de Chajnantor is directly east (downwind) from the Atacama desert, the driest desert in the world. A photo of the site is shown as Figure IX.2. The ALMA site is the highest, permanent astronomical-observing site in the world. As an engineering project, ALMA is 64 precisely tuned mechanical structures each weighing more than 100 tons, superconducting electronics cryogenically cooled to less than four degrees above absolute zero, and optical transmission of terabit data rates—all operating together, continuously, on a site more than three miles high in the Andes mountains.

In order to make efficient use of the exceptional atmospheric transparency above the Chajnantor site it is necessary to design the receiving system such that the noise contributed by the receiver is as low as possible, that is the noise is close to the quantum limit. The ALMA receiver noise specification is set with this requirement in mind. In addition, the ALMA synthetic aperture must remain coherent; this sets a specification on the permissible instrumental phase distortion, which in turn sets a specification for many things including the accuracy of the antenna primary mirror surface, the stiffness of the antenna backing structure and quadripod support, and the phase noise resulting from transmission of the local oscillator reference signal in fiber optic cables. All of these requirements serve to define the ALMA technical system, or project scope and specification, as outlined for the bilateral ALMA project in Table IX.1.

Table IX.1: Baseline Bilateral ALMA Scope and Specification

Array	
Number of Antennas	**64**
Total Collecting Area (ND^2)	**7238 m^2**
Total Collecting Length (ND)	**768 m**
Angular Resolution	**0.2" λ (mm)/Baseline (km)**
Array Configurations	***{Dimension of filled area}***
Compact: Filled	**150 m**
Continuous Zoom	**200-5000 m**
Highest Resolution	**14.0 km**
Total Number of Antenna Stations	**217**
Antennas	
Diameter	**12 m**
Surface Accuracy	**25 μm RMS**
Pointing	**0.6" RSS in 9 m/s wind**
Path Length Error	**<15 μm (sidereal tracking)**
Fast Switch	**1.5° in 1.5 seconds**
Total Power	**Instrumented and gain stabilized**
Transportable	**By vehicle with rubber tires**
Receivers	
84-119 GHz SIS	***{All frequency bands}***
211-275 GHz SIS	***-Dual polarization***
275-370 GHz SIS	***-Noise performance limited by atmosphere***
602-720 GHz SIS	
Water Vapor Radiometer	**183 GHz**
Intermediate Frequency (IF)	
Bandwidth	**8 GHz, each polarization**
IF Transmission	**Digital Fiber Optic**
Correlator	
Correlated baselines	**2016**
Bandwidth	**16 GHz per antenna**
Spectral Channels	**4096 per IF**
Data Rate	
Data Transmission from Antennas	**120 GB/s per antenna, continuous**
Signal Processing at the Correlator	**1.6×10^{16} multiply/add per second**

Project Status

The construction phase in the U.S. began in 2002, while ESO formally began construction in January 2003. The current status of each of the level one WBS elements is described below.

Administration

The principal administrative task involves establishing a thorough management structure for the joint U.S.-European project and implementing that structure within the technical teams. The approach adopted is based on Integrated Product Teams (IPTs) in which the responsibility for each major task is assigned to one partner or the other but the work is executed jointly by the technical teams of both partners. That is, responsibility is assigned but the effort is shared.

A Joint ALMA Office (JAO) has been created by the ALMA Board as the central management structure for the ALMA construction phase. The JAO will ultimately have an ALMA Director, Project Manager, Project Scientist and Project Engineer. At present, only the ALMA Director, Massimo Tarenghi, has been appointed. An international search for the remaining JAO staff is underway.

Site Development

Detailed design for the civil infrastructure on the Chajnantor site is underway. In addition to the foundations required for the more than two hundred antenna stations, a technical building will house the Correlator and centrally located portions of the Back End and Local Oscillator subsystems. A perspective view of the building is shown in Figure IX.3.

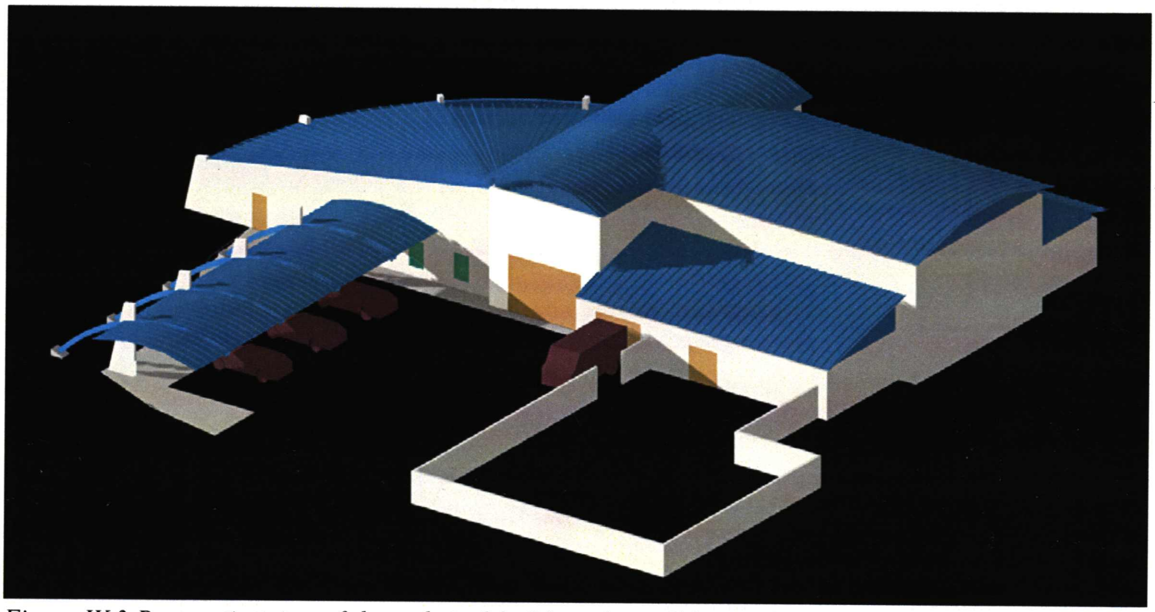


Figure IX.3 Perspective view of the technical building that will house the correlator and centrally located portions of the Back End and Local Oscillator subsystems.

Road access from the public highway, a European responsibility, has begun (Figure IX.4). This will provide access to begin construction of the technical building and the initial antenna stations next fiscal year.

IX. ALMA

Figure IX.4 Road access to the ALMA site.

Antennas

Three prototype antennas will be evaluated at the ALMA Test facility (Figure IX.5) located at the VLA site in New Mexico. The VertexRSI antenna, purchased by NRAO, is the middle antenna in Figure IX.5. This antenna was delivered in March and is being tested. The prototype from Alcatel, procured by ESO, is being erected inside the temporary building seen on the right. It will be available for evaluation this fall. The antenna on the left was built by Mitsubishi and supplied by our Japanese colleagues for the possible addition of a Compact Array should the Japanese join the project in 2004.

Figure IX.5 ALMA Test facility

IX. ALMA

An evaluation of the VertexRSI antenna (Figure IX.6) is underway that will demonstrate the performance of the antenna for critical parameters such as surface accuracy and pointing performance. Identical evaluation of the Alcatel antenna will be initiated as soon as it is available. The design of the production antennas will be selected based on the outcome of these tests.

Figure IX.6 Vertex RSI Antenna.

Front-end Subsystem

The ALMA front end is a single cryogenic dewar, or vessel, that is designed to accommodate ten frequency band receivers or cartridges. Initially only four cartridges will be built, for the bands at 3 mm, 1 mm, 0.85 mm, and 0.45 mm, respectively. Current plans are for the 3 mm cartridge to be built in Canada and the 1 mm cartridge to be built at the CDL. The 0.85 mm and 0.45 mm cartridges are the responsibility of the Europeans. Significant progress has been made for the components that make up each of the cartridges.

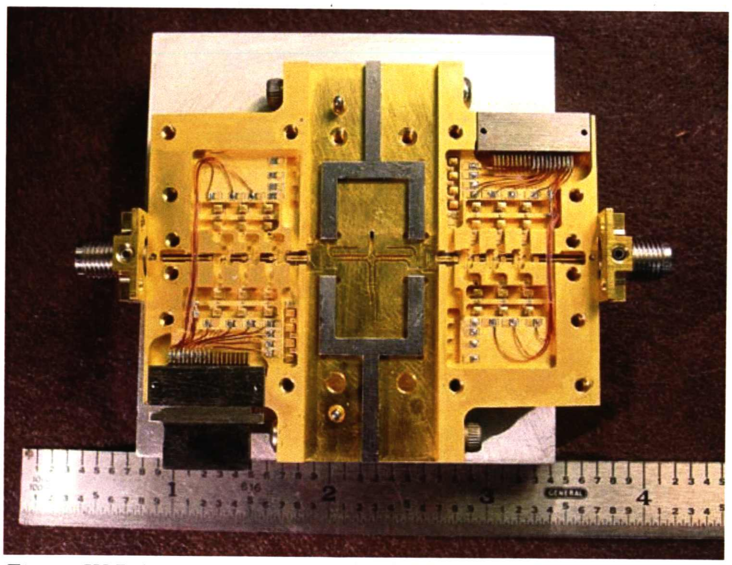


Figure IX.7 A prototype cryogenics (SIS) Superconductor-Insulator-Superconductor mixer for Band 6.

A prototype cryogenics SIS mixer for Band 6 (Figure IX.7) has been built and shown to meet the demanding ALMA low noise requirements.

Back-end and Correlator Subsystems

The 16 GHz analog IF output of each ALMA front-end is digitally sampled at the antennas and the digital signal is sent by fiber optic cables to the correlator. Prototype designs of the hardware needed for the sampler and the IF transmission are shown in Figure IX.8.

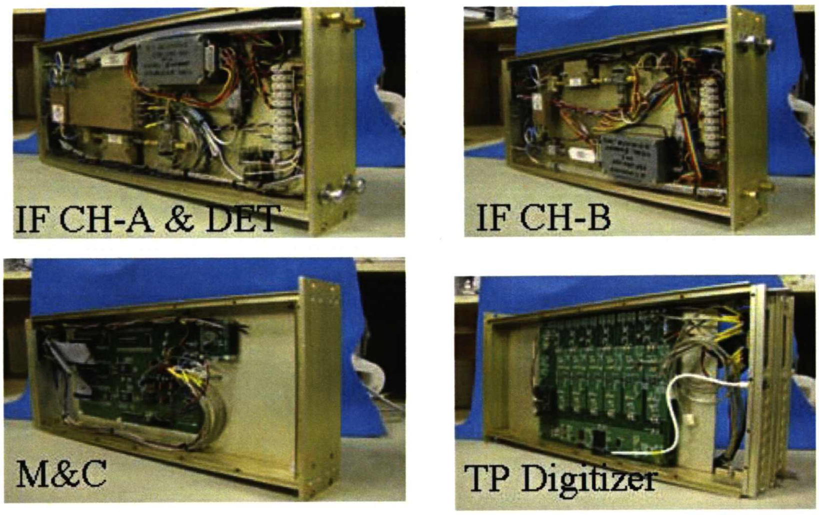


Figure IX.8 Prototype designs of the hardware needed for the sampler and the IF transmission.

The task of the correlator is to cross-correlate the digital IF signals from all 2,016 pairs of ALMA antennas. Prototype correlator boards have been successfully tested The correlator computation is done in a specially designed ASIC chip. Pre-production prototypes of this chip have been received fully tested. A two antenna prototype correlator, shown in Figure XI.9, has been assembled and is undergoing hardware testing and software integration.

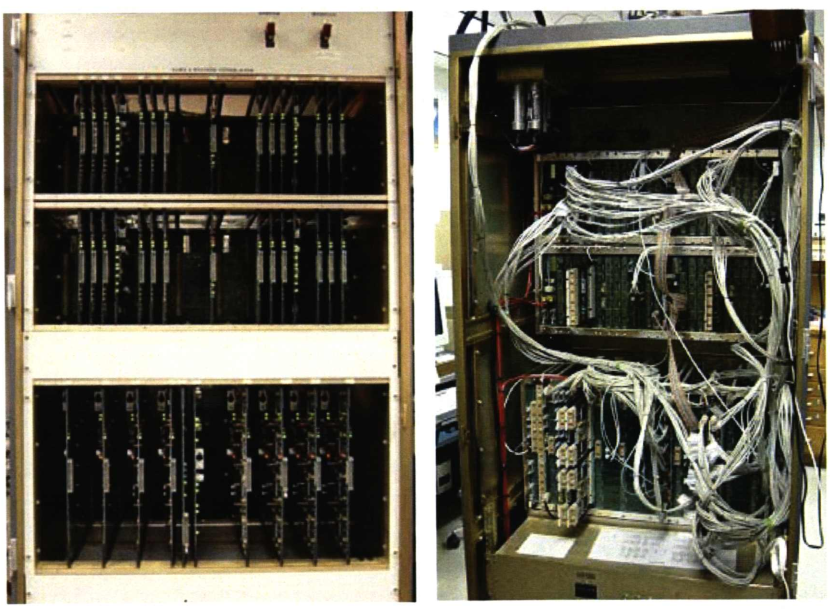


Figure IX.9 A two antenna prototype correlator.

Computing Subsystem

The computing subsystem provides the software needed to operate ALMA as well as collect, calibrate and archive the astronomical data. The software system design is being developed in concert with the ALMA software group in Europe, design decisions are made (such as the decision to use an AMBSI standard monitor and control bus), and a division of effort for the software task in the construction phase of ALMA is negotiated. Detailed science software requirements have been developed for all ALMA software elements.

A successful Computing Preliminary Design Review (PDR) was held during FY 2003. The review panel included software experts from outside the project as well as from the project itself. The panel was chaired by Rodger Doxsey of the Space Telescope Science Institute.

System Engineering and Integration

Significant effort has been put towards strengthening the Systems Engineering IPT. Richard Sramek was appointed IPT lead for Systems Engineering. He brings a wealth of experience in commissioning and operating radio interferometers from years of experience at the VLA.

Larry d'Addario has been appointed systems architect with overall responsibility for defining and maintaining the system configuration and the interfaces between subsystems. A detailed block diagram has been generated for the entire ALMA system. A high level version of this diagram is shown in Figure IX.10

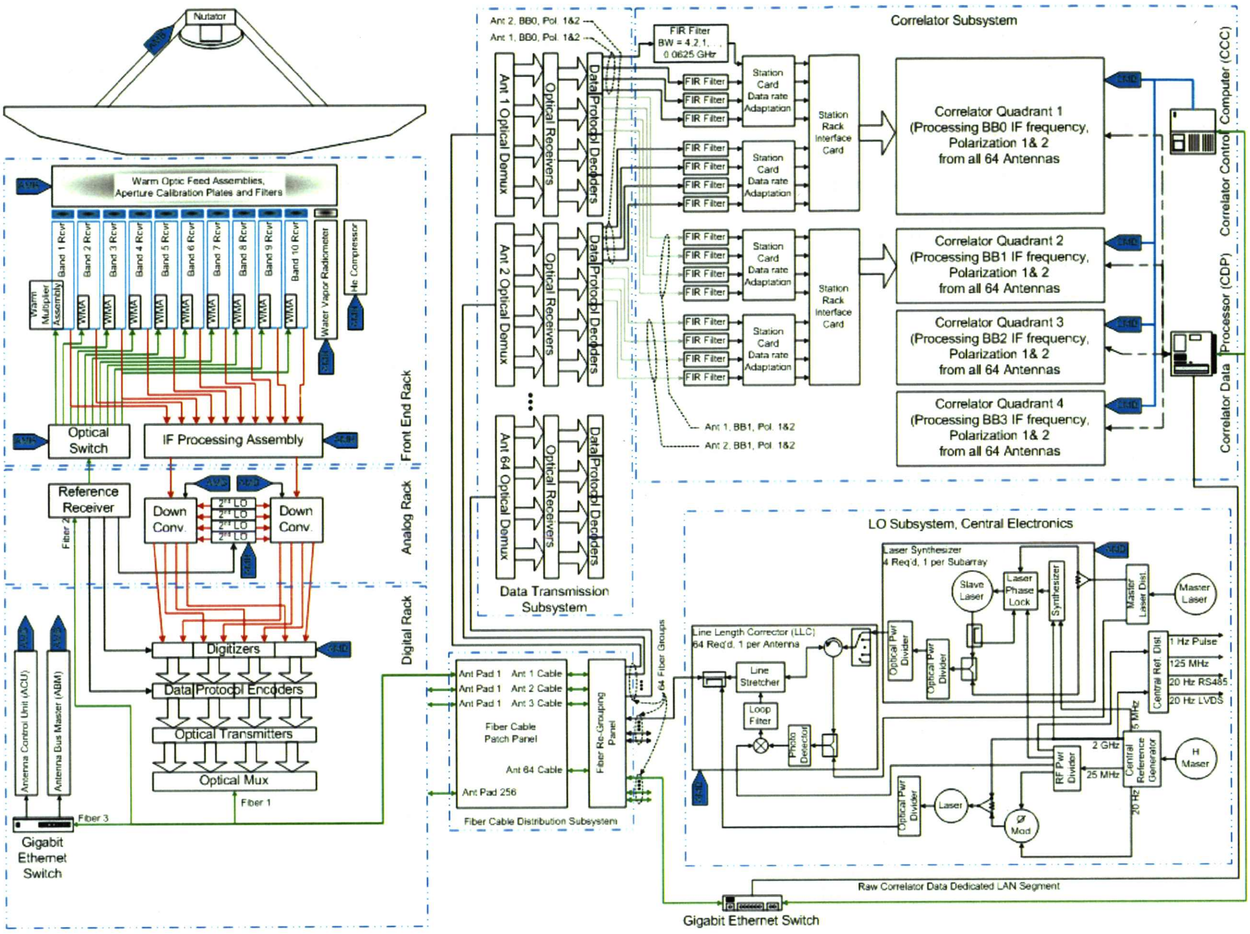


Figure IX.10 A detailed block diagram of the entire ALMA subsystem.

Science and Imaging

The science and imaging team has the responsibility to establish the array configuration layout that will maximize the imaging capability of the instrument, and to establish the calibration system necessary.

Design of the configuration and location of the antenna stations has been completed. Each of the antenna station locations have been surveyed and staked at the site. Based on the geotechnical conditions found at each station location, a small number of stations may require relocation to avoid poor soil and subterranean rock conditions.

The Science and Imaging IPT is developing a comprehensive Design Reference Mission (DRM). The DRM will include a set of observing sequences that are designed to be representative of the observations expected to be made with ALMA. The DRM will allow analysis of, for example, the efficiency of various operational scenarios, tests of assumptions about data volume and appropriate sizing of data communication and storage infrastructure.

Program FY 2004

The pacing item for the ALMA Project is procurement of the production antennas. As a result, a major focus of the ALMA effort in 2004 will be completion of prototype antenna evaluation and procurement of production antennas. Another major activity in 2004 will be the start of construction of the civil infrastructure on Chajnantor.

Additional activities planned for 2004 include integration and test of the prototype Back End, Local Oscillator and Correlator subsystems and the ALMA software that controls this hardware. With the completion of the two antenna prototype correlator, the correlator group will begin assembling the first of four quadrants of the correlator that will ultimately be shipped to Chile. Finally, detailed design of the front end subsystem, and the planning for front end integration, will be completed during this period.

Table IX.2 ALMA FY 2004 Major Tasks and Milestones

WBS Level 1	WBS Task	Milestone or Deliverable
1	Administration	Permanent staff hired for Joint ALMA Office Establish effective Earned Value Analysis across both partners
2	Site Development	Complete road access to OSF and AOS Complete construction of a contractors camp at the OSF Begin construction of the AOS civil infrastructure
3	Antennas	Complete procurement process for production antennas
4	Front-end Subsystem	Deliver first cryostat to FE integration center Complete design of FE integration center Complete detail design of FE cartridges
5	Local Oscillator	Complete assembly of prototype end to end LO subsystem Demonstrate that prototype meets ALMA specifications
6	Back-end Subsystem	Deliver ALMA Back-end modules for integration

WBS Level 1	WBS Task	Milestone or Deliverable
7	Correlator	Deliver prototype correlator for system integration Place orders for components for first correlator quadrant
8	Computing Subsystem	Support ATF and system integration tests Continue ALMA software development based on plans approved at PDR
9	System Engineering and Integration	Complete antenna evaluation at the ATF Plan and execute system integration of the prototype Back End, LO, Correlator and Computing subsystems.
10	Science and Imaging	Deliver ALMA calibration plan Deliver Design Reference Mission

The entire scope of activities planned by both the U.S. and European partners in ALMA are set forth in the ALMA WBS. The milestones table above was abstracted from that WBS. The ALMA FY 2004 budget and ALMA personnel are included in Section XII of this NRAO Program Plan.

X. Initiatives and Other Activities

New Initiatives

In fulfilling its mission of designing, building, and operating large radio astronomical facilities, the NRAO plays a major leadership role in the wider astronomical community. In addition, as a key source of both technical and scientific expertise, the NRAO serves as a valuable resource to the radio astronomical community. Typically, many years are required to define and develop a major new facility. Participation in this process maintains and strengthens the NRAO leadership role while, at the same time, enhances our ties with and fosters the health of the broader radio astronomical community. Conversely, participation in these broadly based initiatives benefits the NRAO to the extent that it enables the Observatory to keep pace with and exploit technological innovation.

Currently, the NRAO staff are involved with four initiatives: the Solar radio telescope (FASR); the extension of VLBI baselines to space (RadioAstron); the large low frequency array (LOFAR); and the largest project, the Square Kilometer Array (SKA). Of these, the principal activities in FY 2004 will be concentrated on FASR and SKA.

The Frequency Agile Solar Radio Telescope (FASR)

The Frequency Agile Solar Radio telescope project is an initiative of the solar-physics community to build an optimally designed instrument to perform broadband imaging spectroscopy over a frequency range of ~0.1-30 GHz. Recently, the project was ranked as the number one small project (<$250M) by decadal review of the NAS/NRC Solar and Space Physics Survey Committee of the Space Science Board. The project has also been endorsed by the decadal review of the NAS/NRC Astronomy and Astrophysics Survey Committee as one of three solar projects for the coming decade: the Advanced Technology Solar Telescope (optical/IR), the Frequency Agile Solar Radiotelescope (radio), and the Solar Dynamics Observatory (optical/EUV/SXR).

FASR will probe the solar atmosphere from the chromosphere up to the middle corona. It is designed to address an ambitious science program, including coronal magnetography, the physics of flares, drivers of space weather, and the thermal structure and dynamics of the solar chromosphere. FASR will bring unique capabilities to bear on these problems, capabilities that are highly complementary to existing and planned ground- and space-based facilities.

The NRAO will play an important role in the FASR project. It is currently participating in a preliminary design study, funded through the NSF/ATI program. More recently, the NRAO, in collaboration with the University of Maryland and the Swiss Federal Institute of Technology, Zurich, was awarded an NSF/MRI grant to develop a broadband spectrometer at the NRAO site in Green Bank, beginning in FY 2004. The development effort will include a FASR R&D component that will focus on broadband feed design and robust, broadband RF packages. Several NRAO staff members are presently involved in FASR activities. It is expected that the NRAO can also bring its expertise to bear on problems associated with broadband signal transmission, digital signal processing, RFI mitigation, and data management. Many of these problems are closely aligned with other projects that the NRAO has underway or is studying for the future: EVLA, ALMA, LOFAR, SKA.

Partner institutions are also moving forward with technical studies. The NJIT, in collaboration with Berkeley and the University of Maryland, has submitted an NSF/ATI proposal to design and prototype elements of the ultra-wideband data transmission system. A collaborating group (Laboratoire d'Etudes Spatiales et d'nstrumentation en Astrophysique, LESIA) at the Observatoire de Paris is funded to begin studies of digital signal processing across the decimeter wavelength range.

Discussions are underway to form the FASR Project Consortium (FPC) in early 2004. The FPC will be an international consortium that will be responsible for the design and construction of the instrument. Possible members include the NRAO, NJIT, Berkeley, University of Maryland, and Observatoire de Paris, and possibly others. Discussions are ongoing with a number of additional partners and collaborators, including groups at the NSO, NRL, ETH/Zurich, and AIP/Potsdam. Discussions are also underway with other planned projects, notably LOFAR and the Allen Telescope Array. In the former case, project coordination is under discussion for both scientific and logistical reasons. In the latter case, we expect to learn valuable lessons from the technical effort of the ATA.

The Square Kilometer Array (SKA)

In recent years there has been increasing discussion within the international radio astronomy community about developing a radio telescope having up to two orders of magnitude improved sensitivity compared with existing instruments. Because current receivers are close to their theoretical limits, the only way to achieve significant improvement in sensitivity is to greatly increase the collecting area. However, any simple extension of conventional approaches to obtaining large collecting area will be prohibitively costly, hence the need to break the cost curve to achieve a collecting area equivalent to one square kilometer. This development project is known as the Square Kilometer Array (SKA). The NRAO is a member of the U.S. SKA Consortium and is represented on the International SKA Steering Committee; these two bodies are charged with the coordination of national and international efforts, respectively, to develop the next generation of radio astronomy instrumentation needed to address the scientific questions of future decades. The NRAO staff have been active in developing the scientific case for the SKA, in organizing meetings to focus the attention of the U.S. and international radio astronomy community on the challenges presented by the SKA, and in working with SETI to develop the Allen Telescope Array. NRAO staff will continue to work on various aspects of the design as members of the Engineering Management Team which is charged with evaluating the competing technical approaches being developed throughout the international community and as members and chairs of the SKA technical and scientific working groups.

In addition, many of the techniques and instrumentation currently being developed for the EVLA are an important part of the planning for the SKA. This includes wideband low noise receivers and feeds, an advanced correlator designed to minimize the impact of RFI, the use of broad band fiber optic transmission systems, configuration optimization, advanced data management and archiving techniques including multiple-field calibration in the presence of non-isoplanatic screens, non co-planar and high dynamic range imaging, the effective use of data archives, and real time imaging from complex data acquisition.

Many NRAO scientific and engineering staff have been actively involved in developing the U.S. Strawman Design of the SKA, one of seven which were developed by the international community including groups in Canada, Australia, China, India, and Europe. The U.S. SKA design consists of 4,400 12-m diameter dishes most of which will be located near the current VLA site and throughout the state of New Mexico. Other proposed sites are in Western Australia, China, and South Africa. Much of our SKA related activity during Program Year 2004 will be devoted to developing a formal siting proposal to the international steering committee which is due in May 2005 in anticipation of a site choice or short listing in early 2006. This work, which will include the characterization of the RFI environment, tropospheric phase stability, the distribution of existing roads, power, fiber optic communication, political stability, costs and access to land, will be done in collaboration with national partners, particularly those from the University of New Mexico.

Charlottesville Facilities

Charlottesville operations are now divided between (a) Stone Hall, a 24,423 gross sq. ft. building built by the University of Virginia to the specifications of the NRAO and leased from the University by NRAO/AUI since 1964, and (b) 12,972 gross square feet. of commercially leased space in the Dynamics Building on Ivy Road. This space has been used for many years by the Central Development Lab (CDL).

The NRAO is implementing a plan to locate all of the ALMA North America related functions at Charlottesville as part of the NRAO "one Observatory" concept. In an important step, a project has been initiated to add 38,360 square feet to Stone Hall, thus providing the space needed to accommodate the North America ALMA Science Center (NAASC), the focal point for support and development of the North American component of ALMA Operations. This addition, which was described previously in the Program Plan for FY 2003, will also provide for growth of the Library and conference facilities, the renovation and upgrading of the HVAC and communications infrastructure in much of the existing building, and the improvement in fire protection and accessibility, providing a safer and more efficient work environment. The construction work on the site began May 2003 and is progressing well. It is anticipated that the NRAO will be able to occupy the new space during the fourth quarter of CY 2004.

To engender a more synergistic and collaborative environment for the development and production of the ALMA electronics, the ALMA Tucson and the Charlottesville Central Development Laboratory will be consolidated into one facility, to be called the NRAO Technology Center (NTC). In February 2003, the announcement was made that the NRAO Tucson office would close, and a majority of the thirty-nine Tucson employees will be relocated to Charlottesville. A suitable site for the NTC has been identified. The site, formerly the ITT complex, is close to the Edgemont Road facility and therefore close to the NAASC. It has two buildings with a total of 38,500 square feet that are well-suited for the needs of the Center. A lease on this space has been negotiated, and work began in August 2003 to modify the interior of the buildings to meet the specific needs of the ALMA and CDL efforts, including the installation of the requisite infrastructure for the combination of laboratory and office space. First occupancy of the new facility will occur in the last quarter of CY 2003. The lease of the CDL Dynamics Building will be allowed to lapse at the end of CY 2003, and the employees now at the Dynamics Building will move to the NTC.

Spectrum Management

Spectrum management at the NRAO covers a wide range of activities, including monitoring of interference in the neighborhoods of the Observatory's telescopes, developing techniques for excision of interference from both single-dish and interferometer observations, and representing the radio astronomy community in national and international regulatory bodies.

In Green Bank, RFI-related activities are undertaken by the Interference Protection Group (see www.gb.nrao.edu/IPG). They administer operation of the National Radio Quiet Zone, which receives several hundred applications each year for new transmitters. Group members monitor the environment for externally-generated RFI using a remotely-controlled field measurement station, and employ a sophisticated new anechoic chamber to examine equipment used for on-site operations. Under their supervision, the new Science Center at Green Bank and other on-site locations in the Jansky Lab have been carefully shielded to permit RFI-free observations by the GBT. The general program of RFI mitigation is of course an ongoing one, since the suppression of one source might reveal the presence of a weaker source. In FY 2004 mitigation of RFI will continue, with emphasis on eliminating any remaining sources on the telescope structure itself. Administration of the Quiet Zone will also be an important element of the program.

The work of the Interference Protection Group for VLA and VLBA activities in New Mexico and elsewhere is summarized online at www.vla.nrao.edu/astro/rfi/, including updated spectral scans of the local RF environment. Substantial effort has recently gone into calibration of their anechoic chamber and construction of equipment crates providing ~ 170 dB of shielding. The IPG monitors the ALMA antenna test site and is developing wideband, small-aperture radio direction finding equipment. They have recently completed development of a 10 Hz BW tracking generator and spectrum analyzer which gives ~160 dB of dynamic range while measuring shielding.

Nationally and internationally, NRAO staff participated as members of the NRC's Committee on Radio Frequencies (CORF) and the ICSU's Scientific Committee on Frequency Allocations for Radio Astronomy and Space Science (IUCAF). IUCAF is sponsored by the IAU, URSI, and COSPAR, and is recognized by the ITU as an international non-governmental entity, participating in ITU meetings with a status almost equal to that of a sovereign nation. It is the radio astronomy community's only direct voice, unfettered by other considerations that are involved in, and sometimes dominate, national inputs to ITU proceedings. Staff members also participated in ITU activities such as WRC2003 and its preparatory cycle of working parties and study groups (WP7D, TG1/7 etc), both here and abroad. On the behalf of NRAO, MOUs were concluded between the NSF and several satellite and airborne mobile service operators, providing for protection in certain vulnerable frequency bands during specified periods. The first international summer school on techniques of spectrum management was held at Green Bank under IUCAF auspices during the summer of 2002 (see http://www.iucaf.org/sschool/), and it provided a unique opportunity for radio astronomers and regulators to appreciate the many dimensions of the growing problem that interference poses for radio astronomy.

Spectrum management activities at the national and international level during FY 2004 will consist of: participation in the US and international activities of ITU Working Party 7D (WP7D) on radio astronomy, in preparation for WRC2007; convening phone meetings of US university- and observatory-based parties interested in spectrum management, for the purposes of information sharing; holding similar informational meetings within the NRAO; servicing the somewhat occasional requirements of various MOUs with Boeing, Globalstar and Iridium regarding spectrum sharing; and responding to occasional FCC and other inquiries related to spectrum allocation.

XI. Impact of Alternate Funding Levels

Introduction

This Program Plan has been written to a funding level of $52,643k, for NRAO Operations, an amount which includes $5,434k for the next stage of the EVLA Phase I construction, and $2,500k for the repair of the GBT track. This amount is essentially the Mission Requirements Level (MRL) discussed with the NSF on June 16, 2003, in the context of the preparation for the request for funds for FY 2005.

The President's Request Level (PRL) is $42,730k and includes the funding of the EVLA at $5,434k. This level of funding is less that the MRL above by $9,913k.

In the course of the appropriations process in Congress, a possibility of funding at a level greater than $52,643k has been raised. Although the magnitude of the augmentation is not known precisely, the areas which would be impacted by the receipt of additional funds are described below.

It is helpful to examine some of the principal differences that have led to a higher requirements budget. At the outset it is to be noted that the PRL for FY 2004 is lower than the actual expenditures and commitments projected for FY 2003 ($47,305k) by $4,575k. The remaining difference between the PRL and the MRL ($5,338k) represents a growth in the Observatory budget. The major part of this growth ($4,126k) arises from increases in personnel costs because of salary adjustments, and from a program to repair the GBT track. The other increases appear a s smaller amounts in a number of areas, and total $1,212k, as outlined in the following summary.

• Change in salaries, including upgrade of professionals	$1,226k
• The associated change in benefits	400k
• One-time Funds for the Repair of the GBT Track	2,500k
• Increment in building costs and leases	500k
• Changes in insurance, training, etc.	100k
• Increase in Infrastructure Support for VLA	100k
• Augmentation of the Jansky Fellowships	400k
• Increment in EVLA Funding	112k
Total Change from FY 2003 to FY 2004	$5,338k

The Impact of Augmented Funding

The additional funding that has been discussed during the appropriations process would be focused in two specific areas. First, there is interest in accelerating the pace of construction in the project to expand the VLA, EVLA. If funding for the project is increased from the baseline amount of $5.4 M to $9.4 M the size of the purchase orders for equipment required to convert VLA electronic systems to EVLA designs will be increased. This will result in reduced total project cost of $0.5 M, due to economies of scale, and a reduction of 5 months in total project duration because the rate at which antennas are modified will be increased. If accelerated funding is continued for the out years of the project the total project duration would be reduced by two years with completion in 2009.

Second, an amount of $4,600k may be added to support the fabrication and installation of components needed to effect a repair of the azimuth track of the GBT. Although the concepts for the track repair are still being evaluated, the preliminary estimate is that funding at this level will be required to install an entire new system of wear strips. The new wear strips would be of material with a greater resistance to fatigue, and would be installed in a new pattern such that the junctions in the wear strip segments would not coincide with the junctions in the base plates, as they do in the current design.

The augmented funding also envisions an additional $1,000k for operations at the Green Bank site. Were such funding to be made available it would initially be held in reserve as a contingency for the work on the GBT track. If it were not needed for the track, it would be applied in other areas of the Green Bank Operations. Of high priority are a number of instrumentation projects which would enhance the capability of the GBT at higher radio frequencies.

The Impact of Funding at the President's Request Level

The FY 2004 Preliminary Financial plan shows the WBS breakdown of the budget beginning on page XII.3 with funding at the President's Request Level and funding at the Mission Requirements Level. The Mission Requirements Level shows the FTE levels needed to support the program presented in this document. In view of the current uncertainty in the budget the FTE levels under the PRL have not been estimated in detail. Instead, the upgrade to the GBT track (WBS 4.3) was deferred, and the total salary and benefit amounts for all operating units except the EVLA (WBS 6.0) and ALMA Construction (WBS 7.0) were reduced by an average of 15 percent, spreading the effect of the reduction across all parts of the Observatory Operations. As is described below, it may be preferable to reduce or eliminate specific activities, rather than make a general reduction in the level of effort.

Possible Approaches to Addressing the Shortfall

Maximizing the Carryover from FY 2003

The NRAO has been making an aggressive effort to conserve funds during the latter part of FY 2003, in anticipation of the dire circumstances which the Presidential Request would lead to. We currently project that we will be able to carry forward $2,156k in uncommitted FY 2003 funds. Thus, the difference between the request and the requirements budget is reduced to approximately $7,750k.

The GBT Track

A careful assessment will be made of the state of the track of the GBT. There is no question that the track will eventually have to be rebuilt or replaced. However, if the current efforts in shimming the track and replacing the most seriously damaged section of the wear strip can stabilize the track against rapid deterioration, then it may be possible to defer the major work on it until FY 2005. Doing so would reduce the mission requirement level in FY 2004 by $2,500k.

Reduce Programs Not Directly Supporting Observations

There are a number of activities which the Observatory could cancel or defer without an immediate impact on the quality of the observations being undertaken with the telescopes, but which would have a serious negative impact on the Observatory's capabilities in the long run. Examples are the suspension of the student support for students using the GBT; the enhancement of the Jansky Fellowship Program designed to stimulate wider interest in the program, thereby attracting to the Observatory post docs of the highest caliber; and a reduction in the amount of infrastructure work (examples: painting the GBT, repairing the VLA railroad track). In response to a management study of the Observatory Business and Personnel operations, plans are being formulated to augment the software systems to improve the processing of personnel records, and to enhance the security systems in all NRAO buildings; these efforts could be deferred for an additional year. Reductions in these activities could total between $1,800k and $2,000k.

A General Reduction in the Level of Effort

This approach is difficult because the NRAO operations have already been reduced to an austere level.

Although the current level of support for maintenance is the minimum that is required to keep the instruments on the air, the PRL would require some reduction in this area. One example is the azimuth bearing replacement program on the VLA, where there are perhaps five suspect bearings which could require attention in the near future; it may not be possible to replace more than one in FY 2004. Other economies might be sought in deferring the painting and structural inspections of the GBT; the reduction from eight to five in the number of VLA antennas undergoing major preventive maintenance during the year; the canceling of the major maintenance visits to three or four VLBA antennas which would normally be undertaken during the coming year; and the deferment of the purchase of materials needed to implement the improved environmental health and safety programs. Each of these reductions would result in a savings of funds, but would come at a price; the price would be determined by what element failed because of the reduced maintenance program. As an example, it should be noted that during the routine inspection of the St Croix VLBA antenna in FY 2003 it was discovered that the elevation bearing was in the process of failing. Had it actually failed, the damage to the antenna would have been extensive. As it was, a special maintenance trip was scheduled and the bearing was successfully replaced, in a timely manner.

Serious consideration would have to be given to reducing the amount of observing time scheduled on the VLA, the VLBA, and the GBT. Operating these telescopes is costly in terms of personnel, materials and supplies, utilities, and maintenance, and a reduction in the number of operating hours would yield some savings. If the staff size is maintained, so as to not lose observing capabilities permanently, then the savings are primarily in supplies, utilities, and overtime for personnel.

However, since the number of successful observing hours is the most important measure of the Observatory's productivity, such a step would be taken only after other austerity measures have been implemented.

The total savings in maintenance and operations if all of these reductions were implemented ranges between $600k and $800k. The consequences of these reductions of this would be extremely serious. Preventive maintenance programs would be reduced or eliminated, leading to an increase in observing time lost due to system failures.

In view of the large shortfall, it is inevitable that there will need to be a reduction in the number of employees. The details of this reduction have not been worked out, but the level of the reduction which is required can be estimated in general. A typical employee at the NRAO earns $54k per year, and the benefits reckoned at 32.5% require an additional $17.5k. However, the typical employee has served the Observatory for fifteen years, and is thereby eligible for a severance package which is about 40 percent of salary, or $21.5k. Therefore, for each employee who is laid off there will be a reduction in personnel costs of $50k. To achieve a reduction in the budget of $2,000k will entail laying off 40 persons, or approximately 9 percent of the total workforce.

The level of support for the visiting observers would have to be reduced. There would be little effort available for the development of either hardware or software, and the level of effort in the maintenance in these two areas would be greatly reduced. Thus, even though the telescopes would not be closed, their effectiveness in serving the astronomical community would be significantly jeopardized. In addition, with a reduction of this magnitude it seems inevitable that there would have to be a reduction in the amount of contributed effort in EVLA I construction, with a resultant slowing in the progress on that project.

Elimination of a Program Element

It may be determined that the reductions required would so severely impact the ongoing operations as to call into question their viability. In that case, the alternative is to eliminate one of the major program elements entirely. However, the elimination of any one of the elements would represent a major loss in the capabilities available to the astronomical community, since each makes a unique contribution to that effort. These elements are:

The *Central Development Laboratory and the Basic Research Group* in Charlottesville. The CDL serves as the innovator for new technology at the Observatory, and the Basic Research Group provides scientific effort for Observatory projects and initiatives, in addition to performing individual astronomical research. The Charlottesville Edgemont Road building is being expanded to serve as the North American ALMA Science Center. The management and business functions housed in Charlottesville, and the ALMA construction activities could not be eliminated.

XI. Impact of Alternate Funding Levels

The *Very Large Array* is the world's premier radio telescope. It is currently being expanded to augment its capabilities. It cannot be closed without also eliminating the EVLA project, which is predicated on using the VLA antennas and infrastructure.

The project to expand the capabilities of the VLA, the *EVLA* project. Now in its third year, this project will greatly enhance the scientific capabilities of the VLA. The project was highly recommended in the decadal review, and has been authorized by the Board of the National Science Foundation.

The *Very Long Baseline Array* is the only dedicated astronomical instrument capable of imaging at milliarcsecond scales. Now in its tenth year of service, it is in demand for studies in astrometry, earth rotation, and the physics of evolving stars, supernovae, and extragalactic jets.

The *Robert C. Byrd Green Bank Telescope* is among the most advanced radio telescopes ever constructed, featuring an unblocked aperture, an active surface, a rotating turret for fast selection of receivers, and state of the art electronics. With the commissioning phase essentially complete, it is being used to address projects ranging from low frequency radio phenomena such as atomic hydrogen and pulsar emission, to high frequency molecular line and dust emission.

It might be asked if one of these programs could be suspended for one year, thereby achieving the desired savings but maintaining the possibility of resuming the operation of the facility in FY 2005. This is not a practical option. If the operation of one of these units is suspended for one year, the technical staff consisting of outstanding scientists and engineers, and highly-skilled technicians, will be laid off. They will surely seek employment elsewhere, and because of their technical and professional skills will almost surely find work, even in the current poor environment. They will naturally have lost confidence in the Observatory, and would be unlikely to return after operations are resumed in a year. It took years to build this staff; it is unlikely that it could be rebuilt quickly. It is concluded that it would be difficult to resume operations after a year of suspension, and that a year of suspension is tantamount to closing the facility.

XII. FY 2004 Preliminary Financial Plan

Table XII.1. NSF New Funding by Function
($ k)

Operational Functions	Salaries & Benefits	Materials, Services & Equipment	Travel	Total New NSF Funds Request Level
Observatory Wide Activities	$9,726	$3,034	$721	$13,481
GBT Operations	6,371	1,644	130	8,145
VLA/VLBA Operations/EVLA	12,998	6,939	413	20,350
Device Revenue & Common Cost Recovery		(314)		(314)
ALMA (U.S.) (SPO-2)	12,469	35,829	1,271	49,569
Research Experience - Teachers & Undergraduates (SPO-3)		167	22	189
Green Bank Solar Radio Burst Spectrometer (SPO-4)	288	159	21	468
Management Fee		2,339		2,339
Total NSF	**$41,852**	**$49,797**	**$2,578**	**$94,227**

Source of New Funds

Operations (SPO-1)	*$42,730*
ALMA (U.S.) (SPO-2)	*50,840*
RET/REU (SPO-3)	*189*
GB SRB Spectrometer (SPO-4)	*$468*
TOTAL	*$94,227*

Table XII.2. Non-Programmatic Funding
($ k)

Funding Source	FTE	Salaries & Benefits	Materials & Services	Travel	Total Request Level Budget
Misc. Grants		87	98	30	215
Total Non-Programmatic		**87**	**$98**	**30**	**$215**

Table XII.3. NSF Funds (Request Level Budget) by Budget Category
($ k)

	New NSF Funds	Uncommitted Carryover of 2003 Funds	Total Available for Commitment at Request Level	Commitments Carried Over from 2003 Funds	Available for Expenditure at Request Level
Personnel Compensation	$31,587		$31,587		$31,587
Personnel Benefits	10,266		10,266		10,266
Travel	2,578		2,578		2,578
Materials & Services	47,771	25,357	73,128	3,112	76,240
Management Fee	2,339		2,339		2,339
Common Cost Recovery	(304)		(304)		(304)
CDL Device Revenue	(10)		(10)		(10)
Res & Oper Equipment			0		0
Total NSF Operations and ALMA	**$94,227**	**$25,357**	**$119,584**	**$3,112**	**$122,696**
MRI		55	55	46	101
CISE		276	276	0	276
Education (RC & CTW)		235	235	328	563
Total NSF	**$94,227**	**$25,923**	**$120,150**	**$3,486**	**$123,636**

XII. FY 2004 Preliminary Financial Plan

		New NSF and Carryover Budget	Mission Requirements	
			FTE	Totals ($k)
1.0	**Observatory Management**			
1.1	Director's Office	1,389,000	6.0	1,549,000
1.2	Observatory Business Services	3,244,000	24.8	3,489,000
	FY03 (carryover)	2,156,000	-	2,156,000
1.3	Program Office	132,000	1.0	153,000
1.4	Research Equipment	-	-	-
1.5	Spectrum Management	51,000	0.3	57,000
1.6	[not used]	-	-	-
1.7	Environment, Safety, and Security	333,000	3.5	372,000
1.8	Human Resources	498,000	6.0	567,000
	subtotal Observatory Management	**7,803,000**	**41.6**	**8,343,000**
2.0	**Education and Public Outreach**			
2.1	Administration and Management	244,000	3.4	281,000
2.2	Informal Education	271,000	12.9	333,000
	Education and Public Outreach (carryover)	235,000	-	235,000
2.3	Formal Education	87,000	1.3	102,000
2.4	Community Relations	26,000	0.4	30,000
2.5	Astronomical Community	80,000	0.4	85,000
2.6	[not used]	-	-	-
2.7	Media Information	87,000	0.8	96,000
	subtotal Education and Public Outreach	**1,030,000**	**19.1**	**1,162,000**
3.0	**Engineering and Technical Development**			
3.1	Management & Administration	269,000	2.4	308,000
3.2	Production	433,000	6.8	502,000
3.3	Maintenance	58,000	0.4	63,000
3.4	Research Equipment	37,000	0.3	41,000
3.5	Development	608,000	6.6	716,000
3.6	Operating Site Support	168,000	2.1	197,000
	subtotal Engineering and Technical Development	**1,573,000**	**18.6**	**1,827,000**
4.0	**Green Bank Operations**			
4.1	Management & Administration	1,019,000	20.8	1,215,000
4.2	Plant Maintenance	635,000	11.7	727,000
4.3	Facilities & Infrastructure	5,936,000	80.9	9,308,000
	GBT User's Support (carryover)	-	-	-
4.4	Research Equipment	140,000	-	140,000
4.5	Operations Funded Projects	-	-	-
4.6	Staff Scientific Research	144,000	2.2	170,000
4.7	Major Research Instrumentation	-	-	-
	Major Research Instrumentation (carryover)	55,000	-	55,000
4.8	University Built Instrumentation Projects	272,000	-	272,000
	University Built Instrumentation (carryover)	-	-	-
	subtotal Green Bank Operations	**8,201,000**	**115.5**	**11,887,000**
5.0	**New Mexico Operations**			
5.1	Management & Administration	3,579,000	13.7	3,933,000
5.2	Facilities	1,250,000	-	1,250,000
5.3	VLA/VLBA Operations	8,849,000	165.5	10,430,000
	CISE (carryover)	276,000	-	276,000
5.4	Research Equipment	-	-	-
5.5	Operations Funded Projects	261,000	3.3	480,000
5.6	Staff Scientific Research	977,000	5.0	1,147,000
5.7	Major Research Instrumentation	-	-	-
	subtotal New Mexico Operations	**15,192,000**	**187.4**	**17,516,000**

XII. FY 2004 Preliminary Financial Plan

		New NSF and Carryover Budget	Mission Requirements FTE	Mission Requirements Totals ($k)
6.0	**EVLA**			
6.1	Project Management	603,000	3.0	603,000
6.2	System Integration and Testing	1,092,000	2.6	1,092,000
6.3	Civil Construction	601,000	10.0	601,000
6.4	Antennas	416,000	4.0	416,000
6.5	Front End Systems	1,612,000	6.2	1,612,000
6.6	Local Oscillator System	141,000	1.8	141,000
6.7	Fiber Optic System	200,000	3.7	200,000
6.8	Intermediate Frequency System	134,000	2.2	134,000
6.9	Correlator	4,000	-	4,000
6.10	Monitor & Control	379,000	3.0	379,000
6.11	Data Management and Computing	251,000	2.3	251,000
6.12	Education and Public Outreach	-	-	-
	EVLA (carryover)	4,363,000	-	4,363,000
	subtotal EVLA	**9,796,000**	**38.8**	**9,796,000**
7.0	**ALMA**			
7.1	Management & Administration	1,284,000	5.3	1,284,000
7.2	Site Development	6,334,000	4.6	6,334,000
7.3	Antenna Subsystem	20,756,000	4.7	20,756,000
7.4	Front End Subsystem	7,264,000	49.5	7,264,000
7.5	Back End Subsystem	4,103,000	20.7	4,103,000
7.6	Correlator	3,885,000	9.2	3,885,000
7.7	Computing Subsystem	2,080,000	17.7	2,080,000
7.8	System Engineering and Integration	1,550,000	12.9	1,550,000
7.9	Science	548,000	4.6	548,000
7.99	Overhead	3,036,000	-	3,036,000
	ALMA (carryover)	18,777,000	-	18,777,000
	subtotal ALMA	**69,617,000**	**129.2**	**69,617,000**
8.0	**Computer and Information Services**			
8.1	Management & Administration	54,000	3.2	60,000
8.2	[not used]	-	-	-
8.3	[not used]	-	-	-
8.5	Central Computing Services	1,061,000	7.6	1,199,000
8.6	Staff Scientific Research	93,000	1.0	107,000
8.7	Telescope Computing	203,000	2.0	238,000
8.8	Digital Infrastructure	495,000	-	495,000
	subtotal Computer and Information Services	**1,906,000**	**13.8**	**2,099,000**

XII. FY 2004 Preliminary Financial Plan

		New NSF and Carryover Budget	Mission Requirements	
			FTE	Totals ($k)
9.0	**Division of Science and Academic Affairs**			
9.1	Management & Administration	40,000	0.3	47,000
9.2	Library	666,000	3.7	707,000
9.3	Research	2,799,000	22.7	3,250,000
9.4	Science Training and Education	774,000	19.0	904,000
9.5	[not used]	-	-	-
9.6	Archives	35,000	0.3	38,000
	subtotal Division of Science and Academic Affairs	**4,314,000**	**45.9**	**4,946,000**
	Research Experience (SPO-3)			
	Research Experience - Teachers	49,000	-	49,000
	RET (carryover)	18,000	-	18,000
	Research Experience - Undergraduates	140,000	-	140,000
	REU (carryover)	44,000	-	44,000
	subtotal Research Experience	**250,000**	**-**	**250,000**
	Green Bank Solar Radio Burst Spectrometer (SPO-4)	**468,000**	**1.0**	**468,000**
	Observatory total	**120,150,000**	**611**	**127,911,000**

Appendix A - Scientific Staff Research Activities

Cosmology, Large Scale Structure, Galaxy Formation, and Gravitational Lensing

Radio observations, unaffected by extinction due to dust, are able to probe the most-distant galaxies and provide insight into both star formation and AGN (active galactic nucleii) in the early universe. HI studies with the 21 cm line are complementary to both optical and IR investigations since they can detect gas rich systems and isolated HI features. Star formation and starbursts mold the overall appearance of galaxies. It is now believed that star formation proceeded at higher rates in the early universe compared to current levels.

Simulations of the appearance of the faint millimeter/submillimeter sky as viewed by the Atacama Large Millimeter Array and by the Green Bank Telescope will continue as part of efforts to construct the former and to instrument the latter with high frequency receivers. The Green Bank Telescope will be used to measure CO emission from a sample of galaxies at intermediate z, taking advantage of its broad spectral coverage and great sensitivity to prove its usefulness as a redshift machine.

The GBT and VLA will be used to search for HCN emission in high redshift CO sources. HCN luminosity is a better indicator of the rate of star formation in a galaxy than is CO luminosity. Several high redshift galaxies with known CO emission are candidates for HCN detection programs.

Sensitive VLA observations to detect faint galaxies at a wide range of redshifts are continuing at 1.4 and 8 GHz. The faintest of the sources, below 100 microJy, are generally 1 arcsec in size and often extended in a similar direction compared to the optical counterparts. Their radio spectral index is generally steep. Most of the emission is probably associated with starburst activity.

A deep, high-resolution VLA survey has been carried out on several fields investigated at moderate depth by the Chandra X-ray Observatory. In 2004, the VLA data will be analyzed, and compared to the complete set of X-ray sources having 2-8 keV fluxes above 10^{-14} ergs cm^{-2} s^{-1}. The investigation will determine whether the radio/X-ray ratio is characteristic of "classical" accretion, or has the much higher value that indicates low-radiative-efficiency accretion. The radiative efficiency then can be used to test the most simplifying assumption that is used to model the accretion history of the Universe, namely the assumption that radiative efficiency has been constant as a function of redshift. If the radiative efficiency does turn out to be a function of redshift, then the accretion rate probably evolves much less strongly than currently believed.

Optical identifications and spectra will be obtained for the 3400 radio sources detected by the VLA in the SIRTF First-Look Survey (FLS) area. The spectra will be used to calculate distances and to help distinguish between star formation and active galactic nuclei as the origin of the radio emission. Extinction-free estimates of the space density and evolution of both the star-formation rate and the amount of nuclear activity in galaxies will be made for the redshift range $0 < z < 0.5$.

Appendix A - Scientific Staff Research Activities

NVSS radio sources will be identified with quasars in the 2dF/6dF quasar survey samples. The cosmological evolution of radio emission from quasars will be determined with low statistical errors and compared with the corresponding optical evolution in the redshift range $0 < z < 2.5$.

Very deep VLA 20cm observations using the A, B, C, and D arrays will be used to study the radio-FIR relation as a function of redshift. This survey will be the deepest radio image yet with an rms noise level below 3 microJy. The radio survey is being carried out in a special region of the SIRTF SWIRE Legacy survey in the Lockman hole. A variety of optical/NIR surveys and a Chandra X-ray survey are also being carried out in this region to exploit these data.

Sensitive 20 cm radio observations using the VLA A, B, C, and D configurations will be analyzed to understand the evolution of the star-formation in rich clusters and the properties of the background sources in the same fields. A370, A851, and A2125 are the primary targets for this FY 2004. Besides the radio data, X-ray, submillimeter, and optical/NIR surveys are being used to understand these fields. Optical spectroscopy of selected objects with the Keck and Gemini telescopes is also underway.

New 20 cm, 90 cm and 4 m observations with the VLA in the A and C configurations are being used to test ideas about the origin of diffuse synchrotron emission in clusters of galaxies and in cool cluster cores. It is known that particle acceleration is taking place in merging clusters of galaxies because synchrotron emission in the form of relics and halos is often observed. However, the acceleration mechanism still remains uncertain: candidates include compression, shocks and turbulence. The new low frequency capabilities of the VLA allow observations of these rapidly steepening sources where the spectrum is steep. Observations will be carried out at several sets of scaled wavelengths to look for spectral index changes in relation to the morphology of the relic/halo and the distribution of the colliding cluster members, thus discriminating between candidate mechanisms.

Low frequency VLA observations will be performed for the Centaurus Cluster. Not to be confused with Cen A, this less famous radio galaxy PKS 1246-410 shows a strong interaction with the X-ray emitting gas. A filament in the X-rays appears to encircle the radio lobes. Chandra will be used to obtain a moderately deep, 200 ksec observation of the Centaurus cluster to aid in the detailed comparison between X-ray and radio emission.

A sky survey at 73.8 MHz, using the VLA B and BnA configurations, will continue during the following year. The survey, called '4MSS' (4-Meter Sky Survey) will cover 10.3 sr of sky (all declinations north of -40 degrees), with 80 arcsec resolution, and a limiting (5-sigma) sensitivity of 400 mJy/beam. The scientific goals of this survey are: I) To construct the first really large flux-limited sample of sources at a very low frequency. More than 130,000 sources are expected to be cataloged. ii) To find large unbiased samples of steep-spectrum objects, such as pulsars (100 are expected to be detected), steep-spectrum radio halos around radio galaxies, and fossil or relic radio sources. High-redshift radio galaxies are efficiently found through their steep radio spectra. iii) To extend the radio spectra of known sources to 74 MHz, where free-free absorption and synchrotron self-absorption become increasingly important. iv) To image extended steep-spectrum objects, such as galactic SNRs and halos and tails of nearby radio galaxies. v) To disentangle the superposition of sources along complex lines of sight in our Galaxy via the contrast between non-thermal emitters and free-free absorbing HII regions. vi) To establish a calibrator list for future low-frequency surveys. Because of the large primary beam (11.4 degrees FWHM), the time taken for the survey is much less than other radio sky surveys—approximately 750 hours. Like the NVSS, the survey is a service to the entire astronomical community, and the results will be released promptly via the web.

The VLA and VLBA will be used to carry out follow-up observations of candidate gravitational lens systems discovered in the Cosmic Lens All-Sky Survey (CLASS).

The Cosmic Background Imager (CBI) will be used to image the Cosmic Microwave Background radiation (CMBR) from the ALMA site in Atacama, Chile. Powerful data analysis techniques with which to analyze interferometric observations of anisotropy in the intensity and polarization of the CMBR will be developed.

The VLA and GBT will be used to identify, characterize, and monitor the polarization and total flux density properties of faint radio sources that are foreground contaminants of CMBR surveys such as that being carried out by the CBI. The new sensitive Ka-band (26 to 40 GHz) receiver on the GBT, along with a fast-switching broad-band continuum back-end, will be used to characterize the point source foregrounds which limit the accuracy of small-scale intrinsic anisotropy measurements. These observations will provide experience in testing the new 3 mm continuum bolometer camera now under construction for the GBT.

The VLA will be used to complete the survey of the HI line emission in the galaxy cluster Abell 2029, one of the densest known. The complete absence of HI emitting galaxies located within 1 Mpc of the cluster core and the HI-deficiency of galaxies located at larger distances place important constraints on the evolutionary history of this cluster. Observations of off-center regions will be made to complete this study.

The VLA is being used in order to further investigate the high-redshift HI-absorption against the radio galaxy B2 0902+343 (at $z = 3.4$) which was first detected with the VLA. The goal is to confirm the substructure hinted at in follow-up VLA B and C array observations with a spectral resolution of 12 kHz. The absorbing system is perhaps the signature of a forming dense cluster of galaxies.

The wide field HST survey undertaken as the COSMOS HST Treasury project is essential to understand the interplay between large scale structure evolution and the formation of galaxies and AGNs. The HST ACS imaging data will be combined with ancillary (space- and ground-based) data from the X-ray to the radio domain in a single archive. This will provide a comprehensive database to investigate the following questions: cosmic variance, clustering of AGN galaxies in redshift, and cosmological star formation history. The sensitive, high-resolution radio data will be used to measure the obscured star formation rate out to redshifts $z \sim 2$, and to trace the formation of elliptical galaxies harboring AGN even to z ~ 4. The combination of the unprecedented spatial resolution of the HST with the radio data will especially enable the following scientific topics to be investigated: correlation between galaxy morphology provided by the HST data and the star formation rate estimated from the radio data, similarly a correlation between galaxy morphology and AGN properties, evidence for enhanced star formation in interacting galaxies resolved by HST, and dependence of the AGN properties on the host galaxy environment as observed in the HST data.

Radio Galaxies, Quasars, Active Galaxies, and Gamma-ray Bursts

The VLA will be used to study the radio afterglows from gamma-ray bursts (GRBs). This is part of a large, multi-wavelength effort at gamma-ray, X-ray, infrared, submillimeter and centimeter radio wavelengths. Some of the goals are to understand the nature of GRB progenitors, constrain the energetics of the explosion and the compact central power source, and to use GRBs as a probe of the early Universe. NRAO scientists are involved in a dedicated gamma-ray burst mission called "Swift," which, when launched in January 2004, will revolutionize GRB studies. Swift will carry instruments that are capable of monitoring the light curves of 150 bursts per year at gamma-ray, X-ray and optical wavelengths. It will also provide accurate arcsec positions to ground-based observers of each GRB within 50 seconds of the initial detection of the burst. The VLA will be a vital node in the Swift ground-based follow-up effort. Bright, nearby bursts will be observed with the VLBA in an attempt to resolve these superluminally expanding sources.

The VLBA will be used in the ongoing monitoring of the nearby (z=0.1685) gamma-ray burst of 20 March 2003, GRB 030319. Since this burst reached flux density levels 50 times larger than previously studied events, global VLBI observations can be used to measure the source diameter and any possible proper motion of GRB 030319 at sub-milliarcsec levels. These observations may lead to constraints on theories describing the dynamical evolution of the fireball. In the next year, further imaging of the expansion and the search for possible jet components will continue.

The VLA and VLBA will be used to investigate radio sources that have been suggested as new identifications for gamma-ray emitters detected with the last large gamma-ray telescope, the EGRET instrument aboard NASA's Compton Gamma-Ray Observatory. Less than 50 percent of the several hundred confirmed gamma-ray sources found by EGRET currently have confirmed identifications at other wavelengths. However, in 2006 or 2007, NASA plans to launch the Gamma-ray Large Area Space Telescope (GLAST), which will detect roughly 5,000 to 10,000 new gamma-ray sources. Radio properties of the weaker EGRET sources, including multi-epoch VLBA imaging, will be critical for determining the expected properties and the ultimate identifications of the thousands of new gamma-ray sources found by GLAST. Over the next year, VLA imaging of candidates at southern declinations will be completed, and the first epoch of VLBA imaging will be carried out for candidates in the north that are well away from the Galactic plane.

A large proposal will continue using the VLBA to study the radio brightness and polarization variations in the 130 most prominent jets associated with active galaxies in the northern sky. The program is MOJAVE - Monitoring Of Jets in Active galaxies with VLBA Experiments. These jets are believed to be powered by the accretion of material onto supermassive black holes found in the nuclei of active galaxies. The rapid brightness variations and apparent superluminal motions indicate that they contain highly energetic plasma moving close to the line of sight at speeds close to the velocity of light. The observations in all Stokes parameters will be made at 2 cm using the VLBA at intervals of about 1.5 to 2 months. The angular resolution will be 1 mas. These data will lead to an improved understanding of the kinematics and magnetic field structures of these jets at the pc scale, originating close to the central engine of the galaxy or quasar. This project began in May 2002.

A pilot program for a "VLBA Interferometric Polarization Survey" will be carried out in 2004. The ultimate aim of this project is to provide polarimetric imaging of several thousand flat-spectrum compact radio sources, an order of magnitude more than in other VLBI imaging surveys. This survey is being carried out in anticipation of the identification of many of these sources with GLAST gamma-ray objects. If the entire survey is carried out, it will provide reference images and a large statistical sample for use in correlating radio-jet and gamma-ray properties, with the aim of determining the mechanism and location of the gamma-ray emission from within the inner radio jets.

Two novel VLBA studies of the NOAO Bootes and Cetus fields will be submitted for publication during the planning period. The first study involves a survey of about 200 active galaxies stronger than 10 mJy in the FIRST catalog. This 5 GHz VLBA survey, now half complete, is not biased against flat-spectrum targets. About one source in three is detected with the VLBA at 2 milliarcsec resolution. Optical identifications to 26th magnitude are becoming available from the NOAO. The VLBA images either locate the active nuclei within the optical hosts, or impose upper limits on emission from the active nuclei. A Chandra survey, underway by others, will further constrain the spectral energy distribution of the active nuclei. In the second study, one of the VLBA detections in Bootes has served as an in-beam phase calibrator, leading to the deepest and widest VLBI survey yet completed: an observation at 1.4 GHz with the VLBA and GBT has achieved an rms noise of 9 microJy per synthesized beam. Three sources were detected at 10 milliarcsec resolution within the GBT primary beam (9 arcminute FWHM), including the 20 mJy calibrator and two sub-mJy sources. VLBI surveys to such depths, and over such wide patches of the radio sky, have only recently been possible due to advances in correlator and computing resources. By tapering the visibility data, portions of the VLBA primary beam (30 arcminute FWHM) were imaged at poorer sensitivity and resolution to yield five further detections. More broadly planned developments at JIVE will permit deeper and wider VLBI surveys at full sensitivity, enabling new types of survey science with NRAO antennas.

VLBA observations with the GBT and Effelsberg are sufficiently sensitive to determine if the microJy source radio population contains small-diameter components, less than 10 milliarcsec. It is only with these high resolution observations that AGN emission can be unambiguously distinguished from dense starburst activity.

Appendix A - Scientific Staff Research Activities

Modeling of the compact radio emission from low-luminosity active galactic nuclei (LLAGNs) will be carried out, based on VLBA imaging that shows these nuclei to be extremely compact and to have slightly inverted radio spectra out to frequencies as high as 43 GHz. The observations are not consistent either with simple jet emission models or with emission from accretion disks having low radiative efficiency. The modeling will attempt to combine disks and jets to account for the radio sizes, powers, and spectra of the LLAGNs, as well as for their relative radio and X-ray powers.

Measurement of the magnetic field structure near the AGN core is fundamental in order to understand the physical processes of jet formation. The magnetic field structure is clearly detected in VLBI jets, and is predicted to be orders of magnitude stronger near the core. However, in previous observations, the magnetic field in the core has been hidden by extreme Faraday rotation. The GBT will be used to search for extreme Faraday rotation measure (FRM) in bright quasars and active galaxies using a new method of observation, based on the technique of pulsar observations with high-time resolution (coherent de-dispersion). Extreme values of FRM are anticipated and would confirm predictions of the presence of a strong and highly ordered magnetic field close to central super-massive black holes.

The VLBA will be used to study the frequency dependent VLBI core shifts of the radio jets in the quasars 1655+077 and 2001+315 at 13, 6, 3.6, and 2 cm, by using a phase referencing technique. In addition to using phase referencing, a second technique of measuring the core shifts will be applied by assuming that optically thin structures in the radio jets have frequency independent positions. The results of these observations will be combined with available proper motion data and integrated multifrequency monitoring data to investigate the physics of radio outbursts in these AGN. These observations will refine techniques for measuring frequency dependent VLBA core shifts at several frequencies simultaneously.

The nearby galaxy NGC 1316, associated with Fornax A, will be investigated in detail at four radio frequencies, using the VLA, and with Chandra. This extended object is unusual. It has a weak, steep-spectrum core, a weak asymmetric jet, and two large prominent lobes filled with filamentary emission. The nature of the energy flow from the galactic nucleus is unclear, and this question is the focus of these observations.

3C31 will be observed with the VLA, Pie Town Link, and GBT over the frequency range 74 MHz to 8 GHz to examine continuum spectral variations across this large FR I source. The goal is a detailed comparison with detailed models of its evolution and improved estimates of its spectral age, jet composition and other dynamical properties. The spatial statistics of rotation measures across several radio sources with well-known depolarization asymmetries will be carried out. This program will test the hypothesis that these asymmetries are caused by fluctuations of foreground FRM across the beam and will use the statistics of these fluctuations to examine the power spectra of the magnetic fields within the Faraday-rotating medium. These observations are relevant to problems in radio galaxy dynamics and evolution, and to understanding the nature of the magnetoionic media near the radio sources

Appendix A - Scientific Staff Research Activities

The VLBA will be used at 43 GHz to try to find jets in which it is possible to observe the collimation region as has apparently been done in M87. Sources are selected, based on black hole mass estimates and distance measurements, to have the largest possible Schwarzschild radius angular size. Sources are also selected on the basis of radio flux density. Three sources have been observed so far and all were detected with phase referencing. However, believable structures outside the point-source cores have not yet been detected.

Following up the observation of free-free absorption, presumably by the accretion disk region, of the milliarcsec scale counter-jet in 3C84 using the VLBA, efforts are being made to use counterjet absorption to detect spectral lines. An unsuccessful attempt to detect a recombination line at 23 GHz was recently published. New observations will attempt to detect molecular lines near 15 GHz. In addition, new observations will be made in order to detect possible time evolution of the free-free absorption regions near the core of 3C84.

VLBA observations of the 3C120 radio jet are providing much useful information for comparison with physical theory. The source has some of the fastest superluminal components, in terms of angular rate, of any source, so motions can be studied over many beam widths; in addition, many different components can be observed. At the lower frequencies, the jet is well resolved in the transverse direction and shows a number of complex structures, including strong suggestions of helical patterns. Comparison of jet speed, pattern speed, and morphology with physical theory can constrain the physical conditions in the jet and in the surrounding medium. A long term monitoring effort at 1.7 GHz will continue with another epoch in 2004. Also older, high resolution global plus Halca VLBI observations will be imaged in the hope of clearly showing the transverse structure on scales between those observed at 22 GHz by other groups and at 1.7 GHz.

A significant effort will be made to use the VLBA at 327 MHz to image the structure of the jets in 3C120 and M87, and the lobes in Cygnus A. Such observations are sensitive to structures on scales that traditionally fall between the regimes covered by the VLA and VLBA. Also, the typical spectral index distribution indicates that the core regions will be less dominant at these frequencies while the jets will be brighter, hopefully allowing detailed images of large regions to be made. Integrations of up to 100 hr per source will be performed.

VLBA polarimetry will image the FRM distribution toward AGN. Observations show that substantial FRMs are present in the central parsecs of AGN. The most extreme FRMs are found in radio galaxies and provide a likely explanation for the low fractional polarization typically observed. Substantial FRMs exceeding 1000 rad/m^2 are found in quasars, while BL Lac objects show significantly lower FRMs. The differences between FRM properties can be explained in the context of unified schemes. The most likely cause of the spatial and temporal variability is a thin Faraday screen external to the jet (though possibly interacting with it.) The VLBA will be used to test recent claims of FRM gradients perpendicular to the jet axis produced by a twisted magnetic field that also collimates the jet.

Appendix A - Scientific Staff Research Activities

VLBA follow-up observations will be performed to confirm the binary black hole system 0402+379. VLBA observations taken in 2003 revealed two central, compact, flat-spectrum components, which may be identified as possible active nuclei. At a separation of just 7 parsecs, this would be the closest active binary system known by a factor of more than 1000.

In connection with the starburst-AGN connection, high resolution near-UV images, will be obtained with the Hubble Space telescope to study the frequency of circumnuclear starbursts in Seyfert galaxies. Based on these images it will be possible to detect and characterize faint star forming regions, down to levels that cannot be detected with ground-based observations. The influence of starbursts on feeding the nucleus will also be studied; this mechanism may permit the build up of the mass of the black hole. In addition, the relation between the black hole and bulge masses will be investigated. Ground-based spectroscopy will be utilized to study the stellar population of LINER and LINER/HII transition galaxies, extending recent work done on Seyfert galaxies to lower luminosities. It will be possible to determine if the latter objects have a higher contribution from young stars than the former, as suggested by their emission-line ratios, and if the AGN and starburst luminosities are, in fact, related.

New 20 cm observations with the VLA C array are being used to extend the radio luminosity function of brightest cluster galaxies to lower levels and to use these data, combined with an HST snapshot survey to study the relation of the black hole masses in these systems to radio emission levels.

The GBT will be used in the coming year to study extragalactic water masers at 22 GHz. Early projects have demonstrated the superb sensitivity of the GBT at these frequencies. In 2004, the concentration will occur in two areas: (I) monitoring known water maser systems, and (ii) sensitive searches for new extragalactic water maser systems. While not every extragalactic water maser system appears to be associated with a disk, the few that show disks provide excellent laboratories for studying dynamics of gas within about a parsec of the central engine in the AGN. By tracking velocities of individual components in a disk maser over time, the centripetal acceleration in the disk can be determined. We plan to measure this acceleration in several maser systems, including those which were discovered during a GBT survey in 2003. The black hole mass can be calculated from the acceleration and disk rotation velocity, which is also available from the single dish spectrum. The VLBA will be used to determine the rotation curves of the nuclear gas for the systems at modest red-shifts.

New surveys for water maser sources aim, primarily, to provide additional examples of disk masers. They also improve our knowledge of megamaser phenomenology. Because water maser surveys are sensitivity limited, the GBT makes it possible to detect sources considerably more distant than previous surveys. We plan to exploit this capability by searching for water maser emission in a sample of Seyfert 2 galaxies more distant than previous surveys. A detection of an NGC4258-like water maser in a distant galaxy would be noteworthy because a geometric measurement of the distance to such a source could potentially be achieved in follow-up observations.

VLBI imaging of OH megamaser galaxies have, by combining high sensitivity and resolution, demonstrated that the OH megamaser emission is confined to sub-kpc scale regions. Including the velocity information, the bulk of the emission is best explained by circumnuclear torus structures. However, in several sources, portions of the OH emission cannot be explained by a disk model. An example is the OH emission in IRAS12032+1707 where the emission may be related to a galactic scale outflow related to a starburst. During 2004, the work on OH megamaser galaxies will continue using the VLBA, global VLBI, the EVN and MERLIN arrays. In particular a major goal will to investigate whether the combined disk/outflow scenario is plausible in explaining the kinematics and morphology of the OH distribution.

An additional tool in the investigation of the relative locations of the various kinematic components is HI absorption. Two OH megamaser sources have previously shown HI absorbing disks, with velocity gradients and sense of rotation similar to the proposed OH maser disks. Several sources which show evidence for both OH disks and OH outflows will be observed in HI using the VLBA. Based on these observations it will be possible to compare the HI kinematics to the previously imaged OH. In addition, multi-epoch VLBI imaging of the continuum will determine whether the radio emission, which presumably provides the input to the OH maser, arises from young radio supernovae or supernova remnants.

Observations of continuum emission and HI absorption from ultra-luminous infrared galaxies will continue with the VLBA. Such observations require both high angular resolution and extremely high sensitivity, achievable only by combining the VLBA with several large-aperture instruments such as the VLA, GBT, and Arecibo. The objects of study, among the most luminous in the universe in the infrared, are generally believed to result from mergers and/or close encounters between galaxies. The planned observations will improve our understanding of the merger process and how it may lead to a starburst or to the formation of one or more active nuclei.

An extensive program of high-resolution VLA imaging of merger galaxies will be continued using the VLA and the VLBA. The core of the merger galaxy Arp 299 will be monitored using the VLBA in order to search for fading in recently discovered supernovae, as well as to look for new supernova events. High-resolution VLA imaging of several other merger galaxies will be used to determine which ones are candidates for the presence of supermassive black holes and active galaxies along with their starbursts. A program of searching for these active galactic nuclei will be initiated with the VLBA.

Normal Galaxies

The VLA will perform 21 cm HI observations of the highest quality (6 arcsec,5 km/s resolution) of nearby galaxies to investigate key characteristics related to their morphology, mass distribution and evolution across the Hubble sequence. A sample of 35 objects at distances 3 < D < 10 Mpc will be targeted, covering a wide range of star formation rates, total masses, absolute luminosities, evolutionary stages, and metallicities. Observations will start at the end of 2003. The VLA HI data (B, C, and D array) will be complemented by the products of SINGS, the SIRTF Nearby Galaxy

Survey Legacy project; hence high quality observations from the X-ray through the radio will be available at comparable resolution for each galaxy. The high quality VLA observations will be used to investigate such issues as the small scale structure of the ISM, its 3D structure, the (dark) matter distribution, the processes (at 90-270 pc linear scales) leading to star formation, and, most importantly, the variation of each of these properties as a function of galaxy environment.

The VLA will be used to study the kinematics of super-thin galaxies by probing their HI emission with unprecedented resolution and sensitivity. The systems range from "isolated" to "mildly interacting" to "being in a group" and will also include a super-thin galaxy which shows a recently detected polar ring. These systems are among the most dark-matter-dominated galaxies known and exhibit highly interesting dynamical features such as warps (even in the isolated galaxy).

VLA spectral line observations of the neutral hydrogen within the tidal tails of nearby interacting galaxies will be compared to the location of young star clusters identified in HST/WFPC2 imagery of these regions. This comparison will help determine if structure formation within tidal tails is driven by gaseous instabilities or by stochastic processes. These data will also provide important constraints on the dynamical nature of several so-called "Tidal Dwarf Galaxies" which are thought to be forming within these tidal tails.

The GBT has been used to search for hydrogen clouds in the vicinity of normal spiral galaxies. For each galaxy, a comparison is made between an accurately-calibrated HI flux density which was measured using the 140 Foot Telescope and an accurate flux density measured with the smaller beam of the GBT. The observations of 100 apparently isolated spirals were completed in the spring of 2003, and the comparison of the data from the two telescopes will be completed during the coming year.

The VLA will be used to observe the distribution of HI in four galaxies suspected of having dwarf HI companions, based on material in the literature. Two of the objects show small faint features which may be either simply extensions of the galactic disks, or discrete clouds. The more sensitive VLA data will distinguish between these two possibilities. The other two objects are instances of an interaction between a galaxy and an associated HI cloud; the HI cloud has no obvious counterpart in either case.

The GBT will be used to tie the distance measurement of normal galaxies using neutral hydrogen line profile widths directly to recent supernova type Ia distance measurements by obtaining high quality line profiles of SNIa galaxies. The GBT will also be used to look for HI in small galaxies whose star formation has been quenched. These galaxies can provide tracers to dark matter condensations that are otherwise invisible.

A complete sample of galaxies brighter than $K = 11.25$ from the 2MASS will be identified with radio sources in the NVSS. Separate luminosity functions of galaxies whose radio sources are powered by star formation and by active galactic nuclei will be determined, the latter with unprecedented accuracy. The K-band luminosity is a good indicator of total stellar mass independent of star-formation history, while the radio luminosity of star-forming galaxies is proportional to the current star-formation rate. Thus, the radio/K-band ratio is an extinction-free indicator of the normalized star-formation rate. The behavior of this indicator will be investigated as a function of galaxy morphological type, mass, and environment for clues about the global properties of star formation in the universe today.

The center of Andromeda will be imaged at 6 and 3.5 cm with the VLA in A and B array, at 20 cm with MERLIN and the VLBA, and at 3.5 cm with Global VLBI. A major goal is to study the polarization characteristics of the newly discovered supernova remnants, which indicate that the star formation rate in the center of Andromeda is much higher than previously thought. Also, the detection of these supernova remnants in X-rays with Chandra and in the H-alpha line with HST will enable direct high-resolution comparison with Galactic supernova remnants in the nearest galaxy comparable in size and metallicity to the Milky Way. Furthermore, the probable nuclear black hole candidate in Andromeda's center, M31*, will be observed in order to investigate its structure and emission intensity; previous observations have indicated time variations on scales of hours. M31* is a direct analog to Sgr A* in the nucleus of the Milky Way, a low-luminosity nuclear black hole in a normal galaxy; however M31* has very different X-ray and radio frequency properties. The study of these low-luminosity black holes will be critical in unifying and distinguishing between the different models proposed for super-massive black holes in the centers of galaxies.

The Interstellar Medium, Interstellar Chemistry, Molecular Clouds, Cosmic Masers, Planetary Nebulae, Star Formation, and Stellar Evolution

The GBT will be used to image the distribution and properties of HI clouds in the interface between the Galactic disk and halo. These clouds, discovered in GBT observations over the last year, may be material returning to the disk after condensing out of a hot halo. Observations of a few of the clouds will be made with the VLA to deduce their internal structure. The density and temperature in the halo clouds should reflect the physical conditions in their surroundings, and should be especially sensitive to the local pressure. The distribution of neutral clouds in the disk and halo is not yet known; observations with the GBT will determine their scale height and determine if their radial distribution is correlated with any large-scale Galactic structures.

Some high-velocity HI clouds have a 'head-tail' structure, and appear to be interacting with a gaseous component of the Galaxy which must extend many tens of kpc from the galactic disk. Observations with the GBT in the 21 cm line will be made of clouds which show this interaction in order to measure their column density and velocity fields. These data will be used in hydrodynamic models to determine the trajectories of the clouds and properties of the halo gas that shapes them.

Statistical analysis of HI emission in Galactic surveys reveals that the spatial fluctuations in the gas can be described by a power-law, consistent with a turbulent cascade of energies on scales of a few parsec. The nature of HI on small scales (10-100 AU) has been probed by VLBI HI absorption studies toward background objects and multi-epoch HI absorption measurements toward pulsars with large proper motions. The GBT will continue to monitor variations in the neutral hydrogen absorption toward the pulsar B0329+54 with a primary goal of detecting the inner scale of turbulence. Because of the GBT's sensitivity and sky coverage, sub-AU HI structures can be measured toward B0329+54. Thus far, no variations in the HI absorption have been detected for this pulsar over the time scale of several days. If the HI turbulence is hydrodynamical and the inner scale of the turbulence is measured, then a direct estimate of the kinematic viscosity can be made.

Stars are the fundamental objects of our Universe, and their births and deaths provide its pulse. A number of investigations will seek answers to such questions as to how dense cores of molecules and dust form, and how they transformed by the stars created within them. *How does the character of star formation fuel a transgalactic starburst? How and in what form do moderately massive stars return material to the interstellar medium? What is the influence of star deaths upon star formation within a galaxy and how does stellar death mold its form?*

Before a molecular core is lit by the fires of its firstborn star, it has transformed itself from a cold and barren core to an expectant parent—*What are the changes which initiate this transformation?* The VLA, OVRO, CSO and the GBT are being used to investigate chemical change in protostellar cores. Observations of molecular distributions will be contrasted both with existing observations of the distribution of dust and with models derived from observations of dust to investigate the role of molecular depletion. Observations of ammonia (VLA) and the related N2H+ molecule (OVRO) in one core which is currently forming a very low mass star have revealed that both molecules are depleted by orders of magnitude in regions where the density exceeds about 1.5 x 10^6 cm^{-3}. Depletion is so complete that no known molecule can be used to trace the core kinematics, with the possible exception of H2D+, a molecule which is exceedingly difficult to detect. Is depletion a feature of protostellar cores on the verge of star formation? The aforementioned survey of the densest cores from a recent compendium has begun to answer this question.

The youngest stars have not yet heated their birthplace, nor have they even accreted most of their mass from it; they inhabit the coldest of molecular cloud cores. Within these cores, the spectral energy distribution has yet to be shaped by the star; it peaks in the submillimeter with a characteristic temperature of only tens of degrees Kelvin. Cores showing these so-called *Class 0* energy distributions (SEDs) will be observed in the ammonia lines with the VLA. Simple cores, characterized by cold dust and bipolar flows, have been targeted in order to explore the rotational properties of the cores in these early stages.

It is generally held that the N2H+ molecule is an unbiased probe of dense pre-protostellar cores (PPCs). Recently, systematic differentiation of CO, CS, N2H+, and NH3 toward a sample of five starless cores in the Taurus region has been observed. The results of these measurements indicate that the abundances of the CO and CS molecules drop dramatically within the denser (n(H2) > 10^5 cm^{-3}) regions of these cores, while the abundances of N2H+ and NH3 remain flat or increase in these regions. However, OVRO and VLA observations of the N2H+ and NH3 emission toward the cold core containing the low luminosity IRAM04191 protostar are not consistent with these conclusions. In the densest regions of the cores (n(H2) > 10^6 cm^{-3}) very high resolution is required to properly study abundance variations, and the VLA and OVRO results suggest that for densities exceeding n(H_2) >106 cm^{-3}, over regions <15 arcsecs in diameter, both ammonia and N2H+ are depleted. This result is important because it means that the only molecular probes presently observable in the innermost regions may be H2D+ and H3O+ . Without such probes, the kinematics of these inner regions which are critical to disk/star/outflow interactions cannot be elucidated. To explore this critical issue, the OVRO Millimeter Array will be used to image a sample of protostellar cores for which there have been observations suggesting depletion, in the 1-0 transitions of N2H+ and H13CO+. These images of the N2H+ distribution within cold (< 20 K) and dense (n(H2) > 10^6 cm^{-3}) regions will clarify the depletion status of N2H+.

Understanding the physical structure of star-forming cores is vital to assessing the relative importance of physical forces (magnetic fields, rotation, and turbulence versus gravity) during protostellar collapse. In particular, the density structure of the core is a strong discriminator between theoretical models. The latest models for isolated low-mass star formation do not reproduce the density and temperature structures deduced from dust continuum emission and near-infrared absorption studies. The picture for high-mass star formation is even more confused as the basic formation mechanism is still debated (accretion dominated processes versus collisional processes). Two major projects have begun in order to improve the observational constraints on theoretical models of low-mass and high-mass star formation:

(I) The dust continuum emission at mm wavelengths from deeply embedded low-mass Class 0 protostars is being analyzed by observing with BIMA in multiple array configurations. The density structure of the inner and outer envelope will be constrained (on scales of 102 to 105 AU) by integrating interferometric and single-dish bolometer observations. While the dust continuum is an excellent tracer of density and temperature structure, observations of molecular species, such as ammonia, are required to probe the velocity structure of the core. High resolution VLA 23 GHz ammonia observations of these Class 0 cores now exist and GBT spectra (for zero spacing data) will be obtained during the coming year.

(ii) An attempt to derive a consistent observational data set will be made in a number of high-mass star-forming cores. Continuum images at 350 microns of over 60 high-mass (M > 50 solar masses) star-forming cores and complementary CS J = 5-4 line observations have been obtained with the CSO. In order to minimize the uncertainties in the physical parameters new observations in the 850 micron continuum and the N2H+ 3-2 lines will be carried out with the CSO. The resulting images will provide a comprehensive compilation of high-mass star cores and set constraints on the large scale structure of high-mass star-forming cores (103 - 105 AU).

Using data from the 2MASS survey an early-B star was discovered in the massive star forming region W75N (W75N IRS2). The object has an infrared excess which suggests the presence of warm, circumstellar material. An analysis of OVRO millimeter and VLA centimeter continuum emission along with OVRO CO(J = 1-0) mosaics of the outflows in W75N suggests that W75N has been producing mid to early-B stars for a few million years. This implies that IRS2 is roughly a million years old, about the same age as low-mass YSOs with debris disks that may be in the process of building planetary bodies. VLA/GBT 7 mm observations of the circumstellar material around

IRS2 will be made to determine if a debris disk is indeed present. It is possible that IRS2 will be one of the more massive stars discovered with a debris disk. In this case, it could help place constraints on how massive a star can be and still produce a protoplanetary disk.

The VLA will be used to investigate the magnetic field structure of dense cores in molecular clouds, using the Zeeman effect in the CCS molecule. Emission from CCS and ammonia will also be combined to establish the physical conditions of cores undergoing star formation.

The JCMT will be used to study the interaction between the supernova remnant and giant molecular cloud in the W51 complex, as part of a program to investigate the role of triggering in large-scale star formation.

The only available probe of the inner AU or so of a protostar remains water maser emission. Using the VLA, the VLBA and the Pie Town link, a number of regions will be observed to determine the true space motion of the flow. Class 0 sources are thought to be in an active accretion phase, with observed highly collimated powerful molecular outflows. These flows, and the protostellar jets which power them, could play an essential role in the evolution of a protostar into a star approaching the main sequence. In the favored paradigm, the jet dominates angular momentum transport in the accretion disk; it regulates protostellar rotation so that the star continues to accrete without reaching breakup speeds. As the outflow dissipates angular momentum, it also dissipates the parent core. Therefore, jets determine the final stellar mass by controlling infall and outflow motions; the acceleration and collimation of the jets probably involve magnetohydrodynamic processes in the vicinity of the stars. At present the only technique for imaging these processes is through water maser emission generated at the shocks where the jet impinges on the cloud, whether these lie where the outflow shocks ambient material or at the protostellar accretion shock. The VLA/VLBA/Pie Town link will be used to investigate these regions in a number of objects with Class 0 SEDs; all show that the masers occur in shocks propagating into a molecular sheath surrounding the outflow jet. In cases in which the stellar position is known, it can be shown that the masers occur within several tens of AU of the star; some appear to coincide with the stellar position. These observations support an 'X-wind' theoretical model of outflow initiation. Since magnetic fields are expected to play a role in this model, a search for Zeeman splitting in the water lines will also be carried out.

Maser proper motions in regions forming more massive stars will also be initiated. In one such region a complex system produces water masers over a broad velocity range with a complex pattern. However, a nearby maser at an even higher velocity has appeared which apparently is not associated with the main complex and its millimeter continuum core. Observations at OVRO have detected a weaker continuum component coinciding with the extremely high velocity maser (nearly 100 km/s removed from the main complex). Observations to study this unusual system will continue.

The VLBA has been used in the studies of proper motion of water masers in low-mass young stellar objects (YSOs). Water masers are a unique tracer of the kinematics of the gas near the central YSO producing the collimated outflows. A monitoring program of these water masers using the GBT will be carried out, and will serve to trigger the VLBA observations when the strength of the water masers reaches the appropriate threshold.

A series of phase-referenced VLBA observations of water masers will be undertaken as a test of this astrometric technique. This program will determine the limiting factors of both troposphere and instrumental errors, and can provide an estimate of the best astrometric accuracy in a variety of conditions and calibrator-target angular distances. This technique may also lead to parallax and proper motion determinations throughout the Galaxy.

Observations of water masers using the VLBA and VLA will be made of the region surrounding the massive protostar G192.16-3.84. The water masers delineate jet-like outflows around low-mass protostars clustered near the massive young stellar object (YSO) and also in dense gas near YSOs. Ammonia observations at 22 GHz previously made with the VLA showed the location of cold, dense gas. Kinematics derived from the water maser observations will be compared with the dense gas distribution with the aim of understanding the role of jets and circumstellar disks in the process of clustered star formation. A new, compact ammonia core has been discovered 30 arcsec south of G192.16-3.84, with no associated water maser, or continuum at either cm or wavelengths. The absence of these tracers suggests this may be the site of the next generation of star formation in this massive system.

Studies of the fine-scale structure in the Galactic magnetic field will continue, using observations of the Zeeman effect in water maser lines with the VLBA. In the presence of a tangled magnetic field, an average of the magnetic field over the observed spatial region is obtained. Higher angular resolution observations sample smaller regions and thus allow the determination of higher fields; comparison of the results obtained with varying resolutions allows conclusions to be drawn concerning the spatial scale of field tangling.

The Galactic Center, Pulsars, Novae, Supernovae, Microquasars, and other Radio Stars

Pulsar science with the VLA and VLBA continues to make great strides. Accurate astrometry, leading to proper motions and parallaxes of several pulsars, has enabled several pulsar-SNR associations to be solidified. A distance to B0656+14 has enabled the pulsar's radius to be estimated when combined with thermal X-ray data. Additionally, the kinematic properties of pulsars are being probed. Pulsar observations supporting science of this kind will continue through this upcoming year. The number of accurately measured pulsar parallaxes is expected to double over the next two years as a large VLBA project concludes.

Current models of pulsar radioemission predict that the polarization position angle at a specific location in the pulse should remain rigidly fixed on the plane of the sky. However, position angle histograms constructed from single pulse, polarization observations are much wider than what is expected from the instrumental noise. Polarization observations of pulsars will be interpreted in the context of a statistical model of radio polarimetry to determine the origin of the excess dispersion in position angle. Possible origins include an analog of stochastic Faraday rotation in the pulsar magnetosphere, random changes in the orientation of the pulsar's magnetic field lines, and randomly polarized radiation in the emission.

X-ray observations with RXTE, and radio data from the VLA and VLBA, will be used to further explore the connections between accretion and relativistic ejection in X-ray binaries.

Conditions in the inner accretion flow around collapsed objects such as neutron stars and black holes, accreting from a binary companion, reveal, in coordinated multi-wavelength observations, unexpectedly rich evolution on timescales of milliseconds to months.

Profiles of individual projects in progress:

(i) Accretion disk X-ray spectra, spectral hardness, and power-law index, indicate systematic changes in the accretion properties as a function of the AU-scale jet emission imaged by the VLBA. The relationship of X-ray intensity fluctuations (timing properties) to the radio jet will be further explored, by observing the changes surrounding major radio/X-ray flare events.

(ii) A VLA monitoring is expected to continue, providing crucial radio data on X-ray transients candidates for VLBA follow-up imaging. Surprises continue to emerge from this project, including images of superluminal jets, the fact that in some cases radio emission arises in shells (i.e., spherical shocks) rather than in jets, and radio emission is seen at unexpected times and levels from accreting pulsars.

(iii)VLA and VLBA radio observations in support of x-ray binaries observed by the ESA/NASA high-energy mission, INTEGRAL, launched in early 2003. The hard X-rays observed by INTEGRAL are, in many cases, believed to be lower-energy disk thermal X-rays, up-scattered by the relativistic radio-emitting electrons, via the inverse Compton process.

(iv) A program is under way using Chandra and the VLA, to observe black-hole transients as they return to quiescence. The study of the radio/X-ray relation as a function of mass accretion rate, covering 6 or more orders of magnitude in X-ray luminosity, constrains the models of accretion flow (e.g., ADAFs) and jet production.

(v) A program of astrometry on X-ray binaries undertakes to measure their space velocities and Galactocentric orbits based on VLBA proper motion and optical radial velocity. The VLA is also used, to filter close astrometric calibrators for suitability, prior to VLBA astrometry.

Two examples of the astrometric program are well developed: VLBA astrometry established the eccentric, high-velocity orbit of the unusual high-latitude X-ray binary XTE J1118+48, showing that it is probably a halo object (2001, Nature, 413, 139). Also, the most massive known stellar black hole, GRS 1915+105, with 14 solar masses, has been tracked astrometrically, showing that it moves at the galactic plane, with momentum equivalent to a pulsar traveling at 700km/s.

The space velocity relates to questions such as: *Do black holes receive a substantial birth kick as do young pulsars? Can stars evolve to very massive black holes without going through a supernova, and hence are expected to be slow moving? Is the binary part of the disk, the bulge, or the halo population? Are black hole binaries born in the galactic plane or are they born in globular clusters and ejected after close dynamical encounters, as theorized for millisecond pulsars?*

The VLA will be used to investigate the radio counterparts of the ~2400 X-ray point sources found in a deep Chandra observation of a 17' x 17' region around SgrA* in the galactic center. VLBA follow-up of the high brightness sources, probably X-ray binaries, is an ongoing, related project.

A 48-hour campaign on Sco X-1, using global VLBI at 8 GHz, INTEGRAL at hard X-rays, soft gamma-ray, and optical support from various institutions, was made on July 31-August 01, 2003. The radio observations will show the evolution and variability of the radio core and lobes associated with this X-ray binary with a resolution of 1 milliarcsec. Correlations of the X-ray and optical intensity and spectral variations with the radio structure should pinpoint the locations of the high energy emission. A major question is the location of the soft gamma rays; near the core, in the jets, or in the lobes.

The Solar System and Other Planetary Systems

Passive radio observations of solar system objects allow properties of their atmospheres, surfaces, and magnetic fields to be inferred. Active radio observations (radar) allow additional properties of surfaces and magnetic fields to be inferred, and can also give insights into the spin state of the probed body. Radio wavelengths are unique in their ability to probe into regions inaccessible to shorter wavelengths, (e.g., into the deep atmospheres and into the subsurfaces of planets). They are also unique in their ability to observe in conditions which would make shorter wavelength observations useless (daylight, cloud cover, etc.). They have therefore made, and continue to make, very important contributions to planetary astronomy and planetary science in general.

Observations of comets at radio wavelengths yield important information on the state of the nucleus, on the production of volatiles from the nucleus surface, on the composition and structure of the coma, and on the history of the comet. Attempts to directly detect the ammonia in the atmospheres of comets will continue, following on the heels of the first such successful detections from Hyakutake and Hale-Bopp. The 140 Foot Telescope has been superseded by the GBT for these observations. The newly developed technique of observing the occultation of bright background sources by the OH in cometary comae will also be continued. Probing of other volatiles in cometary comae via this occultation technique will also be attempted. There are two very good comets during the spring of 2004 (Q4 NEAT and T7 LINEAR) on which these techniques will be attempted.

Sulfur compounds play an important role in the atmosphere of Venus, most noticeably through the formation of the H2SO4 clouds which mask the surface at optical wavelengths. In addition to supplying important information on atmospheric composition and chemistry, observations of these compounds might be used to infer active volcanism on the surface, if their abundances changed significantly over short time periods. These compounds can be probed through multi-wavelength radio wavelength observations, combined with very accurate lab measurements of the constituent gas opacities. A program of this type of observation will continue at the VLA.

Observations of the radio wavelength emission from outer solar system bodies, in combination with knowledge of physical temperatures, may help constrain the volatile composition of their surfaces. This volatile composition holds clues as to how volatiles were distributed in the nebula from which our solar system is thought to have formed. Unfortunately, this radio wavelength emission is very weak from the bodies in the outer reaches of our solar system. However, the development of the new high frequency receivers at the VLA has put even the outermost larger bodies (Pluto/Charon and Triton) within detectable limits. A program to attempt to detect this emission from these bodies will be continued at the VLA.

Radar observations of Mars provide important constraints on the surface and subsurface properties, including structure (or *texture*). The combination of the Goldstone transmitter and the VLA provides a powerful direct-mapping bistatic radar instrument which has been used successfully during the oppositions of 1988, 1992/93, and 1999 to make radar reflectivity maps of the planet. The opposition of 2003 will be a fantastic opportunity to continue the successful Goldstone/VLA experiments in this respect. Questions regarding the differences between the south and north ice caps, "Stealth" regions, the Hellas basin, and other interesting areas on the planet can be addressed with this data. Such an experiment will be conducted during this opposition.

Radio observations of Uranus provide important information on the deep atmosphere, including temperature and abundance (notably of ammonia, the major variable contributor to opacity at these longer wavelengths). Observations during the next few years will be especially important, as the planet is approaching equinox. In 2007, its north pole will emerge into sunlight for the first time in 42 years. Observations of the deep atmosphere are critical in deducing the dynamics of the deep (and shallow) atmosphere. A program of VLA observations of the planet (during every A-configuration) will continue.

With the Cassini spacecraft approaching the Saturn system, observations of that planet are especially important during the next few years. Radio wavelength observations help constrain the deep atmosphere of the planet, and provide ring properties as well. When combined with optical and IR observations, they provide a complete picture of the planet—its temperature and constituent profiles, dynamics, and ring system. A program to analyze historical observations of the planet, in addition to making new observations, will be undertaken at the VLA.

Astrometry, Geodesy, and Geophysics

The VLBA will be used in a set of 24-hour programs of astrometric observations at 22 and 43 GHz. This program, begun in 2002, is aimed at extending the International Celestial Reference Frame to higher radio frequencies. The high-frequency reference frame would be used for differential navigation of interplanetary spacecraft whose primary downlink frequency is 33 GHz. By the end of 2004, it is expected that a preliminary assessment will be made of the accuracy of the astrometric data, the variability and density of sources suitable for spacecraft navigation, and the effort required to complete an all-sky reference frame at the high frequencies.

Instrumentation

Practical RFI mitigation strategies continue to be developed at Green Bank and Socorro. A weak HI galaxy line profile was successfully observed with the GBT at a redshift of 0.1 at the frequency of a very strong local radar transmitter. A similar technique will be developed to suppress airborne distance measuring equipment (DME) signals in the 1020-1150 MHz band. Collaborations with the University of Virginia, Brigham Young University, and the SETI Institute on RFI mitigation research will continue. Adaptive cancellation of GLONASS Signals near 1612 MHz was successfully demonstrated on the GBT by a BYU masters student, and we will be developing ways of integrating this technology into the GBT observing systems.

Appendix B - Scientific Staff/PhD Professionals

D. S. Balser - Galactic structure and abundances, H II regions, and planetary nebulae; GBT scientific support.

T. S. Bastian - Solar/stellar radiophysics, flares, coronal mass ejections, solar chromosphere, radio propagation in the interplanetary medium; radio interferometry; Frequency Agile Solar Radio telescope (FASR) planning; grad student support.

J. M. Benson - Extragalactic radio sources, VLBA image processing; scientific support for VLA/VLBA correlator and real-time software development.

S. Bhatnagar - Supernova remnants, HII/UCHII regions, low frequency mapping of the Galactic plane, Interferometric calibration and image reconstruction and related algorithm development; AIPS++

R. C. Bignell - Planetary Nebula, polarization; GBT Scheduling.

J. Braatz - Masers, active galactic nuclei and cosmology; scientific software development.

R. F. Bradley - Millimeter electronics, low-noise amplifiers, array receivers, adaptive RFI excision; advanced receiver development.

A. H. Bridle - Extragalactic radio sources; Data Management scientific support; intersite communications support.

W. Brisken - Pulsars, astrometry, disk-based VLBI.

E. W. Bryerton - Millimeter-wave receiver development and HEB mixer research; ALMA local oscillator development.

B. J. Butler - Planetary astronomy; EVLA project scientific support.

C. Carilli - Galaxy formation, radio galaxies, QSO absorption lines, epoch of reionization; VLA support, ALMA planning, SKA planning.

C. Chandler - Star formation, circumstellar disks, protostellar outflows, millimeter-wave interferometry; VLA scientific support.

S. Chatterjee - Multi-wavelength investigations of neutron stars, their distances, velocities, and relativistic winds; with an emphasis on high-precision VLBA astrometry, which yields accurate parallax distances to radio pulsars; Jansky Research Associate.

J. Cheng - Structural engineering and antenna design theory; Antenna Division - ALMA Project.

B. G. Clark - EVLA control and software development; VLA/VLBA scheduling.

M. J. Claussen - Masers, young stellar objects, AGB stars, protoplanetary nebulae, spectropolarimetry, VLA+Pt link support, VLA and VLBA scientific support.

J. J. Condon - Nearby galaxies, evolution of star formation, radio surveys; Project Scientist, GBT precision telescope control system.

T. J. Cornwell - Interferometry, image reconstruction methods, coherence theory, and radio source scintillation.

W. D. Cotton - Extragalactic radio sources, interferometry, computational techniques for data analysis; scientific support: NRAO sky surveys and VLBI.

L. R. D'Addario - Telescope design, correlators, millimeter receivers, cryogenics, and radio astronomy from space.

V. Dhawan - Radio and X-ray observations of microquasars; VLBA holography and millimeter-wave development; VLBA scientific support.

Appendix B - Scientific Staff/PhD Professionals

D. T. Emerson - Nearby galaxies, millimeter-wave instrumentation and research into the history of microwaves; Chair of the NA ALMA Technical Advisory Committee, ALMA Division Head.

J. R. Fisher - Cosmology, signal processing, and antenna design; advanced receiver development.

E. B. Fomalont - Astrometry, X-ray binaries, deep imaging, relativity tests, VSOP and RadioAstron coordination, VLBA support, AIPS++ testing.

D. A. Frail - gamma ray bursts, soft gamma ray repeaters, pulsar/supernova remnant associations, pulsar wind nebulae, masers, HI absorption and interstellar scattering.

R. W. Garwood - Galactic 21 cm line absorption, interstellar medium, and high redshift 21 cm line absorption; AIPS++ Group.

F. D. Ghigo - X-ray binaries, AGNs, interacting galaxies; GBT scientific support (VLBI).

B. E. Glendenning - ALMA Computing.

K. Golap - Wide-field low-frequency imaging; AIPS++.

M. A. Gordon - CO, galactic structure, gas-rich galaxies, and interstellar medium.

W. M. Goss - Galactic Center studies, Galactic Masers, pulsars, supernova remnants and nearby galaxies; Head of Division of Science and Academic Affairs .

E. W. Greisen - ISM structure and computer analysis of astronomical data; AIPS Group.

C. E. Groppi - Protostellar/protoplanetary accretion disks, molecular outflows, molecular cloud structure, submillimeter and terahertz technology development, heterodyne array receivers, applications of micromachining, ALMA front-end development; Jansky Research Associate.

E. J. Hardy - Cosmology, galaxies, and stellar populations; NRAO / AUI representative in Chile.

J. E. Hibbard - Extragalactic HI, gala xy evolution, and merging galaxies; spectral synthesis imaging; software testing and student programs.

D. E. Hogg - Radio stars and stellar winds, and extragalactic HI; GBT scientific support; Interim Deputy Director.

M. A. Holdaway - Imaging methods, mosaicing, calibration, tropospheric transmission, site testing, simulations, operational optimization, ALMA.

G. C. Hunt - Advanced communication technologies for astronomy, real-time computer control techniques; Head, Computing and Information Services.

P. R. Jewell - Interstellar molecules, molecular spectroscopy; Assistant Director, Green Bank Operations

K. I. Kellermann - Radio galaxies, quasars, cosmology, and radio telescopes; Chief Scientist.

A. R. Kerr - Millimeter-wave receiver development; SIS mixer design - ALMA Project.

L. Kogan - Maser radio sources; theory of interferometry; design of array configurations; AIPS group.

D. Koller - Optical components and cryogenic systems; ALMA.

Y. Y. Kovalev - Extragalactic radio sources, single-dish and VLBI; Jansky Research Associate.

G. I. Langston - Gravitational lenses, Galactic Plane Transient Surveys and searches for Extra-Solar Planets; GBT scientific support

H. S. Liszt - Molecular lines, mm-wave absorption line spectroscopy, diffuse clouds, the galactic center and galactic structure; manager of NRAO's foreign telescope travel support program, and director of NRAO's spectrum management activities.

Appendix B - Scientific Staff/PhD Professionals

K. Y. Lo - Galactic Center, star formation in dwarf galaxies, star-burst galaxies and high redshift galaxies, mega-masers and AGN, intergalactic medium, microwave background radiation, millimeter- and submillimeter-wave interferometry; Director.

F. J. Lockman - Galactic structure, interstellar medium, and H II regions; GB education and outreach, GBT scientific support.

R. J. Maddalena - Molecular clouds, galactic structure, interstellar medium; GBT scientific support.

J. G. Mangum - Star formation, astrochemistry, and molecular spectroscopy of comets; ALMA.

R. G. Marson - ALMA computing (control system), optical aperture synthesis algorithms.

B. S. Mason - Cosmology & Cosmic Microwave Background; high frequency instrumentation development for the GBT.

M. M. McKinnon - Pulsar astrophysics, radio polarimetry, statistics; Deputy Assistant Director, New Mexico Operations.

J. P. McMullin - Star formation, interstellar medium, astronomical software systems; IPT Lead AIPS++.

A. H. Minter - Interstellar turbulence and galactic HI; GBT scientific support.

A. J. Mioduszewski - Microquasars, Symbiotic stars, modeling of Supernovae, AIPS and VLBA support.

G. Moellenbrock - VLBI polarization, AGN, interferometry calibration and imaging algorithms and software, VLBA scientific support.

T. Morgan - Parallel computing, numerical computing involving large data sets, and imaging and signal processing algorithm development; Senior Software Engineer.

S. Myers - Cosmology, cosmic background radiation, gravitational lenses, astronomical imaging; AIPS++ Project Scientist, ALMA and VLA/EVLA scientific support.

P. P. Murphy - Clusters of galaxies, galaxy evolution, scientific visualization; Division Head, Charlottesville Computing; Webmaster.

P. J. Napier - Antenna and instrumentation systems for radio astronomy; EVLA Project Manager.

K. O'Neil - Extragalactic gas and dust; Low surface brightness galaxies; GBT spectrometer; GBT scientific support.

R. A. Osten - stellar coronae, stellar flares, multi-wavelength observations of flares, stellar radio emission, flaring in very low mass stars/brown dwarfs, interrelationship of radio/soft X-ray stellar emissions; Jansky Research Associate.

F. N. Owen - Clusters of Galaxies, Radio galaxies, Deep Continuum Surveys; EVLA.

S. K. Pan - Superconducting millimeter and sub-millimeter wave low-noise devices, circuits and receivers development; CDL.

D. H. Parker - Metrology, applied physics, electrical engineering; Group leader, GBT Antenna Metrology.

J. M. Payne - Telescope optics, millimeter-wave receivers, metrology systems, and cryogenic systems; Local oscillator development - ALMA.

R. A. Perley - Radio galaxies, QSOs, and interferometer techniques; EVLA Project Scientist.

Y. Pihlstroem - Absorption studies of AGN, compact radio galaxies (GPS/CSS sources), OH megamaser galaxies, VLA high frequency support.

Appendix B - Scientific Staff/PhD Professionals

M. Pospieszalski - Microwave and millimeter wave low-noise devices, circuits and receivers; CMBR radiometers; EVLA/VLBA/GBT/ALMA receiver development support.

R. Prestage - Telescope and instrument control; Deputy Assistant Director, Green Bank.

S. J. E. Radford - Starburst galaxies and millimeter interferometry; ALMA Site Characterization, ALMA Site Development.

M. Rafal - Electro-optical systems, large project management; ALMA Project Manager.

J. D. Romney - Active extragalactic radio sources, interstellar medium, VLBI instrumentation; VLBA scientific support, VLBA Spacecraft Navigation Pilot Project manager, spectrum management.

M. P. Rupen - X-ray binaries and transient sources; supernovae; interstellar medium; VLA and EVLA scientific support.

E. Schinnerer - Gas dynamics in galaxies, NIR star formation history, starburst-AGN connection, starburst and Seyfert galaxies; Jansky Research Associate.

H. R. Schmitt - Active galactic nuclei, starburst galaxies; NRAO Research Associate.

F. Schwab - Applied mathematics, numerical analysis, radio-astronomical data analysis, synthesis imaging, hybrid numeric/symbolic computing.

D. S. Shepherd - Star formation, molecular outflows, disks around luminous young stellar objects, molecular chemistry, millimeter interferometry and mosaic techniques; ALMA scientific support.

Y. Shirley - Star formation, astrochemistry, protostellar disks, and molecular spectroscopy; Jansky Research Associate.

R. S. Simon - Nearby stars, extrasolar planets, searching for Earth-like planets, interferometry and imaging; Project Controller - ALMA project.

L. O. Sjouwerman - Circumstellar masers and AGB stars, centers of the Galaxy and Andromeda, VLBA data calibration and logistics, VLA/VLBA scientific support

R. A. Sramek - Normal galaxies, quasars, supernovae, and aperture synthesis techniques; ALMA.

G. B. Taylor - Gamma-ray bursts, active galactic nuclei and their environments, polarimetry; Head of Scientific Services Division - Socorro Operations.

B. E. Turner - Galactic and extragalactic interstellar molecules, interstellar chemistry, and galactic structure; Newsletter editor.

J. S. Ulvestad - Seyfert, LINER, and starburst galaxies, and extragalactic gamma-ray sources; Assistant Director, New Mexico Operations.

J. M. Uson - Clusters of galaxies and Cosmology, Superthin galaxies, dark matter; Spectral synthesis imaging; Newsletter Science editor.

P. A. Vanden Bout - Interstellar medium, molecular clouds, and star formation; research leave.

G. A. van Moorsel - Dynamics of galaxies and groups of galaxies, and techniques for image analysis; Head - New Mexico Computing.

R. C. Walker - Extragalactic radio sources, VLBI, and VLBA development; VLBA scientific support.

F. Walter - molecular gas in the epoch of reionization, SIRTF SINGS legacy project, structure and evolution in dwarf galaxies; Jansky Research Associate.

J. C. Webber – VLBI techniques, analog and digital instrumentation development. Assistant Director - CDL.

Appendix B - Scientific Staff/PhD Professionals

D. C. Wells - Digital image processing and extragalactic research; GBT scientific support.

H. A. Wootten - Star formation, structure and chemistry of the ISM in galaxies, and circumstellar material; ALMA Project Scientist.

J. M. Wrobel - active galactic nuclei, sky patches at milliarcsec resolution; VLA/VLBA scheduling, GBT student support coordinator, phase calibrators for synthesis arrays.

H. Ye - high performance numerical algorithms and programming and architecture for parallel and distributed computations; software engineer.

Q. F. Yin - Normal galaxies and imaging techniques; NRAO sky surveys.

R. Zavala - polarization in the central regions of AGN, close binary stars, and interferometric techniques at a variety of wavelengths; NRAO Research Associate.

Appendix C - Committees

The NRAO Visiting Committee

The NRAO Visiting Committee is appointed by the AUI Board of Trustees to review the management and research programs of the Observatory. The Visiting Committee met in Socorro in 2002 and in Green Bank in 2003. The current membership of the Committee is:

Philip Diamond, Chair, Jodrell Bank Observatory
Roger J. V. Brissenden, Smithsonian Astrophysical Observatory
Ralph E. Pudritz, McMaster University
Jacqueline H. van Gorkom, Columbia University
Sander Weinreb, California Institute of Technology
Philip R. Schwartz, Naval Research Laboratory
Eric M. Wilcots, University of Wisconsin
Roger D. Blandford, Stanford Linear Accelerator Center
John E. Carlstrom, University of Chicago
George K. Miley, Leiden Observatory
Rodger Doxsey, Space Telescope Science Institute
Paul T. P. Ho, Harvard-Smithsonian Center for Astrophysics

The Users Committee

The Users Committee is made up of users and potential users of NRAO facilities from throughout the scientific community. It advises the Director and the Observatory staff on all aspects of Observatory activities that affect the users of the telescopes. This committee, which is appointed by the Director, meets annually in May or June. The current membership of the Committee is:

Rachel L. Akeson, Caltech, IPAC
David Boboltz, U.S. Naval Observatory
John M. Dickey, University of Minnesota
Sean M. Dougherty, Dominion Radio Astrophysical Observatory
Gary Fuller, University of Manchester Institute of Science and Technology
Mark Gurwell, Smithsonian Astrophysical Observatory
Deborah B. Haarsma, Calvin College
Andrew I. Harris, University of Maryland
Deidre A. Hunter, Lowell Observatory
Victoria M. Kaspi, McGill University
Henry Kobulnicky, University of Wyoming
Stanly Kurtz, UNAM
T. Joseph W. Lazio, Naval Research Laboratory
Colin Lonsdale, MIT Haystack Observatory
Kevin B. Marvel, American Astronomical Society
Michele Thornley, Bucknell University
Stephen E. Thorsett, University of California, Santa Cruz

Appendix C - Committees

Eric M. Wilcots, University of Wisconsin
Edward Wollack, NASA GSFC
Min Yun, University of Massachusetts
Farhad Yusef Zadeh, Northwestern University
Liese van Zee, Indiana University

The Program Advisory Committee

The Program Advisory Committee reviews and provides advice on the long range plan of the Observatory, on new programs and projects being considered for implementation, and on the priorities among Observatory program elements. Current membership is:

Donald Backer, University of California
James M. Cordes, Cornell University
Lee Mundy, University of Maryland
Mark Reid, Center for Astrophysics
Lawrence Rudnick, University of Minnesota
F. Peter Schloerb, University of Massachusetts
Eric Wilcots, University of Wisconsin
Christine Wilson, McMaster University

Observatory Computing Council

The OCC will look over computing issues from the Observatory-wide perspective and advise the NRAO Director on what needs to be done, or the NRAO Director would ask the OCC to examine issues that should be reviewed.

The members of this council have been asked to serve for a one-year term.

Bill Cotton, Chair
Barry Clark
Ed Fomalont
Brian Glendenning
Eric Greisen
Gareth Hunt
Joe McMullin
Nicole Radziwill
Doug Tody
Mel Wright, UC Berkeley

Appendix C - Committees

Observatory Science Council

The OSC will advise the Director on policy issues related to science and academic affairs at the NRAO. Specific issues include the policies and activities of the DSAA (Division of Science and Academic Affairs.)

Other issues include (i) the review of ideas for new telescopes, or new projects, and new instrumentation for existing telescopes; (ii) to stimulate the scientific environment for research throughout the NRAO, including the organization of research support for the scientific staff.

The members of this council have been asked to serve initially for a one-year term. The membership includes:

Fred Lo, Chair
Claire Chandler
Jim Condon
Dale Frail
Miller Goss
Dave Hogg
Ken Kellermann
Jay Lockman
Frazer Owen

Observatory Technical Council

The Council will advise the NRAO Director on technical issues that confront the Observatory, and will provide Observatory-wide perspective and coordination in all technical areas, including future planning and R&D, current operations and problems, and projects such as the EVLA and ALMA.

The members of this council have been asked to serve initially for a one-year term.

Darrel Emerson, Chair
Larry D'Addario
Barry Clark
Rick Fisher
Brian Glendenning
Anthony Kerr
Peter Napier
John Payne
Richard Sramek
A. R. Thompson
John Webber

Appendix C - Committees

ALMA North American Technical Advisory Committee

In September 2002, a small advisory group was created, to perform an in- depth and end-to-end look at the technical progress of the ALMA construction, on the North American (NA) side. The committee is to report to the NRAO Director, who will feed findings back to the JAO and others, as appropriate. It is anticipated that our European partners may want to be involved in this review process too, but for expediency ANATAC has been asked to commence its work immediately.

This will be a standing committee, but may or may not need to be active at all times.

Current membership is:

Darrel Emerson, Chair
Barry Clark
Larry D'Addario
Peter Napier
John Payne
R. Sramek
A. R. Thompson

NRAO Organization Chart