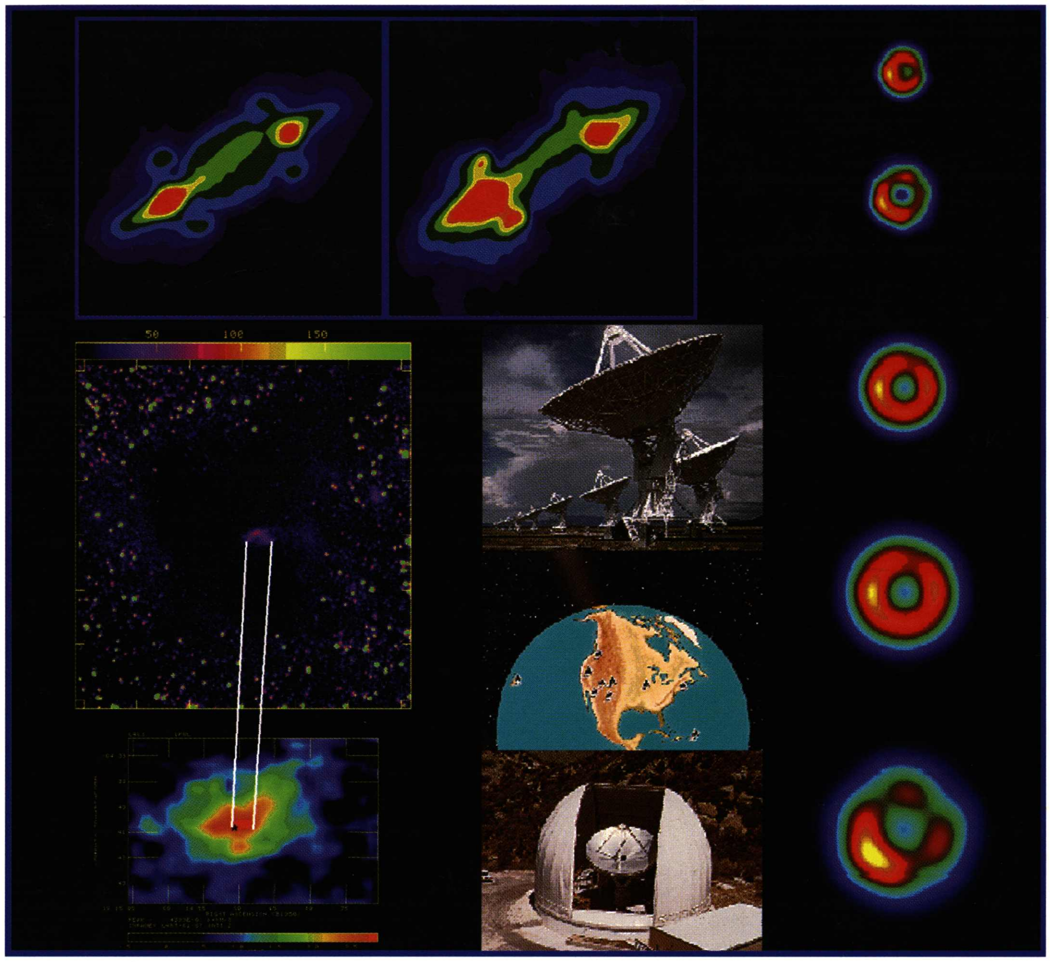

PROGRAM PLAN 1997

NATIONAL RADIO ASTRONOMY OBSERVATORY

Cover Image, clockwise from upper left: VLA images of Jupiter before and after the impact on Jupiter of comet Shoemaker-Levy; sequential VLBA images of supernova 1993J in the galaxy M81; the 12-meter telescope on Kitt Peak, AZ; a 12m telescope on-the-fly image of the CO emission in the L183 dark cloud together with an optical image of that cloud. The two center panels show the VLA antennas and the VLBA station locations respectively.

NATIONAL RADIO ASTRONOMY OBSERVATORY

CALENDAR YEAR 1997

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I. INTRODUCTION

In 1997 radio astronomy will make another significant step forward with access to a new tool, very long baseline interferometry (VLBI), using a radio antenna in space, that has the potential to provide astronomical images with detail sufficient to resolve all features in the radio structure of celestial sources. The orbiting antenna, the VLBI Space Observing Program (VSOP) is a project of the Japanese Institute for Space and Astronautical Science. The Very Long Baseline Array (VLBA) and other earth-based radio antennas provide the remainder of the array. In the U.S. data correlation will be done with the VLBA correlator. This extension of VLBI to space is the continuation of decades of work at the NRAO and elsewhere in which the instruments and imaging algorithms for exceptionally high resolution astronomy were developed. It is very gratifying to see the culmination of this effort and we look forward to the VSOP observations with anticipation in 1997.

The overall plan for the NRAO in 1997 is to build further on the capabilities of the NRAO instruments and facilities (hardware and software) so that they too can be prepared to launch future initiatives for radio astronomical research. The 1997 NRAO Program Plan outlines ways in which this can be achieved. In Section II a brief overview is given of the science we expect to see performed on the NRAO instruments in 1997. The telescopes themselves are described in Section III followed by a description of activities in electronics and computing in Section IV. The next sections describe the plans for new instruments: progress on the construction of the Green Bank Telescope (GBT) in Section V and then a review of the development work on-going for the Millimeter Array (MMA), work planned for the Very Large Array (VLA), and work on the AIPS++ Project in Section VI. Section VII describes the scope of research at the NRAO that is done on behalf of, and supported by, agencies other than the NSF. The next section is an overview of educational activities at the Observatory. Finally, the preliminary financial plan for the NRAO in 1997, designed to support all the NSF research activities, is given in Section IX.

II. 1997 SCIENTIFIC PROGRAM

1. The Very Large Array

The VLA has passed the 20th anniversary of its first astronomical observation. Versatility remains the hallmark of this instrument. And as new ground- and space-based instruments increase the pace of astronomical discovery around the world, the VLA remains a vital resource for researchers in a wide variety of specialties. As new fields of investigation emerge, the VLA quickly finds its role as a tool of discovery. From studies of solar-system objects to extrasolar planets to microquasars in the Milky Way to cosmology, the VLA is in demand—at nearly double the amount of observing time available.

In 1996, the observational phase of the NRAO VLA Sky Survey (NVSS) was completed, and data reduction will continue in 1997. The NVSS maps, covering the 82 percent of sky north of declination -40, will represent an invaluable resource to the scientific community for years to come. Many of the 4-degree by 4-degree continuum map cubes with three planes containing Stokes I, Q, and U images already are available on the Internet. Demand for these maps has been high, and the NVSS has generated numerous follow-on studies of sources found by the survey.

The FIRST (Faint Images of the Radio Sky at Twenty-centimeters) survey will continue observations in the B configuration in 1997. The FIRST project is designed to produce detailed maps of a region of sky around the North Galactic Cap, to coincide with the area covered by the Sloan Digital Sky Survey at optical wavelengths. Like the NVSS, the FIRST survey already has made data products from earlier observations available to the scientific community, and it, too, has spurred follow-on studies.

As the planetary-science community expands its efforts to include studies of newly-discovered planetary objects beyond our own Solar System, the VLA's capabilities make it a powerful tool to aid those studies. The list of planetary or brown-dwarf companions of nearby stars for which there is conclusive evidence continues to grow. If these planets have magnetic fields, then it is expected that they may produce meter-wavelength radio emissions that could be detected by the VLA. Such radio emissions will be sought by observing the positions of already-confirmed extrasolar planets. If the emissions are detected, further VLA studies could yield important information about the planets, including strengths of their magnetic fields, their rotation periods, and limits on the electron density of their magnetospheres.

Other observers will seek to make images of protoplanetary disks by studying young stars with the 7 mm capability of the VLA. Such images would provide information about the early process of planetary formation.

Within our own Solar System, Comet Hale-Bopp, with an unusually large nucleus and offering excellent observing conditions, will provide an opportunity to resolve important questions about water in comets and their comas. Researchers will use the VLA to try to make the first unambiguous detection of the 1.35 cm water line in a comet. If successful, these efforts could produce the first image of a cometary coma in this line and check an hypothesis of possible circumnuclear water maser activity.

A longstanding program of solar studies will continue, with a set of observations planned to use background radio sources to study the nature of turbulence in the solar wind. This will produce information about the solar wind during the current period of minimum solar activity. This information will be compared to similar measurements made in 1992, shortly after a solar maximum, to help determine the degree to which the solar wind's properties depend on the solar cycle.

A number of observers will use the VLA to investigate many aspects of the star formation process. Continuum observations at a variety of wavelengths will be aimed at gaining information about the ionized winds of young stellar objects (YSOs), the radial density distributions of those winds and how such winds interact with the surrounding medium. Another study will seek to learn if recently-discovered discrete radio sources within a compact HII region are actual protostars or, alternatively, clumps, shock ionization fronts or cavities within the region. A radio source in the W3OH star-forming region will be investigated to learn if it is a young stellar object or a possible jet-emitting binary system. A pair of *Class 0* very young protostars, where mass infall is presumed to be very active, will be studied by observing water masers in their vicinities. Multi-epoch observations of the masers should yield their kinematics, which in turn can constrain the masses of the protostars, or, if the masers are part of an outflow, give important information about outflow phenomena. Another Class 0 object will be studied in detail, again through observation of water maser features, to learn about the outflow structure within 100 AU of the source, the physical conditions under which the outflow is launched and collimated, and to compare it to similar objects.

Water masers will be an important part of another study of a set of young stellar objects. In this study, the masers will allow cross-calibration for simultaneous continuum observations, providing milliarcsecond accuracy in measuring the relative positions of the masers and the continuum emission. This study will also seek to find radio jets in YSOs, to learn the distribution of the masers around the YSOs, and possibly to infer the presence of circumstellar disks around the YSOs.

Using the VLA's Q-band system at 7 mm, observers will study a radio source in an infrared nebula in the Orion star-forming region to obtain precise relative positions for SiO masers and to measure their proper motions. This will provide information on the kinematics of the circumstellar disk of which the masers are a part. Simultaneous continuum observations will seek to determine the structure and size of the IR nebula's dominant radio sources.

Other studies of the star-formation process will include mapping of YSOs on the scale of the Solar System in conjunction with Hubble Space Telescope (HST) and infrared observations; new-epoch observation of a complex radio source in the Corona Australis region that was observed ten years ago to determine proper motions of its components; and measurement of proper motions in thermal radio jets associated with low-luminosity YSOs. A newly discovered proto-binary system will be observed to learn the properties of the circumstellar disks around each protostar, as well as to image the system's circum-binary disk. A Herbig-Haro complex with a large, collimated stellar jet system will be monitored to confirm and measure large proper motions, measure brightness decay of condensations in the jet, and provide additional information on the system prior to an ejection event expected in the next few years.

More mature stars will be scrutinized in a wide variety of observing projects at the VLA. OH maser activity at 1720 MHz associated with the unusual star V1057 Cygni will be observed for the first time in more than a decade. If successful, the VLA observations may be followed by VLBA observations to learn about either the region where the winds of V1057 Cygni interact with the circumstellar disk or about the disk itself. VLA observations of the radio star WR 147 will seek to learn the nature of clumps in an anisotropic circumstellar envelope.

A number of VLA projects will target red giants. A study of Betelgeuse at 7 mm will seek to resolve that star's extended chromosphere to produce an empirical model that can be used for testing theoretical models of the chromosphere's generation. Other studies of red giants will seek to measure their angular diameters and any asymmetries in their photospheres, and to simultaneously detect red-giant radio photospheres and circumstellar SiO maser emission and thus gain better information on the sizes of the stars, the position of the maser emission, and the persistence and motions of the maser spots.

The VLA will join the EUVE and SAX satellites for a coordinated observing program of the star 47 Cas, to monitor its coronal energy releases. Observations of RX Pup, one of the most active and complex of the known symbiotic Mira-type stars, will provide a recent image of its circumstellar nebula to allow researchers to follow its morphological evolution. A pair of symbiotic novae will be imaged as part of a long-term project to trace their orbital motion through successive radio images. The VLA, along with the MERLIN array in Great Britain, will be used to produce very deep images of recently-discovered bipolar nebulae in a pair of quiescent symbiotic binaries.

Q-Band observations will seek to resolve, for the first time, the R Aquarius binary system and to test conflicting hypotheses surrounding the peculiar binary emission-line system MWC 349A. Other binary systems will be observed to learn such things as: the angular separations of components; the nature of the region where the stellar winds of binaries collide; and whether a specific system is actually a colliding-wind system or a cataclysmic variable. The nearby dMe binary EQ Peg will be monitored, in conjunction with EUVE, McDonald Observatory, and KPNO, to detect for the first time hard X-ray bursts on a star other than the sun and to compare the timing and energetics of the impulsive heating and gradual cooling phases of stellar flares. Also in conjunction with spacecraft observations, a neutron star binary X-ray transient known as the Rapid Burster will be monitored in an attempt to learn what triggers its Type II X-ray bursts, thought to occur when matter from an accretion disk spasmodically streams onto the neutron-star surface.

Continuing previous work at the VLA, observers will study the Crab pulsar at multiple wavelengths in an attempt to learn the bandwidth of the pulsar's *giant* pulses. The bandwidth of these pulses remains unknown, but it is a critical parameter for understanding their emission mechanism. The double-shelled planetary nebula IC 4997 will be studied to resolve the structure and search for possible high-density regions where interaction is taking place. Researchers using the VLA discovered the first superluminal motion in a radio source located within the Milky Way in 1994. The black-hole binary candidate GRS 1915+105, which showed apparent superluminal motion in condensations in jets that year, will be studied further to track possible future ejection events and to determine if its core exhibits proper motion. The VLA has been particularly successful in detecting newly discovered supernovae, providing investigators with the valuable tool of early, high-quality, multi-wavelength light curves. This program of target-of-opportunity observations will continue, along with an ongoing program of monitoring known supernovae to complete their radio light curves.

The VLA remains a premier instrument for studying the Galactic Center. As part of an international campaign, observers will use the VLA to study Sgr A*, the source at the dynamical center of the Galaxy, nearly simultaneously at wavelengths from many centimeters to submillimeter, in order to determine its spectral shape. This will help discriminate among competing models of galactic radio cores in general. High resolution observations of Sgr A* and nearby sources will seek to learn about variabilities, radio properties of the infrared sources near Sgr A*, provide a first epoch image for measurement of possible proper motions, and to improve relative astrometry between radio and infrared sources.

Additional studies of the Galactic Center will include: 7 mm observations of WR/WN and OH/IR stars; observations of shock-excited OH masers; a survey of the central 100 pc of the Galactic Center to search for pulsars that would provide opportunities for probing ionized gas, the gravitational potential and star formation there; and high-resolution observations of Sgr B2. A related project will search a number of nearby galaxies for compact radio cores similar to Sgr A*.

Galaxies make up a large percentage of the observing targets of the VLA. Galaxy studies include investigations of the structure, dynamics and evolution of individual galaxies and clusters of galaxies, and the physics of galactic interactions. Throughout its operational history, the VLA has produced a wealth of data for researchers studying galaxies, and this tradition will continue unabated in 1997.

Currently popular unification models for active galactic nuclei (AGN) generally rule out the possibility of radio emission from large-scale jets or lobes emerging from spiral galaxies. However, recent VLA observations seem to indicate that just such an object may exist in a nearby Abell cluster. Additional high-sensitivity and high-resolution observations will seek to clarify this situation, with obvious implications for theory.

The galaxy NGC 4258 recently has become an important laboratory for studying the physics of AGNs. Observations with the VLBA revealed a circumnuclear disk of water masers, rotating in perfect Keplerian fashion about a central object of 3.5×10^7 solar masses. A VLA monitoring program will provide information about the drift of high-velocity maser features in this disk, track low-velocity features, and monitor the intensity variations of the high-velocity features. A compact continuum source, thought to be synchrotron emission from the base of one of the galaxy's jets, will be monitored for variations in its brightness and spectral index, to provide information on the physical conditions at the base of the jet. Another galaxy, NGC 5793, recently has been found to have strong water maser emission similar to that of NGC 4258, and researchers will use the VLA to observe it in detail as a possible additional means of studying parsec-scale kinematical structure of AGNs.

VLA observations will explore a wide range of galactic phenomena. Studies of individual galaxies will include: a search for extended HI in a nearby galaxy by investigating absorption against a background quasar; low-frequency observations of Pictor A to investigate tentative evidence for extreme values for a magnetic field or of thermal absorption; and polarization observations of a possibly young, forming galaxy at high redshift. Another project will search for continuum emission associated with star-formation activity in two high-redshift protogalaxy candidates. Studies of selected samples of galaxies will seek to answer questions such as: does depolarization in radio lobes correlate with redshift or radio luminosity, and is there some evolutionary effect that significantly increases the number of radio galaxies in rich clusters?

Starburst galaxies will be investigated by programs to observe clusters of star formation in galactic nuclei, to seek shock-excited OH maser activity in supernova remnants of starburst galaxies (M82 and NGC 253) and to study HI absorption against the starburst of M82 to help understand the neutral component of its interstellar matter.

Many workers will use the VLA to study jets of galaxies and the regions from which they emerge. The jet of M87, the closest jet in the northern hemisphere, will be monitored in conjunction with HST and ROSAT. This program will produce detailed information on the inner part of the jet, as well as on its evolution with time. Observations of a knot in the jet of 3C120 will seek to resolve a question about possible superluminal motion on kiloparsec scales. High resolution imaging and polarimetry of NGC 315 and 3C 31 will help test a model for the kinematics of jet deceleration in FRI radio galaxies. The powerful radio galaxy Cygnus A, which previously was observed with most frequencies and configurations of the VLA, will be observed with the new Q-band system at 7 mm to complete the suite and help resolve questions about the intensity, spectra, and polarization of the galaxy's radio emission.

Three objects in which HST found optical emission coincident with radio hot spots and knots in their jets will be studied in detail with the VLA, to clarify the optical-radio relationship. A search for HI absorption and OH maser emission in a sample of FRI radio galaxies will probe the circumnuclear regions of these galaxies and help learn more about the masses of the central objects, the feeding rate, and the feeding mechanism of the AGN. A sample of FRII radio galaxies will be studied to constrain the luminosity function of their jets. Seyfert galaxies will be studied to help us understand the physics of an interaction between radio plasma and optically-emitting gas and to investigate the interaction between the radio jet and the interstellar medium. This will be done by detailed imaging of Seyferts whose narrow-line regions exhibit a complex morphology of strands and arcs. One study will seek to confirm suspected structural differences between Seyfert 1 and Seyfert 2 galaxies.

A program of high dynamic range imaging of radio- and X-Ray-selected BL Lacertae objects will seek to test unified schemes for BL Lacs and FRI radio galaxies.

Observations of quasar samples will seek to resolve a number of questions about these objects. Deep, high-resolution imaging of lobe-dominated quasars will seek support for a *tired-jet* model that could unite the descriptions of FRI and FRII jets. Broad absorption-line QSOs, which have been suggested as a possible link between radio-quiet and radio loud QSOs, will be observed to learn their flux densities and morphology. A set of quasars observed by HST will be studied to investigate a radio-optical alignment effect.

Background radio sources will help investigate neutral hydrogen in galaxy clusters in a pair of VLA projects. One project will look at the M81 group, the other at a pair of newly discovered cooling-flow clusters. Both projects will seek to detect HI through absorption against the background sources.

Many VLA observers use the instrument to address cosmological questions, and 1997 will see a number of observing projects with cosmological themes or significance.

In a follow-on to the VLA FIRST survey, a number of rapidly-varying extragalactic radio sources will be observed to determine their spectral indices. A deep 90 cm observation of a field previously observed at 20 cm and in the optical seeks to identify and investigate a population of faint, low-frequency radio sources. Observations of radio-loud IRAS galaxies will allow researchers to investigate AGNs and hyperluminous IRAS galaxies and quasars at high redshifts.

A team of observers will use the VLA to find and investigate radio sources in the Hubble Deep Field, a region of sky imaged by HST to study galaxy populations at high redshifts. This team expects to find about 50 radio sources in and near this field, which also is being studied intensely by ground-based optical imaging and spectroscopy as well as by infrared and X-ray projects. Radio spectral indices produced by the VLA will complement the large base of information being accumulated on this region. A series of projects undertaken by different teams will look at successively more-distant populations. These projects include: making high angular resolution maps of radio galaxies at redshifts near 1; high-resolution imaging of rotation measures and radio spectra of a complete sample of radio sources with redshifts of 2 or greater; observations of optically faint sources with ultra-steep radio continuum spectra that are candidates for very high redshift radio galaxies; and a radio-optical campaign to search for radio galaxies at redshifts above $z = 5$. Such studies will address a number of cosmological questions such as evolutionary effects in the populations, the source of high rotation measures found in distant radio sources, the origin and evolution of galaxies, and where the *redshift cutoff* in density of radio galaxies may be found.

Gravitational lenses are an important cosmological tool, and several teams will use the VLA in 1997 to study gravitational lens systems. One project will seek to learn if a number of radio-loud quasars with damped Lyman-alpha systems in their spectra are in fact gravitational lenses. Other projects will examine individual lens candidates in detail to determine if they are lenses, and if so, their morphologies. One of these candidates, MRC 0406-244, may have the most distant lensing object yet found, an intervening galaxy at redshift 1.6. Lens systems offer the ability to study the nature of the lensing mass. A strong radio source that appears to have two intervening mass concentrations along its line of sight will be observed in hope of detecting stimulated emission of radio recombination lines and thus to allow studying ionized gas in either or both of the lensing systems. Q-band observations will seek to find formaldehyde and ammonia absorption toward the Einstein ring B0218+357. Such absorption could provide valuable information on the excitation condition and interstellar medium of the lensing galaxy, as well as information on its velocity field and mass distribution.

Six known lens systems (0218-356, MG0414+0534, CL1600+434, CL1608+656, PKS 1830-211, and B1938+666) will be monitored to measure time delays in variability among components of the lens. With an accurate model for the lensing mass, such time-delay measurements can yield distances and thus calibrate the Hubble Constant. To contribute to this valuable cosmological goal, these programs must include both high-precision measurements of the time delays and high-resolution imaging to constrain models of the lensing system. In addition, such measurements must be made of a number of systems.

2. The Very Long Baseline Array

The VLBA has entered the phase of routine operation, and is being utilized by researchers in a variety of fields. While extragalactic objects are often considered its primary targets, the VLBA has produced impressive results in stellar research and study of Galactic objects, notably the black-hole X-ray binary GRO J1655-40, in which superluminal motion clearly was shown by the VLBA. Its value to the geophysical community, and its reputation in that community, continue to grow. As the instrument matures, the range of investigations pursued with it expands.

The VSOP satellite is scheduled for launch early in 1997. When this spacecraft is fully operational, NRAO will devote up to 30 percent of the VLBA's observing time to VSOP observing programs. VLBA observations in conjunction with the satellite will be correlated on the VLBA correlator in Socorro.

An ongoing program will advance toward the goal of producing an *all-sky* grid of calibrator sources for phase-referenced observing. This suite of calibrators will serve not only VLBA users but also the entire VLBI community. In addition to producing a list of phase-reference calibrators, this program also can benefit research in areas such as gravitational lensing and cosmology. Another program will complete single-epoch snapshot imaging of compact extragalactic radio sources used to establish a celestial radio reference frame. This program will measure structure and monitor changes in these sources that affect their suitability for the reference frame. This will result in a subset of *core* reference sources to serve as *super calibrators* for sub-milliarsecond astrometry.

As a participant in the NASA Space Geodesy Program, the VLBA has become an important resource for a variety of geophysical investigations. The high quality of VLBA geodetic data has been praised by the geodesy community and demand for continuing data is high. The VLBA is used for three major types of geodetic programs: monitoring the motions of the VLBA stations within the terrestrial reference frame; high-precision measurement of Earth orientation parameters; and measurement of the terrestrial and celestial reference frames.

Geodetic observations with the VLBA already have produced significant results, raising intriguing questions that can be answered only by continued, long-term monitoring. For example, the continental VLBA sites appear to be showing horizontal motions that exceed those predicted by models of rigid tectonic plates. If continued work confirms these motions, this will have implications for the degree of stability and rigidity of the North American plate. In addition, measurements of the daily variation in Earth orientation parameters show a signal that appears to differ from current models based on tidal effects.

The Earth orientation data also are used for atmospheric modeling, by measuring variations in atmospheric angular momentum. Geodetic observations over long time periods seek to detect Earth orientation variations due to mass redistribution in the hydrosphere. The importance of VLBI data to reference-frame maintenance was cited by the International Earth Rotation Service (IERS), which stated that "VLBI is the technique that holds together the IERS celestial and terrestrial reference systems, and that provides the long-term monitoring of universal time, precession and nutation."

One of the candidate extrasolar planets announced in 1996 was detected by optical astrometry, revealing the effect of the planet's mass on the observed proper motion of the star. A VLBA program of astrometric observation of a pair of nearby dMe stars will measure their proper motions in an attempt to detect any such effect. The VLBI astrometric accuracy is sufficient to detect sub-Jupiter-sized companions within a few AU of these stars in a few years.

VLBA studies of stars will include: using an extragalactic background source to measure turbulence in the solar wind; determining the polarization of OH masers in the envelopes of OH/IR stars, imaging the maser components, and studying the kinematics of the maser shell; and imaging the milliarcsecond structure of microwave emission of rapidly-rotating, magnetically active single stars of the FK Comae class.

Observations with the VLBA, the VLA, and European telescopes have produced a sequence of images of Supernova 1993J in M81. This sequence clearly shows expansion of the explosion shell. Monitoring of this supernova will continue, with the ultimate goal of producing a time series of multi-wavelength images of the supernova to model and display the complex expansion of an exploded star.

A program to observe Class I methanol masers will seek to provide accurate positions for these masers and to associate them with particular objects, such as compact HII regions, OH masers, and Class II methanol masers. Multi-epoch observations of strong water masers will provide information on the polarization structure of these masers and on their proper motions, to help study the physics of star-forming regions.

The interstellar medium will be probed by a pair of observing programs that will measure the scattering of radiation from background sources. One program seeks to help identify the mechanisms that generate fluctuations of electron density in the ISM, while the other will observe an individual background source to seek the location along the line of sight of the scattering material.

Active galactic nuclei, their host galaxies, and their jets are the subjects of a large number of planned VLBA observations. With the resolving power of the VLBA, researchers can observe structures at parsec scale in the jets of AGNs. Multiwavelength observations of NGC 1052 will study recently-discovered two-sided jets in this object and seek to locate its core. Polarimetric imaging of 3C 216 will seek to learn if Faraday rotation arises within the source or external to it. The BL Lac object Markarian 501, which showed a twisted jet in an earlier, low-resolution VLBA image will be re-observed to study in detail newly-found multiple sharp bends in the jet. The radio galaxy 3C 120 will be observed in two studies. One will compare high-resolution images of the jet to models based on relativistic hydrodynamical simulations, and the other will use multiwavelength imaging to reconstruct the magnetic field distribution along and across the jet and establish the relative contribution of shocked and non-shocked plasma to the jet's radio emission. A study of 3C 84 and BL Lac will seek to unambiguously identify the cores of these objects, an important datum for studies of their jets. Another program on 3C 84 will continue structural monitoring of the source, attempt polarization imaging and seek to find recombination lines in the counterjet discovered a few years ago by the VLBA.

Several objects will be monitored to follow the evolution of their jets. Some of these programs will continue previous monitoring campaigns and others will include simultaneous monitoring by spacecraft at non-radio wavelengths. In addition to providing records of structural changes within the jets, various of these studies will yield spectral information on jet components, polarization information, and data on the evolution of individual jet components. Overall, these monitoring programs will produce valuable information on the kinematics and physics of jets, and allow testing of theoretical models.

A number of investigators will use the VLBA to probe the nature of AGN central engines, the relation of the central engine to the jets, and to test models of AGN unification.

The galaxy NGC 4258, with its well-characterized circumnuclear disk of water masers, will serve as a valuable laboratory for studying central engines and jets. Further VLBA observations will seek to trace its jet structure in the regions closest to the maser disk and the central engine. Another program will seek to find a proposed accretion-dominated torus at the center of NGC 4258 and to further study a nuclear component found in previous observations. Another galaxy, IC 1481, recently has been found to have strong water-maser emission and will be observed with the VLBA to see if the structure and dynamics of its maser emission can be characterized as well as that of NGC 4258. Another candidate for a parallel to NGC 4258 is the galaxy NGC 5793, which is presumed to have a circumnuclear disk of water masers. This galaxy, too, will be studied in detail in the coming year.

In other projects, formaldehyde absorption along the line of sight to Centaurus A will be studied to learn the location of the molecular gas with respect to the AGN; a nucleus will be sought in the enigmatic object CTD 93 to learn if it is a compact double or a compact symmetric source; observation of the radio galaxy 3C 353 will investigate the relationship between its core and jet; and the nucleus of the unusual active galaxy NGC 3079 will be studied at multiple wavelengths.

BL Lac objects, including the namesake source, will be studied. BL Lac will be observed to follow the motion of a highly-polarized superluminal shock component that emerged from a point apart from the presumed core. Further observation of this component will test an hypothesis that it is a shocked knot moving in a helical trajectory such as a Kelvin-Helmholtz instability might produce. Six BL Lac objects, again including BL Lac itself, will be monitored to follow transverse relativistic shocks in their jets. This will allow detailed study of their cores as they give birth to new shock components and provide information on the evolution of the shocks as they propagate outward. A study of 12 X-ray loud BL Lacs, not previously observed with VLBI, will try to measure proper motions in their jets and determine jet strengths relative to the cores. This study will seek to test the hypothesis that X-ray loud BL Lacs are a transition population intermediate in viewing angle between highly-beamed radio BL Lacs and unbeamed FR I radio galaxies.

Studies of blazars will include a program of multiwavelength monitoring of the gamma-ray blazar NRAO 530 (recently in a high frequency outburst mode), to probe the dynamics and energetics of its jet and radio imaging of the gamma-ray blazar Markarian 421, which, in a 1996 outburst, emitted the brightest TeV signal seen from any cosmic source. Other blazar studies will seek, through observations both of individual sources and of multiple sources, to answer questions such as: how many types of blazar are there?; are superluminal jet components created during gamma-ray flares?; what is the correlation between parsec-scale radio structure and flaring gamma-ray emission?; and what are the properties of the magnetic fields near the cores of blazars?

A continuing program will study polarization structure in the quasar 3C 309.1 to image the Faraday rotation measure and depolarization arising from the intercloud medium of its narrow-line region. Other workers will seek to map structure of the extreme gigahertz-peaked quasar RXJ1459.9+3337.

One VLBA observing program is both a follow-on to the VLA FIRST survey and preliminary to a set of observations with the VSOP satellite. A sample of flat-spectrum compact sources identified in the FIRST survey will be observed with the VLBA and other VLBI instruments to determine their structure and identify candidates for the VSOP program.

A pair of gravitational-lens systems offers the opportunity to study the lensing objects through molecular absorption lines. The lens B0218+357 consists of a background quasar at a redshift of 0.93 with an intervening galaxy at $z = 0.68$. Observation of the absorption lines will allow study of very small scale structure in a distant molecular cloud. Molecular absorption from an intervening galaxy also is found in the lens PKS 1830-211. Both these lens systems are potentially valuable for determining cosmological distances, because in each system only one lensed component of the source shows the molecular absorption. This allows absorption measurements to estimate the time delay between the two images, and thus produce an estimate of distances in the system. Other lens systems will be observed by the VLBA in attempts to refine their mass models by resolving compact structure. Accurate mass models are a key element in using the systems to measure distance.

3. The 12 Meter Telescope

The 12 Meter Telescope is now equipped with sensitive, dual-channel SIS receivers covering all the primary wavebands of the telescope from 68 to 300 GHz. The sensitivity and flexibility of these systems allow observers to attack the most challenging and topical problems confronting millimeter-wave astronomy today. Astronomers most often use these dual-polarization, single-beam receivers to achieve the utmost sensitivity toward a single point on the sky, or perhaps to map a limited region. Some of the most fundamental discoveries of recent years, such as the detection of molecular gas in high-redshift galaxies and the discovery of new interstellar molecules have been made with these systems. To enhance further our instrumental capabilities for point-source observations, a new 8-receiver, 4-beam, 3 mm receiver is being constructed. This receiver will allow dual-polarization, double-Dicke beam-switched observing for point sources as well as efficient wide-field imaging.

Many astronomical problems require the ability to rapidly image large fields. Such problems concern the structure of external galaxies and the large-scale structure of molecular clouds and star-forming regions in the Milky Way. The imaging capability of the 12 Meter has undergone a revolution in the past few years with the advent of on-the-fly (OTF) observing modes. This is a highly efficient observing technique that can be used in either spectral line or continuum modes. This technique is made possible by a marriage of the powerful and flexible on-line computer systems and the high-sensitivity receivers at the 12 Meter. OTF observing can be used with all of the 12 Meter facility receivers. Further developments in wide-field imaging are planned, including the construction of the 4-beam, dual-polarization receiver mentioned above.

On-the-fly observing is having a substantial impact on the scientific program of the 12 Meter. In the present observing term about 20 percent of all observing programs specifically request the technique and we expect the demand to grow even more. OTF mapping targets include a variety of Galactic and extragalactic sources. For example, one group will study CO (1-0) emission in the nearby barred spiral NGC 253 with the aim of determining how the structure and kinematics of the molecular gas relates to the bar of the galaxy. Since the OTF technique can be used with any of the receiver systems, another group will image CO (2-1) emission in the large, nearby galaxy IC 342. The intent of this study is to determine why there is little star formation in the bar of the galaxy despite large concentrations of molecular material there. Other OTF mapping programs will focus on regions of our own Galaxy. For example, one program will image the ring nebulae around Wolf-Rayet stars to study the nature of mass loss from these rapidly evolving objects.

Astrochemistry continues to be a specialty of the 12 Meter and one of the largest components of the 12 Meter research program. Over the years, the facility has accounted for a substantial majority of the detections of interstellar and circumstellar molecular species. This trend continues; in the past two years the 12 Meter produced detections of over six new species. About 100 species are now known.

Astrochemistry has matured so that directed chemical studies and new species detections can now be used to address some very challenging problems in astrophysics. For example, in the coming year one program will search for an aluminum isotope in the envelope of an evolved star. This study will constrain some specific predictions of theories of nucleosynthesis. By studying interstellar sulfur isotopes, another program will address specific predictions of nucleosynthesis theories. Further programs will study the details of interstellar chemistry such as grain surface reactions and the chemistry of translucent clouds. Translucent clouds are the simplest category of interstellar cloud to support complex chemistry; hence, they are good astrophysical laboratories.

Research on external galaxies continues to be major component of the 12 Meter research program. In recent years, the 12 Meter has been a leader in studies of molecular line emission from very high redshift galaxies. Many other projects have concentrated on the structure and star formation in more nearby galaxies. One upcoming project will search for CO emission in a complete sample of low-z powerful radio galaxies detected by IRAS. This program will test the theory that the radio sources are triggered by gas-rich galaxy mergers. Another group will seek to complete a comprehensive survey of spiral galaxies with the intent of defining the molecular content of normal spirals as has been previously done for HI in these objects. Other upcoming programs focus on the properties of specific prototypes for general classes of galaxies such as early-type galaxies or barred spirals. The power of the on-the-fly imaging technique will be particularly useful for these studies.

A number of programs will use the new polarimeter at the 12 Meter. This instrument is available for use with the 3 mm receiver and can measure both linear and circular polarization. Astronomers are using this device to search for Zeeman splitting in selected molecular lines. The results will be used to measure the strength of the magnetic fields in these clouds, a critical parameter of the star formation process. Other projects will use the polarimeter to measure linear polarization in SiO maser emission and to measure the polarized component of dust emission in protostellar dust cores.

The 12 Meter is participating in millimeter-wave VLBI with increasing regularity and is a participant in the Coordinated Millimeter-Wave VLBI association. Kitt Peak forms an essential baseline for most experiments and the sensitivity of the 12 Meter makes it critical to the success of many VLBI experiments. The 12 Meter is now linked to the Kitt Peak VLBA station by fiber optics and makes use of the VLBA maser time and frequency standard and the VLBA data recorders. With a global network, millimeter-wave VLBI can achieve resolutions of 50 micro-arcseconds. In the coming year the 12 Meter will participate in several VLBI sessions that will seek to image the cores of distant quasars and active galactic nuclei, study the structure of 86 GHz SiO maser emission about evolved stars; and measure details of the millimeter-wave emission from our own Galactic Center.

Although most of the observing programs at the 12 Meter fall into one of the categories mentioned above, the flexibility and sensitivity of the telescope allow a number of other important projects. For example, one project will monitor the CO absorption profiles from the atmospheres of Mars and Venus. The 12 Meter planetary studies have provided unique information not available from any other source. This specific project allows, among other things, for the detection of dust storms in the Martian atmosphere. Another project will address poorly understood variations of ozone and water isotopes in the upper atmosphere of the Earth, as well as twilight variations of molecular oxygen and solar cycle variations of NO. The collecting area and precision surface of the 12 Meter are not strictly necessary for this project, but the wide frequency coverage of the receivers and its versatile backend instrumentation together make the 12 Meter Telescope a unique facility even for terrestrial studies. Finally, an upcoming project will study the chemistry of carbon-bearing molecules in Kuiper Disk comets. This project hopes to use cometary data to constrain models of solar system formation.

4. The 140 Foot Telescope

In 1997 the 140 Foot Telescope will start being phased out as a facility for visiting astronomers, as the attention and energy of the Green Bank staff becomes focussed on the GBT and as equipment is transferred to the new telescope. To reduce demands on support staff, we have been encouraging a shift to long observing programs that do not need frequent instrument changes. This emphasis will continue through 1997 as the telescope carries out programs of spectroscopy, pulsar studies, and VLBI.

Use of the telescope for VLBI will be dominated by observations in conjunction with the Japanese VSOP satellite, scheduled to be launched in January 1997. The 140 Foot will be a critical element of ground radio telescope arrays that support initial engineering tests and subsequent astronomical observations. The VSOP satellite will carry out several scientific programs that involve the 140 Foot Telescope. One is high-resolution mapping of compact extragalactic sources to determine statistical properties of the sub-milliarcsecond structure, including the brightness temperature distribution, orientation, spectral index, and variability. A VSOP survey of H_2O masers using the 140 Foot Telescope will delineate the distribution of masers in star forming regions and the structure and dynamics of masers in evolved stars. Some extragalactic megamaser sources may also be detectable to VSOP using the 140 Foot Telescope as a ground resource. It is expected that more than ten percent of the available telescope time in 1997 will be devoted to VLBI observations with VSOP.

Pulsar studies will continue throughout the year. Regular monitoring of a select group of milli-second pulsars will place limits on the density of gravitational radiation in the solar neighborhood. Individual pulsars will be monitored for evidence of spindown, glitches, or other period anomalies that shed light on the evolution of these objects and provide data on their reliability as time standards. As more pulsars in binary and more complex systems are discovered, regular monitoring is required to untangle the orbital dynamics and to make mass determinations.

The comet Hale-Bopp has already been detected by the 140 Foot in the 18 cm OH lines, and observations will continue throughout 1997. The OH lines are used to infer the velocity of gas in the coma and to estimate the rate at which water ice sublimates from the comet nucleus. Comet Wirtanen will also be observed.

The telescope will be used for numerous programs of interstellar spectroscopy during 1997. Measurements of the abundance of ^3He will give important limits on the photon/baryon ratio in the early universe. Studies of carbon recombination lines will be used to determine conditions in photo-disassociation regions at the boundary between HII regions and molecular clouds. There will be several searches for previously undetected molecules of astrophysical interest prompted by new laboratory measurements of the molecular transitions.

Observation of the 18 cm OH lines will also be used to monitor conditions in the extended atmospheres of late type stars.

Studies of galactic HI and extragalactic HI in various environments will be made. There will be programs of observation of the HI in dwarf and shell elliptical galaxies, in the direction of galactic high-velocity clouds, and toward the galactic plane. The interaction of supernova remnants with the interstellar medium can produce spectacular shells, bubbles, and arcs in galactic HI. Several objects known to have HI shells from preliminary searches will be mapped at higher sensitivity and resolution with the 140 Foot. Also, there will be directed searches for HI shells towards regions of star formation and other areas of interest identified by optical and IR observations.

It is expected that 1997 will be the last year in which the 140 Foot Telescope is operated as an NSF-supported general user facility. By mid-year the GBT cassegrain receivers will be removed from the telescope for refurbishment and installation on the GBT, and after this time spectroscopy will be confined to wavelengths of 6 cm or longer. The SETI Institute has indicated their interest in using the telescope for their privately funded Project Phoenix, and it is expected that an increasing fraction of the telescope's time will go to this work in 1997, culminating with removal of the telescope from general scientific use at the commissioning of the GBT in early 1998.

III. USER FACILITIES

1. Very Large Array

Present Status

More than 600 scientists used the VLA for their research work in 1996, and a similar or larger number will do so in 1997 as time previously scheduled for the NVSS becomes available for general use. Demand for the VLA arises both from the multi-wavelength nature of contemporary astronomical research and from the flexibility of the telescope. With regard to the former, it is now 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. Radio observations also may be the focus of research with complementary data provided from observations at other wavelengths. For either case, the fact that the angular resolution and field of view of the VLA is nearly identical or better than that achievable with modern detectors at other wavelengths means that all the data can be merged with no ambiguity. This is the capability astronomers need for their research.

Present Instrumentation

The VLA consists of twenty-seven, 25 meter antennas arranged in a wye configuration, with nine antennas on each 13 mile arm of the wye. The antennas are transportable along 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 0.59, 1.95, 6.39, and 21.0 km, respectfully. Reconfigurability provides the VLA with variable resolution at fixed frequency or fixed resolution at variable frequency.

The VLA supports eight frequency bands, remotely selectable; the six upper bands by means of subreflector rotation. The following table summarizes the parameters of the VLA receiver system.

The VLA receives two intermediate frequencies (IF), each with 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.

Table III.1. VLA Receiving System

Frequency (GHz)			T_{sys} (K)	Amplifier
0.070	-	0.075	1000[1]	Bi-Polar Transistors
0.308	-	0.343	150	GaAsFET
1.34	-	1.73	33	Cryogenic HFET
4.5	-	5.0	45	Cryogenic HFET
8.0	-	8.8	31	Cryogenic HFET
14.4	-	15.4	108	Cryogenic GaAsFET
22.0	-	24.0	160	Cryogenic HFET
40.0	-	50.0	95[2]	Cryogenic HFET

[1] Eight antennas equipped; T_{sys} includes galactic background.

[2] Thirteen antennas equipped.

Future Plans — Electronics

When the VLA went into operation in 1980, it gave an improvement in resolution, sensitivity, speed, and image quality of more than two orders of magnitude over existing arrays. Since that time, the VLA has been an extraordinarily productive scientific instrument. However, as a result of technological advances during the past decade, new instrumentation is needed to keep the VLA at its current leading position among the world's radio astronomy facilities.

A program to upgrade the VLA is described as a Major New Initiative in Section VI of this Preliminary Program Plan. It amounts to a major overhaul of the entire VLA electronics system. The upgrade will include a new correlator, a new fiber optic data transmission system, and several new wideband receiver systems. Until major funding for the upgrade is available, improvements to the VLA will be in the form of yearly improvements to smaller parts of the electronics.

Modifications are being made to the 21 cm local oscillator system to reduce radio frequency interference produced by intermodulation products. This retrofit involves introducing a 180 degree phase switch at the first local oscillator in this band as is done at the other VLA observing bands. This project should be completed by mid 1997.

Design and prototyping has begun for the next generation of wide bandwidth VLA receivers. A circular polarizer with a bandwidth ratio of 1.5 has been successfully designed and fabricated at the NRAO Central Development Lab. This will allow a single receiver to operate from 18 to 26.5 GHz as proposed for the VLA upgrade. Two prototype receivers for this band now are under construction and should be installed on the VLA around April of 1997.

Two 3 mm receivers are now under construction for installation on the VLBA. These will be installed on the PT and LA antennas before the end of 1996.

A plan is being prepared for incorporating the PT VLBA antenna as a real-time active element of the VLA. In this arrangement the PT antenna would provide a long baseline for the VLA A-configuration. This is now feasible since a fiber optic connection recently has been completed by Western New Mexico Telephone Company between the VLA control building and the PT antenna. A design concept and budget estimate to add this interferometer element to the VLA should be ready by October 1996.

VLA — Repair and Maintenance

The maintenance of the VLA infrastructure continues as a high priority, but is impacted by declining NRAO budgets. The major long-term projects are rail maintenance, manhole replacement, and antenna painting.

Rail system maintenance continues as a routine but highly important task. In 1996 twenty-four spur lines are being realigned and six intersections are being rebuilt. The rail system will also be surveyed with new markers installed by the end of the year. An extensive leveling program for the mainline, begun in 1996 will continue.

The aging of the VLA is clearly seen in the rust and staining on a large number of the VLA antennas. A program for painting the VLA antennas was initiated in 1993 to attack these problems before mechanical deterioration set in. By the end of 1995, eight antennas had been repainted and three more antennas should be completed in 1996. This work is performed by a three-man NRAO summer crew. It will take about six years to address the current problem, and after that, antenna painting will become a regular maintenance item.

In 1991, the azimuth bearing in VLA antenna 21 failed, putting the antenna out of service for almost a year. Monitoring of the metal content of the bearing grease and the vertical play of the azimuth bearings shows that there are other antennas with worn or damaged bearings. In 1994 the azimuth bearing of antenna 9 was replaced as part of its regular overhaul. In late August 1996, the bearing of antenna 23 was replaced. There are several other antennas that will need bearing replacements in the near future.

There is a program to replace the waveguide manholes at the VLA with steel culverts. The existing concrete manholes are deteriorating and collapsing. By the end of 1995, 45 manholes had been rebuilt out of a total of 122. Due to a lack of funds no progress was made on this project in 1996. This replacement program will be restarted in 1997 in order to keep ahead of the deterioration; it will take at least six more years to complete.

Much of the VLA outdoor maintenance is done during the summer months with the longer days and moderate weather. During this period, the regular NRAO staff is augmented by seasonal employees, and the VLA maintenance staff goes to a ten-hour workday. In 1996, only six temporary employees were hired for work on the rail and painting crews. Two to three times this number were hired in previous years.

In order to return to our desired level of maintenance, a larger number of temporary workers will be needed in 1997.

2. Very Long Baseline Array

Status

Since last year's program plan the amount of observing on the VLBA has increased from 50 to 60 percent of the available time. The ramp up is somewhat slower than expected due to two factors: a) the backlog of unprocessed data has resulted in the correlator not running at full efficiency for current observations; and b) personnel shortages. However as of August 1996 the backlog is gone and the time lag between observing and correlation has dropped to 10 days on average.

One highlight is that the long-awaited switch to high density recording occurred in April/May of 1996. This means that the VLBA now can record at its nominal sustained data rate of 128 Mbits/second. Meritorious projects can request a data rate of 256 Mbits/second.

Present Instrumentation

The VLBA is a dedicated instrument for very long baseline interferometry. The ten antennas are distributed about the U.S in a configuration designed to optimize the distribution of baseline lengths and orientations (u-v coverage). Baselines between 200 and 8000 km are covered, which provides resolution as fine as 0.2 milliarcseconds at 43 GHz. The shorter baselines, and hence the highest concentration of antennas, are near the VLA for optimal joint observations and to allow for a future project to fill the gap in the range of baselines covered by the two instruments. The antennas are 25 meters in diameter and of an advanced design that allows good performance at 43 GHz and useful performance at 86 GHz. The antennas are designed for remote operation from the AOC. Local intervention is required only for changing tapes, for maintenance, and for fixing problems.

The VLBA is outfitted for observations in nine frequency bands as shown in Table III. The receivers at 1.4 GHz and above contain cooled heterostructure field effect transistor (HFET) amplifiers from the NRAO Central Development Laboratory (CDL). The low-frequency receiver (330 and 610 MHz) is a room temperature GaAsFET. The cooled receiver for each band is in a separate dewar mounted directly on the feed to minimize noise contributions from waveguides, etc. All receivers cover both right and left circular polarization. There is a dichroic/ellipsoid system that allows simultaneous observations at 4 and 13 cm, primarily for geodesy and astrometry.

Table III.2. VLBA Receiving Systems

Frequency Range (GHz)	Typical Zenith SEFD[‡] (Jy)	Typical Zenith Gain ($K\ Jy^{-1}$)
0.312 - 0.345	2256	0.092
0.600 - 0.630	2261	0.084
1.30 - 1.70	316	0.097
2.13 - 2.35	338	0.092
2.13 - 2.35*	425	0.078
4.50 - 5.14	309	0.131
7.88 - 8.93	323	0.117
7.88 - 8.93*	398	0.113
12.0 - 15.4	562	0.111
21.1 - 24.6	1001	0.103
42.3 - 43.5	1339	0.084

‡System equivalent flux density

* With 13/4 cm dichroic.

VLBI requires highly accurate frequency standards and a wide-bandwidth recording system at each site. The VLBA sites use a hydrogen maser manufactured by Sigma Tau Corporation for the frequency standard. The recording system is based on a Metrum (formerly Honeywell) longitudinal instrumentation tape recorder that has been modified extensively by the Haystack Observatory. The recorder is similar to the one used in the Mark III and Mark IV VLBI systems. There are two drives at each VLBA station to allow more than 20 hours of recording at 128 Mbits/second between required visits by station personnel for tape changes. The tapes are 16 microns thick, with about 3.4 miles of tape on a 14-inch reel.

The VLBA correlator is located at the AOC in Socorro. It is able to correlate as many as eight input data channels from each of 20 antennas simultaneously. For most modes, 1024 spectral channels can be provided for each input channel. The correlator is of a novel design, pioneered by the Nobeyama Radio Observatory in Japan, in which each bit stream is Fourier transformed to a spectrum before cross correlation (the "FX" architecture). Output data is archived on DAT tapes, while the input tapes are recycled for more observing shortly after correlation. Users receive their correlated data in FITS format on any of several media, including DAT and EXABYTE tapes.

The correlator now is in routine operation. It can handle the full complement of 20 stations for the majority of types of continuum and spectral line observations, including full polarization data. The core of the correlator real-time code was re-written in late 1994/early 1995 in order to improve its reliability. The improved robustness has been evident in the smoothness of correlator operations since the software upgrade. VLBA postprocessing is done in the astronomical image processing system (AIPS). Software development for VLBI in AIPS is essentially complete apart from support for some advanced capabilities of the array such as phase referencing. Much work has been done to make the AIPS VLBI sub-system more robust and user-friendly. Astrometric/geodetic processing will be done primarily in the system developed by the Crustal Dynamics Project, now Dynamics of Solid Earth (DOSE), at NASA. The in-house computing for the VLBA is done mainly on workstations of the SUN Sparc 20, Ultra and IBM RS/6000-580 classes.

Future Plans

There are several major milestones to be achieved in the near future.

(a) The major task facing the VLBA is developing the ability to handle Space VLBI data once the Japanese VSOP satellite is launched (early 1997). NRAO has committed up to 30 percent of the science time of the VLBA to co-observing with VSOP and other ground antennas and also has committed to correlating data on the VLBA correlator. Our major goal is to ensure that the VLBA correlator is capable of processing such data. In August 1996, tests with the VLBA correlator successfully obtained fringes with data from a 1986 space VLBI test observation using a TDRSS satellite and two ground stations. We should have full Space VLBI capability by the end of 1996.

(b) The VLBA correlator already handles much greater quantities of data than previous VLBI correlators. In order to achieve maximum efficiency, we must ensure that the handling of VLBI data is as automated as possible at all stages of the process, from the schedule generation, the tracking of the data tapes, the generation of correlator control scripts, to the correlation, generation of distribution data and quality control over the final data product. Our plan envisages a coherent software suite to govern all stages of this procedure. Some pieces are currently in place and others will be developed over the next few years.

(c) As shown in Table III.2, the VLBA is equipped at nine frequency bands. Work is in progress to add a tenth, at 86 GHz. The VLBA antennas are designed to work at such high frequencies and the scientific benefits from observing at 86 GHz will be tremendous. We shall be able to extend the highly successful 43 GHz SiO maser observations to another transition of SiO and be able to investigate the physics of these interesting objects. The resolution available at 86 GHz will be ~ 90 microarcseconds. This will be of great benefit to astronomers studying the nuclei of AGNs. We hope to fully equip the VLBA at this frequency over the next few years.

3. 12 Meter Telescope

The NRAO 12 Meter Telescope began as the 36 Foot Telescope, the telescope responsible for the birth of millimeter-wavelength molecular astronomy. Following a period of explosive growth in this new area of astronomical research, during which most of the dozens of molecular species known to exist in the interstellar medium were first detected at the 36 Foot, the telescope's reflecting surface and surface support structure were replaced and the 36 Foot was re-christened in 1984 as the 12 Meter. Subsequently, the scientific program has evolved from one dominated by observing programs in astrochemistry to one with a broader mix of studies of molecular clouds and galactic star formation, evolved stars, astrochemistry, and external galaxies. The 12 Meter is the only millimeter-wavelength telescope in the U.S. operated full-time as a national facility. More than 150 visitors make use of the telescope annually. It offers users flexibility and the opportunity to respond quickly to new scientific developments. Low-noise receiving systems at a wide range of frequencies, currently covering all atmospheric windows from 68 GHz to 300 GHz, are maintained. Operational reliability throughout is emphasized. Flexible spectral line and continuum backends allow the observer to match the instrument to the scientific goals. The development of multi-beam receivers and the on-the-fly observing technique has inaugurated a new era of high-speed source mapping on angular scales complementary to those of the millimeter-wave interferometers. The new telescope control system offers great flexibility and provides a proven remote observing capability. It has also increased the efficiency and convenience of the 12 Meter Telescope; the experience gained will benefit future millimeter-array operation.

Present Instrumentation

Telescope

The basic specifications of the 12 Meter Telescope, its site, receivers, and spectrometers are:

Diameter: 12 meters

Astrodome with slit	
Pointing accuracy:	5 arcseconds
Aperture efficiencies:	52% at 70 GHz
	49% at 115 GHz
	32% at 230 GHz
	22% at 300 GHz

As many as four receivers are mounted simultaneously at offset Cassegrain foci on the telescope. Receiver selection is by means of a rotating central mirror and can be accomplished in minutes. The receivers are configured remotely from the control room with a computer-aided tuning system.

Receivers

The NRAO tradition of providing receivers equaling or bettering any others in the world is also true at millimeter wavelengths. A closed-cycle 4.2 K system capable of holding eight SIS receivers sharing the same dewar has been developed. A complete set of state-of-the-art, dual-channel superconducting-insulator-superconducting (SIS) receivers is operational over the entire range 68-300 GHz. The arrangement of several receivers sharing the same dewar is extremely effective in terms of cost, manpower, and in operational demands.

Table III.3. 12 Meter Receiver List

Frequency Range (GHz)	Mixer	SSB Receiver Temperature (K) Per Polarization Channel	Notes
68 - 116	SIS	60 - 90	
130 - 170	SIS	120	
200 - 260	SIS	200 - 400	
260 - 300	SIS	400 - 500	
Eight-beam Receiver:			
220 - 250	8-SIS	260	

Notes:

1. Receiver noise is around 200 K single sideband for most of the band, increasing somewhat at the high frequency limit.

Note: All single-beam receivers have two orthogonal polarization channels. Receiver temperatures include all receiver optics.

Spectrometers

The following filter-bank spectrometers are maintained so that the astronomer will have access to the proper frequency resolution for a particular astronomical observation.

Table III.4. 12 Meter Filter Bank List

Resolution (kHz)	Number of Channels	Number of Filter Banks Per Channel
30	128	1
100	256	1
250	256	1
500	256	1
1000	256	2
2000	256	2

Note: All filter banks except the 30 kHz units can be divided into two 128-channel sections to accept two independent IF channels.

To enhance the telescope's spectroscopic capability and to accommodate the 8-beam receiver, a hybrid filter bank/autocorrelator is available. Its instrumental parameters are as follows:

- 8 independent, tunable IF sections;
- 1536 spectral channels (can be split into 8 sections);
- maximum total bandwidth options:

  1 x 2400 MHz

  2 x 1200 MHz

  4 x 600 MHz

  8 x 300 MHz

  frequency resolution (per channel): variable in steps of two continuously between 1.56 MHz and 24 kHz for each of two IF channels.

Note that the current instantaneous bandwidth is limited by the receiver IF bandwidth. The center frequency of the IF for some receivers is being changed from 1.5 GHz to ~3.5 GHz, to increase this instantaneous bandwidth beyond 1 GHz. This is particularly important for extragalactic observations of high redshift galaxies.

Future Instrumentation Plans

Most millimeter-wave spectroscopic studies of star formation, interstellar chemistry, galactic and extragalactic composition, etc., require observations of a number of molecules in a number of transitions, occurring at many different frequencies. These studies can be carried out most expeditiously, and most thoroughly, if high-sensitivity receivers are available for all the atmospheric windows and if a high-speed imaging capability is available at the most important wavelengths. Together, these requirements define the focus of the long-range plans for the 12 Meter.

All the developments described here are of immediate relevance to the 12 Meter Telescope, and most are equally relevant to the MMA.

One-Millimeter Imaging SIS System

Millimeter-wave telescopes inevitably have small beams, and hence, with the usual single-beam system, true imaging of large fields is particularly difficult and time-consuming. For large-scale imaging, the smaller diameter of the 12 Meter Telescope compared, e.g., with the IRAM 30 meter telescope in Spain, is no disadvantage. We plan to provide a powerful imaging system at our optimum wavelength of 1.3 mm. The 8-feed Schottky system has been upgraded to use SIS mixers, thereby giving state of the art sensitivity in all feeds. This upgraded system was released to observers early in 1996. The key to future development is the backend electronics. We are cooperating with the Green Bank Telescope correlator group to make use of the same printed circuit cards and chips as are being developed for that project for a multi-feed digital auto-correlator spectrometer for the 12 Meter Telescope. As a prototype development for a spectrometer to support multiple beams, we first plan to build a new 8-IF spectrometer. This will immediately give the 12 Meter 8-feed, 230 GHz extra capability. The current hybrid spectrometer is limited to 300 MHz instantaneous bandwidth per beam, when supporting the 8-feed system. For extragalactic work this total bandwidth is inadequate. The new prototype system will support 1.2 GHz instantaneous bandwidth simultaneously on 8-IF channels, a substantial improvement on our existing capability. All multi-feed systems put severe demands on the computer hardware and software. The telescope real-time control system has been completely replaced with a modern design which offers great flexibility for future developments. Already, remote observing, controlling the 12 Meter Telescope over a wide-area network has been demonstrated, and is expected to become a more common mode of operation in the next few years. Recently we have concentrated on improving the observing efficiency of the telescope and on developing and implementing new observing techniques. The data acquisition rate will have increased by between one and two orders of magnitude. The postprocessing environment is becoming a network of modern workstations. We have begun to build this network with existing funds, but a great deal of new computer hardware and software development will be required in the next three to four years.

A New 8-Feed SIS System for 3 mm

We have begun construction of a new 8-feed multibeam system for 3 mm, to replace the existing 3 mm system. The new system will support simultaneously dual polarizations in each of four beams on the sky, and will give substantially increased sensitivity both for point-source observations and for mapping of extended objects. Each of the eight receiver channels will have lower noise than any of our existing 3 mm receivers, by a factor of 1.7. The improvement results from a careful study of the various losses and sources of noise mainly within the receiver optics. In reasonable weather, this sensitivity improvement becomes a factor of ~2 reduction in observing time on the telescope to reach a given sensitivity. For point source observing, two of the dual polarization beams will be separated on the sky by an angle equal to the beam throw from the nutating subreflector. This makes the system a dual-polarization double-Dicke switching system, with a further factor of two gain in observing speed compared with our existing single-beam dual-polarization system. That is, overall a gain in speed by a factor of ~4 for point source observations with the new system. For mapping of extended sources, all four dual-polarization beams will be used, giving an observing speed gain of ~8 compared to our current system. The existing hybrid spectrometer supports 8-IF channels. We hope to have this new 8-receiver, 3 mm system on the telescope within about one year.

Future Single-Beam Systems

Experimental HFET amplifiers have been tested in the CDL which may be capable of performance competitive with SIS devices at 3 mm. As soon as feasible, we intend to construct a specialized continuum receiver using HFET devices, for the 3 mm band. This receiver will have an instantaneous bandwidth of up to 20 GHz, and will give a continuum sensitivity far higher than any existing coherent receiver or bolometer.

Antenna Improvements

With the improved surface accuracy, operation of the 12 Meter Telescope at the highest frequencies (~300 GHz) is becoming more productive. This puts a more critical demand on the pointing characteristics of the telescope. In order to improve the pointing, we have implemented several upgrades in the past year. We are also installing an improved real-time monitoring system for movements of the prime focus, utilizing a laser and x-y translation detector. We have reevaluated feedleg insulation and are installing blowers to circulate air through the interior of the feed legs. We expect to implement additional instrumentation (inclinometers, strain gauges, temperature sensors), replace the feed legs with a carbon-fiber design giving less temperature dependence and less aperture blockage, and install a sun screen to reduce thermal distortions of the telescope during daytime operation. We now routinely use an auxiliary optical pointing system to determine the telescope pointing model and to diagnose pointing anomalies. We intend to explore a higher level of automation, with the possibility of offset guiding on optical stars to give accurate tracking of weak sources.

Polarimeter

We have constructed a polarimeter for the 12 Meter Telescope, which will be used to study linearly and circularly polarized emission in both the broad-band continuum and the spectral-line mode. This device became available in mid-1994. The design uses an adjustable grid and plane reflector combination, is quite compact, and will become a prototype design able to give similar capability to the MMA. A future project is to construct a version for a wavelength of 1 mm.

Telescope Control, Data Acquisition, and Data Analysis Improvements

New enhancements continue to be incorporated into the telescope control system. The analog servo system that positions the telescope will be upgraded to a fully digital system. This should reduce the settling time required after telescope movement and could result in a ten percent or more improvement in the duty cycle of most observing modes (note that ten percent improvement in observing efficiency is equivalent to approximately 30 days of observing time in a typical season at the 12 Meter). The user interface has been enhanced to allow the observer more direct control over the telescope.

On-the-Fly Observing

The on-the-fly observing mode has now become the preferred mapping mode. With this technique, the observer makes several rapid passes over the field of interest, recording data continuously. The results are averaged to improve signal-to-noise. The gains with this mode of observing have far exceeded our original expectations. The observing efficiency is much improved, because most of the dead time required to move the telescope beam from one discrete point on the sky to the next is eliminated. A factor of nearly two in sensitivity is gained because it becomes possible to use a single off-source reference position for perhaps hundreds of on-source spectra. The ability to make complete coverage of a given field quickly gives much higher consistency and quality in the individual data sets. In averaging the N data sets, the random noise is of course reduced by the square root of N, but for a small number of systematic defects, e.g., the occasional bad scan due to weather or other drifts, the artifacts are reduced by a factor closer to (N). The ability to cover a field with full Nyquist sampling or better adds to the scientific worth of the observations. Compared with the conventional point-by-point mapping, an increase in effective mapping speed of as much as one order of magnitude can be experienced. Substantial sizes of maps, e.g., one-third of a degree on a side, can be observed to a useful sensitivity limit in tens of minutes.

Naturally this observing mode produces enormous quantities of data. Special tasks have been added to the classic AIPS data reduction system to support the 12 Meter OTF mapping mode in spectral line. Further development is taking place to support continuum OTF observing as well.

Longer Term Future Plans

In addition to continued improvements in the 12 Meter, the Tucson staff will play a growing role in the development of the Millimeter Array. As the MMA project develops, there will be the necessity for real hardware design, prototyping, and testing, including multi-band, millimeter, and submillimeter-wave receivers, digital spectrometers, and continuum backends. Software evaluation in astronomical observations such as described above is another important area where the prototyping done at the 12 Meter will further the development of the MMA. Many of the projects already underway in support of the 12 Meter Telescope will become prototypes for, or otherwise contribute to the eventual MMA project. The Tucson staff are already actively participating in site testing for the MMA, with the construction of a portable centimeter wavelength interferometer to be used to study atmospheric phase instabilities at potential MMA sites. An innovative antenna design for the MMA is being explored, and shows great promise for a robust, high precision antenna. It is anticipated that Tucson participation in MMA development and support activities will continue to increase in the coming years.

4. 140 Foot Telescope

When the Green Bank Telescope comes on-line, the 140 Foot Telescope will cease operations as an NSF supported facility for general users. The transition is expected to be gradual.

The Cassegrain receivers now on the 140 Foot Telescope that cover the frequency range from 8 to 26 GHz are scheduled to be removed in April 1997 so that they can be refurbished and installed on the GBT later that year. There is a possibility that the K-band system will remain on the 140 Foot throughout much of 1997 to be used for VLBI observations in connection with the Japanese VSOP satellite. However, even if this occurs, it is most probable that the receiver will be equipped with a special-purpose, fixed-frequency LO and be useful only to VLBI after April.

The 140 Foot Telescope will continue to be used as a test bed for GBT development during 1997. The 680-920 MHz prime focus GBT receiver will be tested on the 140 Foot in late 1996 and early 1997. More extensive tests of the GBT Monitor and Control software as well as the AIPS++ data analysis software are anticipated on the 140 Foot in 1997. A holography system will be tested on the 140 Foot Telescope using GBT software in preparation for similar observations on the GBT. The GBT metrology group has been using the 140 Foot site during 1996 to calibrate and test the laser ranging system by tracking retroreflectors mounted on the telescope. These tests are expected to continue during 1997 with little or no effect on the normal operations of the 140 Foot.

An S2 tape recording system will be installed at the telescope courtesy of the Canadian Space Agency. This will allow VLBI observations to be made in either the VLBA or S2 tape formats. The VLBA tape unit has been upgraded to use thin tapes. Although most high-frequency receivers are expected to be removed from the 140 Foot by mid-year, the L-band and C-band receivers will remain at the telescope (together, possibly, with the K-band) and be available for VLBI observations throughout the year.

The SETI Institute has proposed to use the 140 Foot as a dedicated instrument for their program, with all costs being paid by the SETI Institute. Under this proposal the SETI Institute would begin moving their equipment and personnel into the 140 Foot by the end of 1996 and have full use of it in 1998 and beyond.

IV. TECHNOLOGY DEVELOPMENT

1. Electronics Development Equipment

Cooled HFET Development

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. State-of-the-art HFET's using Indium Phosphide substrate were made for NRAO by Hughes Research Laboratories and successfully incorporated into amplifiers in 1995 and 1996. The latest amplifiers cover the frequency bands 65-90 GHz and 75-110 GHz with noise performance comparable to SIS mixers and much wider instantaneous bandwidth. This has the potential to provide superior performance in continuum receivers and increased operating ease for spectral line work in the frequency range below 115 GHz.

NRAO has produced many HFET amplifiers for use on NRAO telescopes (VLA, VLBA, 12 Meter, 140 Foot, and GBT) and for others in the radio astronomy community and other research areas. These range from low-frequency amplifiers (< 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 feature elimination of the need for bulky isolators and better immunity to the effects of interference.

In 1997, a major goal is to develop amplifiers using exclusively InP devices covering the entire radio astronomy bands of interest between 22 and 115 GHz. This will be closely tied to the MAP project (see below) efforts. Designs will be aimed at the best possible performance coupled with ease of manufacture and reliability. The properties and cause of low-frequency gain fluctuations (1/f noise) in cooled HFET's will be investigated further, as this is the principal source of noise in wideband continuum observations.

Major effort will be expended on the development of amplifiers which will be used in the Microwave Anisotropy Probe (MAP) project, a joint effort with Princeton and NASA Goddard Space Flight Center. The receivers at 22, 30, 40, 60, and 90 GHz will be used in a new satellite to be launched in 2000 which will provide unprecedented accuracy in measurements of the cosmic microwave background radiation at angular scales down to 0.25 degrees and whole-sky connectivity. The amplifiers (except 60 GHz) will be directly usable on NRAO telescopes.

Millimeter-Wave Receiver Development

The design and fabrication of SIS (Semiconductor-Insulator-Semiconductor) mixers covering the frequency range 68-300 GHz are done by the Central Development Laboratory (CDL) primarily 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. A highlight of mixer design and manufacture in 1995-6 was the production of a well-matched set of tunerless mixers for the 8-beam 230 GHz receiver of the 12 Meter Telescope. This receiver significantly speeds spectral line mapping observations. Mixers have been produced not only for the 12 Meter, but for other radio astronomy organizations as well. The noise temperatures now being attained in operational receivers are only three to four times the quantum limit, so in many cases the dominant noise sources are external to the mixers.

A new 200-300 GHz tunerless mixer will be fabricated and tested which is expected to increase the instantaneous IF bandwidth; it is a forerunner of the future development of a mixer with an integrated IF amplifier. A 260-370 GHz mixer of modern design will be developed to replace the existing mixers on the 12 Meter Telescope and achieve lower noise.

Spectral line observations require only a single sideband response, whereas mixers typically provide a double sideband response. At the 12 Meter Telescope, zenith system temperature is typically 60 K at 230 GHz, of which about 30 percent is due to unwanted image noise. Design and fabrication are underway for a 200-300 GHz image separating mixer, which will use two properly-phased mixer elements to achieve sideband separation. A single mixer block will contain a quadrature hybrid, LO power splitter, two mixers, and a cold internal image termination; it will provide both upper and lower sideband outputs simultaneously. This device will be manufactured by JPL's Center for Space Microelectronics Technology in a new collaboration. If successful, such a mixer can decrease spectral line observing time for a given SNR by a factor of two.

A development effort in collaboration with the University of Virginia and the Smithsonian Astrophysical Observatory has produced an experimental traveling-wave SIS mixer for the 260-370 GHz range. The first device produced had good noise temperature but less than expected tuning range. Such mixers have been shown to work well at frequencies above 300 GHz and their development may allow mixers that work up to 700 GHz to be made by the University of Virginia; this is important for development of receivers for the MMA.

Present single-ended mixers are susceptible to LO sideband noise, which often has severe effects, increasing receiver noise temperature by as much as a factor of two. They also require high LO power because the LO is injected by means of a directional coupler. Both of these problems could be significantly helped by development of a balanced SIS mixer. A balanced mixer for 200-300 GHz will be developed which incorporates a quadrature hybrid, two mixers, and a 180-degree hybrid.

The instantaneous bandwidth of present mixers is limited because of the need for an isolator between the mixer and IF amplifier. Results obtained at Owens Valley Radio Observatory show that it is practical to produce a mixer with an integrated IF amplifier and achieve a bandwidth of 4 GHz. A development of this type is planned to achieve an IF bandwidth of 8 GHz for use by the MMA.

From the above discussion, it may be deduced that the ultimate goal of the mixer development effort is to produce an image-separating balanced mixer with integrated IF amplifiers, which will provide both upper and lower sidebands with the lowest possible noise, low LO power requirements, and wide IF bandwidth.

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 waveguide band response. A new orthomode transducer has been designed and fabricated for the 18 to 26 GHz band as the first of a new generation of such components. It provides excellent, resonance-free polarization separation over a fractional bandwidth > 0.4, thus covering the entire waveguide band. Also, a new polarizer to convert between dual linear and dual circular polarization has been designed and built. It provides a 90-degree phase shift with an axial ratio less than 1 dB over the entire waveguide band. Further work will be done to make similar devices more compact at lower frequencies and easier to fabricate at higher frequencies.

The combined goal of amplifier and passive polarization components is to enable full waveguide band frequency coverage without tuning for continuum and spectral line measurements. At lower frequencies, where severe interference may cause amplifier saturation problems when full waveguide coverage is implemented, other solutions to wideband frequency coverage must be sought.

86 GHz VLBA Receivers

Two prototype receivers employing InP HFET amplifiers are being completed for use on VLBA antennas. These will be used to measure antenna performance and for participation in millimeter VLBI array observations. The receivers will be completed, installed, and undergo initial tests before the end of 1996, and used extensively in 1997. Full upgrade of the VLBA to 86 GHz will require additional funds.

Green Bank Spectrometer

System testing began in 1996 for the GBT spectrometer, which will be able to analyze instantaneous bandwidths up to 800 GHz an d will have 262,144 spectral channels. Integrated testing of the basic functioning of the entire spectrometer will be completed in 1996. The spectrometer will be capable of operating in many different modes, and the implementation and testing of those modes will continue through the early part of 1997.

Interest has been expressed by the James Clerk Maxwell Telescope in purchasing major subsystems (circuit boards) of the spectrometer, and the South Korean astronomers have expressed serious interest in obtaining a complete system one-fourth of the total size. Planning for a spectrometer duplicate for the 12 Meter Telescope is under way.

Other Hardware Developments

Spillover shields for the GBT have been designed to reduce scattering by the feed arm structure in the vicinity of the subreflector. These shields redirect the energy outside the subreflector onto the main reflector and onto the sky. They will reduce the system noise temperature accordingly.

using a copper sulfite solution which appears to give good plating results with low current densities. These experiments will continue in a search for the most reliable copper plating procedure.

Radio Frequency Interference

The CDL contributes to frequency coordination and interference reduction through the activities of A. R. Thompson, Chairman of the U.S. Working Party 7D of the ITU Radiocommunication Sector, which is concerned with radio astronomy. Current concerns include allocations to the Mobile Satellite Service below 1 GHz, space-to-earth links in the 15.4-15.7 GHz band, and a satellite radar at 95 GHz. Frequency coordination activity includes multiple meetings and teleconferences with various U.S. committees and North American radio astronomy sites. Preparations are being made for testing the interference levels produced by the Motorola Iridium satellites in the 1610.6-1613.8 band in 1997. Major meetings in 1997 include WP7D in Geneva and WRC-97, at which certain areas of radio regulation are open to amendment. Important issues for radio astronomy will be the adoption of regulations on spurious emissions from the work of TG1-3, and allocations to satellite downlinks which can produce serious problems if they are too close in frequency to radio astronomy bands.

2. Computing

The revolution occurring in computing hardware provides an unprecedented opportunity to leverage the current state of the art for computing into major scientific advances and new capabilities. Comparatively small investments in new hardware should significantly improve NRAO's ability to support current facilities as well as new facilities coming on line over the next few years.

There have been major advances in imaging algorithms over the past year. Significant new scientific results using advances such as robust weighting and various improvements in AIPS will appear this year. For example, ultrahigh dynamic range observations using advanced algorithms are now possible with the VLBA, and should start to have a scientific impact during the coming year.

The Japanese VLBI satellite mission, VSOP (scheduled for launch in January- February 1997), will be completely dependent on NRAO software for key steps in data reduction, especially for fringe finding and calibration.

Computing facilities at the NRAO provide vital functions for both NRAO operations and for the scientific research conducted by NRAO users and visitors. Besides the obvious necessity for computer control of the systems which comprise a radio telescope, the use of computers and data reduction systems are essential to translate most of the raw data from radio telescopes into the imagery and other products which lead to scientific results. Significant processing is required before scientific analysis can even begin. In radio astronomy computer analysis is fundamental to the process, not merely a useful adjunct to scientific analysis.

Indispensable though they are, computing facilities are not the reason why NRAO is here! This fact results in a tendency for computing capabilities, especially data analysis facilities, to lag behind the development of other facilities at NRAO. Computers, software, and computing support are only truly needed if instruments exist to collect data, or if scientific data exist to be analyzed. The constrained resources over the past few years have forced the Observatory to borrow from the future, by deferring all but the most essential investments in computing.

In 1997, with the rapidly advancing observational capabilities of the VLBA (including the start of orbiting VLBI) and with the promise of GBT operations starting the same year, it will be an ideal time to enhance certain critical areas of the NRAO's computing facilities and infrastructure. The rapid improvements in computing technology over the past few years give the NRAO an opportunity to upgrade current facilities to meet pressing needs and meet the demands of new scientific opportunities, at comparatively modest costs.

Maintaining observational and scientific capability remains the fundamental goal of computing at NRAO. Implicit in this goal is the necessity of constant striving to keep ahead of computing demands at NRAO. Computing systems and software should not be the limiting factor in the science which users are able to accomplish with NRAO facilities. As observational requirements on computing increase, driven by improved observational methods, new technological capabilities, and deepening scientific understanding and knowledge, the observatory must respond.

For 1997, the following areas are priorities for computing facilities, equipment, and support:

System Upgrades

During 1997, approximately one-third of the workstations at NRAO should be upgraded to more capable systems. These machines were purchased in 1991 and earlier, and are now showing their limitations. Their upgrading or replacement is required by the increasing demands on computational capability at NRAO from both increased demands from NRAO users and increased observational capabilities brought about by technological advances and improved observational techniques. These upgrades will allow most workstations at NRAO to be replaced or upgraded by the end of their useful lives (typically 3-4 years for scientific workstations). Without this level effort, NRAO will continue down the path returning to the situation of the late 1980's, where use of observational facilities was restricted solely to prevent overloading of data reduction capabilities. These upgrades are now especially urgent, in view of the VLBA's operational status, and the newly developed mapping capabilities at the 12 Meter Telescope. The cost of this effort will be ~$500,000 for hardware acquisition during 1997. This level of investment will accomplish three goals:

- Reduce the difficulties faced by users getting time on higher end workstations at NRAO for medium to large problems;
- Allow the NRAO to address the problems it faces with an aging computer infrastructure; and
- Provide capability for addressing high-end scientific problems which are beyond the capacities of current computing facilities at the NRAO.

If, as expected, resources are constrained during 1997, the focus will remain on the first goal above. Resolving the infrastructure and high-end computing problems can be deferred, but the overall return on the investment in NRAO facilities and instruments will be reduced.

Networking and Networking Upgrades

At each of its major sites NRAO operates a complex networked computing environment. This offers numerous advantages for efficiency and flexibility in meeting the needs of computer users at NRAO, and allows a small support staff to support a large number of workstations. The tightly networked computing systems at NRAO also allow the Observatory to provide significant support to its users, especially outside users. For example, NRAO is able to provide support and documentation to its users through the facilities of the World Wide Web on the Internet (NRAO's home page on the WWW is http://www.nrao.edu/). Users can access on-line documentation, download software, peruse recent NRAO preprints, newsletters, and technical memos, or download available images from the ongoing VLA sky survey projects, the NRAO VLA Sky Survey (NVSS) and the Faint Images of the Radio Sky at Twenty-centimeters survey (FIRST).

The networks at NRAO have limitations, particularly for data bandwidth between machines. A salient feature of radio astronomy is the large size of typical data sets. The network links between machines may result in bottlenecks, and can reduce the effectiveness of sharing computing resources at a site. Resolving this situation will allow increased efficiency in the use of computers at NRAO, and allow more flexibility in meeting future computing demands.

During 1996 we were able to begin the process of modernizing NRAO's network infrastructure. This process needs to continue during 1997, and will include upgrading the networks at the sites to provide improved bandwidth to critical workstations and groups of workstations. This process should be accomplished in time for major new observational capabilities and opportunities at NRAO associated with the GBT and OVLBI, as well as the VLBA and the 12 Meter. A related goal is to provide high speed links between NRAO sites, and between NRAO and external institutions. Current network connections only allow limited access for remote observers; the pioneering efforts at the 12 Meter to provide support for remote observers should be enhanced and expanded to provide such capabilities for remote observer access for NRAO's other instruments.

The estimated cost for improving the performance of the internal computer networks at NRAO will be $250,000, spread over 1997 to 1998. A small amount of this effort cannot be deferred (e.g., network installation into the new building in Green Bank); deferring the rest will reduce the overall engineering and scientific productivity of NRAO staff and visitors.

Engineering Computing

NRAO is pursuing several initiatives leading to development of major new observational instruments, or greatly enhanced capabilities for existing instruments. Chief among these efforts are the Green Bank Telescope (GBT) project, the proposed Millimeter Array (MMA), and the proposed VLA upgrade. These projects are heavily dependent on the use of advanced engineering workstations to carry out various aspects of their design and fabrication, even at an early stage. Presently, many engineers at NRAO are faced with carrying out design efforts using obsolete or inadequate workstations and PC's. Rectifying this situation will increase the productivity of NRAO's engineers, and the effectiveness of NRAO's operations over the long term. Although efforts in this area have been planned in past years, the budget situation forced these plans to be deferred. Estimated cost of this effort during 1997 will be approximately $160,000. This will allow both the acquisition of appropriate workstations and required software. Deferring this expenditure during 1997 will reduce the productivity of NRAO engineers and may also reduce NRAO's ability to attract the top-level talent it needs to pursue future initiatives.

VLA On-line System Upgrade

The current VLA On-line Control System is nearing the end of its useful lifetime. The computers and disks used in the system are nearly ten years old, and represent a growing maintenance problem. Some of the disk systems are completely obsolete, and can be maintained only by having a large number such ancient disks for spares (support and repair from the manufacturer is no longer available). This situation can be rectified before any disastrous failures occur by continuing the effort begun in 1995 to upgrade and replace the aging systems with modern systems. The effort will yield several benefits, including a large reduction in risk of major system failures, a modest reduction in downtime for the VLA, and lay the preliminary ground work for any upgrades to the VLA which may occur later in the 1990's. The effort will cost approximately $150,000 during 1997. Deferring this effort increases the operational risks faced by the VLA and the risk of significant down time for the array.

Mass Data Storage

A hallmark of radio astronomy is the large volume of data which must be managed, stored, and reduced. Three efforts will stretch the capabilities of NRAO's computer facilities for dealing with extreme data volumes. First, results are beginning to appear from two large-scale surveys being conducted with the VLA. To provide broad access by the astronomical community to these results, NRAO will make them available on-line, via the Internet. Although NRAO may not be the only such source for these data, NRAO is certainly the only institution with a long-term interest in maintaining access to these surveys. Depending on how rapidly results from the surveys become available, several score gigabytes will be needed during 1997. Eventually, as these surveys are completed, versions will be made available through other distribution media (such as CD-ROM).

Second, new techniques and capabilities at existing NRAO instruments (such as mosaicing with the VLA, On-the-Fly imaging at the 12 Meter, or the GBT Spectrometer) are increasing the amount of data which must be handled by off-line data reduction systems. Current facilities at sites for managing voluminous data sets are inadequate, with particularly lengthy delays caused by lack of data storage space and limited tape drives.

Finally, and most importantly, experience with the VLBA shows that early computing estimates were underestimating the VLBA's needs by perhaps an order of magnitude. A VLBA-only observation of a single source in continuum mode may be greater than 1 gigabyte in size, for example. Substantial improvements in data storage and tape facilities at the AOC will be needed during 1997 to meet the expected demand.

A desirable level for data storage and handling facilities at NRAO during 1997 would be $180,000. This would allow significant enhancement of current facilities and add new capabilities for especially large scientific problems. Deferring this expenditure is possible, but NRAO users will have to curtail certain types of experiments on various instruments.

Computing Personnel

Development of new instruments at NRAO (e.g., the VLBA and soon the GBT) and enhanced capabilities of existing instruments (e.g., new observing techniques at the 12 Meter) have increased the need at the Observatory for computing support personnel. Unfortunately, lean budgets at NRAO during the past few years have led to reduced personnel in computing support and software development. As a result, NRAO is barely able to provide adequate support to its computer users, and must neglect them in certain areas. Support personnel in computing are often forced to work in crisis mode, and must neglect long term planning for enhancing computing support.

During 1997 NRAO should move to address critical shortages in certain areas of computing support. Particular needs for support and programming personnel exist at all four NRAO sites. Significant software challenges face our plans to get the VLBA and the GBT fully operational. Increased personnel for software development for the VLBA would dramatically enhance the observational capabilities of the VLBA, while additional personnel for the GBT will reduce the time required to bring the GBT laser ranging system into full operation.

The total number of new positions in computing at NRAO which could be justified in 1997 is ten (three new support personnel, four new positions for VLBA on-line programming, and three for GBT-related software development). These positions would have an impact of about $350,000 on the 1997 budget, and about $700,000 per year in subsequent years. In the likely event that we defer creation of these positions, overall productivity of users of NRAO facilities will be reduced, and various software projects will be delayed. None of these positions is currently budgeted in the accompanying Preliminary Financial Plan (section IX); they would require an augmentation above and beyond the 1997 NRAO funding requested.

V. THE GREEN BANK TELESCOPE

Antenna Construction

The accompanying photograph of the Green Bank Telescope (GBT) construction site, taken in early September 1996, shows the recent status of the antenna structure. The 140 x 163 x 40 foot elevation box structure, which one year ago was only half trial-erected, is now completely assembled and installed on the structure and 99 percent welded. The box structure will act as the support for the reflector backup structure, feed arm and elevation wheel. Its completion is a major project milestone.

The elevation wheel is complete. The counterweight boxes have been installed and will be filled with concrete in a pre-determined order to keep the antenna balanced and *tail heavy* as the structure grows. The elevation drive assembly is approximately 90 percent complete.

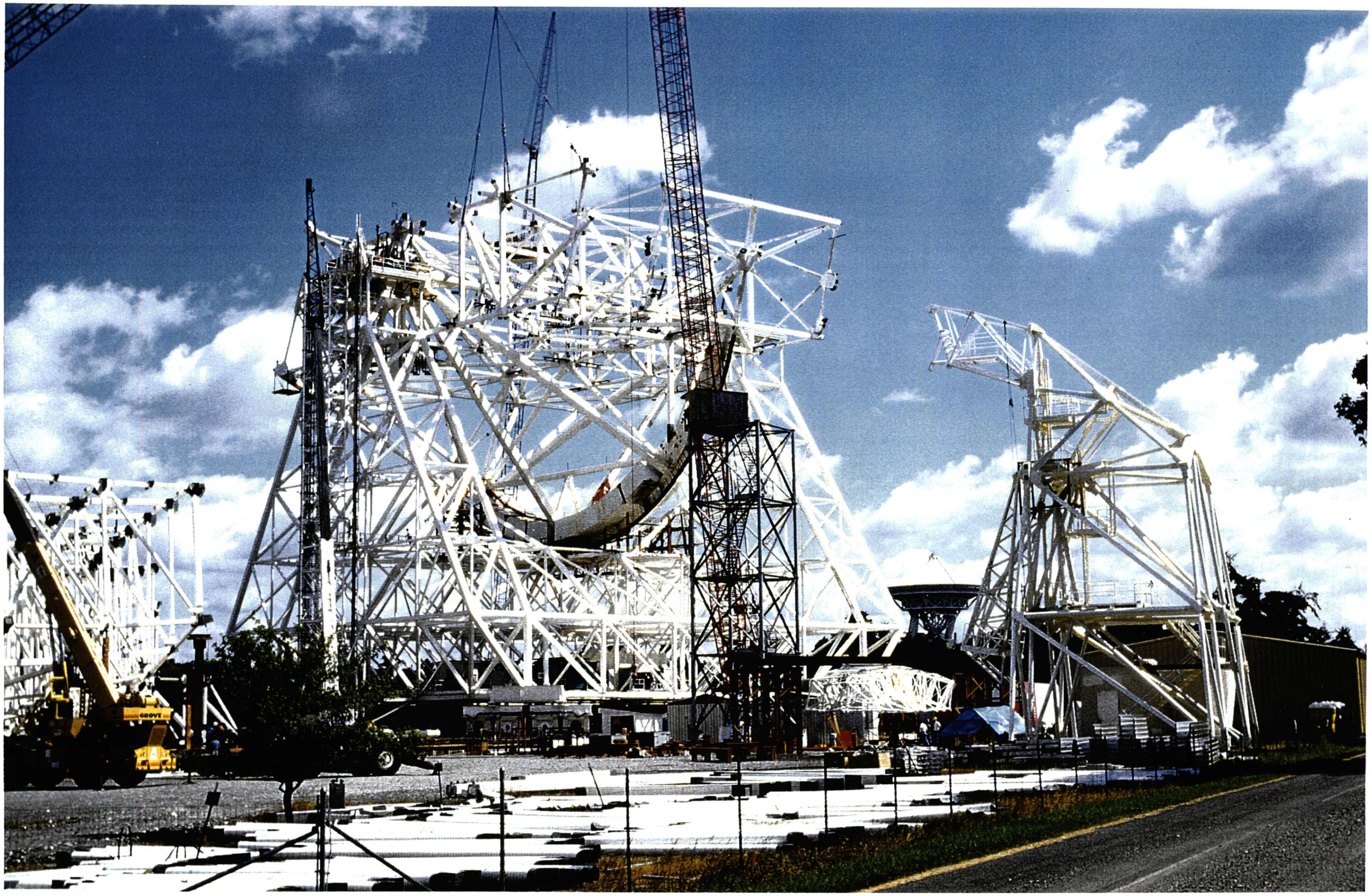
The top 60 feet of the upper vertical feed arm have been completely trial erected at Green Bank. This assembly will be used for final setting of the subreflector surface and testing and calibrating all mechanical elements on the feed arm including the prime focus boom, the prime focus feed rotation mount (FRM), the subreflector adjustment mechanism, the turret in the feed/receiver room, and the entire feed arm servo. If possible, the entire assembly will be installed as a unit on the antenna following this extensive testing.

The subreflector frame is completely assembled and is at the site awaiting installation of the subreflector panels. The panels have been manufactured, tested and accepted, having met the specified tolerances, and are now being painted.

In addition, the feed/receiver room, including the installation of the interior walls, insulation and, the feed turret has been completed.

The completed backup structure (BUS) will contain 7,625 pieces. Of those, 6,593 pieces have been fabricated and shipped to the site, and approximately 3,000 pieces are already in place. At this writing, the BUS trial erection is proceeding and trusses 19L through 19R are in place and aligned on the erection pad. The BUS is divided into 22 modules (1L through 11L and 1R through 11R) for assembly purposes; of those, the inner five are already completely welded. The Contractor's schedule calls for the completion of the trial erection of the BUS in November 1996. Following completion of the trial erection and installation of the horizontal and lower vertical feed arms, the BUS will be disassembled into its 22 modules and lifted into place on the antenna. This disassembly and installation is currently scheduled by the Contractor to be completed in June 1997.

The 2,200 main reflector panels, currently in production and painting at the Contractor's plant, are scheduled to be shipped to Green Bank between January and June 1997 and installed on the BUS from June through October 1997.



CONSTRUCTION PROGRESS OF THE GREEN BANK TELESCOPE (GBT)

Servo

NRAO's initial responsibility with respect to the GBT servo involves monitoring the progress of the servo contractor. This entails reviewing schedules, test procedures and other documents. It also involves witnessing tests of various subsystems and evaluating the results. Finally, it requires the clarification of requirements and specifications as the design process evolves. The Contractor is providing two servo systems for the GBT, one to control the AZ/EL motion (AZ/EL servo) and a second to control motion of various components near the tip of the feed arm (Feed Arm Servo). The Contractor will deliver a servo system which enables the telescope to operate at 15 GHz; NRAO assumes the responsibility of assuring that the servo will be suitable for frequencies higher than this.

Several major accomplishments were achieved during the past year:

- The factory testing of the Feed Arm servo was completed. This involved a thorough test of both the hardware and software, and included everything but the antenna itself. (Device positions were simulated by integrating the tach feedback from the drive motors.)
- As part of the plan to calibrate the subreflector and associated positioning mechanism, a specification was generated and sent out with an RFQ. Based on the replies to the RFQ, an excellent photogrammetry firm was selected to perform the required measurements.
- A comprehensive test procedure for the field tests of the AZ/EL and Feed Arm servos was delivered by the Contractor and reviewed by NRAO staff and consultants. The reviews resulted in two extensive revisions of the procedure.
- Potential enhancements to the "as-delivered" GBT continue to be studied by consultants and NRAO staff. One limitation to accurate tracking at low tracking rates is stiction, or dry friction, in the AZ motors and gear boxes. A recent study has been shown that adding dither at the azimuth drive rate input, of frequency 30 Hz, and amplitude 0.18 deg/sec would reduce the error due to dry friction from 1.4 mdeg to 0.04 mdeg.
- Both the AZ/EL and Feed Arm servo systems have been delivered to the site.

Plans for 1997 include the installation of the servos by the Contractor and field testing. After delivery, during the early operations phase of the telescope, the performance of the servo system will continue to be characterized.

Schedule

The current schedule from the antenna contractor indicates a final antenna delivery in April 1998. Discussions continue with the Contractor over schedule slippage and coordinating the phased acceptance. The increases in NRAO's internal project costs associated with further schedule slippage will be covered out of the project contingency. It is anticipated that through careful interfacing with the Contractor and the continued use of the 140 Foot Telescope as a test bed, the GBT commissioning phase will be shortened.

System Integration

During 1996, use of GBT software and hardware in test observations at the 140 Foot Telescope continued on a scheduled basis. Use of the 140 Foot Telescope included tests of the optical fiber IF system, the GBT local oscillator for frequency switched observations, and continued evaluation of the antenna control system for pointing and mapping observations.

Because its primary purpose is to provide reliable acquisition of data for visiting astronomers, a working telescope is an excellent vehicle to find unexpected problems, but not for initial testing and for correcting problems. Laboratory testing of the individual GBT subsystems has been underway since early in the project. We are now working on assembling in the laboratory an integrated testbed, or mock-up, of the GBT systems. This mock-up will be available full-time for use by the GBT project. Initially it will emphasize integrated testing of the Electronics and Monitor/Control systems, software and hardware interfaces, and operator and observer interfaces. Assembly of the mock-up will be completed in the last half of 1996, and will be heavily utilized in 1997 to complete testing and development of the GBT NRAO systems.

Electronics

In 1995 NRAO deployed a number of GBT systems around the site in anticipation of weeding out issues and problems with systems and interfaces before the GBT came on-line. Over the past 12 months we have identified system and interface issues and problems and have successfully addressed each one. Putting these systems into operation around the site has been very good for the GBT. We have deployed a few other systems around the site in 1996, but most of our efforts have been focused on larger projects which will come into fruition in 1997.

A Mock-up Area will be setup for full scale integration of virtually all NRAO GBT equipment. This will include equipment from the Receiver Room, Equipment Room, Alidade Servo Room, and Control Room. The following systems will be tested and then installed in the Mock-up Area for integration:

- The LO rack which includes LO synthesizers, and LO Reference signals.
- The IF rack which includes the optical fiber drivers, IF router, noise source, and spectrum analyzer.
- One Converter Rack which includes 1-8 GHz converters, fiber optic receivers, and LO synthesizers.
- The Fiber Rack which includes LAN, RS232, and special purpose serial interfaces.
- The Analog rack which includes 100 MHz converter/filter modules, 1.6 GHz sampler/filter modules, and LO Reference signals.
- The Digital Receiver rack which includes the Digital Continuum Receiver, and the Holography system.
- The Motor Rack which includes the refrigerator power supplies, and feed defrost controller.

- The C-Band receiver and a few other GBT receivers will be cycled through this mockup/integration area.
- The 1PPS, 500/10 MHz LO Reference distribution, IRIG-B time code, IEEE-488, time critical signal distribution, and other special purpose signals will all be tested in their final designs.

In addition to the Mock-up Area the following actions are planned:

- The first four bands of the Prime Focus receiver will be completed and tested on the 140 Foot Telescope. This will include the HEMT amplifiers and the feed and dipole antennas.
- Sixteen 1-8 GHz Converter modules will be fully tested.
- All 100 MHz Converter/filter modules will be assembled and tested.
- All 1.6 MHz Sampler/filter modules will be tested.
- The L-Band receiver and feed will be tested in the laboratory and at our antenna test range. System noise measurements will be complete and long-term cryogenic tests will be performed.
- Fiber optic problems identified in 1996 in the IF system will be solved and field tested.

Monitor and Control

During 1996 major effort went into preparing the monitor and control software for production use. This was the result of regular use of some of the systems at the 140 Foot Telescope and of preparation for building an initial version of the operators' control console.

By the end of 1996, the following progress will be completed:

- Observing Frequency Formula - The design and implementation of a system to define or verify the IF's observing frequency formula by equation, matrix, or component settings will be completed.
- Task Independence - enhance libraries so that programs on the Suns or single-board computers may be restarted or initialized independently. This includes shutting down gracefully upon receiving a termination signal.
- Glish Accessor - implement a Glish client for interfacing to the Accessor to allow users to read any monitor point and to generate streams of monitor values as Glish events.
- Console enhancements for operators - Features were added to the control system GUI (Console) needed for the operators' workstations, e.g., monitor components able to handle high speed updates; new components such as dial, bargraph, and state indicator; and dynamic libraries.
- Improvements for production use - Production use of the GBT software at the site timing, weather station, and 140 Foot Telescope required certain improvements and utilities to be written including a program for controlling system daemons and operator documentation.
- Antenna secondary axes - The major development for the control of the secondary axes will be completed.
- Metrology interface - The initial interface between the antenna and the metrology system will be finalized.

- Tracking LO - The tracking local oscillator control will be completed.
- Holography - Control software for the holography backend will be completed as well as initial pointing tests for holography on the 140 Foot Telescope.
- Data Archive - A data archiver system for astronomical data and engineering logs was accomplished.
- SBC Reset System - Design for the hardware and software for a SBC remote access and reset system was completed.
- Computer Architecture - A design for the complete computer architecture was reviewed and approved.

To complete the monitor and control system by the end of 1997 major systems to be completed are:

- Panel Gateway - design and implement a system for the M&C LAN/site LAN gateway machine which: (1) allows the operator to control all network access to the GBT, (2) buffers I/O to GBT managers so clients' performance (e.g., consoles and Glish) cannot affect the managers, and (3) minimize Internet traffic by passing the minimum information needed by remote clients.
- Setup DAP - save defining setup parameters for each scan into a FITS file as data associated parameters.
- Watchdog System - design and implement a system to detect failure of any task in the GBT system.
- Message System - Enhancement of the current message system including a MessageViewer for organizing and controlling the display of messages.
- Antenna - Completion of the antenna control system including the servo monitor.
- Observer Interface - Implemented in Glish and Glish/Tk.
- Electronics - Completion of electronics including remaining receivers and IF system.
- Lab Mock-up - Mock-up of GBT equipment in the lab including receiver, IF chain, backends, and the antenna emulator for testing and development.

Open Loop Active Surface

During the last year, several tasks have been accomplished in the Open Loop Active Surface project:

A cable tester for evaluating all the actuator cables has been selected and purchased. The work involved in integrating it into a cable/actuator testing system has been completed.

Actuator power supply turn-on transients were found to be larger than expected and were suspected of causing damage to several motor drivers. Circuits to keep the transients in an acceptable range have been built and tested.

The bulk of the effort in the past year has been expended on software development. The software interface between the active surface and the telescope control system has been written and tested.

Similarly, the software interface between the master and slave processors has been written and tested. Software to interface to various devices associated with the active surface, such as power supplies and temperature sensors has been written and tested with either actual or simulated hardware. Considerable effort has been expended on system self test during initialization.

Plans for 1997 include the completion of the hardware and software, the installation and integration of the complete system on the telescope. The completion of the hardware entails a few minor purchases and designs which have been delayed because they are best done close to installation. The "completed" software will be sufficient to monitor and control all actuators and associated hardware, providing accurate positioning of all actuators as well as a variety of diagnostics, and safeguarding the system against various malfunctions. System installation will commence with the testing of cables run to the actuator room by the Contractor; associated actuators, mounted on the back up structure, will also be tested at this time. The control system will then be installed and cables connected to it. System self tests and integration with the telescope monitor and control system will conclude with the system ready for operation.

Closed Loop Active Surface and Laser Pointing

By the beginning of 1997, the laser metrology system will have completed the following steps:

- The laser mirror heads, optics assemblies, control panels, and surface retroreflectors will be complete.
- The 18 glass optical components of the University of Arizona spherical retroreflectors will be on hand.
- The first 9 of 12 GBT laser monuments will have been poured.
- The 140 Foot Telescope demonstration will have produced engineering data and performance specifications will have been measured.
- The embedded instrument software (ZY) will have undergone 20 machine months of production instrument field testing, and the central computer (ZIY) will have undergone 6 months of field testing.
- The GBT systems architecture and error analysis documentation will be under development.

In 1997, experimental work will continue at the 140 Foot Telescope in order to refine algorithms and test software. Outfitting of the GBT ground based laser monuments and structural locations will be conducted to the extent the Contractor and manpower permit. The surface setting tools and the surface retroreflectors will be turned over to the Contractor for mounting on the surface. Laser enclosures will be designed and purchased. The instrument base design will be finalized and built. Access platforms and ladders to the lasers on the left feed arm will be designed and built. Contractor supplied data on the as-built panels will be compiled into a database. The Finite Element Analysis model of the structure will be incorporated into the software.

GBT Data Analysis

Standard GBT data analysis is expected to be based in AIPS++, now under development at NRAO. During 1996, the AIPS++ single-dish group worked to produce a fully functional spectral line analysis package. Prototypes of this package are now expected by the end of 1996, and a beta release of AIPS++ is expected in the first quarter of 1997. Detailed AIPS++ plans are described elsewhere in this document.

Other areas of development include data archiving of both observational data and telescope monitor data. The use of FITS binary tables for all data insures compatibility with an astronomical data standard. Having data in a standard format makes it possible to process GBT data using several data analysis systems in addition to the AIPS++ system.

Pointing

In 1997, the Precision Pointing group will be completing work on the several systems which will be used to improve the pointing accuracy and surface accuracy of the GBT.

The heart of the GBT positioning challenge is in two stages. First, the principal axis of the primary must be directed toward the source of interest (the "pointing" problem). Second, the optics, either the prime focus feed or the combination of Gregorian mirror and secondary feed must be positioned to achieve optimum gain (the "focus tracking" problem). Location of the prime focus will be accomplished in Phase I using an algorithm which models the various components of the systematic, repeatable pointing errors. This algorithm, which has already been installed in the Monitor and Control system, will be updated by observations when the GBT becomes available. In later Phases of the project the pointing accuracy will be enhanced by introducing information from the laser ranging system. In the first half of 1997 efforts will be directed towards completion of the hardware and the development of the software needed for the analysis of the precision data. In the second half of the year there will be initial tests of the software, with first application perhaps to test data from the 140 Foot Telescope pilot project.

In the first half of 1997, the effort in the development of the focus tracking module which commands the location of the prime focus feed and the Gregorian subreflector will concentrate on the integration of the command algorithms into the Monitor and Control system. The positioning of the subreflector will be based on the results of ray tracing of the off-axis mirrors and on the results of modeling the gravitational deformation of the structure as a function of telescope position.

In Phase II the figure of the primary mirror surface will be determined by the positioning of the actuators. The commanded position will be deduced from the structural model of the telescope. Since the optimal position for the telescope optics requires knowledge of the figure of the primary mirror, a program has been developed to command the actuators to drive the requisite distance to attain the desired surface figure. During the next year the program will be refined and integrated into the Monitor and Control system.

One of the uncertainties in the design of the Gregorian focus-tracking module is the actual displacement of the subreflector mirror corresponding to the motion of one or more of the six actuators on which the subreflector is mounted. The complicated problem of the calibration of the mirror mounting is similar to the calibration of certain Stuart Platforms, a problem which has been discussed in the literature of mechanical engineering and robotics. The calibration of the GBT system will begin with an extensive study once the subreflector has been received in Green Bank late in 1996. It is expected that these calibrations will be sufficient to provide the capability to position the subreflector in Phases I and II. In the later phases it will be necessary to update the initial ground-based calibration with a series of measurements using the GBT itself. The design of the system for calibration in the later years will begin in 1997, following the completion of the ground calibration program.

The Quadrant Detector development has been promising. This device will provide information about the position of the Feed Arm relative to the primary mirror at rapid intervals. The information will be used in the Metrology system to update the positions of the feed-arm lasers, and in the focus-tracking module to improve the estimate of the motion of the subreflector needed to maintain focus. It is planned to make a first integration of a prototype of this device into the focus-tracking module late in 1997.

In a related study, an effort will be made to model the effects of observational errors on the calibration of the position of the subreflector, in order to better understand the precision with which in situ calibration can be performed, and to explore which observational techniques will be most useful.

VI. MAJOR INITIATIVES

1. The Millimeter Array

The design effort on the Millimeter Array (MMA) is being done by the NRAO in concert with university-based astronomers and engineers associated with the Owens Valley Radio Observatory (OVRO) and the Berkeley-Illinois-Maryland Association (BIMA) array. The mechanism for this cooperation is the Millimeter Array Development Consortium (MDC) which is comprised of five topical design working groups overseen by a steering committee of four members (two from the NRAO and one each from OVRO and BIMA). All the MDC work, in turn, is reviewed annually by the Millimeter Array Advisory Committee (MAC), the membership of which is given in Appendix D.

In 1997 the activities to be given emphasis include site studies, the antenna design, and design of the MMA receiver and local oscillator.

Site Evaluation

After eight years of testing potential sites for the MMA in the continental United States, in Hawaii and in Chile, a site selection document will be issued for review by the MMA advisory bodies that identifies the Llano de Chajnantor in Chile as the best site for the MMA. This site, at 5000 m elevation, is above most of the atmospheric water that absorbs millimeter and submillimeter-wavelength radiation from cosmic sources and which limits the sensitivity of a millimeter-wave telescope. The site is also very large which will allow for expansion beyond the initial 3 km configuration that is planned for the MMA should that be desirable in the future. It also permits effective utilization of the submillimeter atmospheric windows at 450 and 350 microns (650 and 850 GHz, respectively) thereby enhancing the capabilities of the MMA.

Although a telescope site in another country is a new enterprise to the NRAO and a site at such a high elevation as 5000 m brings with it operational considerations that have not previously been encountered by the NRAO, nevertheless for the scientific mission of the MMA the Chile site is overwhelmingly the favored location. The essence of the argument is this: The scientific productivity of the MMA, the sensitivity and imaging speed, is determined by the quality of the electronics, the precision that can be achieved by the antenna design and the mean atmospheric opacity of the site. The former two are technical design issues. The MMA goals in these areas based on state-of-the-art technology, if achieved, will make the instrument of sufficiently high performance that its sensitivity will be dominated by the site atmospheric opacity unless that mean zenith opacity at a fiducial frequency of 225 GHz is equal to or less than 0.05. The Chile site has such a low mean opacity. Were the MMA to be located on a site with a higher mean opacity such as Mauna Kea the science that could be accomplished in a typical year would be less than half that that will be accomplished with the MMA site in Chile. This comparison provides a strong cost/benefit advantage to the high Chile site.

MMA Submillimeter Capability

At the MMA Science and Technical workshop held in Tucson in September 1995 the MMA advisory committee recommended that the MMA have as part of its initial capabilities instrumentation for operation in the 450 micron atmospheric window. The scientific motivations for this recommendation involve the desire to image high excitation spectral lines and the desire to image dust continuum emission in the submillimeter.

Preparations are underway to measure the usefulness of the site for submillimeter astronomy. The 225 GHz tipping scans that give the opacity at 1300 microns suggest that the transparency in the 450 and 350 micron atmospheric windows should be very good. However this inference is based on atmospheric models that have as their input the column density of atmospheric water. This quantity is indirectly inferred from the 225 GHz opacity measurements: the 225 GHz opacity is a sum of a contribution proportional to the precipitable water vapor (PWV) and a "continuum" contribution that is itself the integrated effect of the opacity in the very distant line wings from many 0_2, N_2, and 0_3 lines in the IR. It is very difficult to disentangle these two terms and extract PWV from the opacity measurements. There was an entire session at the recent URSI meeting in Lille addressed to this subject that served to emphasize how complex the analysis is. Fortunately, our interest is in the total submillimeter opacity and this is a quantity we can simply measure. To this end a 350 micron bolometer tipper has been built in Tucson as a collaboration between the NRAO and the CARA south pole observatory. In the next three months copies of the tipper will be installed both on the Chajnantor site and in Antarctica. A comparison of the 350 micron opacity with the 1300 micron opacity will give us a reliable estimate of the fraction of the time submillimeter astronomy can be done from the Chilean site and it will be useful to atmospheric scientists as well.

Antenna Design

The antenna design is an activity being conducted under the auspices of the MDC. The MMA antenna must meet the performance specifications given in the table below.

Table VI.1. MMA Antenna Specifications

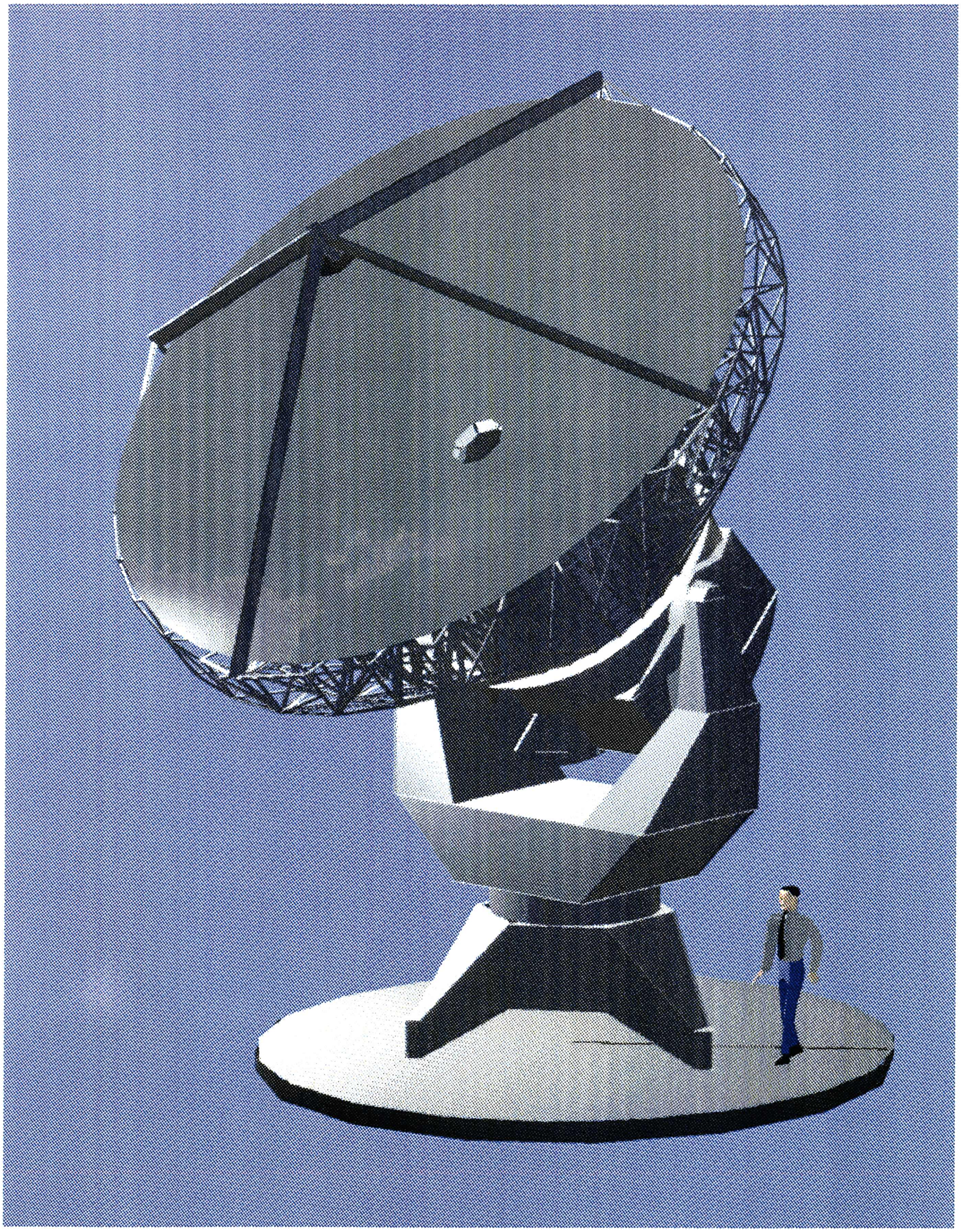
Description	Specification	
Antenna Diameter	8 m	
Frequency Range	30-690 GHz	
Surface Accuracy	≤ 25 μm RMS	
Pointing Accuracy	≤ 1" 50% of the time ≤ 2" 75% of the time	
Phase Stability	≤ 10 μm RMS ≤ 22 μm RMS ≤ 56 μm RMS	25% of the time 50% of the time 75% of the time
Dynamic Performance	Move 1°5 in 1^s to 3" accuracy	
Subreflector Nutation	3 beamwidths at 30 GHz	
Close Packing	< 10.4 m	
Physical Design	Simple and durable	

The MDC antenna working group has converged on a design for the MMA antenna that is a derivative of the design of the BIMA antenna. The antenna design is exceptionally clean so that very little spillover power falls on the ground or any other warm surface. It is a minimum blockage design, small subreflector and feed legs extending to the edge of the dish, and it uses simple cassegrain optics. There will be no grids, mirrors or diplexers in the optical path. The antenna design is shown in Figure 2.

The antenna working group is concentrating on a goal of having a fiducial design complete in sufficient detail by the start of FY98 that a contract for a single prototype can be let at that time. The hope is to test that prototype sufficiently well that subsequent antennas can be bid as "build to print" contract which will allow a significant cost savings to be achieved.

Receivers and Local Oscillator

The design goal for the MMA receivers is to achieve a noise temperature performance that is twice the so-called "quantum limit" or photon noise, $2h\nu/k$. This is the current state-of-the-art for millimeter-wave mixer receivers. One can achieve this performance over a wider frequency band if the unwanted



MMA ANTENNA DESIGN

sideband response can be eliminated. An SIS mixer design that incorporates this capability is being fabricated as a proof of concept. If successful, the MMA will employ such quantum-limited, balanced, sideband separating mixer receivers. Development and refinement of this technology is important for the MMA and it will be a focus of the work in 1997.

The local oscillator for the MMA is another area that can benefit by exploitation of new technology. Currently millimeter-wave receivers use as an LO a GUNN oscillator at 50 - 80 GHz and a chain of semi-conductor multipliers to reach high frequencies. For the 40 MMA antennas it is desirable to minimize the complexity of such a system and one way to do so is to use a photomixer as a LO source. Here the idea is to shine two optical/IR lasers on a Schottky diode and use the beat note from the two lasers as a LO source. Experimental work being reported now in the literature appears sufficiently encouraging that we will begin experiments in 1997 to assess its viability for the MMA. The prospect appears real for a great reduction in the complexity and cost of the MMA local oscillator system.

Schedule and Planning

MMA planning is predicated on the potential availability of Phase I (Design and Development) funding being available in FY98. In addition to the technical work described above, we have embarked on project planning built around a desire to minimize the inherent complexity in constructing a major research facility on an offshore site. We believe that an expeditious way to handle this is to fabricate major subsystems of the MMA at the NRAO and ship those operating and tested units to Chile. Ideally all that will be required on-site will be some installation and connection, but not major fabrication, testing or debugging. It is important to get the planning for such activities right and significant effort will go into this area in 1997.

Community Interaction

All the MMA activities will continue to be documented in writing with those documents placed on the WWW for inspection by interested individuals. Monthly teleconferences will be held that provide a forum for questions to be asked and suggestions given. The annual review by the MMA Advisory Committee is very effective in enforcing a measure of community discipline on the entire enterprise.

2. VLA Upgrade

It has been clear for some time that the VLA's impact on astrophysics can be dramatically increased by adding new frequency bands; by upgrading or replacing current receivers, the data transmission system, and the correlator; by improving its frequency coverage; by improving its ability to image large regions of low surface brightness and wide fields of view with a super-compact configuration; and by increasing its angular resolution by adding VLBA antennas to the array, and incorporating new antennas between the VLA and the VLBA.

The VLA upgrade will make possible a wide variety of new scientific programs by providing greatly increased sensitivity, much broader frequency coverage, enhanced spectral line capabilities, and better angular resolution. Factors of ten improvement in most of the critical areas can be attained at modest cost. It does so largely by returning the VLA to the state-of- the-art in receiver technology, in the transmission and processing of broadband signals, and in correlator design. The scientific potential also poses new technological challenges. How can optimum performance (polarization and sensitivity) be maintained across the large bandwidths now proposed? Can broadband, high-performance, low-frequency feeds be designed? What is the optimum way to transmit broadband signals from antennas hundreds of kilometers from the VLA for real-time ultra-high-resolution interferometry?

The impact on astrophysics of returning the VLA to the state of the art will be profound. Many hard limitations now constraining VLA observations will be removed or greatly relaxed. The continuum sensitivity will increase ten fold in several bands. New frequency bands and increased bandwidth ratios could permit continuous frequency coverage. The bandwidth that can be processed by the spectrometer, and its spectral resolution, will simultaneously increase by about ten fold. The resolving power will improve fifty fold. Finally, the new instrument, when cross-linked with the VLBA and with new antennas located about 50-300 km from the VLA, will result in a VLBI instrument with greatly increased dynamic range, field of view and frequency scalability, compared to the present VLBA. The following technical capabilities are therefore key ingredients in a VLA development plan:

Phase 1: An Ultrasensitive Array

- New receivers: lower noise temperatures and much wider bandwidth performance (1 GHz in each polarization channel) in existing bands; addition of 2.4 GHz and 33 GHz bands at the Cassegrain focus; complete outfitting for the 40-50 GHz band; extension of the 1.4 GHz band to lower frequencies. The goal is to provide continuous frequency coverage from < 1 GHz to 50 GHz.
- 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.
- A new correlator, able to support 33 or more antennas, to process both broadband continuum signals and to provide improved resolution and flexibility for spectral line work.
- Improved low frequency (< 1 GHz) capability, using prime focus feeds and new receivers.
- New antenna stations for a super-compact E configuration to enable fast mosaicing of large fields.

Phase 2: The VLA Expansion

- Additional new antennas to provide now unavailable baselines between those in the VLA and those in the VLBA.
- Fiber optic links between the VLA and the inner VLBA antennas, and between the VLA and the additional new antennas.

The combination of these enhancements will yield an instrument with many fundamentally new capabilities. The continuum sensitivity will improve by more than an order of magnitude in some bands. New and powerful spectral line observations will be possible and significantly more frequency choices will be available. The super-compact E configuration will allow fast imaging of large fields and large objects, greatly enhancing the capabilities of surveys. Linkages to the innermost VLBA antennas and to the added new antennas will increase the maximum angular resolution by a factor of at least seven. The sensitivity increases will allow the increase in angular resolution to be exploited fully when observing a wide (and in many cases for the first time, representative) variety of thermal and nonthermal objects, both galactic and extragalactic. Each of these project elements is now discussed in more detail.

Antenna and Receiver Improvements

At the antennas, the project involves: improving receivers at existing observing bands, adding receivers to support new observing bands, and modifying the antenna structure for improved operation.

Improved Low Noise Receivers

The VLA receivers have been upgraded gradually since the early 1980s. Initially, better low-noise amplifiers were used in existing receivers. More recent systems have used the VLBA receiver design, in which the receiver is attached directly to the feed and the polarizer is cooled in the cryogenic dewar. This design reduces the noise contribution from the polarizer and eliminates long, ambient temperature waveguide runs that add to the system temperature.

The VLBA-style receivers are now used in the 1.4, 8.4, and 45 GHz bands. These receivers will remain with perhaps only minor modifications. The greatest improvement in system temperature can be made in the 5, 15, and 22 GHz bands using the VLBA-style receivers and modern HFET amplifiers. Completely new receivers will be built for these bands, and should reduce the system temperatures as much as a factor of three. The new receivers also will provide 1 GHz bandwidth per polarization channel (needed for continuum sensitivity) and will tune over a wider frequency range (to include spectral lines, e.g., methanol, whose astrophysical significance was unknown when the VLA was built). Current plans call for bandwidth ratios of order 1.4-1.5:1 in many bands. At present, only thirteen VLA antennas are outfitted for 45 GHz operation; this band will be made available on all antennas.

New Observing Bands at the Cassegrain Focus

Two new receiver systems will be added at the Cassegrain focus: 2.4 GHz and 33 GHz. A stand-alone 2.4 GHz feed will fit on the feed ring at the Cassegrain focus and will give higher performance than the alternative approach, a 1.4 GHz/2.4 GHz dual-band feed such as that used on the Australia Telescope Compact Array. The 2.4 GHz system will allow the VLA to participate in bistatic planetary radar observations with Arecibo Observatory. The 33 GHz band also can support bistatic radar experiments, with the Goldstone 70 meter antenna, and it will allow imaging of many interesting molecular lines, including redshifted CO and 0_2. Table VI.2 summarizes the proposed new and upgraded VLA Cassegrain observing bands.

Table VI.2. Proposed VLA Cassegrain Observing Bands

Band	Range (GHz)	BW (GHz)	BW ratio	
L	1.20-1.80	0.60	1.50	Upgrade
S	2.20-3.40	1.20	1.55	New
C	4.80-7.20	2.40	1.50	Upgrade
X	8.00-12.00	4.00	1.50	Upgrade
Ku	12.00-18.00	6.00	1.50	Upgrade
K	18.00-26.50	8.50	1.47	Upgrade
Ka	26.50-40.00	13.50	1.51	New
Q	40.00-50.00	10.00	1.25	Complete

An alternate plan providing continuous frequency coverage from < 10 to 50 GHz is also being considered. This would require both a larger, new subreflector and ten frequency bands. Depending on the diameter of a new subreflector, optimum cassegrain performance could be extended as low as ~700 MHz.

New Prime Focus Systems

Plans for new prime focus receiver systems are less well defined. A 330 MHz system is currently located at the prime focus, as is a low-performance, dismountable 74 MHz system on eight antennas. The presence of the 74 MHz dipole feed may degrade performance of the 1.4 GHz band by up to ten percent. Hence, if 74 MHz feeds are deployed on all antennas, it may be necessary to dismount them (or otherwise move them from the prime focus position by mechanical means) so that the L-band sensitivity is not compromised.

Other specific proposals for prime focus systems include:

- A new system covering 580-640 MHz, matching that of the VLBA.
- A broadband UHF (150-600 MHz) system, including a simple system suitable for solar work.
- A sensitive 240 -1200 MHz system, comprised of four scalar feeds, mounted on the quadruped legs, which can individually be swung into position.

The form of the low frequency, prime-focus system will critically depend on the Cassegrain systems, since in all cases the subreflector must be removed for prime focus operation.

Sensitivity Goals

Table VI.3 compares the continuum sensitivity of the current instrument to that we hope to achieve. We assume a maximum useable bandwidth with RFI excision at the lower frequencies, and add an atmospheric contribution where relevant. The number under δS refers to the continuum sensitivity in μJy/beam achieved in 12 hours' integration, summing over two orthogonal polarizations. The total bandwidth assumed for 0.33, 0.60, 1.0, 1.4, and 2.4 GHz is 50, 100, 200, 500, and 1000 MHz, respectively. All other estimates assume 2 GHz net bandwidth.

Table VI.3. VLA Sensitivity

	Enhanced VLA		Current VLA	
Wavelength (cm)	T_{sys} (k)	δS (μJy)	T_{sys} (K)	δS (μJy)
90	80-135	40-70	150	120
50	45-90	13-25		
30	25-32	5.3		
20	30	2.7	40	7.1
11	31	1.9		
6	29	1.3	45	6.4
3.6	31	1.3	31	5.3
2	37	1.7	110	20
1.3	50-70	2.6	160	37
0.9	38	2.0		
0.7	60	4.0	90	60
0.6	170	15		

New LO/IF Transmission System

To transmit 2 GHz of bandwidth from each antenna, we will use optical fiber links to all of the VLA stations, to the nearby VLBA antennas, and to additional new antennas located between the VLA and the present VLBA stations. Separate fibers will carry the LO reference signal and the wideband IF signal. Between four and six single mode fibers will run to each antenna station. Although low temperature coefficient fiber will be used on runs exposed to ambient temperature, a round-trip phase correction system probably will still be needed.

A New Correlator

The specifications for a new correlator are still under discussion, as is the architecture best suited to meet them. It is not yet clear whether the more appropriate architecture is a lag correlator, as presently used at the VLA, or an FX correlator, as used by the VLBA. A detailed design study is needed to choose between the two options. Note that the product of the number of antennas, N, and the maximum bandwidth, B, analyzed by the correlator will be at least NB = 66 GHz. This figure of merit for the correlator is an order of magnitude less than the Millimeter Array (NB = 640 GHz); and at least an order of magnitude larger than the existing VLA correlator (NB = 5.4 GHz) or the VLBA correlator (NB = 2.6 GHz).

The new correlator should be able to process data from at least 33 antennas and have enough delay capability to accommodate baselines as large as 500 km. It could then process some combination of the twenty-seven VLA antennas, two or three of the innermost VLBA antennas (those at Pie Town, Los Alamos, and Fort Davis), and four or more new antennas on baselines between those in the VLA and in the VLBA.

High Surface-Brightness Sensitivity – the E-Configuration

When the VLA was designed, most astronomers were not aware of the necessity to image with high brightness sensitivity, or to image very large fields, or to image with an angular resolution below that provided by the D configuration. Mosaicing techniques did not exist and it was believed that, in any case, these issues were better addressed with large single dish instruments. It is now recognized that compact arrays with total power capabilities fill a gap between the imaging capabilities of conventional interferometer arrays and those of large single dishes. A super-compact E configuration with maximum baseline lengths of a few times 100 meters would fill this gap. Given that, e.g., the Arecibo 305 meter telescope samples a similar aperture, how, specifically, would the capabilities of an E configuration compare with a large single dish?

A large single dish has superior point-source sensitivity – the Arecibo 305 meter is roughly five times more sensitive than the proposed E configuration due to its larger surface area. The advantages of the E configuration lie in its imaging capabilities, where the E configuration could be more than five times faster than a single-feed receiver system on Arecibo. Hence, the role of the E configuration would be to provide a fast, low-resolution imaging capability over large fields via mosaicing.

Several other considerations make the E configuration attractive. Unlike the Arecibo 305 meter dish, to which roughly 30 percent of the sky is visible, the VLA has access to 85 percent of the sky and will also provide frequency coverage up to 50 GHz. As an interferometric instrument, the VLA also has lower systematic errors than a large single dish, i.e., it is less susceptible to pointing errors, and ground pickup is uncorrelated between antennas, so that the spectral baselines are flat.

High Angular Resolution – The A+ Configuration

There is a serious gap in u-v coverage between the 35 km longest baseline of the VLA and the 200 km shortest baseline of the VLBA. We plan to bridge this gap by allowing some VLA, some VLBA, and some new antennas to be used interchangeably as members of either array. These will (a) increase the resolution of the VLA at all frequencies and enlarge the range of resolutions over which it has scaled-array capability, (b) improve the dynamic range, field of view and extended source sensitivity of the VLBA, and (c) provide the VLBA with a scaled-array capability similar to that of the VLA; currently such a capability is lacking in the VLBA.

New antennas would be built in New Mexico and Arizona to make the density of u-v coverage in the 40-400 km baseline range similar to the VLBA now beyond 400 km. The first step would be to complete the Pie Town ring around the VLA. Possible sites are near Dusty, NM and Bernardo, NM. (Linking just the Pie Town antenna to the VLA would double the resolution of the A configuration for northern sources only. Linking the Dusty and Bernardo antennas extends this capability to the whole sky.) The second step would be to add further antennas in the Los Alamos ring. Two possible sites are near Holbrook, AZ and Vaughn, NM. The VLA's delay and fringe rotation systems would be expanded to correlate these signals in real time with the present A configuration (processing would be done at the new 33 station VLA correlator).

Prior studies have indicated that six outrigger antennas would enable good u-v sampling over the 35-250 km baseline range for the entire visible sky. However, detailed studies to estimate the quality of imaging as a function of number of outrigger antennas, as well as their location, must be undertaken to understand the trade-off between cost and imaging versatility.

Sub-arcsecond resolution observations with the present VLA are possible only at the higher frequencies where, unfortunately, the brightness sensitivity needed to detect nonthermal phenomena is usually inadequate because of the source spectra. These frequencies also may be inappropriate for any projects in which Faraday depth effects, wide-band spectral shapes, or low-frequency spectral lines are needed to probe source physics at these resolutions. There also are many instances where studies of normal stellar radio emission will benefit greatly from increasing both the resolution and sensitivity of the VLA at higher frequencies.

The reconfigurability of the VLA (its capacity for scaled array observations with the same angular resolution at several frequencies) has been vital to its astrophysical success. This distinctive capability of the VLA is now present across the whole frequency range from 330 MHz to 22 GHz only at resolutions near 5". No problem that requires higher angular resolution than 5" and full frequency coverage can now be tackled in scaled-array mode. This situation changes dramatically if we can add data from longer baselines in the A+ configuration or the VLBA.

Finally, we note that the availability of optical imagery at 0.″1 resolution from the Hubble Space Telescope is emphasizing the need for better coverage of this resolution regime over a full range of radio frequencies. This resolution falls squarely in the uncovered gap between the VLA and VLBA at just the frequencies where imaging would be least corrupted by atmospheric and ionospheric phenomena.

Other Capabilities

Several other instrumental improvements that lead to new scientific capabilities are also being considered. They include: ultra-wide (35%) bandwidth at the highest frequencies, a robust total power system to support mosaicing and simultaneous multi-band performance (2.4 and 8.4 GHz or 4.9 and 15 GHz).

Table VI.4. Illustrative Budget

	Cost ($M)	Subtotal (SM)
PHASE 1:		
Antenna LO/IF	5.5	
Antenna Mechanical	2.3	
LO/IF Transmission	2.5	
Central LO/IF	2.5	
Correlator	7.5	
Test Equipment	0.2	
CASSEGRAIN:		
1.20-1.75 GHz	0.8	
2.13-2.70 GHz	1.6	
4.80-6.70 GHz	1.4	
12.0-18.0 GHz	1.5	
18.0-26.5 GHz	1.5	
26.5-40.0 GHz	2.2	
40.0-50.0 GHz	1.5	
NRE	0.5	
PRIME FOCUS:		
75-300 MHz	0.8	
300-800 MHz	1.2	
800-1200 MHz	3.5	
SUB-TOTAL		37
E CONFIGURATION:		
18 Stations	4.0	4
SUB-TOTAL PHASE 1		41
CONTINGENCY PHASE 1	6.0	
PHASE 1 TOTAL		**47**
PHASE 2:		
Four new antennas	25.0	
Fiber to DS, PT	2.0	
Fiber to BN, HL, VN, LA	8.0	
SUB-TOTAL PHASE 2		35
CONTINGENCY PHASE 2		6
PHASE 2 TOTAL		**41**

3. The AIPS++ Project

The AIPS++ Project is a collaborative initiative to develop a new data reduction and analysis package for radio astronomy. Its origins can be traced to concerns within NRAO and other institutions that the current data reduction packages do not provide the flexibility and future potential desired, despite the success of these packages at meeting some current needs. AIPS++ will be a considerable improvement in programmability (at various levels from professional programmer to astronomer), maintainability, portability, and exportability. Seven institutions are collaborating on AIPS++: the Australia National Telescope Facility, the Berkeley-Illinois-Maryland Array consortium, the Canadian Herzberg Institute, the Netherlands Foundation for Radio Astronomy, the Nuffield Radio Astronomy Observatory, the National Center for Radio Astronomy in Pune, India, and the NRAO. Of these, ATNF, BIMA, NFRA, and NRAO are currently devoting substantial resources to the project and so the project is overseen by an Executive Committee comprised of the Directors from these four institutions. In spring 1995, the project acquired a full-time project manager who reports to the Executive Committee.

AIPS++ is going through alpha (that is, in-house) testing at the moment and a beta (or out-of-house) release is expected early 1997, followed by a full release about six months after that. The first release will have support for synthesis processing, including calibration and imaging of polarization observations, some single dish functionality, general processing of tabular information, and some simple image display and analysis. Other capabilities such as VLBI processing and sophisticated image visualization will be added subsequently. The first release will be targeted primarily to astronomical users of the system, but later more emphasis will be given to professional programmers working inside the system.

VII. NON-NSF RESEARCH

1. United States Naval Observatory

The new 20-meter telescope has been in use for over a year with the USNO geodetic VLBI array. Other antennas used regularly by USNO in this array are located in Kauai (Hawaii), Forteleza (Brazil), Fairbanks (Alaska), and Wettzell (Germany). This array provides fundamental data on earth rotation and polar motion needed for timekeeping and navigation, and are essential to the analysis of observations from the VLA and VLBA. A weekly 24-hour observing run, along with daily 2-hour runs, provides data for the IERS (International Earth Orientation Service) Bulletin A, published weekly by the USNO. The IERS bulletin lists the most recent polar motion and UT1 data and includes predictions for the next three months.

Current status and operational data on the 20-meter telescope are listed on the WWW at URL: http://info.gb.nrao.edu/gbint/GB20m.html.

The 20-meter is also used for other geodetic VLBI experiments, designed to explore geophysical effects on earth orientation, such as oceanic and atmospheric currents, plate tectonics, and core and mantle morphology. These are organized by the NASA geodetic group in cooperation with USNO.

In 1996 an addition to the Jansky Lab building funded by the U.S. Navy to support its activities in Green Bank will be completed. The addition will have space for the USNO 20-meter control room and VLBI facilities, offices and lab space for engineers, operations personnel, and scientists associated with USNO activities. USNO and Orbiting VLBI related operations are expected to move into the building in late 1996 to early 1997.

2. Green Bank Interferometer

The two-element interferometer, consisting of two 85-foot telescopes, was closed in April 1996 after the cessation of its funding by the USNO. It had monitored 80-160 variable radio sources every 1-2 days, providing valuable flux density data at X- and S-bands for many important objects, including 3C 273, BL Lac, Cygnus X-3, and SS 433. Daily monitoring data by the GBI on many objects extends back to 1978 and earlier. Efforts are underway to secure alternative sources of funds for renewed operation of the interferometer.

3. Pulsar Monitoring

A third 85-foot telescope is used for timing a set of 35 pulsars and measuring their flux density variations at 327 and 610 MHz. These data are used by researchers at NRL, NRAO, Princeton, Oberlin, and Berkeley. Two dedicated pulsar data aquisition systems simultaneously record data from the 85-foot telescope. One, installed by the Princeton group in 1989, uses filter banks to select 20 adjacent frequency channels at 327 and 610 MHz. A second system, recently installed by D. Backer of Berkeley, uses digital techniques for de-dispersion and provides improved frequency and time resolution. The pulsar monitoring in 1997 will be funded by NASA in support of Compton Gamma Ray Observatory observation of pulsars, and to determine local ionispheric conditions through pulsar polarization measurements.

4. NASA - Green Bank Orbiting VLBI Earth Station

In 1997, shortly after the first of the year, the Green Bank OVLBI earth station will begin operations with the Japanese VSOP orbiting radio antenna. The earth station has the dual role of transmitting a timing reference signal derived from a hydrogen maser to the spacecraft and of receiving the wideband science data from the spacecraft. Information recorded at the earth station is made available in the form of computer files for use in Japan at the Institute for Space and Astronautical Sciences (ISAS), and at the Jet Propulsion Lab (JPL). In addition, the wideband science data which is recorded on VLBA tapes is shipped in a timely manner either to Socorro to the VLBA correlator or to an alternate correlation site should that be specified in the particular astronomical observation being performed.

The earth station staff in Green Bank includes a project manager, a programmer, an electrical engineer, a maintenance technician, and two operators. Access to these people on-site will be a great asset in the debugging and modification process that is sure to follow once the VSOP spacecraft is in orbit and the Green Bank earth station, as well as the other tracking stations around the world, begin to receive the first "real" orbiting VLBI data.

5. NASA-Orbiting VLBI Science Support

The NRAO Space VLBI Project, based at the Array Operations Center includes the NRAO activities funded by NASA through the U.S. Space VLBI Project at JPL, in support of the international Space VLBI missions VSOP and Radioastron. The Project now comprises the following tasks. All these areas will experience major activity in 1997 as the VSOP mission is launched in February 1997 and as it is commissioned.

Management and Science

This activity, which continues throughout the duration of the project, involves management and scientific oversight by NRAO personnel with respect to project goals, implementation plans, and progress. Since both Space VLBI missions are international in scope, frequent interactions are necessary to maintain coherent interfaces with other mission elements. NRAO personnel are members of the two International Scientific Councils which serve as steering committees for the missions, of the VSOP Scientific Review Committee which performs peer review of submitted proposals, and of the International Mission Operations Group in which most of the interfaces are being developed.

VLBA Correlator Enhancements

Modification of the VLBA correlator to support Space VLBI observations will be substantially complete by the end of 1996. A major test of the correlator was completed in the third quarter of 1996 when the wideband tapes from the 1988 TDRSS OVLBI observations were re-correlated with the VLBA correlator and fringes were detected at the expected amplitude and with the expected delay. The correlator is ready now to handle data from VSOP.

AIPS Enhancements

New software has been written to generate realistic simulations for tests of Space VLBI imaging, and to provide displays of Space VLBI data beyond those currently available in AIPS. The interactive model fitting task is nearly complete, and further enhancements are being added to the baseline-oriented fringe-fitting tasks. Real data from VSOP will be needed to guide development of additional software tools. The basic functionality is ready for VSOP.

Operations Support

Tasks in this area will reach their full level in 1997. These include scheduling of the VLBA for joint observations with VSOP, operation of the VLBA correlator and shipping of tapes.

User Support

Two user support staff members were hired early in 1996, to insure that adequate training can be completed before the results from VSOP's first scientific observations must be analyzed. The initial complement of computing hardware provided for visiting users also was procured, and this functionality is ready to assist VSOP science users.

VIII. EDUCATION PROGRAM

With observing sites and scientific offices located in ten states and the territory of the U.S. Virgin Islands, the NRAO has a public visibility that is being exploited to further science awareness and science education. Formal education in the form of supervised research experiences with the NRAO radio telescopes is provided to professional and pre-professional scientists. Programs that emphasize how scientists work and what they hope to accomplish are provided to secondary science teachers and interested amateur astronomy groups. Finally, public educational activities are sponsored at all the NRAO observing sites in the form of guided and self-guided tours, public access to the images of objects in the radio sky, and descriptions of the nature of objects studied by radio astronomers. A few of the highlights of the NRAO educational program are summarized below.

In an attempt to convey the excitement of scientific discovery in general and the rewards of astronomy in particular to the general public, the NRAO maintains visitor centers at the observing sites in Green Bank, West Virginia, and at the VLA site in New Mexico. Both of these centers are open year-around and each draws nearly 20,000 visitors annually from throughout the United States and around the world. The visitor centers feature automated slide presentations with audio narration, displays on the instrumentation and operation of NRAO radio telescopes, and illustrations of recent radio astronomical research. We hope to convey to the public visitors of the NRAO the following: (1) the value of astronomy to society and its importance among the sciences; (2) the place of radio astronomy and its value to astronomy as a whole; (3) the techniques of radio astronomical observations; and (4) the technology of radio astronomy and the operational basis of the NRAO instruments.

Green Bank Public Educational Programs

In addition to scientific research, the NRAO in Green Bank, West Virginia is host to a number of educational activities. The largest of these is science teacher training, a series of programs conducted in partnership with West Virginia University. These programs have been in existence since 1987 supported by the Education division of the National Science Foundation, and in 1990 by the Benedum Foundation. The training targets middle school and high school science teachers, from whom most students get their initial exposure to science in the classroom. The goal is to increase teacher's understanding of science and technology, and their ability to teach it, by exposing them to real scientific research at the Observatory. Teachers receive college credit from West Virginia University for their participation in the NRAO programs.

Since its beginning in 1987, the science teacher training programs have brought more than 450 teachers to Green Bank for one to two week summer courses that involve lectures on astronomy, actual scientific research using a 40 foot diameter radio telescope, and detailed science education workshops. The teachers work closely with NRAO scientists, and also have a chance to interact with many professional astronomers who come from around the country and the world to use the telescopes at Green Bank. After participation in an NRAO training program, teachers host workshops for other teachers in their home district to spread information about effective ways to present science. It is estimated that more than 15,000 teachers have benefited indirectly from our programs.

The unique combination of scientific research experience and educational training that results from the NRAO/WVU collaboration has been quite successful in improving the educational abilities of the participating teachers. Almost 80 percent of the participants said that the teacher training programs had changed their views on science teaching and inspired them to create investigative experiences for their students. As one teacher put it, "Over the past few years I have heard an awful lot about changes in the educational system but little has been done to provide teachers with concrete examples to follow. This institute has shown me by example how to guide students in a learning experience rather than telling them about it." It has been estimated that the NRAO/WVU programs have improved the education of more than 100,000 students so far. Many teachers who received training at the Observatory return with groups of their students to use Observatory facilities. More than twelve hundred high school students have been able to gain first-hand research experience using the NRAO educational facilities.

Teacher training initially concentrated on science teachers from West Virginia, then was broadened to include participants from the entire country. In 1994 the program was redesigned to focus on teachers and teachers-in-training from West Virginia and involves two West Virginia institutions of higher education: West Virginia University and Glenville State College. Preservice teachers participate in a one week institute as part of their Science Methods course. So far, 88 preservice teachers have participated in this experimental program. Evaluation results show that the program positively impacts preservice teachers knowledge of the nature of science and desire to teach inquiry-based science.

In September, 1996, NRAO Green Bank submitted a proposal to the NSF Teacher Enhancement Program to expand our summer institute program to include elementary teachers. Teachers from predominantly rural areas of West Virginia, Kentucky, Virginia, North Carolina, Tennessee, and Ohio will be targeted. If funded, this program will run from 1997-2001.

Chautauqua Workshops for College Teachers: The Observatory hosts two 3-day workshops each spring for science faculty of small colleges throughout the country to share results of current research in astronomy with as wide an audience as possible. This program is partially funded by the NSF. In 1996, 55 college teachers participated in a Chautauqua held at NRAO-Green Bank.

High School Student Mentor Program: Local high school students who have interests in engineering, electronics, and astronomy can participate in a mentorship program at NRAO. These students spend one to two days per week at the Observatory working with a staff member (their mentor). In 1995/96 NRAO Green Bank staff mentored four high school students. This year, six students have indicated interest in working at NRAO.

Public Tour Program: The public is encouraged to visit the site. Hourly tours are given each day during the summer months, and tours can be scheduled for groups at any time of the year. Special in-depth tours are also occasionally arranged. In 1995/96 22,059 people visited the Observatory. School groups comprised 20 percent of the visitors.

Plans are underway to overhaul the tour program at the Observatory. In June, 1996, NRAO submitted a proposal to the National Science Foundation's Informal Education Program. Funds are being sought to construct a series of interactive science exhibits which would allow the public to experience the ongoing research at NRAO more directly. If funded the project will proceed over three years.

Socorro Public Educational Program

The Socorro educational program is a multi-faceted effort that, while centered around the VLA Visitor Center, also includes cooperation with local and regional schools and colleges, public lectures, support for amateur events and organizations, and dissemination of scientific information to the public in a variety of ways. The VLA Visitor Center has been a popular tourist attraction since its opening in 1983. The VLA and its Visitor Center recently have been featured in tourism-oriented television shows in Arizona and New Mexico and in a number of regional and national publications, including *National Geographic Traveler*. When the Warner Brothers movie *Contact*, filmed in part at the VLA in 1996, is released, probably sometime in 1997, the facility will gain significant additional exposure. For these reasons, we anticipate a substantial increase in the number of visitors.

Currently, the Visitor Center features an automated slide show with audio narration, displays on the history of radio astronomy, the operation of the VLA and VLBA, and changing displays on scientific results from both instruments. The visitor center is the starting point for a self-guided walking tour of the central portion of the VLA site. A free brochure provides background information and a map for visitors making the walking tour. Signs at stops on the walking tour explain the components of the VLA visible from each stop. The walking tour provides visitors with close-up views of an antenna, the antenna assembly building, the transporter vehicles, and, from an outdoor balcony on the control building, views of the VLA's electronics and control rooms.

Though the visitor center is not staffed, we provide regularly scheduled guided tours on summer weekends, using NRAO summer students as guides. Throughout the year, by appointment, we provide staff tour guides for educational and scientific organizations. The number of such guided tours averages about 40 annually.

In 1995 and 1996, we obtained significant private donations that will enable us to undertake a complete renovation and upgrade of the VLA Visitor Center. We plan to replace and redesign the scientific displays in the visitor center in 1997.

The visitor center upgrade effort began with a survey of visitors, to determine the demographics and knowledge base of our audience. We found that the vast majority of VLA visitors come with little or no detailed knowledge of astronomy, and a majority have no formal training in science. However, the visitors are remarkably well-educated, with a majority having college training. Based on analysis of the survey results, we feel that the VLA Visitor Center has the potential to have significant impact on public understanding of astronomy and its importance to society by effectively conveying this message to a geographically diverse audience of opinion leaders. Members of the NRAO staff have visited other science centers and museums in the region and discussed aspects of the upgrade with museum professionals around the country. Our next step is to assemble a group of educational experts, both regional and national, into a formal advisory panel. This panel of experts, which we hope to assemble and support with the help of grant funds, will assist NRAO in developing new exhibits to make the visitor center an effective, exciting center for informal science education. We will seek to incorporate interactive techniques, new technology, and proven approaches to learning. We also will explore avenues of providing staffing for the visitor center, an addition that would significantly improve the quality of the experience for the visitor.

Once we have obtained the recommendations of our advisory panel, we will seek to leverage the donated funds by preparing a proposal for an educational grant. We thus hope to produce a center for informal science education that is more effective than could be achieved using only the donated private funds. Both in Socorro and at the VLBA sites, NRAO staff members frequently give lectures at schools and to local organizations. Some area teachers regularly use NRAO staff members as guest speakers, and we attempt to make the availability of our staff well known to the schools. NRAO provides a display and staffing for career days at local schools, a particularly important function in a region where there are large numbers of minority and disadvantaged children who need to be made aware of the possibility of scientific or technical careers. NRAO also contributes significant staff time to provide judges for area science fairs.

We widely distribute a pamphlet aimed at educators which outlines the NRAO services available to them. In this document, we offer tours, speakers, literature, and the assistance of our staff in serving as a resource for information about science, engineering and computers. We have seen the effect of this effort in a continually increasing number of inquiries from educators not only from New Mexico but also from across the nation.

With increasing public awareness of research results from the VLA and VLBA, NRAO has had greater opportunity to advance public education by teaching members of other organizations that have frequent contact with the public. We now regularly provide information on astronomy and NRAO's role to rangers and interpretive staff at parks and wildlife refuges. We provide brochures about the VLA Visitor Center to area hotels and to Chambers of Commerce and tourist welcoming stations around the state.

NRAO is ideally positioned to use the amateur radio community as a force multiplier for public education efforts. As expected, many of our staff members are radio amateurs and are involved in local and national radio organizations. Staff members present lectures to amateur radio organizations and NRAO provides displays on radio astronomy at amateur radio events. We also have frequent contact with national amateur radio publications, resulting in articles on NRAO scientific results and technical developments.

Amateur astronomers also are a proven resource for public education, many of them showing great enthusiasm for bringing astronomical information to the public. NRAO has forged close ties with New Mexico's extensive amateur astronomy community. We regularly provide lectures and tours for amateur groups and provide displays at public events such as National Astronomy Day observances, held by these groups. In addition, NRAO provides staff assistance, VLA tours and lecturers for the annual Enchanted Skies Star Party, an amateur astronomy event that draws participants to Socorro from across the U.S. and several foreign countries. Participants at this event have commented that the VLA tour and the opportunity to interact with professional astronomers have been the highlight of their visit.

Undergraduate Education

According to the American Institute of Physics, the typical undergraduate curriculum for a student majoring in physics or astronomy includes six hours or fewer in required laboratory courses. This means that, as seen by the student, science research is largely a pursuit of theoretical studies. As a way of broadening the exposure, the NRAO conducts a summer research program under the auspices of the NSF

Research Experiences for Undergraduates (REU) program. At least twenty students participate each year. Each student is assigned a NRAO staff scientist or engineer as a supervisor and each participates with his or her supervisor as a professional colleague for the summer. This provides an intense exposure to real research that serves to complement and enhance the intellectual understanding of the role and purpose of scientific discovery that the student acquires in the classroom.

A second avenue of student involvement at the NRAO is the program of cooperative education also done with NSF sponsorship. The co-op students are in residence for three to six months a year and are given intellectually creative tasks to do, and they are provided with the resources needed to complete the tasks. In 1997, co-op students at the NRAO will build and test parts of the laser metrology system being built for the Green Bank Telescope.

Graduate Education

As astronomy becomes a more phenomena-oriented discipline, and less divided by observing wavelengths, radio astronomical observations play an important role in a wide variety of astronomy Ph.D. theses. Some of the universities awarding degrees in astronomy have few, or no, radio astronomers to guide student research in radio astronomy. To rectify the situation and train students in the techniques of radio astronomy specifically needed for the individual student's research, the NRAO staff scientists collaborate with university astronomers in the supervision of Ph.D. thesis students. The students spend as long as twenty-four months in residence at the NRAO taking data, reducing it, and writing their theses – all with the guidance of NRAO staff scientists.

Presently there are five resident Ph.D. thesis students at the NRAO doing research in astronomy, microwave engineering, and computer science. This program principally benefits the student, but it has a salutary effect as well for the NRAO staff supervisor.

In addition to the thesis students resident at the NRAO, more than 150 Ph.D. thesis students use the NRAO facilities each year for their research. While these latter individuals receive no direct salary support from the NRAO, their stay of one to a few weeks at the Observatory is supported directly by a housing subsidy (in Socorro), travel reimbursement, computer time, and supplies; and it is indirectly supported by assistance from the NRAO scientists and staff as needed. Many of the students using NRAO facilities this year will receive their introduction to radio astronomy from NRAO staff scientists.

Postdoctoral Education

At the NRAO postdoctoral appointees are given Jansky Postdoctorals with a term of two years that may be extended an additional year. In the selection process recent graduates are given preference to those who are applying for their second postdoctoral position. In principle, Jansky Postdoctorals are available not only to those in radio astronomy but they are also available to recent Ph.D. recipients in engineering and computer science.

Postdoctorals at the NRAO are encouraged to define their own research program; they are not asked to serve as apprentices to NRAO staff scientists. The purpose of the program is to provide an opportunity for young scientists to establish their research credentials so that they may more effectively compete for permanent positions and become themselves better teachers of, and researchers in, radio astronomy. Approximately ten Jansky Postdoctorals are in residence at the NRAO at any time.

IX. 1997 PRELIMINARY FINANCIAL PLAN
by Budget Category

(NSF Funds, $ in thousands)

	New Funds	Uncommitted Carryover of 1996 Funds	Total Available for Commitment	Commitments Carried Over from 1996 Funds	Available for Expenditure
Operations					
Personnel Compensation	$17,283		$17,283		$17,283
Personnel Benefits	5,444		5,444		5,444
Travel	682		682		682
Material & Service	6,911	250	7,161	600	7,761
Management Fee	630		630		630
Common Cost Recovery	(800)		(800)		(800)
CDL Device Revenue	(150)		(150)		(150)
Total Operations	$30,000	250	$30,250	$600	$30,850
Research & Operating Equipment	0	0	0	0	0
Total NSF Operations	$30,000	250	$30,250	$600	$30,850
Design & Construction	0	0	0	0	0
GBT	0	1,500	1,500	2,000	3,500
TOTAL NSF PLAN	$30,000	$1,750	$31,750	$2,600	$34,350

IX. 1997 PRELIMINARY FINANCIAL PLAN

NRAO Non-NSF Funding

($ in 000's)

Organization/Project	1997 Funds
USNO:	
Ops & Maintenance	$420
GB/HA Repairs	215
Hardware	100
NASA:	
Science OVLBI	500
Earth Station OVLBI	699
MAPS	1,450
Miscellaneous	100
TOTAL	$3,484

APPENDIX A - NRAO SCIENTIFIC STAFF ACTIVITIES

There are approximately 80 individuals with Ph.D. degrees at the NRAO. Most of these people are astronomers, some are engineers, and some are computer science professionals. All of them include a strong research program as one important component of their Observatory responsibilities. In carrying out their tasks these individuals see ways to enhance the observing equipment, to streamline observing techniques, and to improve the software. They take the opportunity to do so by conducting challenging observations or otherwise experimenting within the bounds of a competitively reviewed observing program. In so doing the NRAO staff scientists develop a proficiency with the instruments and data analysis procedures that can be communicated to NRAO users. This has been, and continues to be, an effective mechanism to expand the horizons of radio astronomical research.

The specific astronomical research planned by the NRAO scientific staff in 1997 is summarized below by area of research.

1. Sun and the Solar System

The Solar System

Radio observations of objects in the solar system provide information about the temperature, the composition and the structure, roughness or texture, of the material of which they are comprised. In 1996 observations are planned of several planets. These data will complement data obtained at other wavelengths and with other space and ground-based instruments.

The 1994 collision of the comet Shoemaker-Levy/SL9 with Jupiter had the very unexpected consequence of causing the non-thermal emission from Jupiter to increase. This result was particularly surprising because the non-thermal radiation comes from relativistic particles spiraling in the magnosphere of that giant planet. The comet, largely a mass of ice and dust, has no relativistic particles and no magnetic field. It is therefore unexpected that any effect on Jupiter's relativistic particles or magnetic field would be seen. But such was the case. In fact, the non-thermal radio emission remains elevated, decaying only slowly with time. In 1997 observations at 1400 MHz with the 140 Foot Telescope will continue to monitor the decay in the hope that these observations will help to unravel the source and mode of transport of the energetic electrons in Jupiter's magnetosphere.

The 1996 close passage of Comet Hyakutake and the arrival of Comet Hale-Bopp in 1997 has created intense interest in the chemistry of comets. Among the many observations planned in 1997 is a project to monitor the kinetic temperature evolution of Comet Hale-Bobb by measuring its methanol and formaldehyde emission line strengths as a function of heliocentric distance.

2. Stars and Stellar Evolution

The youngest stars we know of are identifiable by their thermal infrared emission as localized warm spots in an otherwise cold molecular cloud. Such young stars are commonly associated with maser emission from OH, H_2O, or CH_3OH. In either case the emission is from thermally heated gas or dust. Throughout their *youth* and *middle age*, while stars are on the main sequence, the light they emit is again the result of thermally heated gas, but not entirely so. Some stars, and some regions of nearly all stars, are sources of non-thermal radiation which is reflective of the production of relativistic particles and strong magnetic fields in the stellar atmosphere or environment. At the end of their nuclear-burning lives, stars expel the successive outer regions of their atmospheres until they reach the point that most of the stellar mass has been removed. For such evolved stars the residual stellar atmosphere cools and radiates thermal molecular line emission as well as thermal dust continuum emission. Each of these three stages of stellar evolution will be investigated at the NRAO in 1997.

Active and Main Sequence Stars

Binary star that emit x-rays and that exhibit non-thermal radio emission are the best source of information we have as to how accretion disk environments serve to accelerate relativistic particles. This is so because we are able to study such objects across the electromagnetic spectrum from the radio to gamma-rays, and we are able to do so while the binary system is in a quiescent emission state. While spacecraft with x-ray and gamma ray detectors are operational we have a unique opportunity to conduct multi-wavelength studies. In 1997 radio observations with the VLA and VLBA will focus on the black hole x-ray transient sources GRO J1655-40, GRS 1716-249 and GRS 1739-278. The observational data will provide the basis for a source and event theoretical modeling analysis.

Binary stars systems known as RS CVn systems will be studied with the VLBA. One of these systems, UX Ari is known to flare brightly in the radio and observations of this star will be modeled as a source of gyrosynchrotron emission in an attempt to understand its energetics and the strength of its magnetic field.

Evolved Stars

The circumstellar envelopes of mass-losing evolved stars will be probed by high resolution VLBA observations. The observations will involve full polarization imaging of both water and SiO masers. Such observations are crucial in helping us understand the physics of the circumstellar masers, the kinematics of maser outflows and the morphology and strength of circumstellar magnetic fields. Target sources in this work include late-type starts as well as proto-planetary nebulae. The latter form part of a study of the post-AGB evolution of stars in the transition region of the H-R diagram. The work will include numerical modeling of maser kinematics using a generalized ellipsoidal outflow model for the circumstellar shell.

Moderate mass stars replenish the interstellar medium with molecules rich in processed material. Large molecules formed in their envelopes may proceed undestroyed in the ISM with their isotopically distinct signature. VLA maps of a family of such large molecules, the cyanopolyynes HC_3N, HC_5N, and HC_7N in the envelope of the nearby carbon star IRC+10216 vividly illustrate that the longer more complex cyanopolyynes form from fragments of smaller molecules photodissociated in the shell. The larger molecules robustly channel ultraviolet energy into infrared energy through their many vibrational modes, surviving to large distances in the shell. The smaller molecules cannot degrade the UV energy, having few bonds, and fall apart deep in the shell to provide fodder for larger molecules. The investigation has been successfully extended to HC_3N in CRL 2688 using the 7 mm facility at the VLA. The HC_3N emission lies in two polar patches, where penetration of UV light into the dense material surrounding the star is greatest. A synthesis of all this information will be attempted in 1997.

A survey of southern planetaries in the CO lines has unmasked a remarkable cool J-type carbon star planetary, M1-16 with a $^{12}C/^{13}C$ ratio of three—the lowest known for any star. In common with many planetaries, it exhibits a bipolar morphology. Common bipolar morphologies may result from redeposition of angular momentum, stored in a planetary system during the main sequence lifetime of the central star, into the expanding circumstellar envelope. If this hypothesis proves viable, it constitutes another route for radio study of planetary systems about normal stars.

3. Supernovae and Supernova Remnants

There has been no supernova recorded in the Milky Way for the past 400 years. All our information on the supernova phenomenon comes from the study of supernovae in other galaxies and, indirectly, from observations of the sites of very old supernovae in the Milky Way. Observations of both recent supernovae beyond the Galaxy and of the remnants of historical supernovae nearby will be made in 1997.

The earliest stages of supernovae can be studied only by observing supernova events in distant galaxies. At this time fourteen radio supernovae have been detected with ages less than 25 years. Multi-wavelength radio light curves have been determined for ten of these objects as part of the observational program with the VLA. The goals for the continued study in 1997 include:

- Attempts to establish the density distribution of the pre-supernova circumstellar envelope and thus the mass-loss rate for the progenitor stars. This can only be done if the supernovae are detected early in their development. The optically thick multi-frequency radio light curves are a powerful probe of the physical conditions of this medium.
- Efforts to establish the range of the radio luminosity distribution of supernovae. Supernova Types Ib and II have been detected as radio emitters with 6 cm luminosities between 10^{26} and 10^{28} ergs/sec/Hz. No Type Ia supernova has ever been detected. The low end of the SNII luminosity range can only be studied by observing nearby supernovae.
- Studies of the prompt radio emission that will eventually fade completely or enter the phase of a traditional radio supernova remnant, where the radio emission is produced by interaction with the interstellar medium. It is hoped that this transition can be observed in older supernovae such as SN1979C and SN1970G.

In addition to the search for new radio supernovae, monitoring will continue of six supernovae to establish their radio light curves. Supernova 1979C in M100 remains the definitive example of the SNII class and has shown flux density variation with a four-year period during its decay phase. Supernova 1980K is still being intensely monitored optically and in its X-ray emission. Supernova 1986J and 1988Z are examples of the Type II optically peculiar subclass. Supernova 1993J is strong, still evolving and will be the best studied supernova to date with the extensive time series of VLBA images presently being obtained.

4. Pulsars

Observations of pulsars have the capability to tell us about the statistical properties of the final stages of stellar evolution, and they can be used as probes of the interstellar medium, of general relativity, and of the physics of neutron stars. All of these things will be pursued observationally in 1997.

The radio emission from a pulsar is highly linearly-polarized, and the position angle of its polarization vector usually varies in a smooth, S-shaped, fashion as the pulsar's radio beam sweeps past an observer's line of sight. In many cases, however, this monotonic sweep of position angle is disrupted by abrupt, 90 degree transitions. The transitions in angle and the associated depolarization of the radio emission reveal the presence of orthogonal modes of polarization. In addition to depolarization by orthogonal modes, observations of individual pulse polarization also indicate that some subpulses are almost completely linearly-polarized. These observations suggest that the radio emission is composed of two, highly-polarized, orthogonal modes. A statistical model has been developed for the polarization of pulsar radio emission assuming that it is determined by the superposition of two, completely-polarized orthogonal modes. The predictions of the model compare favorably with polarization observations of individual pulses from PSR B2020+28. The flux densities of the modes in this pulsar appear to be normally-distributed. By studying the observed distributions of mode flux densities, one can learn more about the underlying physics of the radio emission.

The studies of the modes that have been made to date have led to a number of interesting conclusions: (1) old pulsars depolarize rapidly with frequency, (2) the depolarization of the emission at high frequency is due to the orthogonal modes, and (3) the modes tend to become nonorthogonal at low radio frequency. Verification of these conclusions requires a number of observational campaigns that will occur in the next few years. For example, multifrequency observations of the oldest pulsars, the millisecond pulsars, will confirm the apparent correlation of depolarization rate with pulsar age, and single pulse observations can be made a low frequency (200 MHz) to explore the properties of the nonorthogonal modes.

5. Molecular Clouds and Star Formation

Star formation is such a profoundly complicated process because it involves the chemistry, density, temperature, magnetic field, and kinematics of the material that will make up the star. Our knowledge of all these parameters of a molecular cloud is still poor. Nevertheless, we can make some progress in out understanding by probing molecular clouds, and young stars, both on the large scale in molecular clouds and on the smallest scales characteristic of the protostars themselves. Both such investigations will be conducted in 1997.

The coldest molecular cores have been shown to be propitious locales in which to seek the youngest stars. These objects, with spectral energy distributions of Class 0, have been targeted in an ammonia survey, which has now obtained VLA maps of ten or so of the about a dozen known objects. Curiously, these objects tend to occur gregariously, with several cases of multiple objects within a single core known. The study has concentrated on these, both because of the usefulness of having more than one object in a field of view, and to study reasons why some cloud cores give birth to more than a single star at nearly the same epoch. In these maps, differences among the objects become quite apparent. In objects so young that no bipolar flow has commenced such as IRAS 16293B or NGC 1333IRAS4C, ammonia structures are readily discerned. In another group of objects, including L483, IRAS 16293A, NGC 1333IRAS4B, and VLA1623-2418, very cold ammonia exists, but shows only subtle correlation with cold dust structures enveloping the star. During the coming year studies will begin of L483, unusual among these objects in the very high optical depth of its ammonia lines. Owing to the high optical depth, it has not been possible to detect infall occurring onto the central protostar. In a final group of objects, such as L1448C, L1448IRS3, NGC 1333IRAS4A, and S106FIR, warm ammonia correlates well with the dust emission, and may show up in outflowing gas as well. It appears that ammonia becomes severely depleted, perhaps through freezing onto grains, in the final stages before stellar ignition.

Water maser monitoring in low mass stars, a continuing project on the 43 m telescope and the VLA, has revealed some interesting parameterizations of low mass stellar masers. One study has found that most of these masers occur within one hundred AU of the protostar, as revealed by millimeter continuum positions (centimeter continuum positions appear to frequently locate the outflow, rather than the star). Even on these scales, the velocity shifts associated with the bipolar flows are evident. How, then, does the maser emission arise? One possibility is that it arises at the working surface of the bipolar jet on the ambient molecular cloud; another holds that it occurs where material entrained in or along the jet interacts with the surface of a protoplanetary disk.

The warmer high mass star forming region DR21(OH) displays a variety of phenomena associated with high mass star formation. Maps of 1.3 mm H_2CO emission have been made at OVRO and at the VLA (2 cm). An attempt has been made to combine the interferometric maps with single antenna maps made at the CSO, in order to disentangle density and thermal structures in the core – two prominent dust cores lie only 8" apart.

The study of physical and chemical conditions in small translucent molecular clouds will continue. Physically self-consistent models (hydrostatic equilibrium polytropes) have been fit to extensive observations of $C^{18}O$ and ^{13}CO, which include the effects of external radiation fields and provide the radial distributions of all physical quantities including electrons. Once these conditions are known, the chemistry of other molecules can be derived. Many molecules are detectable in these objects (2-4 mag extinction) and extensive observations in more than one line have been made in an ensemble of 38 objects of the species H_2CO, NH_3, HCO^+, N_2H^+, SO, SO_2, SO^+, HCS^+, CS, SO^+, H_2S, HCN, HNC, C_3H_2, HC_3N, C_2S, SiO. The models have now been applied to all of these species up to H_2S in the list. Ion-molecule chemistry is found to describe all of the species except H_2CO and H_2S, which require photocatalysis on grains. All species exhibit a distinct transition from diffuse cloud to dense cloud chemistry, that is, their fractional abundances increase sharply between ~ 0.6 magn and 3 or 4 magn extinction. This work will continue with an analysis of aceylenic chemistry (C_3H_2, HC_3N, C_2S) and SiO. Recently we detected more complex species (HOCO , H_2CCO, CH_2NH, CH_3CN, CH_3OH in translucent clouds. These species must form by radiative association, thus confirming the next level of ion-molecule complexity in these quite tenuous objects. Analysis of these species will be done in the next year also.

A project will be initiated to study the evolutionary relation between various types of molecular clouds (diffuse, translucent, cold dense, warm dense). At present, diffuse clouds and translucent cloud cores are believed to be quiescent (neither contracting nor expanding under gravity). Hydrostatic equilibrium models are the evidence for this conclusion in translucent clouds. Similar modelling has shown that the massive cold dense clouds typically found in the *Lynds* catalog are not in equilibrium, but appear to be over-pressured internally and thus are slowly expanding overall. The new study will apply the hydrostatic equilibrium models to a class of small, low-mass dense cold cores studied by Myers and colleagues for many years.

A highly sensitive spectral survey of the 2 mm band (132-170 GHz) was completed at the 12 Meter Telescope and is being prepared for presentation. The survey is of seven objects: $SgrB_2OH$, $SgrB_2N$, W51M, Ori(KL), Ori-S, W3(IRS5), and IRC 10216. Five-sigma noise level is typically 30 mK, spectral resolution is 768 kHz (1.5 km/s at mid-band), and beam size (FWHP) is 42" at midband. It is the most sensitive millimeter-wavelength survey yet made, and comprises the most objects. The density of lines in most of the objects is unprecedented, and major programs will be required to identify most of them, and to extract the differences in chemistry and excitation that characterize each object. Currently the survey is being prepared for presentation, and this work will continue over the next year.

An unambiguous example of a molecular cloud impacted by a violent shock, W51C, has been discovered. After IC 443, this is only the second clear example of a shocked molecular cloud. Thus shock chemistry is poorly understood from the observational point of view. A collaboration has been formed to apply detailed modeling techniques to this object to derive physical conditions, and to study its chemistry. Observations of $C^{18}O$ and ^{13}CO in several transitions, as well as several other chemically key species, will be made.

Another technique for investigating the chemistry of molecular clouds is to observe not the emission lines but absorption lines toward background continuum sources. Recent results include the unexpected discovery of large abundances of polyatomic molecules at moderate (1 magnitude) extinction toward diffuse interstellar clouds, and a reinterpretation of OH profiles in light of the fact that OH has phases somewhat like HI. Work in 1997 will include a study of CO formation, fractionation, and excitation for about a dozen lines of sight.

The famous interstellar cloud toward the star Zeta Oph is an ideal laboratory for studying the transition of neutral atomic carbon to CO. The patterns in this cloud exhibited by such related species as OH, HCO^+, CO and CH are bizarre and cannot be understood by any existing model of diffuse cloud chemistry.

At the other extreme, a previously unknown but surprisingly bright molecular cloud in the neighborhood of the Pleiades was discovered. Further studies in 1997 of the origin and composition of this cloud are planned extending observations to a variety of different molecules.

6. Emission Nebulae

Ionized gas excited by bright stars is both a conspicuous component of the galaxy and it is a physical environment well-suited to a comparison of our understanding of physics with our understanding of astronomy. Several such tests will be carried out in 1997.

The stars that excite, ionize and heat HII regions are often very young stars that are highly embedded in the material from which they formed. Molecular outflows are now known to be a ready way to identify these very luminous newly-formed stars. The outflows are typically seen as bipolar high velocity neutral molecular gas lobes, but many theoretical models predict that the inner flow, or jet, near the young protostar is very high velocity ionized gas that becomes neutral and entrains molecular gas as the flow proceeds further and further from the protostellar source. Very high velocity wings on recombination lines from ionized hydrogen have been detected in the star forming HII region complex DR21. High resolution VLA observations of these lines are planned to investigate the validity of models of ionized jets as the driving force for molecular outflows from protostellar sources.

Observations of the hyperfine lines of $^3He^+$ in planetary nebulae will be made to confirm the supposition that planetary nebulae are the primary source of the isotopic helium in the galaxy. If possible, the abundance will be measured in planetary nebulae at varying galactocentric radii to explore the suggestion that stellar evolution has proceeded more rapidly near the galactic center than elsewhere in the galaxy.

7. The Galaxy

Gas in the interstellar medium continually changes its phase in response to local conditions. Gas closely exposed to starlight is ionized or heated, cold tenuous gas will be neutral but largely atomic, cold dense gas will combine into a molecular form or find itself deposited onto dust grains. Understanding the quantity of gas in each form and understanding the large-scale processes which cause changes between them are the subject of several studies by NRAO staff in 1997.

On the largest scale, the spatial fluctuation in the concentration of neutral hydrogen will be investigated to see if these fluctuations are in agreement with a Kolmogorov turbulent spectrum as is to be expected from purely hydrodynamical turbulence. The connection between the large parsec-scale HI fluctuations and the fluctuations seen on AU scales will be investigated. Once this is known one can assess the idea that interstellar plasma turbulence causes these fluctuations.

In addition to hydrogen, one can also investigate the abundance of carbon in the galaxy. If we can separately map the distribution of neutral carbon, ionized carbon and molecular carbon (CO), we will have an important diagnostic of the structure, kinematics and physical properties of star formation complexes. In 1997 observations with the 140 Foot Telescope are planned of the carbon recombination lines toward HII regions and toward emission nebulae with low far ultraviolet fields. These observations will be combined with observations of CII emission at 158 microns, with atomic CI data and with existing CO maps of the galaxy.

Closer to the center of the galaxy, the distribution and motion of the gas in the inner region of the galaxy will be analyzed in terms of kinematical rotation to see if this alone can account for the observed features. The continuum emission in this same region will also be mapped at 90 GHz where an attempt will be made to determine the spectral index along the prominent Sgr A radio arc. The goal is to obtain an estimate of the age of the electrons responsible for emission in the arc and, by so doing, to determine the time since a major particle acceleration event (explosion?) occurred at the center of our galaxy. Still another probe of the conditions at the galactic center is a map of the water maser emission. Observations with the VLA will be used to obtain accurate positions and velocities of as many of the 99 known water masers as possible and to determine their gross kinematics. This information will provide an estimate of the mass density at the center of the Milky Way.

Finally, the central object of the Milky Way is the compact radio source Sgr A*. It will be observed by the VLBA at six frequencies nearly simultaneously in an attempt to determine the scattering properties of the medium along the line of sight to the galactic center. Indications from previous observations are that the scattering varies with time and these new observations should eliminate that ambiguity in the interpretation.

8. Normal Galaxies and Clusters

Spiral Galaxies

Many observations are planned in 1997 of spiral galaxies using their HI emission line as a probe of atomic gas and using CO as a probe of the molecular material.

A set of approximately 100 high signal-to-noise HI profiles of small angular size galaxies will be prepared for publication. These profiles represent a unique data set in that they were obtained with a (relatively) large beam, 21', and with extreme care as to calibration and pointing. Further, the galaxies themselves were chosen to be relatively isolated. Such material will allow: (1) Accurate measurement of the HI flux for later comparison with other telescopes of smaller beam, e.g., the GBT and Arecibo. Such comparisons will yield an accurate measure of the HI extent of galaxies as a function of type. (2) Evaluation of the frequency of optically faint, HI rich, companion galaxies. Several have already been identified. And (3) accurate evolution of global profile asymmetries; one free of previous concerns of mispointing or interaction.

As part of an asymmetry in galaxies project, the nearby system NGC 1637 is being studied. This isolated spiral is clearly lopsided, caused in part by an extra "arm" feature on one side of the galaxy. We have CO, VLA-HI, and I-band maps of this galaxy and shall analyze this material in an attempt to quantify and understand the unusual morphology.

To evaluate the interaction of the hot and cold gas components in early-type galaxies, observations in CO, HI, and x-rays were made of several of these systems. The x-radiation is generally confined to the central and the cool gas to the exterior regions. But there appear to be exceptions where cool (CO) material is located in the central hot region. Analysis and modeling of these data are continuing.

An apparently normal spiral galaxy was identified in a survey of rich clusters. This galaxy has radio emission extending over more than 200 kpc and has a radio luminosity of more the 10^{24} W/Hz. The galaxy appears to be the exception to the rule that spirals are never powerful radio sources. Detailed observations are planned to establish whether the galaxy is more related to the seyferts or to twin-jet AGN-dominated galaxies.

Molecular maser emission now provides a new probe of spiral galaxies. VLBI observations of extra-galactic OH masers are planned in the hope of producing definitive images of these objects and demonstrating that the OH masers lie in the molecular tori around the centers of AGNs.

A monitoring program of the water masers in the center of the galaxy NGC 4258 will continue. These observations have already demonstrated the presence of a super-massive black-hole through the discovery of a molecular disc in Keplerian rotation. In addition weak continuum emission believed to be associated with the base of the synchrotron jet has been seen. Close-spaced monitoring of the continuum emission with the VLBA will be done in 1997.

Irregular and Dwarf Galaxies

Observations have been completed of the HI in NGC 2777, an Amorphous galaxy which is a member of the sparse NGC 2775 Group. Amorphous galaxies are a relatively rare morphological type representing about one percent of catalogued galaxies, and are perhaps objects currently interacting with companion galaxies. For NGC 2777, it is found that the HI is extended in the direction of a faint blue galaxy which lies at a distance of about 18 kpc. The hydrogen morphology shows that the galaxies clearly are interacting and thus NGC 2777 is another instance of an Amorphous galaxy showing tidal effects in its HI. However, in this case both the amorphous galaxy and the dwarf companion appear to be in a starburst phase. Additional optical observations are planned in order to distinguish the rotational and tidal velocity components and to estimate the rate of star formation in each galaxy. The dynamics of the tidal interaction in one or two other amorphous systems will be studied using proposed new VLA observations of HI.

Earlier work has shown that the star formation in the Wolf-Rayet galaxy He2-10 is exceptionally vigorous at this time. The observations raise the possibility that star systems similar to galactic globular clusters are currently being formed. If the epoch of star formation is sufficiently advanced, the most massive objects will have evolved to the supernova stage, and it might therefore be expected that the radio continuum will show time variations both in total intensity and in spatial distribution. Continuum maps of this galaxy made over the last decade at several wavelengths with the VLA will be used to examine this possibility. Any variations observed will relate directly to the current supernova rate. This quantity is important to understanding the phase of the starburst event, and to estimate the energy flowing into the interstellar medium of the galaxy.

Some galaxies have been identified as undergoing bursts of star formation for the first time. Of these galaxies, the HI-rich, low luminosity dwarfs may be precursors of normal spiral and elliptical galaxies. A systematic study with the 140 Foot Telescope of the HI envelopes of low-luminosity galaxies should help determine which dwarf galaxies are the best examples of the precursors of normal elliptical and spiral galaxies. The crux of the project requires devising and testing methods for measuring the absolute flux of extragalactic HI emission to an unprecedented accuracy of a few percent.

The extended HI material associated with galaxies may act as a reservoir of material that may fuel star formation within galaxies. Very high signal-to-noise HI observations of galaxies are being made. The galaxies under study are isolated, have no known companions, and have diverse properties. The observations should help evaluate the reservoir of gas. In particular, any observed anomalies in the profiles may arise from HI concentrations or peculiar kinematics, the latter probably because of tidal interactions with a companion.

High-velocity gas (HVG) has been known to exist in the Milky Way galaxy for some time yet has only recently been observed in other galaxies. Since the number of known galaxies with HVG is small, it is difficult to compare the properties of galaxies with and without HVG and, therefore, difficult to determine what causes the phenomenon. As shown by preliminary observations, high signal-to-noise observations of a large sample of face-on galaxies should increase significantly the number of known galaxies with HVG. Galaxies detected to have HVG can then be statistically compared and studied at high resolution with interferometers in order to help solve the riddle of HVG.

Groups and Clusters of Galaxies

A large project is in progress to study the radio properties of clusters of galaxies out to 2.5 Mpc from the cluster center and the relation of the radio galaxies to the Butcher-Oemler effect. So far one blue Butcher-Oelmer cluster, A2125, at z=0.25 has been found which has a large excess of radio galaxies compared with nearby clusters and with red clusters at a similar redshift. We are studying in the radio and optical the properties of about 20 clusters with redshifts up to 0.4 to see if this result extends to other clusters of various properties.

Optical observations of nearby (z=0.02 to 0.08) dense clusters of galaxies are being carried out with observations done at Kitt Peak National Observatory and the Wyoming Infrared Observatory. A tessellating technique has been developed in order to produce wide-field pictures from mosaics of CCD frames with good control of the systematic errors which are kept below 5×10^{-5} of the night-sky level. The goal is to detect diffuse optical light in order to determine the evolutionary history of the clusters through the debris that their formation has left behind. Diffuse light has been detected in dense cD clusters while similarly dense non-cD clusters do not show such a diffuse component. More clusters shall be observed in order to increase the statistics.

9. Radio Galaxies, Active Galaxies, and QSOs

The physical element that ties together the active galaxies that include radio galaxies and, we suspect, the quasi-stellar objects as well, is the presence of a supermassive black hole in the galactic nucleus. Gaseous matter falling onto that black hole somehow, by a process we don't understand, gives up its gravitational energy to the acceleration of relativistic particles that are expelled from the vicinity of the black hole. The observational ramifications of the process include the presence of radio jets very close to the Schwartzschild radius of the black hole. The VLBA is the instrument to make these observations. The radio jets extend to many kiloparsecs from the nuclear region with particle acceleration occurring along this whole length; the VLA allows us to explore these physical phenomena.

Kiloparsec Scale Radio Jets

Observations with the VLA are planned of the prominent synchrotron jet in the galaxy M87. In the longest VLA configuration the angular resolution that can be achieved is less than 35 milli-arcseconds which is somewhat better than the images of this object obtained by HST. Some of the bright knots in the HST images are seen to vary rapidly with time; if a similar effect is found at radio frequencies the interpretation of the knot brightness as synchrotron emission will be called into question.

The kinematics of decelerating relativistic jets will be modeled and compared in detail with VLA imaging and polarimetry of the bases of well-resolved FRI radio jets at high angular resolution and high sensitivity. It is becoming clear that relativistic jet deceleration on kiloparsec scales within elliptical galaxies is a key factor in determining whether an AGN radio source develops the edge-darkened, plumed FRI morphology or the edge-brightened, double-lobed FRII morphology. Also, the intensity asymmetries and apparent polarization states of well-resolved jets provide powerful constraints on the jet kinematics once one accounts fully for both (a) Doppler boosting of the intensities and (b) relativistic aberration of the apparent polarization.

Work on modeling of magnetic field configurations and velocity fields in decelerating relativistic jets will be guided by detailed comparisons with high-quality VLA imaging, primarily of 3C31 at 8 GHz and NGC 315 at 5 GHz. These sources are chosen as bright, well-resolved jets at intermediate angles to the line of sight, offering particularly rich arenas for comparison with the predictions of the models. If successful, this work should provide the first firm constraints on the dynamics of relativistic jet deceleration by entrainment from the atmospheres of elliptical galaxies.

Studies of the spectral index and depolarization asymmetries of the lobes in a sample of powerful double-lobed radio galaxies with detected radio jets will be continued. These results suggest that a separable mixture of relativistic and intrinsic effects governs the large-scale asymmetries of powerful double radio sources, and reinforce the notion that some of the energy transport in powerful radio sources is in Doppler-hidden beams within the observed radio jets (which are then understood primarily as a boundary-layer phenomenon).

Earlier work on the jet-counterjet asymmetries and jet prominence in a small, complete sample of 3CR quasars produced suggestive evidence for both relativistic bulk motion and jet deceleration on large scales (as far as the hot spots and possibly beyond) in these objects. This work will be extended to a larger sample using new VLA observations at 8 GHz.

Parsec Scale Radio Structures

VLBA observations in 1997 will be made of a wide range of radio galaxies and AGNs with the general goal of understanding the mechanism by which relativistic jets of electrons are accelerated and expelled from the region near a supermassive black hole.

The VLBA will be used for multiple epoch observations of a sample of about 100 radio galaxies and quasars in order to determine their internal structures and motions. These data will be used to study the kinematics of radio galaxies and quasars on linear scales of a few parsecs with the hope of understanding the acceleration of relativistic plasma from the "central engine" and to compare the dependence of angular velocity on redshift to distinguish among cosmological models. The sample of radio sources with measured compact radio structure will be extended.

Special attention will paid to the radio galaxies NGC 1275, NGC 1052, and 3C 390.3. In NGC 1275 (3C84) it is possible to trace the motions of the relativistic jet which erupted from the nucleus about 35 years ago and search for recombination lines in the region seen in absorption against the counterjet. The unique capability of the VLBA at 7 mm will be used to explore the subparsec structure of NCG 1275. The nearby relatively weak radio galaxy NGC 1052 has a rare symmetric structure which will be imaged with the VLBA at several wavelengths and at several epochs to determine its kinematics and distance. The VLBA will be used together with the 100 m Effelsberg radio telescope to study in detail the bead-like components discovered in our previous observations which appear to be flowing from the nucleus.

The first VLBA 18 cm image of 3C120 shows a continuous jet structure over 0.5 arcseconds long. This image, despite using fewer antennas than some previous Network observations, is much better than any produced before, and that is before all known corrections have been made to the data. It is about time for the next epoch of these observations. These have been planned to be in conjunction with the VSOP satellite observations of 3C120, but with the delays in launch, we may need another round of VLBA or VLBA+EVN observations. This would be a natural for VLBA+EVN+MERLIN to get the low resolution information.

One of the principle technical goals at the NRAO is to make the VLBA "coherent", that is make it possible to determine absolute positions of the milli-arcsecond radio structures seen in VLBA images. One way to do this expeditiously is to use a phase-referencing technique. In 1997 the technique will be applied to the twin-jet radio galaxy CSO 1946+708. The hope is that these observations will reveal the **absolute** motions of structures in the radio jets.

10. Radio Surveys and Cosmology

The NRAO VLA Sky Survey (NVSS) observations should be essentially complete by the end of September. Production of the final images and catalogs will continue into early 1997. When they are finished, the survey will be used for three major projects:

- Systematic identification of radio sources in the UGC sample of about 12,000 galaxies with angular diameters ≥ 1'. The NVSS should detect emission associated with star formation (HII regions, discrete supernova remnants, and relativistic electrons from old supernova remnants) in most spiral and irregular galaxies. Preliminary tests show a surprisingly high NVSS detection rate of elliptical and SO galaxies as well. These new sources are probably extended since they were not seen in earlier VLA galaxy surveys made with about 5" resolution. They may be powered by weak AGN, diffuse star formation, or both.
- Systematic identification of far-infrared sources in the *IRAS Faint Source Catalog*. The NVSS is about as sensitive as *IRAS* to galaxies obeying the famous far-infrared/radio correlation. Therefore, most *IRAS* sources should appear on the NVSS images. The ratios of their far-infrared and radio fluxes can be used to distinguish starburst galaxies from true active galactic nuclei (Seyfert galaxies, quasars, etc.). The more accurate NVSS positions will yield reliable indentifications of *IRAS* sources with optically faint galaxies that host ultraluminous starbursts and distant AGN.
- Attempt to measure the dipole moment in extragalactic source counts caused by the earth's motion relative to the background of distant ($z \approx 1$) galaxies. This dipole is similar to the dipole in the cosmic microwave background, but the signal is nearly four times as strong because the spectra of radio sources are more favorable than the Rayleigh-Jeans spectrum of the cosmic microwave background. The expected dipole amplitude in only about one percent, so a uniform (« 1% angular variation in the flux calibration) all-sky survey detecting well over 100,000 sources is needed for a significant measurement. The NVSS should be the first survey to meet these requirements.

The VLA is being used to image the Hubble Deep Field with a resolution of a few tenths of an arcsecond at a wavelength of 3.6 cm. When complete this will be the most sensitive radio image ever made. Optical identification of all radio sources with galaxies in the HDF should be possible, and the failure to identify any sources down to the HDF limit of 30th magnitude will itself be of great interest. For the first time it will be possible to directly compare the radio and optical morphology with sub arcsecond resolution at the faintest levels ever reached in the radio and optical bands.

In 1997 a conclusion will be reached in the search for proto-clusters of galaxies through the observation of their (redshifted) 21 cm emission at a frequency in the range of 305 MHz to 335 MHz, which has surveyed a dozen fields at redshifts between 3.1 and 3.7. The VLA P-band system has been pushed to a sensitivity of better than 0.8 mJy/synthesized-beam for spectral channels of width 100 kHz. A number of tests located sources of systematic errors (interference, pointing) and ways have been found to correct them or eliminate their effects. The achieved sensitivity corresponds to a one-sigma value of about 4 x 10^{12} M_o, somewhat dependent on the values of key cosmological parameters.

New observations were made in the last compact configuration of the VLA and the data collection is now completed. New algorithms to correct for the bandpass response in the presence of intermittent strong RFI have proven necessary to properly reduce the data. The new procedures have now been tested and appear to correct the systematics properly. Indeed, signal-free images are free of artifacts and achieve the theoretical sensitivity across the band. The data reduction is now under way and should be completed in 1997.

11. Instrumentation and Observing Techniques

Among the advantages of being close to the telescopes at the NRAO for the NRAO staff is the opportunity to experiment with new observing techniques and to develop new instrumentation. Several such initiatives will occur in 1997.

In the next year observations at the 140 Foot will be made with a prototype, 19-element, phased array feed. The objectives are to verify the design theory, study the effects of mutual coupling of elements, and understand all sources of coherent noise in the focal plane. As far as we know, this will be the first implementation of a fully sampled feed array in radio astronomy. Follow-on work will include design of balanced amplifiers, cooling techniques for distributed amplifiers, and correlator designs.

New Tunerless SIS Mixers will be developed for the 200-300 GHz band. The present tunerless 200-300 GHz mixers are limited by an apparent biasing instability at the low end of the frequency band. It is found that, in this particular design, the RF embedding admittance becomes inductive and the individual junction can exhibit negative output conductance at the low end of the band. For a series array of junctions this can be an unstable situation in which the pump and bias voltages across the individual junctions may not equal. A new tunerless mixer has been designed to prevent this difficulty. Also, since the capacitance in the new mixer's IF circuit is quite low, it should be capable of achieving good performance with a very wide IF bandwidth. The masks for this mixer have been made. SIS devices will be fabricated by the University of Virginia using the new Au-T fabrication process. We will evaluate this new mixer as soon as it is ready.

Distributed mixing in a non-linear superconducting transmission line has been demonstrated by E. Tong *et al.* of SAO at submillimeter wavelengths recently. Since the input impedance of the non-linear superconducting transmission line is essentially real, only a simple real impedance transformer is required to match it to the external circuit. Consequently, excellent broadband performance may be achieved with this new class of distributed (traveling-wave) mixer. Also, because the optimum critical current density of the superconducting transmission line is significantly lower than that of the conventional high frequency lump element SIS mixer devices, fabrication of these devices should be straightforward. Thus, the superconducting distributed mixer is likely to become the mixer of choice for heterodyne detection at the submillimeter wavelengths. In collaboration with SAO and UVA, we have developed an experimental superconducting distributed mixer for 200-300 GHz. The non-linear Nb/Al-Al_2O_3/Nb superconducting line was fabricated using the recently developed UVA edge-junction process. Although the current density of the first wafer received from UVA was wrong , initial tests using devices from this wafer yield very encouraging results: A mixer noise temperature of 22 K (DSB) and conversion loss of 1.7 dB (DSB) was measured at 250 GHz. Although the mixer performance deteriorates at high frequencies, the RF coupling efficiency remains very good. New wafers are being made at UVA for evaluation in 1997.

The design and prototyping of scientific software will remain a vigorous research area at the NRAO in 1997. The "software problem" in astronomy (and science in general) is the enormous difficulty in bridging the gap between isolated programs for piecemeal data reduction and theoretical modeling of phenomena, and systems with reusable components that allow flexible and rapid modification to solve new problems. Various commercial (IDL, PV-Wave, S+, Mathematica, Maple, MathCAD, etc.) and non-commercial (IRAF, MIDAS, AIPS, Miriad, AIPS++, etc.) are partial solutions, but none yet have (or are likely to have) both the needed levels of power and potential for modification and evolution by astronomers, that is desirable.

In 1997 an effort will begin to design and prototype frameworks of classes oriented toward scientific data processing and algorithm development. This effort is a two-pronged approach assisting the Astro Space Center in Russia while prototyping (and using) modules developed in the Oberon/F implementation of Oberon-2. Whether framework design and emphasis on astronomical concepts in object-oriented approaches can help with this problem is the question being addressed.

Advanced methods of polarization calibration and imaging using the new AIPS++ framework as a research platform will be pursued including the following:

- Methods for estimating and correcting instrumental polarization effects for synthesis arrays (and the VLA) such as the leakage of power from one measured sense of polarization to the other.
- Deconvolution algorithms for joint estimation of Stokes I, Q, U, and V parameters from dirty images. Initial investigations show that even simple CLEAN-based variants bring significant improvements in reconstructions.
- Deconvolution of extended sources using the Puetter-Pina pixon approach. In published applications, this approach allows startlingly good reconstructions of complex objects from limited information. Reconstruction of complex, extended objects from synthesis observations is notoriously difficult and prone to error and so the investigation of pixon-based methods may bring significant improvements.

APPENDIX B – SCIENTIFIC STAFF

(Does not include visiting appointments)

D. S. Balser — Galaxy: Abundance, Structure – ISM: HII Regions, Planetary Nebulae – Radio Sources: Continuum, Line.

T. S Bastian — Solar/stellar radio physics; interferometry; image deconvolution and reconstruction.

A. J. Beasley — Radio interferometry; VLBI observing techniques.

J. M Benson — Extragalactic radio sources; VLBI image processing.

R. C Bignell — Polarization and imaging of extragalactic radio sources; planetary nebulae; supernovae remnants.

A. H. Bridle — Extragalactic radio sources.

R. L. Brown — Theoretical astrophysics; interstellar medium; quasar absorption lines.

B. J Butler — Using observations of the planets and their atmospheres at radio wavelengths to deduce information about them.

E. Carrara — Active galactic nuclei; VLBI.

C. Carilli — Radio galaxies; QSO absorption lines; magnetic fields in galaxies; tropospheric effects on interferometer phases.

J. Cheng — Structural engineering, antenna design theory.

B. G. Clark — VLBA control; software development.

M. J Claussen — Masers; HII regions; molecular spectroscopy; spectropolarimetry; radio recombination lines.

J. J Condon — QSOs; normal galaxies; extragalactic radio sources.

T. J. Cornwell — Interferometry; image reconstruction methods; coherence theory; radio source scintillation.

W. D. Cotton — Extragalactic radio sources; interferometry; computational techniques for data analysis.

L. R. D'Addario — Theory of synthesis telescopes; millimeter receivers; radio astronomy from space.

K. M Desai — Space VLBI; development of VLBI imaging algorithms.

V. Dhawan — Extragalactic radio sources; VLBI; instrumentation.

P. J. Diamond — Spectral line interferometry; VLBI; software development.

D. T. Emerson — Nearby galaxies; star formation regions; millimeter wave instrumentation.

J. R. Fisher — Cosmology; signal processing; antenna design.

C. Flatters — VLBI polarization studies of extragalactic radio sources.

E. B Fomalont — Interferometry; extragalactic radio sources; relativity tests.

D. A. Frail — Interstellar medium; pulsars; supernova and nova remnants; radio stars.

R. W. Garwood — Galactic 21-cm line absorption; interstellar medium; high redshift 21 cm line absorption.

F. D. Ghigo — Interacting galaxies; extragalactic radio sources; interferometry.

B. E. Glendenning – Starburst galaxies; scientific visualization.

M. A. Gordon — CO; galactic structure; gas-rich galaxies; interstellar medium.

W. M. Goss — Galactic line studies; pulsars; nearby galaxies.

E. W. Greisen — Structure of the interstellar medium; computer analysis of astronomical data.

J. Herrnstein — VLBI spectroscopy of galactic nuclei; interstellar masers.

R. M. Hjellming — Radio stars; radio and x-ray observations of x-ray binaries; interstellar medium.

D. E. Hogg — Radio stars and stellar winds; early-type galaxies.

M. A. Holdaway — Image reconstruction methods; VLBI polarimetry.

K. I. Kellermann — Radio galaxies; quasars; VLBI.

A. J. Kemball — Spectroscopy and polarimetry in VLBI; interstellar masers; astronomical software.

A. R. Kerr — Millimeter-wave instrument development.

L. J. King — Antenna structural/mechanical analysis and design; optimization methods for antenna structural performance.

L. Kogan — Maser radio sources; theory of interferometry; software for data reduction of VLBI.

G. I. Langston — Gravitational lenses; computational techniques for synthesis imaging.

H. S. Liszt — Molecular lines; galactic structure.

F. J. Lockman — Galactic structure; interstellar medium; HII regions.

R. J. Maddalena — Molecular clouds; galactic structure; interstellar medium.

J. Mangum — Star formation; astrochemistry; molecular spectroscopy of comets.

R. G. Marson — Aperture synthesis algorithms; optical aperture synthesis; imaging stellar surfaces.

M. M. McKinnon — Plasma astrophysics; pulsars; stellar radio emission; signal processing.

A. H. Minter — Interstellar turbulence; space VLBI.

P. J. Napier — Antenna and instrumentation systems for radio astronomy.

F. N. Owen — Clusters of galaxies; QSOs; radio stars.

S. K. Pan — Design of superconducting circuits; SIS devices.

J. M. Payne — Telescope optics; millimeter-wave receivers; cryogenic systems.

R. A. Perley — Radio galaxies; QSOs; interferometer techniques.

M. Pospieszalski — Low noise front-ends and amplifiers; theory and measurement of noise in electronic devices and circuits.

S.J.E. Radford — Starburst galaxies, millimeter interferometry.

M. S. Roberts — Properties and kinematics of galaxies.

J. D. Romney — Active extragalactic radio sources; VLBI; interferometer imaging.

A. Roy — Nearby galaxies; extragalactic radio sources.

M. P. Rupen — Interstellar medium of early type galaxies; galaxy dynamics; supernovae; steep spectrum sources.

E. R. Schulman — Distribution of cooled gas at outer regions of galaxies.

R. A. Simon — Theory of interferometry; computational imaging; VLBI.

R. A. Sramek — Normal galaxies; quasars; astrometry; supernovae.

G. Taylor — Active galactic nuclei and their environments; Faraday rotation measures; HI absorption; survey observations.

A. R. Thompson — Interferometry; frequency coordination and atmospheric effects; distant extragalactic sources.

B. E. Turner — Galactic and extragalactic interstellar molecules; interstellar chemistry; galactic structure.

J. M. Uson — Clusters of galaxies; cosmology.

P. A. Vanden Bout — Interstellar medium; molecular clouds; star formation.

G. A. Van Moorsel — Dynamics of galaxies and groups of galaxies; techniques for astronomical image analysis.

J. S. Ulvestad — Seyfert and starburst galaxies; blazars; space VLBI.

L. Van Zee — Extragalactic HI; galaxy evolution; star formation; elemental enrichment.

R. C. Walker — Extragalactic radio sources; VLBI; VLBA development.

J. C. Webber — VLBI and Space VLBI; superluminal radio source structure.

D. C. Wells — Digital image processing; extragalactic research.

J. J. Wiseman – Molecular clouds; star formation; interferometric image mosaics.

E. J. Wollack — Cosmic microwave background; instrumentation for radio astronomy.

A. H. Wootten — Star formation; structure, and chemistry of the interstellar medium in galaxies; circumstellar material.

J. M. Wrobel — Normal galaxies; active galaxies; polarimetry.

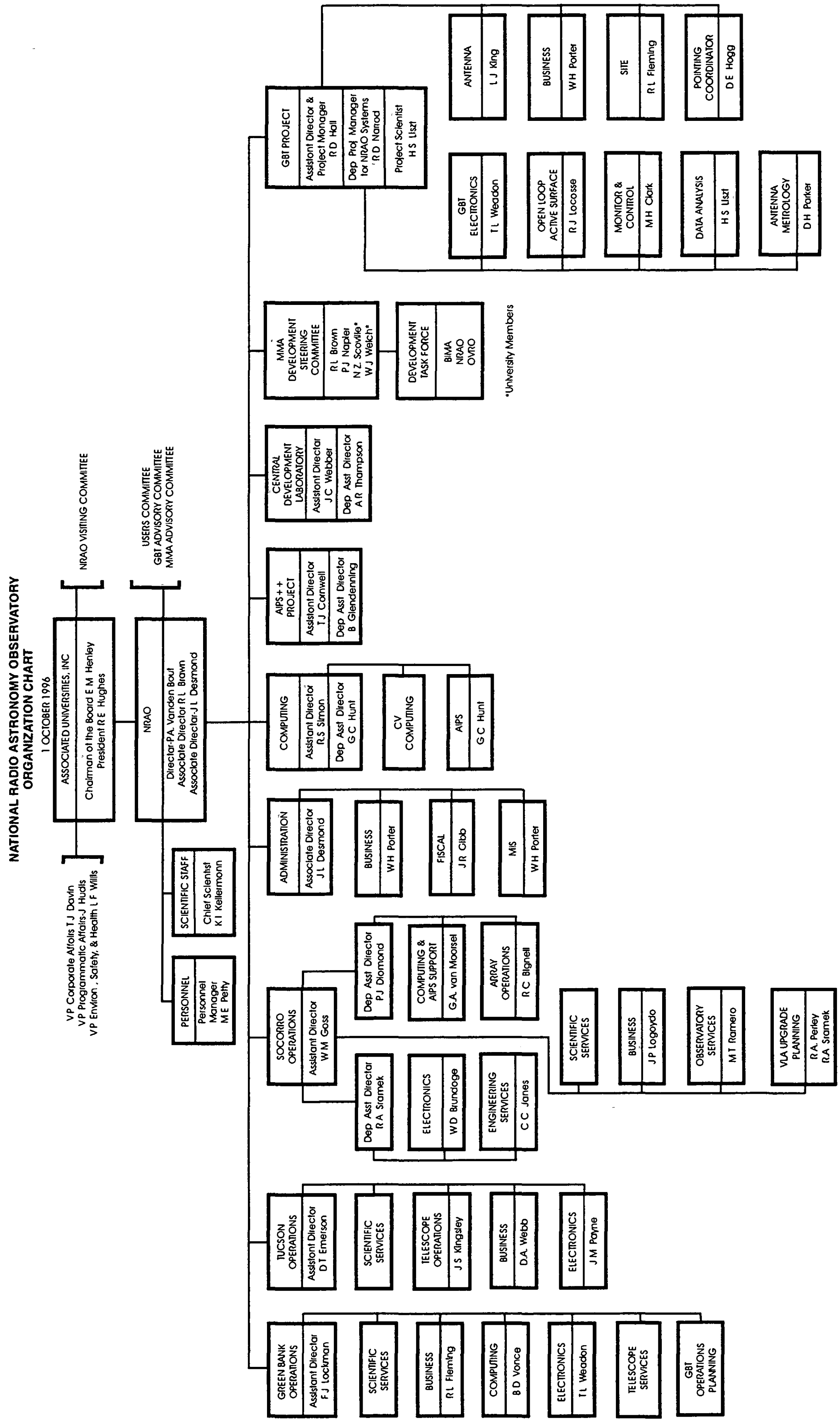
X. Yang — Astronomical software design and development; object-oriented Parallel programming language design.

Q.-F. Yin — Normal galaxies; imaging techniques.

M. S. Yun — Extragalactic radio sources; star formation.

J. A. Zensus — Active galactic nuclei; compact extragalactic radio sources; high resolution interferometry; space VLBI.

APPENDIX C - ORGANIZATION CHART



APPENDIX D – NRAO COMMITTEES

1. AUI Visiting Committee

The Visiting Committee is appointed by the AUI Board of Trustees and formally reports to the AUI Board on an annual basis. Its function is to review the performance of the Observatory and to advise the Trustees on how well it is carrying out its function as a national center, the quality of the scientific work, and the adequacy of its instrumentation and facilities. Current membership is:

T. M. Bania	Boston University
J. E. Carlstrom	University of Chicago
D. B. Campbell	Cornell University
N. J. Evans	University of Texas, Austin
R. Hanisch	Space Telescope Science Institute
K. Y. Lo	University of Illinois
J. Pipher	University of Rochester
M. J. Reid	Center for Astrophysics
L. F. Rodriguez	Instituto de Astronomia UNAM

2. NRAO 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 (development of radiometers and auxiliary instrumentation; operation of the telescopes; the computer and other support facilities; and major new instruments). This committee, appointed by the Director, meets annually in May or June. Current membership is:

A. Arzoumanian	Cornell University
D. C. Backer	University of California, Berkeley
M. A. Barsony	University of California, Riverside
M. Bell	Herzberg Institute of Astrophysics
J. E. Carlstrom	University of Chicago
J. M. Cordes	Cornell University
J. M. Dickey	University of Minnesota
D. M. Elmegreen	Vassar College Observatory
M. Elvis	Center for Astrophysics
A. L. Fey	U.S. Naval Observatory
R. S. Foster	Naval Research Laboratory
R. Giovanelli	Cornell University
L. A. Higgs	Dominion Radio Astrophysical Observatory
D. Hough	Trinity University
C. J. Lonsdale	Haystack Observatory
R. Mutel	University of Iowa

J. Van Gorkom	Columbia University
R. A. Windhorst	Arizona State University

3. Millimeter Array Advisory Committee

The NRAO Director is aided in the planning process for the Millimeter Array (MMA) by the MMA Advisory Committee. Members of the Committee are experienced in the design of millimeter instruments and facilities. At the annual meeting held in the fall of the year, the Committee is asked to review and comment on the technical direction of the MMA project. Current membership is:

F. C. Adams	University of Michigan
T. M. Bania	Boston University
J. H. Bieging	University of Arizona, Steward Observatory
E. B. Churchwell	University of Wisconsin
E. Erickson	University of Massachusetts
N. J. Evans	University of Texas, Austin
P. Goldsmith	Cornell University
R. Hills	Cavendish Laboratory
G. R. Knapp	Princeton University
C. R. Masson	Center for Astrophysics
F. P. Schloerb	University of Massachusetts
P. Solomon	State University of New York
J. Turner	University of California, Los Angeles
E. van Dishoeck	University of Leiden
R. W. Wilson	Smithsonian Astrophysical Observatory
G. Wynn-Williams	University of Hawaii

4. GBT Advisory Committee

This committee periodically reviews the GBT Project. Initially the committee advised the Director on critical design issues facing the GBT project. Review of construction progress and expected telescope performance is the present charge to the committee. The committee is appointed by the Director. Current membership is:

C. Heiles	University of California, Berkeley
R. Hills	Cavendish Laboratory, UK
R. L. Jennings	University of Virginia
J. E. Nelson	University of California, Santa Cruz
V. Radhakrishnan	Raman Research Institute
S. Von Hoerner	NRAO, Retired
S. Weinreb	University of Massachusetts
R. W. Wilson	Smithsonian Astrophysical Observatory

5. AIPS++ Scientific Advisory Committee

This committee advises the AIPS++ Project Manager regarding scientific applications and functionality of the AIPS++ software system. The committee is appointed by the Project Manager with the concurrence of the AIPS++ Consortium Executive Committee. Current membership is:

R. Braun	Netherlands Foundation for Research in Astronomy
J. Chengalur	National Center for Radio Astronomy, India
R. Foster	Naval Research Laboratory
D. Gannon	Indiana University
W. Jaffe	University of Leiden, The Netherlands
L. Mundy	University of Maryland
R. Sault	Australia Telescope National Facility
L. Stavely-Smith	Australia Telescope National Facility
D. Shone	Nuffield Radio Astronomy Laboratories, UK
D. Tody	National Optical Astronomy Observatory
H. van Langevelde	Joint Institute for VLBI in Europe, The Netherlands
A. Willis	Dominion Radio Astrophysical Observatory
A. Wootten	National Radio Astronomy Observatory