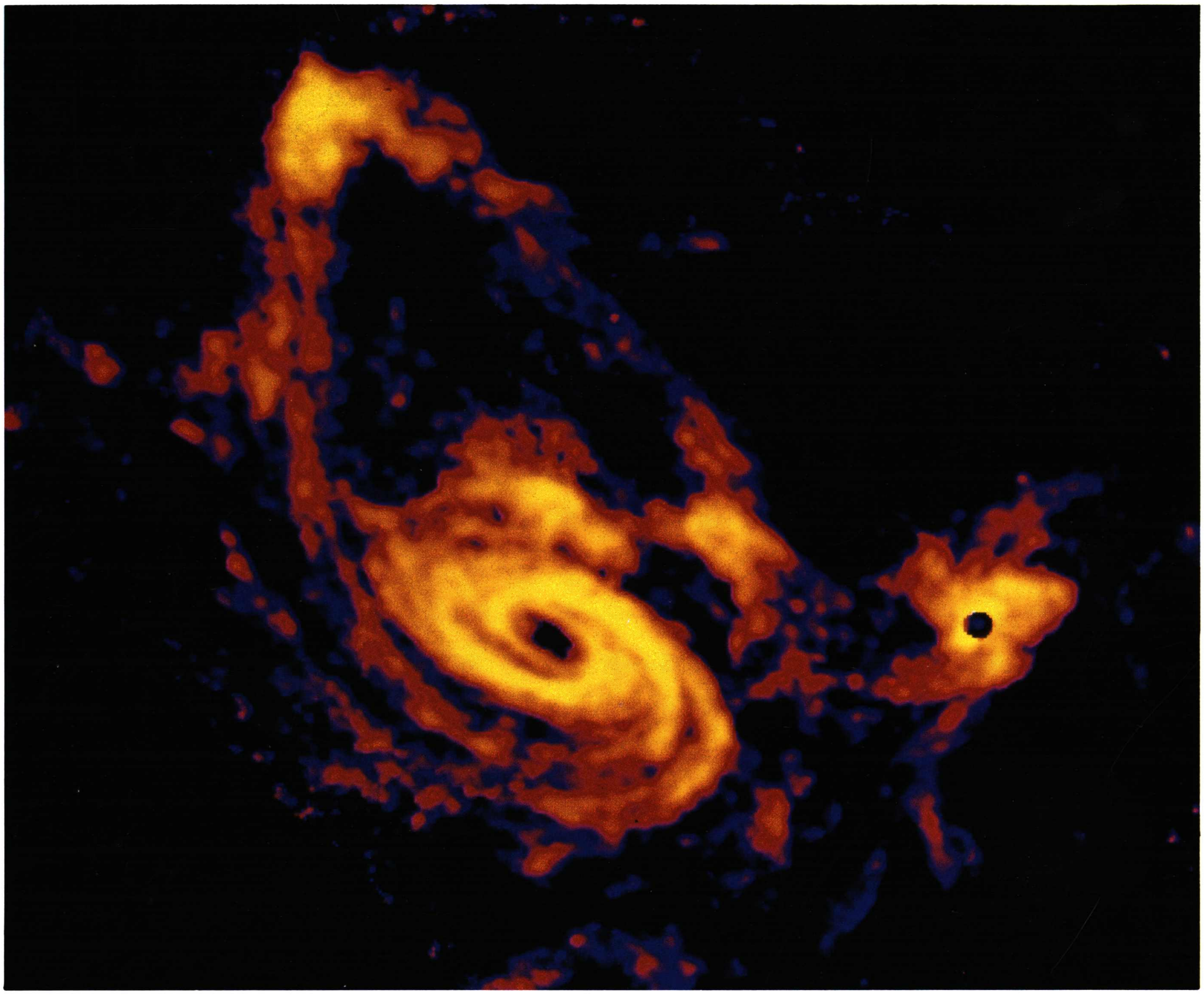
NATIONAL RADIO



ASTRONOMY OBSERVATORY

PROGRAM PLAN 1993

Cover: An image of neutral atomic hydrogen in the triple galaxy system M81 - M82 - NGC 3077. These three galaxies are gravitationally bound to one another; the mutual tidal forces are stripping the hydrogen gas out of each galaxy. Darker red in this radio image indicates an increasing concentration of hydrogen gas. The image seen here is a mosaic of twelve separate images made with the NRAO Very Large Array. VLA observers: Min Su Yun, Paul Ho and K. Y. Lo.

NATIONAL RADIO ASTRONOMY OBSERVATORY

CALENDAR YEAR 1993

PROVISIONAL PROGRAM PLAN

1 October 1992

TABLE OF CONTENTS

I. INTRODUCTION

In 1993 the Very Long Baseline Array (VLBA) begins full operation. The VLBA is the culmination of twenty-five years of technical innovation and development in the techniques of very long baseline interferometry. Pioneered by university researchers and by NRAO scientists and engineers, very long baseline interferometric observations have led to some startling revelations: cosmic radio sources appearing to move apart at velocities greater than the speed of light; the first light of newly formed stars shredding the gaseous material which surrounds them; cosmic rays expelled from stars in intense bursts millions of times more energetic than the most intense solar flare. With the VLBA astronomers will have, for the first time, an instrument capable of providing detailed images of these phenomena that is *dedicated* to their study. The fact that the VLBA will be operated full-time means that it will finally be possible to create true "time-lapse" images of the evolution of cosmic outbursts. We can look forward to "movies" of energetic events on the surfaces of nearby stars and in the nuclei of active galaxies at the fringe of the universe.

For the NRAO, 1993 will be the year we make the transition from construction to full operation of the VLBA. Many activities have to be made to function with a high level of reliability. Not only must the hardware be made reliable, but, for example, such functions as the computer links between the VLBA control center in Socorro, New Mexico, and the ten VLBA antennas, as well as the shipping services that deliver the VLBA tapes to and from the antennas. VLBA operation is a complex enterprise. During restricted interim VLBA operations in the last two years, the NRAO has been able to assemble the nucleus of the operations staff who accept the challenge, and anticipate the rewards, of full-time VLBA operations beginning in 1993.

For the more than 850 scientists and students who use the major user facilities at the NRAO, the Very Large Array (VLA), the 12 Meter Millimeter-Wave Telescope, and the 140 Foot Telescope in Green Bank, 1993 is anticipated as the second year of the program in which it has been possible to make serious progress in restoring the facilities infrastructure of the NRAO. Beginning in 1992, the infrastructure restoration program has allowed the rail system and the power distribution system at the VLA to be improved, the deficiencies in Observatory computing are beginning to be redressed, and instrument upgrades have begun. The benefits can already be seen as detailed in Section III of this Plan. The long-range plan is to double the scale of the current effort and maintain the activity at this level in future years. The infrastructure restoration program is detailed in Section IV.

Progress continues to be made on the Green Bank Telescope (GBT) as noted in Section VI. In 1993 several decisions will be made on the specifications of the initial set of GBT observing instrumentation. Prospective telescope users will be involved in these decisions, beginning with an open forum to be held on this subject at the 181st meeting of the American Astronomical Society. Community involvement with the GBT will be further encouraged and developed as construction proceeds. The GBT is scheduled for operation in 1995.

Beyond 1995 the centerpiece of NRAO planning is the Millimeter Array (MMA). Correctly described by the NSF Advisory Committee for Astronomical Sciences (ACAST) as a "bold and scientifically meritorious project," the MMA is a revolutionary instrument. Capable of imaging the thermal sky with a resolution superior to the design goals of the Hubble Space Telescope, the MMA will greatly expand the horizons of millimeter-wave astronomy. Planning for the MMA is described in Section VII.

The role of the NRAO in the U.S. science community continues to evolve in response to changing needs and desires of astronomers, students, and the public. In some instances the facilities of the NRAO are needed for enterprises that transcend the traditions of ground-based radio astronomical research. Three projects done in support of USNO and NASA are described in Section VIII. In other instances the expertise of the NRAO staff is needed for enterprises that benefit radio astronomy at the NRAO, in U.S. universities, and at observatories worldwide. Two such long-term collaborative activities are described in Section IX. Finally, the opportunity for the Observatory to play a significant role in the scientific education of students and teachers has a number of ramifications described in Section X, some of which are still germinating.

II. 1993 SCIENTIFIC PROGRAM

1. The Very Large Array

The VLA telescope continues to be the lead instrument for ground-based, high-resolution, centimeter wavelength astronomy for the world's astronomers. The telescope has come under high demand as a powerful and indispensable tool for the support of multi-wavelength investigations complementary to space-based observatories such as the Hubble Space Telescope and the ROSAT X-ray telescope. The competition for observing time remains high as reflected in the continued large proposal oversubscription rate and in the exceptional quality of the published data. The number of VLA papers in the literature continues its steady increase.

The VLA will support multi-wavelength solar campaigns with ground, balloon, rocket, and space-based observatories during 1993. Radio, spectral, and morphological observations help to discriminate the physical properties of numerous solar active regions. Critical measurements of background VLA calibrator radio sources will take place during solar occultation events in order to explore the nature of solar wind microturbulence from distances of a few solar radii to the base of the corona. The angular broadening and refractive scintillation of the sources will be measured as a function of elongation from the sun.

In combination with the JPL Goldstone antenna, the VLA will participate in radar imaging of solar system objects. New radar images of Mercury's Caloris impact basin will be obtained at two different look angles to compare directly with the images of three newly discovered basin-like features of similar size. Radar images of Mars will be made to supplement the extremely successful 1988 opposition results. The peculiar "stealth" area with no detectable echo will be mapped over various incidence angles, and ices of the north and south pole will be compared. Using passive 1.3 cm spectral-line observations, Mars's atmosphere and the seasonal variation of its water content and vertical distribution will be studied during the 1993 opposition. The observations will be invaluable for the upcoming Mars Observer spacecraft mission.

The VLA remains a sensitive and versatile instrument for the investigation of stellar radio emission. A survey of the brightest X-ray emitting stars in the young, open cluster α Persei will be carried out in order to compare their radio properties with other stellar properties and to study the age dependence of stellar radio emission. For a representative sample of M dwarf stars in the solar neighborhood, the VLA and the ROSAT X-ray telescope will simultaneously obtain data so that diagnostics of both the hot thermal plasma and the nonthermal electrons can be related to the stellar magnetic fields. Another coordinated program of observations using the VLA, IUE, and ROSAT will be used to study HD 197890, a rapidly rotating late G star. In addition, the changes in the atmospheric structure with time and surface position will be studied. The combined multi-wavelength data will offer the opportunity to study coronal activity of rapidly rotating single stars without the added complications of the binary nature of many objects. For a wider sample of newly discovered radio-emitting K dwarf stars, VLA observations will try to detect temporal variability and specific radio spectral properties to place the K star activity in context with better-known stars such as dMe stars or the Sun. Two RS CVn stars will be monitored in order to investigate the quiescent characteristics of these binary emitters and the relationship between quiescent phases and outbursts. Nine single, cool white dwarfs with strong magnetic fields will be surveyed for the presence of nonthermal radio emission similar to magnetic Bp or RS CVn stars. VLA observations of the binary star T Tau will be used to improve the astrometric parameters of the pre-main-sequence system. Observations of novae radio light curves will be made with sufficient sensitivity so that evolution of the radio images can be measured and shell masses, velocities, and asymmetries can be determined.

Stars in the later stages of stellar evolution exhibit detailed spectral and morphological properties that will be investigated with the VLA. Masers in the circumstellar shells of the late-type star IK Tau will be used for kinematic determinations of the star's distance. For UX Cyg high spectral and spatial OH maser observations will be used to map the magnetic field in the mass-losing circumstellar shell. For extreme asymptotic giant branch stars in the process of mass loss towards the planetary nebula stage, the VLA will monitor the radio continuum of IRC+10216 to specify the nature of its variations. In the protoplanetary nebular shells of OH/IR stars, OH maser observations will be used to determine the fine structure of the shells for comparison with models. NH_3 line observations of the protoplanetary CRL 618 will characterize its high-velocity bipolar outflow. The distribution of electron temperature will be determined directly from multi-wavelength observations of several planetary nebulae. A young, compact planetary nebula will be observed at the highest possible resolution to obtain detailed information on its central ionized region in order to fully understand its evolutionary state. An observation of the compact planetary nebula Vy 2-2 will be added to two previous epochs in order to search for evidence of its angular expansion and to determine its expansion parallax.

Experiments that exploit the new pulsar timing equipment at the VLA continue to pay off, and the search for pulsar companions of planetary mass adds a new dimension to VLA pulsar research. Timing observations of a number of fast pulsars will continue at the VLA as part of a large program in the study of astrometry, binary star evolution, cosmology, gravitation physics, and timekeeping metrology. During 1993 the project will measure the rate of periastron advance, and hence mass, of several binary pulsar systems and will determine the orbital decay rate of an eclipsing binary pulsar. Astrometry of a newly discovered pulsar, the second strongest millisecond pulsar known, will begin while the position of a long-period eclipsing binary pulsar in the globular cluster NGC 6342 will be determined. Another pulsar astrometry program will survey a sample of high-latitude pulsars for a careful comparison with pulsars in the plane to understand differences in the birth and evolution of the two samples. Astrometric observations of other pulsars will test pulsar-supernova remnant associations and examine the case for large transverse velocities in some instances. Polarization profiles will be obtained for two southern pulsars which are known to emit gamma rays in order to improve geometric models and lead to a better understanding of the gamma-ray emission. Searches for pulsar emission will be carried out toward a compact radio/optical nebula which has been modelled as a binary pulsar-powered bow shock.

For the investigation of galactic star-formation regions, the VLA is unparalleled in its combination of sensitivity and resolution. Two star-formation regions with multiple

OB stars and ultracompact HII regions will be searched for the presence of embedded, undetected, ultracompact HII regions that may show morphological evidence for the existence of photoionizing disks. Such disks are postulated to explain the substantial evolutionary time spent by massive stars in the ultracompact HII region stage. For a selected sample of star-forming region sources, the VLA will carry out a search for formaldehyde masers which are known to exist in ultracompact HII regions at locations where OH masers are not detected. Spatially resolved HI absorption maps of the G5.88 ultracompact HII region will be used in conjunction with high-resolution millimeter and IR maps to discriminate among several possible origins for the known high-velocity HI that is present. HI absorption lines will also be sampled from a larger number of ultracompact HII regions in order to identify additional dynamically interesting objects for further study. A detailed high-resolution morphological study of the W51 massive star-forming complex will attempt to discriminate the properties of isolated and interacting ultracompact HII regions as a function of their OB association environments.

The presence of outflows and accretion disks in young star-formation regions will be the focus of several VLA investigations. Observations of the young star HL Tau will try to establish whether its reported 1.3 cm structure is due to a protoplanetary disk or a collimated, ionized outflow. Planned regular monitor observations of the triple radio continuum source in Serpens may provide the first direct evidence of precession or multiple ejections in a jet associated with a young stellar object. Recombination-line observations of the NGC 7538 star-formation region will attempt to confirm the presence of a collimated ionized gas outflow to aid in understanding the connections, if any, between the near-stellar environment and the extended molecular outflow that is present on parsec scales. Potential water-vapor masers in FU Orionis star-accretion disks will be monitored in order to learn more about the dynamics of the episodic outbursts from these young stellar objects. A search in several star-forming regions will be undertaken for a new class of point-like sources that have been identified in Orion to be associated with young stars or young stellar objects.

Interest in the interstellar medium and the galactic center remains high. Information about the galactic magnetic field will be augmented through a search for additional Zeeman-split OH maser lines. Preliminary analysis of OH maser emission from molecular material in a limited sample of ultracompact HII regions favors an axisymmetric configuration for the galactic magnetic field, and additional sources are needed to better map its structure. Formaldehyde absorption from milliarcsecond-scale variations in galactic molecular clouds can be detected against background continuum sources. The VLA is being used to monitor these variations during several observing epochs. A technique has been devised to search for extremely large Faraday rotation in polarized radio emission from the galactic center. Its detection would be valuable evidence for the presence of a significant circum-nuclear disk in the inner part of the Galaxy. The VLA will continue to monitor the galactic center transient source in an effort to measure its angular extent and expansion rate and to understand the relationship between transient events and diffuse nonthermal emission from the galactic center.

Observations of nearby galaxies with the VLA allow detailed investigations of specific galactic phenomena to be undertaken that would be impossible to accomplish for more remote galaxies. Sensitive 21 cm absorption observations of a sample of 24 Seyfert galaxies will be used to determine the location and kinematics of the neutral gas along the line of site to their nuclear radio sources and may help constrain models for fueling AGNs. The measurements will also attempt to uncover differences in the AGN classes. Deep imaging and polarization observations of NGC 1068 and its nuclear triple source will detail its structure, identify the true nucleus, and search for possible variability. VLA observations of a sample of Seyfert galaxies will complement narrow-band imaging data in an attempt to establish a unified scheme that explains the morphologies and energetics of the different Seyfert classes. AGN from the Green Bank 5 GHz survey that have been identified by ROSAT at soft X-ray wavelengths will be quickly surveyed with the VLA in order to obtain arcsecond positions and core flux densities that will be subsequently useful for further radio/optical/X-ray comparisons. VLA observations of supernovae in nearby galaxies continue to form the basis of an ever-increasing statistical database that is invaluable for the analysis of the supernova phenomenon. Monitor observations of historic supernovae will continue, and the detection of additional radio-emitting supernovae will provide important new information about the stellar evolutionary properties and the density of the ambient interstellar medium.

Many investigators will be observing radio emission from sources in clusters of galaxies with the VLA. The morphology and size distribution for a complete sample of radio galaxies near the centers of rich Abell clusters will be obtained in order to study the evolution of individual cluster galaxies in comparison with individual field galaxies. A different survey of distant X-ray selected clusters will be compared with similar radio/X-ray data for nearby cluster galaxies to determine the evolution of the radio galaxy population with cosmic time. Clusters with cooling flows will be searched for evidence of cold HI, suspected on the basis of Einstein Observatory X-ray observations. Cold HI might constitute a significant mass fraction of the intracluster medium. Its detection could provide important constraints on the theories of cooling accretion flows and cluster evolution. Sensitive, high-resolution polarimetry for radio galaxies in cooling flow clusters will be obtained in order to better understand cluster magnetic fields. Large rotation measures are a tool in derivation of the properties of the cooling flows.

Studies of classical radio galaxies at the VLA will encompass observations of their detailed spectral and morphological properties as well as the global features that make them valuable beacons at high redshift. Multi-epoch observations of M87 and Cen A are being taken in order to detect and accurately measure proper motions in the knot-like features of their jets. Ultimately, information about turbulence and the physics of shocks in these jets can be derived from the kinematics that derive from such straightforward, but painstaking, observations. VLA observations of the radio jet in Minkowski's object will be combined with HST data to better understand how the radio source triggered a massive starburst in the host galaxy. High-resolution, multi-configuration VLA observations will be used to probe the unusually rich complex filamentary structure of 3C 353. The source is an excellent laboratory also for studying jet morphology, rotation measure, and the depolarization asymmetry between lobes. Observations of two radio galaxies with redshifts greater than three will be used to determine magnetic field structure, source structure, and spectral aging across the sources. The resultant comparison with the properties of low-redshift radio galaxies can be an important indication of environmental influences on the two source populations. Another study will attempt to increase the known sample of high redshift radio galaxies by focussing on known steep spectra sources identified from single-dish surveys. The VLA positions are crucial to follow-up optical identification and spectroscopic studies of the most interesting distant galaxies. Two additional studies will search for high redshift radio galaxies with widely differing radio properties in an unbiased manner and thoroughly investigate the "alignment effect" whereby radio, optical, and infrared image axes are inexplicably aligned with one another. Snapshot observations of a large sample of 5C 12 survey sources will anchor optical identifications for direct comparison to the much brighter 3C sources and a study of the cosmological evolution of radio sources. Selected radio galaxies will also be observed with the fledgling VLA 73.8 MHz receiver system.

Numerous quasar samples will be exploited in an attempt to determine evolutionary and environmental factors on their observational characteristics. Radio-loud quasars, under detailed UV observation with the HST, will be observed with the VLA in order to establish their radio core dominance parameter and as a prime orientation indicator in the quasar model that postulates a large infall of matter onto a massive central object. A $z=1$ sample of low radio-luminosity quasars will be imaged for comparison to a radio-loud sample at the same redshift to investigate the dependence of the properties of the underlying host galaxies, their environments and the alignment effect, on radio luminosity and epoch. Another test of the "unified scheme" will monitor the core radio variability of lobe-dominated quasars in comparison to core-dominated ones and with the optical light curves. An observational test has also been designed to test for a direct correlation between jet side and lobe spectral-index and/or the presence of narrow-line gas. A positive correlation would favor the hypothesis that jets are intrinsically one-sided as opposed to relativistically beamed. Radio imaging of all HEAO-1 X-ray selected BL Lac objects will be completed in order to investigate the incidence of one-sided jets in the sample. A Faraday rotation image of the quasar 3C 196 will be made in order to learn about the magnetic field morphology of the very distant intervening galaxy and as a discriminant between competing theories of the origin of galactic magnetic fields.

Gravitational lenses have proven to be valuable probes of the physical properties of distant sources; the VLA participates in an increasing number of lens experiments. A VLA survey for VLB and MERLIN phase calibrators also identified several extended objects with flat radio spectra. These will be followed up with multi-frequency observations as a potentially valuable source of lenses with angular extents of less than an arcsecond. Objects that have already been confirmed in this program will be monitored for their variability time delay as a key component of possibly deriving the Hubble constant from the data. For another candidate, VLA and MERLIN observations will be used to probe the rotation measure around the lensed ring image and thereby obtain information about magnetic field structures on a 1 kpc scale in the lensing galaxy. Higher resolution observations of several lens candidates will be made in order to more completely constrain the models of the lens. The VLA will also continue to follow-up on a completely different sample of gravitational lens candidates that was derived from the MIT-Green Bank survey. Once the VLA morphologies are confirmed optically and tested spectroscopically, some of the most promising candidates are monitored with the VLA for flux-density variations for long periods in order to derive relative time delays for different path lengths and thereby directly determine the Hubble constant. Again, detailed VLA maps are needed for some sources in order to propose more sophisticated lensing models. An attempt will also be made to confirm the first example of a lens associated with an Abell cluster.

2. The Very Long Baseline Array

In 1993 the VLBA will officially be in full operation, although much of the observational activity will be devoted to performance evaluations and instrument shakedowns. The number of proposals for observing time has increased as the full instrument has approached completion. The following descriptions illustrate the wide ranging scientific topics to be addressed with the VLBA during 1993.

Major programs investigating the milli-arcsecond morphologies and the energetics in the cores of distant radio galaxies will occupy much of the observing time on the VLBA. Observations at the shortest VLBA wavelength (7 mm) will examine the core of the radio galaxy Cen A. Since it is the closest known radio galaxy, structure at the nuclear engine on the scale of only one light day will be resolvable. Combined VLBA and southern hemisphere VLBI monitoring at other wavelengths will be done in parallel to determine the expansion velocity of the Cen A jet and to place limits on the strength of a possible counterjet. VLBA images of M84 will be compared with the appearance of VLA-scale jets to study the process by which the jets become symmetric at increasing distance from the core. Multi-epoch VLBA observations of the optically violent, variable quasar 3C 273 will form part of a multi-wavelength campaign to test the synchrotron self-Compton model for X-ray emission in such sources. These global VLBI observations will measure emitting region sizes and radio-spectral properties for the source components. In the source 3C 119, high-resolution polarization mapping will attempt to differentiate between models for the source depolarization.

Circumstellar and interstellar maser sources will be the subject of numerous VLBA investigations to determine the structural and kinematic properties of diverse galactic environments. VLBA polarization observations of the OH maser emission from supergiants will be obtained in order to investigate the magnetic field structure in the star's circumstellar envelopes. Multiple epoch data should also constrain the proper motions of the expanding shells. Much will be learned about the environment of the near-stellar surface from SiO maser observations. Multi-transition and multi-epoch data obtained with the VLBA will provide valuable information about the time-variable environment surrounding evolved stars that will complement that which has been learned from the more extensively studied OH and H_2O masers. In the young star-forming region, W3 (OH), VLBA observations of the proper motions of the OH and H_2O masers will help elucidate the evolutionary state of the maser source. In several other star-forming regions, the very strong 44 GHz methanol maser will be observed to establish the very basic parameter of brightness temperature and the position in order to proceed with model calculations interpreting regions of interaction between molecular outflows and the ambient interstellar medium.

Pulsar observations will be used to investigate the interstellar plasma as well as the properties of the pulsars themselves. The VLBA, in combination with the southern hemisphere (Australia - South Africa) SHEVE VLBI network, will observe the Vela pulsar to measure the phase velocity and proper motion of the material that scatters radiation from the pulsar. Using the interstellar scattering disk around the pulsar as a lens, an experiment will attempt to detect the changing position of the rotating pulsar emission region and possibly to image it on nanoarcsecond scales. A measure of the electron-density turbulence in the interstellar medium will result from VLBA observations of a quasar lying behind the NGC 6334 galactic HII region.

The VLA/VLBA combination will prove to be a powerful instrument to investigate solar phenomena on widely separated spatial scales. Background calibrator sources will be monitored by the two instruments as the sources are occulted by the solar corona. The measurement of angular broadening and scattering isotropy as a function of baseline length will indicate the scale sizes of turbulent fluctuations, thereby providing direct experimental evidence for coronal plasma turbulence and tests for theories of heating in the solar corona. Only direct spacecraft probes can provide comparable data.

Astrometric and geodetic experiments will play an increasing role in the VLBA observing program as 1993 progresses and the observing system becomes fully operational. VLBA tests will be performed to evaluate the traditional astrometric technique of using nearby calibrators for phase connection. Monthly geodetic experiments will employ several of the VLBA antennas in order to evaluate and improve the ability to measure local vertical-antenna coordinates with a precision better than 10 mm and to measure high-frequency variations in the earth's rotation parameters. Improvements in the geodetic measurements will eventually lead to better understanding of the dynamics of the solid earth, such as changes in the global sea level and interactions with ocean currents and weather systems.

3. 12 Meter Telescope

By 1993, the 12 Meter Telescope will have achieved its goal of offering state-of-the-art, dual-channel SIS receivers at all usable wave bands, from 68 to 300 GHz. In addition, the upgraded 8-beam, 230 GHz SIS receiver will be available in the coming year. Efforts will then turn to widening the bandwidth of these receivers and to constructing a 32-beam SIS receiver. The scientific program at the 12 Meter will take advantage of the extraordinary sensitivity of the dual-channel SIS receivers and the fast-imaging capability of the multibeam system.

A major development in astronomy, done first at the 12 Meter, was the recent discovery of CO and CI emission in highly redshifted galaxies such as IRAS F10214+4724 ($z = 2.3$). This discovery has profound implications for the understanding of the evolution of galaxies. For example, the look-back time to IRAS 10214 is more than 80 percent of the age of the Universe. This indicates that in the first 3 billion years enough stellar life-cycles occurred in this galaxy such that an abundance of metals and heavy elements, including carbon and oxygen, were able to form. Research in this area will continue in the coming years and will likely concentrate on defining the class of high-redshift objects that exhibits CO and CI emission. The baseline stability and frequency flexibility which allows a broad range of redshift tunings make the 12 Meter ideal for this branch of research. Anticipated increases in intermediate frequency (I.F.) bandwidth should further aid the detection of these broad spectral lines.

In addition to the study of extraordinary galaxies such as IRAS 10214, the 12 Meter will be used extensively to study more nearby galaxies. For example, a search will be made for the missing gas processed through cluster cooling flows. One theory holds that this gas is in molecular form and will be evident as weak, but extremely broad, CO spectral lines. The 12 Meter was chosen for this project because of its sensitivity and flat spectral baselines. Other studies will search for intergalactic molecular clouds and study the evolution of interacting galaxies. A study of the effects of the spiral shock-wave in the arm and interarm regions of M31 is also underway.

Studies of the structure of the Milky Way Galaxy continue to be popular with the 12 Meter. Research into the structure of the outer galaxy will be particularly active in the coming year. For example, one project will study three galactic clouds that are beyond the star-forming disk of the Milky Way. In fact, these clouds are the farthest from the galactic center of any clouds known. The researchers will use up to six transitions of CO and CS in the 1 mm, 2 mm, and 3 mm spectral windows to understand how star-formation proceeds — or does not proceed — in the outer galaxy. Another study of the outer galaxy seeks to analyze methodically about one square degree of the Galaxy. This project aims to study the spiral structure of the Milky Way and the effect of the galactic environment on molecular clouds and associated star formation.

Among its many accomplishments, the 12 Meter is perhaps best noted for its contributions to interstellar chemistry. Research in this field will continue to be very active at the 12 Meter. Over 80 molecules are now known to exist in interstellar or circumstellar environments; many of the recent additions to this list have come from the 12 Meter. As this field has matured, however, emphasis has shifted from prospecting to analysis. For example, one likely project seeks evidence for grain catalysis which will seed and alter ion-molecule, gas-phase chemistry. Another project will study the SO^+ ion, which is believed to be an excellent diagnostic of dissociative shock chemistry. This particular ion is seen in abundance in the supernova remnant IC 443, where shocks are known to be present. Projects seeking to enlarge the scope of interstellar species are searches for metal oxides and hydrides such as FeO and CaH.

Several interesting projects on stars and circumstellar envelopes will be carried out on the 12 Meter in the coming year. One such project is the study of extended envelopes about S stars. These are relatively rare stars whose C/O ratios are near unity. They may be in a short transition period between longer-lived O-rich and C-rich phases. The project will accurately measure the mass loss of these objects. Quite interestingly, some of the objects observed so far in this project seem to have detached shells that are possibly the remnant of episodic mass loss. The spatially extended nature of the emission is ideal for imaging with the 12 Meter. Another circumstellar project is the study of the radio recombination-line emission from the star system MWC 349. The system appears to be a Be star with a surrounding disk and ionized wind. This object may be indicative of a common phase of evolution for massive stars.

As a final demonstration of the broad spectrum of projects supported by the 12 Meter, one upcoming project will involve the study of terrestrial nitrous oxide (NO), ozone (O_3), and several other molecules. The species to be observed describe upper mesospheric ozone chemistry rather completely, and hence are of importance to the global ozone depletion question. The same researchers will also take advantage of the inferior conjunction of Venus and the opposition of Mars to study HDO and H_2O_2 in the planetary atmospheres.

4. 140 Foot Telescope

The 140 Foot Telescope, with its suite of receivers spanning nearly all frequency bands between 100 MHz and 35 GHz, and with backend equipment capable of processing continuum emission, pulsed emission, and line emission, is applied to a wide range of radio astronomy observations. However, in 1993 the focus will be on three primary areas: studies of the interstellar medium of the Milky Way, studies of the properties of pulsars, and studies of the molecules and gas in distant galaxies.

The increasing availability of excellent data both in the ultraviolet and in X-ray wavelengths has spawned an increasing amount of work with the 140 Foot Telescope, mainly in the mapping of the distribution of neutral atomic hydrogen. Some programs will examine regions mapped in X-rays by ROSAT, in order to compare the spatial distribution of the extinction of X-radiation with the distribution of hydrogen, and, in some cases, with the distribution of selected molecules. Such multi-wavelength comparisons offer the possibility of shedding new light on the relationship between atomic and molecular gas, especially molecular hydrogen; will be useful in identifying regions of minimum optical extinction; and will give important constraints to models of the soft X-ray background. Other programs will compare very sensitive measurements of hydrogen emission made in the directions toward which ultraviolet absorption spectra of quasars have been obtained with the Hubble Space Telescope, in an attempt to determine if there is a general population of high-velocity, high-latitude HI clouds.

There will of course be many other galactic studies. A program to study the physics and chemistry of selected small features in the galactic cirrus will be completed with a last set of observations of formaldehyde. A number of studies comparing the distributions of HI and CO will be started, and Zeeman observations will follow-up on the earlier intriguing observations which show an apparent connection between HI, CO, and abrupt reversals in the sense of the interstellar magnetic field.

The 140 Foot Telescope will be used in the study of the regularity with which pulses are emitted by nearby millisecond pulsars, i.e., those having pulse periods less than about 20 milliseconds. Most of these objects are old pulsars whose spin rate has been recently increased because material has been transferred to them from a nearby companion star. High-precision timing measurements of these objects offer the potential of testing the stability of atomic clocks and of providing cosmologically significant measurements of the gravitational-wave background in the universe. The data also will yield important new information about the masses of stars themselves and about how systems comprised of two stars in close proximity evolve, as well as performing accurate tests of relativistic gravitation theories.

Pulsars are a valuable probe of the interstellar medium in the Milky Way. As a radio wave travels through the medium, variations in the electron density which the wave encounters cause changes in the phase of the wavefront, effectively changing the direction of propagation. The result is that the amplitude of the pulses received is a complex function of frequency and time. The 140 Foot Telescope will monitor two dozen of the stronger pulsars over two years, looking at them at several frequencies, with a view to measuring the amplitude variations and the scintillation velocity. The observations also offer a possibility of advancing our understanding of pulsars themselves. If a particularly strong incidence of refraction can be found, the associated amplitude variations will be used to infer the details of the distribution of the emission from the pulsar magnetosphere.

Most of the pulsar research undertaken with the 140 Foot Telescope involves studies of samples of pulsars chosen in such a way as to provide a statistically significant test of the particular phenomenon in question. Occasionally there are individual objects of such interest that they merit an extensive observing program by themselves. Such an object is the pulsar in the globular cluster NGC 6342. The pulsar is in a close binary system and appears to be interacting with the wind from the nearby companion star, but has a pulse period of one second rather than the millisecond scale expected for a pulsar accreting mass from a companion. Multi-frequency observations extending over several years, with emphasis on times of eclipse, will be used to estimate the pulsar's spindown.

This quantity tells about the pulsar's energy loss and magnetic field, and may serve to illuminate the questions as to why this pulsar has not been "spun-up."

The 140 Foot Telescope will be used extensively in the study of both nearby galaxies and distant galaxies and quasars. Typical programs include the examination of the properties of the dust lane in Centaurus A and the measurement of the hydrogen content of the lenticular galaxy NGC 3115. The search for intergalactic hydrogen clouds will be continued. But the greatest effort will involve the study of lines at high redshift, a field that has experienced a great revival of interest following the detection last year of CO emission in the spectrum of the infrared object F1024+4724, a gas-rich galaxy lying a redshift of $z = 2.29$. Programs to be run during the coming year will generally concentrate on gas-rich objects of moderate redshift, but will examine such diverse properties as the neutral hydrogen content, the presence of OH megamaser emission, and the stimulation of radio recombination-line emission by continuum emission from active galactic nuclei.

As in the past, approximately 25 percent of the observing time will be used in support of Very Long Baseline Interferometry. The bulk of this time will be scheduled in collaboration with the VLBA and with Global Network sessions.

III. USER FACILITIES

1. Very Large Array

Status of Present System

More than 625 scientists used the VLA for their research work in 1991, and a similar or larger number will have done so in 1992. 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, or X-ray wavelengths. Or, it may be the focus of one's 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 to that achievable with modern detectors at other wavelengths means that all the data can be merged with no ambiguity. This provides a very comprehensive research capability.

Present Instrumentation

The VLA consists of twenty-seven 25-meter antennas arranged in a wye configuration, 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 a maximum baseline along each arm of 0.59, 1.95, 6.39, and 21.0 km, respectively. Reconfigurability provides the VLA with variable resolution at fixed frequency.

The VLA supports six frequency bands, remotely selectable; the five upper bands by means of subreflector rotation. When the VLA became fully operational in 1981, receiving systems were supported at 1.4, 5.0, 14.4, and 22.5 GHz, with the fundamental amplification at all four frequencies occurring via a 5 GHz parametric amplifier — 1.4 GHz was preceded by a parametric upconversion to 5 GHz, whereas both

14.4 and 23 GHz were mixed down to 5 GHz for amplification. Since 1981, most of these systems have undergone major improvements. Presently,

- 1.4 GHz amplification is done at the signal frequency with a cryogenic HFET developed at the NRAO Central Development Laboratory (CDL);
- 5.0 GHz amplifiers are nearly all CDL HFETs;
- 14.4 GHz amplification is done at the signal frequency with CDL GaAsFET amplifiers;
- 23 GHz amplifiers are CDL HFET units. In addition, two new frequency bands have been installed;
- 8 GHz HFET amplifiers have been added to all antennas. This X-band system was constructed with funding provided by NASA/JPL in support of the Voyager 2 encounter with Neptune;
- 327 MHz prime focus GaAsFET receivers were installed.

The table below summarizes the parameters of the VLA receiver system.

<u>VLA Receiving System</u>

Frequency (GHz)			T_{sys} (K)	Amplifier
0.070	-	0.075	1000*	Bi-Polar Trans.
0.308	-	0.343	150	GaAsFET
1.34	-	1.73	35**	Cryogenic HFET
4.5	-	5.0	60	Cryogenic HFET
8.0	-	8.8	35	Cryogenic HFET
14.4	-	15.4	110	Cryogenic GaAsFET
22.0	-	24.0	180	Cryogenic HFET

* Eight equipped antennas. T_{sys} includes galactic background.

**Eighteen antennas; remainder to be completed in 1993.

The VLA receives two IFs, 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.

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. Since that time, the VLA has been an extraordinarily productive scientific instrument, and has been used by more than 1200 astronomers for a wide variety of investigations, including the solar system and galactic and extragalactic research. However, as a result of technological advances during the past decade, much of the instrumentation needed to keep the VLA at its current leading position among the world's radio astronomy facilities has yet to be installed.

When designed in the mid-1970's, the VLA used state-of-the-art technology. Over the last fifteen years, however, there have been major advances in receiver sensitivity, correlator design, and the transmission of broadband signals which have already been incorporated into other, new radio telescopes such as the VLBA, the Australia National Telescope, and the Nobeyama millimeter interferometer. In its current configuration, the VLA can still observe radio sources which are two orders of magnitude fainter than have been observed by any other radio telescope. By using modern, low-noise radiometers, fiber-optics transmission lines, and a broad bandwidth correlator, it will be possible to gain *another* order of magnitude improvement in sensitivity. New receivers are also needed at wavelengths not presently covered in order to extend both the spectral coverage and the range of sensitivity to low surface brightness observations.

The program to modernize the VLA electronics amounts to a major overhaul of the entire receiving instrumentation. It is described in Section IV of this Preliminary Program Plan as one of the steps needed to restore the Observatory infrastructure. The first step it to complete the upgrade of the VLA L-band receivers to HFET instrumentation in individual cryostats. This project will be completed in 1993. The remainder of the ten-year program to restore the VLA is outlined in Section IV.

2. Very Long Baseline Array

Status

The VLBA will begin the transition from a construction project to an operational user facility in 1993. At the beginning of the year, nine of the ten antennas will be operational and the correlator will be in advanced stages of checkout. Full support will continue to be given to Global VLBI Network sessions, and VLBA stand-alone science observations will increase rapidly. The ramp-up to full-time operation is expected to occur during the first half of the year as the correlator checkout is completed. The last antenna, located on Mauna Kea in Hawaii, is also expected to begin operation during the first few months of the year. By mid-1993, most of the residual construction activities should be complete and the array should be fully functional.

Proposals for the use of the VLBA are being accepted and considerable interest is evident. At the June, 1992 proposal deadline, with full VLBA operation still many months away, proposals for observations involving just the VLBA outnumbered Global Network proposals by 40 to 25. Early observations with the partial VLBA have demonstrated its capabilities in many areas, including high dynamic range, ease of use at high frequencies, frequency agility, and scheduling flexibility. Also, the very important ability of the Array to serve astronomers who are not specialists in VLBI observational techniques has already begun to have an effect.

Present Instrumentation

The VLBA is a dedicated instrument for Very Long Baseline Interferometry. The ten antennas are distributed about the United States 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 resolutions up to 0.2 milli-arcseconds 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 Array Operations Center in Socorro, New Mexico. Local intervention is only required for changing tapes, for maintenance, and for fixing problems.

The VLBA is outfitted for observations in nine frequency bands as shown in the table below. The receivers at 1.4 GHz and above contain cooled HFET amplifiers from the CDL. The low-frequency receiver 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.

VLBA Receiving Systems

Band Designation (Note 1)			Frequency Range [GHz]			Aperture Efficiency (Note 2)	System Temp [K] (Note 3)
330	90	P	0.312	-	0.342	0.45	195
610	50	P	0.580	-	0.640	0.40	200
1.5	20	L	1.35	-	1.75	0.57	32
2.3	13	S	2.15	-	2.35	0.50	34
4.8	6	C	4.6	-	5.1	0.72	40
8.4	4	X	8.0	-	8.8	0.70	35
14	2	U	12.0	-	15.4	0.50	73
23	1	K	21.7	-	24.1	0.60	100
43	0.7	Q	41.0	-	45.0	0.45	100

Notes:

1) MHz/GHz frequency; centimeter wavelength; conventional radio (or VLA) letter codes.

2) Overall aperture efficiency, and total system noise temperature, at zenith. Values are representative of those measured on several VLBA antennas.

3) Single-frequency performance (without dichroic) shown.

VLBI requires a very accurate frequency standard and a wide bandwidth recording system at every 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 heavily modified by the Haystack Observatory. The recorder is similar to the one used in the Mark III and future Mark IV VLBI systems. There are two drives at each VLBA station to allow about 24 hours of recording at 128 Mbits/second between required visits to the station 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 correlate up to eight input data channels from each of up to twenty sites. For most modes, up to 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.

VLBA postprocessing is done in the AIPS system for now. Considerable software development for VLBI in AIPS is still going on. Astrometric/geodetic processing will be done primarily in the system developed by the Crustal Dynamics Project (now DOSE) at NASA. Over the next few years, the postprocessing will shift to the AIPS++ system as that system acquires the necessary capabilities. The in-house computing for the VLBA is done mainly on workstations of the SUN IPX and IBM RS/6000-560 classes.

Future Plans

For the immediate future, much of the available effort will be focused on obtaining the best possible performance from the VLBA. Studies will be made of ways to improve the antenna pointing, the efficiency, and system temperature at both the lowest frequencies and at the dual-frequency system (S/X band), the amplitude calibration, the system phase calibration, and many more items. The performance of the VLBA as a geodetic/astrometric instrument will be tested and improved as the geodesy community works toward their goal of station motion measurements accurate to 1 mm per year. Most of these projects will not involve significant funding, but hardware may be found to be needed. For example, tilt meters may be needed on the antennas to improve pointing.

One the most important projects will be to learn how to make the Array "phase stable." With a connected element array such as the VLA, phase-calibration sources are used for calibration. This allows images to be made without using the self-calibration techniques upon which VLBI normally depends. Weak sources, which require coherent integrations over the whole time of an experiment and over all baselines, can be observed. Imaging of complex sources is simplified. Accurate relative positions can be measured which allows for proper motion and parallax studies and for alignment of images made at different frequencies or different times. If phase calibration using nearby calibrators can be used on the VLBA, it will have a tremendous impact on the science that can be done.

One of the major advantages of the VLBA over the older VLBI Networks is its ability to work at high frequencies. The antennas were designed for good performance at 43 GHz, and receivers for that frequency have been installed and are working well. The antenna structures were designed to work to 86 GHz, and the surfaces were figured as well as possible, within the technologies used, to allow some performance at this frequency. Early measurements, with a substandard subreflector, gave an efficiency near 20 percent, which is very usable. An exciting project will be to build and install 86 GHz receivers, thereby doubling the maximum angular-resolution of the instrument. This project must be accompanied by a serious effort to improve the pointing of the antennas, but there are no obvious reasons why the VLBA cannot soon become the instrument of choice for high-resolution observations at the longer millimeter wavelengths.

Scheduling and Observing

At the beginning of 1993, as during 1992, astronomical observing on the VLBA will consist of Global Network projects during the Network sessions and VLBA projects using the Mark II and Mark III systems at other times. Global Network observing amounts to about three weeks every three months and is expected to continue into the indefinite future. Projects that need more baselines than the VLBA can provide, or that need to use large antennas for sensitivity, will continue to use the Network. Most Network projects use the VLBA, Green Bank, the VLA, Haystack, and antennas of the European VLBI Network. Arecibo, the Deep Space Network, and antennas in places such as South Africa, Brazil, Japan, Australia, and China are occasionally used. The NRAO took over the proposal handling, refereeing, and scheduling functions of the U.S. VLBI Network during 1992, so Network projects are proposed in much the same way and on the same deadlines as VLA and VLBA projects.

Seven of the VLBA antennas are outfitted with Mark II systems and are being used for astronomical observations using this recording format. The Caltech correlator is sufficiently large that there is little problem getting such projects correlated. A few spectral-line projects are correlated on the NRAO Mark II correlator in Socorro. It is intended that the Mark II correlator in Socorro will be shut down during 1993, and it is expected that demand for Mark II observations will cease once the VLBA correlator is fully functional.

All VLBA antennas can record Mark III data; it is one format option for the VLBA recording system. However, correlator (Haystack and Bonn) and tape resources are limited and are committed mainly to Network observations. Therefore, the amount of non-Network Mark III observing done before the VLBA correlator is available is limited. One Mark III group, namely the geodetic group at NASA, has independent correlator resources (that community is the primary funding source for the Haystack and Washington correlators) and has been a major VLBA user. This has been valuable to the VLBA development because they process very quickly, look carefully at their data, demand a high level of performance, and report problems.

During 1993, the major change in observing will be brought about by the availability of the VLBA correlator. We expect the correlator to be reliably used for astronomical or geodetic observations during the first few months of 1993. Once production processing begins, it will take a while to get everything working smoothly enough for full-time Array operation, so there will be a period of a few months while the amount of observing ramps-up. It is expected that ramp-up will begin very early in the year and be complete at about mid-year. As this occurs, the amount of Mark II observing should drop and the processing of Mark III and VLBA format observations, both Network and pure VLBA, will shift to the VLBA correlator. During the latter half of 1993, the VLBA should be in full operation.

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, increasingly, 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 are maintained, and 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 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 provides a 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

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

Telescope Specifications

Diameter: 12 meters	
Astrodome with slit	
Pointing accuracy 5"	
Effective surface accuracy:	60 μm rms
Aperture efficiency:	49% at 70 GHz
	45% at 115 GHz
	25% at 230 GHz
	15% at 345 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

A program to replace all receivers at the 12 Meter Telescope with a new generation of SIS systems is nearly complete. The table below indicates the performance achieved by mid-1992. Note that an entirely new part of the millimeter-wave spectrum, centered on 150 GHz, is available for the first time at the 12 Meter.

Receiver List

Frequency Range (GHz)	Mixer	SS Receiver Temperature (K) (per polarization channel)	Notes
68-116	SIS	60-90	
130-170	SIS	160-300	1
200-270	SIS	160-800	2
270-310	SIS	~200	3
Eight-beam Receiver			
220-250	8-SIS	200	4

Notes:

1. A new frequency band for the 12 Meter Telescope. The receiver temperature is about 160 K at the low to middle part of the band, and rises at the high end. Even better SIS mixers are expected by 1993.

2. Receiver noise is around 200 K SSB for most of the band, increasing to 800 K at the high-frequency limit.

3. Scheduled for installation in the autumn of 1992. A complementary mixer set for the 330-360 GHz band is expected soon. The noise performance is estimated.

4. The 8-feed Schottky system is being upgraded to an SIS system. First testing is expected in early 1993. Given noise performance is based on a prototype tunerless SIS mixer.

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

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

Filter Bank List

Resolution (kHz) Per Channel	Number of Channels	Number of Filter Banks
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 now available. Its instrumental parameters are as follows:

- 8 independent, fully 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.

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.

To this end, the 8-feed Schottky mixer system was made available during the 1989-1990 season. The system was a great success, in spite of compromises in the implementation, namely, the hybrid spectrometer was not yet operating with the full versatility of its original design, and the telescope control system at that time severely restricted the convenience and efficiency of the system. The 12 Meter Telescope now operates under a completely new control system using modern hardware, and we will finish the planned implementation of the hybrid spectrometer by the end of 1992.

The eight-feed Schottky system is being upgraded to use SIS mixers, thereby giving state-of-the-art sensitivity in all feeds. This upgraded system should become available to observers during 1993. An extension to a 32-feed SIS system is planned during 1994. The key to this development is the backend electronics. We have developed a prototype acousto-optic spectrometer (AOS), which could eventually become an 8-spectrometer system to extend the usefulness of the 8-feed system and could ultimately be expanded to serve a 32-feed system. However, new developments in high-bandwidth, digital correlator systems have also allowed us to begin prototyping a new-generation digital correlator card in collaboration with the Caltech Submillimeter Observatory. The prototype should be completed by the end of 1992 and tested during 1993. This system could provide the foundation for both the 32-feed system and the MMA correlator. The choice of which approach to take for the 32-feed system, AOS or digital, will be made on the basis of the two prototypes. Of course, a 32-feed system puts 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. During 1993 we will be concentrating on improving the observing efficiency of the telescope, and developing and implementing new observing techniques. The data acquisition rate will have increased by between 1 and 2 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.

Single-Beam Systems

Receivers. NRAO has traditionally provided receivers equalling or bettering any others in the world, and this is particularly true at millimeter wavelengths. A closed-cycle 4.2 K system capable of holding eight SIS receivers sharing the same dewar has been developed. By the end of 1992, a complete set of state-of-the-art, dual-channel SIS receivers will be operational over the entire range 70-310 GHz; coverage of the 330-360 GHz window will follow soon. The arrangement of several receivers sharing the same dewar is extremely effective in terms of cost, manpower, and in operational demands. These will equal or better the sensitivity of any existing receivers in the world.

To enhance further the flexibility and data acquisition efficiency, we are exploring the possibilities of simultaneous observations in different frequency bands through the use of beam splitters. This would be an important development for the future MMA.

Antenna Improvements

Surface Accuracy. During the summer of 1992, the 12 Meter staff conducted the most successful satellite holography session yet. Using an improved receiver package, a more accurately determined satellite ephemeris, and a new "on-the-fly" observing technique, the staff obtained higher resolution data at more elevation angles and with fewer systematic errors than ever before. The on-the-fly observing technique allows a continuous scanning movement of the telescope while taking data. The reduction in data-taking overhead was so dramatic that a map could be taken in about two hours that was better than one requiring 3-4 *days* of the traditional observing technique! From these high-quality data, we will adjust the primary surface. Because of the advance in data acquisition and analysis, we are now able to perform real-time, iterative adjustments in which the surface is set, a holography map is taken and analyzed, and the surface is reset with as little as a one-day turn-around. This should result in a surface accuracy limited only by the accuracy of the individual panels.

One consequence of resetting the primary reflector is that the error-correcting subreflector used for the past three years will be rendered invalid. It is likely that some residual error will remain in the surface even after the best possible adjustment of the primary. Another shaped subreflector may be machined to correct these errors.

Pointing. With the improved surface accuracy, operation of the 12 Meter Telescope at the highest frequencies (300-360 GHz) is becoming more feasible. 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. First, the azimuth inductosyn angle resolver mount and cable-wrap assembly were rebuilt to eliminate some mechanical hysteresis problems. Second, an improved real-time monitoring system for movements of the prime focus, utilizing a laser and x-y translation detector, was installed. And, finally, the feedleg insulation was redone and blowers have been added to circulate air through the interior of the feedlegs. Additional instrumentation (inclinometers, strain gauges, temperature sensors) is planned, the feedlegs with a carbon-fiber design giving less temperature dependence and less aperture blockage will be replaced, and a sun screen to reduce thermal distortions of the telescope during daytime operation will be installed. An auxiliary optical pointing system is in use to determine the telescope pointing model and to diagnose pointing anomalies. A higher level of automation will be explored, with the possibility of offset guiding on optical stars to give accurate tracking of weak sources.

Active Secondary Optics. The ultimate antenna efficiency can only be accomplished through an active, correcting system. At some juncture, the primary reflector will have been "tweaked" to the extent possible, and the fixed, shaped subreflector will have reached its limits as well. However, the 12 Meter exhibits significant gain-elevation defects owing to the distortion of the primary reflector and backup structure under the force of gravity as the telescope moves through its range of elevation angles. Since the shaped subreflector must be configured for a given elevation angle, active optics are required to remove the gain-elevation effects. Two options are available: active adjustment of the primary reflector, such as with the GBT and the Keck optical telescope, or active adjustment of the secondary, or tertiary, optics. Adjustment of the primary may produce the overall best results, but it is costly and would require significant down-time for the 12 Meter. Active secondary optics is the best option for the 12 Meter. It is technically feasible, economical, and would result in no telescope down-time; it could be developed totally in the laboratory.

Telescope Control, Data Acquisition, and Data Analysis Improvements. Several enhancements will be incorporated into the telescope control system in 1993. 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 10 percent or more improvement in the duty cycle of most observing modes (note that 10 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 to the control system will be enhanced to allow the observer more direct control over the telescope. The option of "batch sequencing" of the telescope will be introduced during 1993. The new, on-the-fly observing mode, which was so successful during the holography session, will now become a routine mode for continuum observing. It is expected that this technique for spectral-line observing will be introduced in 1993. When using this technique, the observer will make several rapid passes over the field of interest, and average the results to improve signal-to-noise. Several rapid maps should produce superior results to one slow one, because drifts in the receiver and atmospheric absorption will be minimized. Such observing techniques as this will require more advanced data-handling facilities than presently available. A concerted effort at advancing imaging software during 1993 is planned.

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.

4. 140 Foot Telescope

The transition of operations from the 140 Foot Telescope to the Green Bank Telescope is scheduled to occur in 1995. Leading up to that event, the capabilities of the 140 Foot Telescope will be maintained or improved to insure continued support for its users. Quality maintenance and operations support will guarantee that current capabilities are retained and not permitted to degrade. Improvements will come about, primarily driven by the need to test GBT concepts, hardware, and techniques, before the GBT is available as the platform.

The user community can expect improved performance in 1993 due to several changes and upgrades in the past year. A new 486 PC Mk IV hardware/software field system for VLBI has replaced the old HP computer that was plagued by disk failures. A Sparc station is now available for observers. In addition, for observers and operators to generate files and to submit files to the Modcomp, an AST PC is now configured with increased hard-disk capacity, cpu speed, multi-floppy drives, and Ethernet. Infrastructure funding provided for extensive repairs to the concrete base of the telescope; for testing to determine a reliable, functional, replacement hydraulic pump for the floating system; and for spare parts inventory replenishment. Containers for metallic filter cartridge elements that are in line to the main spherical bearing pads are now being fabricated at

Green Bank, permitting local assembly for reduced cost and improved reliability. The air-conditioning systems for the first and second floors have been overhauled and maintained to give improved performance. A computer terminal was added to the operator's console for better communication and monitoring between the console and the spectral processor. The software for the spectral processor was enhanced to include self-test and self-healing capability.

In the area of receiver upgrades, one of the two 7.6 - 11.2 GHz Cassegrain upconverter-maser receivers was replaced with a 7.2 - 12.0 GHz system, using HFET amplifiers. Noise-temperature improvement over the band averages 10 K. One of the 12.0 - 16.2 GHz upconverter maser receivers was upgraded to a 12.0 - 18.2 GHz HFET amplifier system. Noise temperature improvement over this band averages about 17 K. The 26 - 36 GHz HFET amplifier receiver has given satisfactory performance for several observing programs. System noise temperature at zenith averages about 90 K over the band. The 140 Foot pointing and focusing stability seems to be adequate. All Cassegrain HFET receivers now use a common, phase-locked, LO system which has met the requirements for frequency agility and stability.

For the pulsar-timing observations on the 140 Foot Telescope, lower noise HFET amplifiers covering 780-820 MHz were installed in the 300 - 1000 MHz receiver. In addition, the method of generating circular polarization was changed, eliminating the 10 - 15 K noise penalty previously encountered. Observations are now performed in the 780 820 MHz range with system temperatures of approximately 40 K.

In 1993, the remaining upconverter maser receiver will be replaced with HFET amplifier systems in the 7.2 - 12.0 GHz and 12.0 - 18.2 GHz bands. A second LO and IF system is nearing completion and, together with the 140 Foot Telescope beam-splitting optics, will allow full frequency diversity over 7.2 - 25.0 GHz. That is, either receiver can be used at any frequency in this band at the same time the second receiver is operating at the same or any other frequency.

Users of the 140 Foot Telescope will have access to an improved 750 - 1000 MHz receiver. This is because the prime focus receiver for the GBT will incorporate several new concepts, all of which will be tested on the 140 Foot. A spin-off advantage to the user of developing this new receiver is that it should be lower noise than the one it replaces due to improved preamplifiers and better feed designs.

An effort will be mounted to replace the MassComp computer attached to the spectral processor. This upgrade is highly desired by researchers studying millisecond pulsars, because they find that the data rates which are now limited by the MassComp are too small. In a deep pulsar search, the data will be sampled at intervals as short as 200 microseconds. Even with relatively coarse post-detection quantization, the data rate will be in the range 0.3 — 0.6 MB/s, compared with the 0.1 MB/s accepted by the MassComp. A modern workstation can provide the increased speed that is necessary.

5. Building Construction

The Joint Operations Center in Green Bank

In January, 1993 the design of a new operations building in Green Bank will be completed, and construction will begin as soon as possible in the spring. The project has been funded by the U.S. Naval Observatory as part of their expanded activity described in Section VIII of this Program Plan.

The new building, called the Joint Operations Center, will provide ample space for the control room and equipment room of the Green Bank Telescope (GBT), and will also have a control room and equipment room to support the operations of the USNO, of the ground station for Orbiting Very Long Baseline Interferometry (OVLBI), and of the NASA SETI project, should the latter be conducted using the 140 Foot Telescope. There will also be a room between the two control rooms which will house the VLB equipment needed to support the GBT, the USNO, and OVLBI.

In addition to enabling the operations of the telescopes in Green Bank to be coordinated in an efficient manner, the JOC will provide much badly needed space for other activities. The operations areas, with the necessary support offices, will fully occupy the second floor. On the first floor will be an auditorium, an anechoic chamber for use as a high-frequency antenna range, a computer area, and a number of offices for visitors, scientists, and engineers. It is expected that the monitoring of the USNO Ultra High

Precision Time Reference System, itself housed in an adjacent clock building, will be conducted at the JOC.

The new building, providing just less than 20,000 square feet of space, will be placed at the west end of the Jansky Laboratory. It will be connected to the Jansky Lab by corridors on both levels.

Visiting Scientists Housing in Socorro

When the Array Operations Center (AOC) in Socorro was occupied in 1989, much of the VLA scientific activity moved from the VLA site to Socorro. In particular, the data reduction and imaging computers used by astronomers were installed at the AOC. This meant that users of the VLA, subsequent to their observations being made, came to the AOC to complete their work. The advice of NRAO staff scientists was also readily available in Socorro but much less so at the VLA site. In addition, the work environment at the AOC was carefully designed as part of the AOC building, and VLA users benefit from the arrangement of AOC facilities. But housing for visitors in Socorro is a problem.

Visitors to the AOC presently stay in Socorro motels, in NRAO rental apartments, and in rooms made available in the dormitory of New Mexico Institute of Mining and Technology. None of these is suitable for the needs of astronomers processing data at the AOC. Visiting astronomers, attempting to keep their time away from home to a minimum and seeking to minimize costs, work intently for long hours each day. Frequently they work all night and sleep part of the day. Motels and especially college dormitories are not conducive to such a "lifestyle." The NRAO users need housing better suited to their needs in Socorro.

With the encouragement of New Mexico Institute of Mining and Technology (NMIMT), NRAO has proposed to build a modest visiting scientist quarters (VSQ) on the NMIMT campus. As a separate facility in a quiet location near the AOC, this VSQ offers the seclusion and amenities AOC visiting scientists seek. The proposed facility will have twelve rooms, two apartments, a kitchen, lounge, and laundry. It will be connected to the AOC computer network so the visiting astronomers can monitor the status of their computing or even work from the VSQ. Construction on the VSQ is expected to begin in spring 1993.

IV. INFRASTRUCTURE RESTORATION

1. Overview

In its recommendation for the restoration of the infrastructure of ground-based astronomy, the Bahcall Committee included instrumentation upgrades, enhancement of computer resources, and strengthening of technical development staff along with the more visible need to repair and maintain the physical plant facilities. In 1992, NRAO began an infrastructure restoration program. The total budgeted was double the (inadequate) level of 1991. The emphasis was on the physical plant, but all the other elements were included as well. In 1993, we plan to continue by doubling the effort again.

The entire schedule of activities is shown in Table IV-1, projected through the year 1998 as best can be estimated. The items given in the 1991 column show what was spent in the last year prior to the availability of additional funds from the NSF for the infrastructure. For 1992 and succeeding years, the total effort is shown, that is, the additional infrastructure funding plus the "baseline" amount spent in 1991, which is included in the normal operations budget.

The new element for 1993 is a serious beginning for the upgrade of the VLA instrumentation; in 1991 only a very modest amount included in the Research Equipment line was spent in this area. Progress and plans in each of the four principal areas of the Infrastructure Restoration Program are given in the sections of this chapter which follow.

TABLE IV-1

Cost Estimates and Schedules (Current Year Dollars)

	1991	1992	1993	1994	1995	1996	1997	1998
Repairs and Maintenance								
Very Large Array								
Rail System:								
Supplies and Contracts	$ 30	$ 150	$ 600	$ 400	$ 420	$ 440	$ 460	$ 480
Replacement Equipment		95	50	50	55	55	60	60
Electrical Power System	45	340	300					
Waveguide Access Stations	25	20	80	80				
Antennas:								
Bearing Replacement	135	5	240	80	80	80		
Antenna Overhaul	30	30	60	60	65	65	70	70
Feed Housings			60	210	210	210	150	
Focus/Rotation Mounts				60	210	210	210	150
Antenna Painting			250	200	200	200	200	
Transporter Overhaul	45	80	75	25	25	25	30	30
Wye Monitor System		35						
Water Tank		15						
Fuel Tanks		90						
Generator Overhaul					50	50		
Road Repairs			250	100				
Stairways			75					
Replacement Vehicles and Equipment		150	100	50	50	55	55	60
Personnel Costs:								
Regular Employees	275	300	525	550	580	610	640	670
Seasonal Employees		40	60	65	65	70	75	75
Total VLA Costs	$585	$1350	$2725	$1930	$2010	$2070	$1950	$1595

	1991	1992	1993	1994	1995	1996	1997	1998
Green Bank								
Sewage Plant	$ 30				$ 30			
Antenna Test Range	10							
140 Foot Painting & Grouting	5	40						
Housing Repairs	5	10	35	10	10	40	10	10
Roofs		25	25					
Air Conditioning			25					
Roads				30		50		
Replacement Vehicles and Equipment			55	20	40	40	20	20
Personnel	200	200	210	220	230	240	250	260
Total Green Bank Costs	$250	$275	$350	$280	$310	$370	$280	$290
Tucson (12 Meter)								
Dome Repairs				195	400			
UPS/Power			50					
Control Room/Lab Modifications		10	20		5	10		
Paving and Drainage			10		20			
Pointing System Repairs			15					
Fuel Tank		5						
Weather/Fire/Safety Monitors			15					
Diesel Generator		30		10				
Replacement Vehicles and Equipment			35	40	50	50	55	55
Personnel	80	80	80	85	90	95	100	105
Total Tucson Costs	$ 80	$ 125	$ 225	$ 330	$ 565	$ 155	$ 155	$ 160
Total Repairs and Maintenance	$ 915	$1750	$3300	$2540	$2885	$2595	$2385	$2045
Research and Operating Equip.	500	785	1600	2000	2100	2200	2300	2400
Computing Resources		500	700	1000	1050	1100	1150	1200
VLA Upgrade			1500	3000	3150	3300	3450	3600
Total Infrastructure	$1415	$3035	$7100	$8540	$9185	$9195	$9285	$9245

2. Repairs and Maintenance

Very Large Array

The major part of the repair and maintenance effort is at the VLA site, and by the end of July, 1992 substantial progress had been made. Three work crews are engaged in track repair and the replacement of electrical power cable. In addition, temporary workers augmented the other crews in installing a new fuel-storage system, waveguide access pit replacement, and other projects.

Nearly 4700 ties have been replaced and eight intersections rebuilt. By the end of 1992, we expect this to increase to 5000 ties and twelve structures. In 1993, we plan to replace 6000 ties and double the number of intersections. Work on rail, ballast, and drainage is also planned.

At the end of July, 110,000 feet of primary electric power cable were replaced, with a goal for 1992 of 231,000 feet. In 1993, we plan to finish this project by replacing a similar amount.

The site power system has been improved by installing more reliable primary power breakers and an uninterruptible power supply (furnished at no cost by Socorro Electric Co-op) for critical equipment.

All underground fuel tanks have been removed in accordance with government regulations, and a new above-ground system has been installed.

The monitoring system that provides communications along the arms of the Array is being replaced, with half the work complete at this point. This will provide improved monitoring of telescope performance and more reliable communications for repair crews.

All axles, hydraulic hoses, bearings, and control systems are being replaced in the antenna transporters. This effort is half complete.

All waveguide access pits judged to be in imminent danger of a collapse have been replaced. Next year we plan to replace a larger number — those showing clear signs of deterioration but remaining functional.

This large maintenance effort has been aided by the acquisition of heavy equipment: a backhoe, cherry-picker, and compactor were purchased; two heavy trucks, a bulldozer, and a crane were obtained on surplus; and funds were used to repair and refurbish existing equipment.

The azimuth bearing replacement for Antenna 21 was successfully completed with heavy equipment contracted in 1991. We have provided for the replacement of six more bearings in the schedule shown in Table IV-1, the projected worst case for the number of bearing failures. Large antenna maintenance items in Table IV-1 are rebuilding of feed housings, focus/rotation mounts, and painting. These have been spread out over five-year periods.

Green Bank

In 1992, the major maintenance item is the repair of the cracks in the foundation of the 140 Foot Telescope. Although superficial, the cracks will propagate if left unfilled. In addition, repairs were made to two houses, and the roof of the physical plant maintenance shed was replaced. In 1993, we plan to repair more houses, replace more roofs, and replace the ventilation/air-conditioning unit in the cafeteria. Several vehicles will also be purchased to replace some very old, high maintenance cars and trucks. Activity similar to this and at this level is expected to continue in succeeding years. A major improvement to the effort to maintain the Green Bank physical plant was made in 1992 by hiring a plant engineer to manage and coordinate this activity.

12 Meter Telescope

Maintenance in 1992 was concentrated on replacement of the standby diesel-powered generator and replacement of underground fuel tanks. Improvements to the laboratory space where receiver systems are built and maintained were also made. In 1993, we plan to continue improving the power system by installing an uninterruptible power supply. Further control-room improvements will be made. Paving and drainage of the road and access areas near the dome will be done. New weather/fire/safety monitors will be installed. Two vehicles will be replaced. Outlying years have similar continuing needs with the addition of two exceptional items: repair of the dome arch beams and replacement of the dome cover.

3. Research and Operating Equipment

Research equipment is defined at the NRAO as instrumentation for telescopes and electronics development. Operating equipment is defined as office and machine shop equipment and vehicles. In 1991, $500k in NSF funds were spent in these categories combined, supplemented by a modest amount of funds received from common-cost recovery sources. In 1992, $785k is budgeted, and we plan to spend $1.6M in 1993. The projected steady-state figure in Table IV-1 of $2M (1994$) restores this category to only a fraction of the historic level; that much was spent in 1984 when the dollar purchased considerably more. After maintenance of the physical plant, this is the most important element of the Observatory infrastructure. Without development of new technology and its implementation in new telescope instrumentation, the facilities become less and less efficient and the science atrophies.

4. Computing Resources

The year 1992 was marked by an influx of computing equipment into Socorro and Charlottesville due to the VLBA construction project. As a consequence, the amount of funds invested in the infrastructure in Green Bank and Tucson could be increased somewhat. Therefore, virtually all staff scientists have now more or less the same computing power available to them as their colleagues in academe. Furthermore, the top computing power available to an individual visiting scientist exceeds that which is usually available elsewhere.

Even so, the more complex problems of VLBA and VLA still require more massive computer power than that which is readily available. The visualization engines that we acquired are good, but still a far cry from the top-of-the-line equipment that is indicated in a branch of science that is so heavily dependent on visualization. The networks that connect the various sites with one another and with the outside world (universities and supercomputing centers) need considerable strengthening, and the capacities of both Tucson and Green Bank need to be enhanced further. As gradual replacement of obsolete workstation with new ones begins, a continuous investment in the computing infrastructure at NRAO is an absolute must.

On the software front, the situation has been driven first by the need to bring the VLBA on-line, which required a heavy investment in data-processing software and second by the AIPS++ effort (see Section IX). Both require a further, major investment of manpower. In the VLBA effort, we expect a gradual shift during 1993 from the AIPS based effort to an AIPS++ based effort, with the attendant increase in effectiveness that AIPS is expected to bring. The single-dish software package (UNIPOPS) is being rounded out for use on the 140 Foot Telescope in Green Bank and the 12 Meter Telescope in Tucson. It is planned to replace UNIPOPS by 1995 with AIPS++ based software.

Table IV-2
(k$)

	Need	1991	Addition Required	1992 (est)	1993 (est)
Real Time	$ 100	$ 40	$ 60	$ 35	$ 75
Compute Engines	150	-	150	15	25
Interactive Graphics	150	-	150	-	50
Imaging Workstations	120	20	100	100	50
Disk Storage & Archive	100	20	80	30	50
Image Recording	85	-	85	-	25
Network & Communication	200	25	175	60	75
Algorithm Development	200	-	200	260	350
Total	$1105	$105 (1)	$1000	$500 (2)	$700

1. In 1991, an additional $597k was spent out of the VLBA construction budget on computing, primarily on imaging workstations and on networks and communications.

2. In 1992, an addiitonal $1506k was spent out of the VLBA construction budget for computing hardware.

5. Upgrade of the VLA

Recognizing the scientific potential of the VLA equipped with more modern instrumentation, the Report of the Radio Astronomy Panel of the Bahcall Committee emphasizes the need for a comprehensive upgrade. Specifically, the operation and maintenance of the VLA should be brought to a level appropriate to its broad scientific impact and great capital investment, and the out-of-date instrumentation should be replaced with modern, low-noise radiometers; fiber-optic transmission lines; and a modern, broad-band correlator. These upgrades will improve the sensitivity by up to an order of magnitude, improve the frequency coverage and spectral resolution, and increase the maximum allowable image size in certain cases.

The significant instrumentation improvements discussed below form the basis of the plan to upgrade the VLA. It can easily be funded incrementally over a decade and yet be useful at each stage of its development.

Receiver Sensitivity

New receivers based on cooled, low-noise, HFET amplifiers are needed to lower the system temperature at all bands except 3.6 cm where these devices already exist. The proposed receivers are based on designs already implemented at the VLBA.

New Frequencies

Three new observing bands, at 610 MHz, 2.7 GHz, and 43 GHz, are being considered for the VLA, and one at 86 GHz for the VLBA. The 610 MHz and 2.7 GHz bands are intended to fill in the gaps in existing coverage, while the 43 GHz system will improve the resolution by a factor of two. The additional frequencies are important for continuum studies of spectra as well as the effect of Faraday rotation and depolarization which are tied to: specific critical frequency regimes that are determined by source physics, for pulsar work where the critical frequencies of observations are determined by the spectra and dispersion, and for unique spectral lines such as SiO at 43 GHz. An initial set of nine 43 GHz receivers will be built in 1993 with funding from the National

Autonomous University of Mexico. It is planned to complete this project on all 28 antennas in succeeding years with NSF funding.

Fiber-Optics IF Transmission System

In order to distribute 2 GHz of bandwidth from each antenna (two polarizations, each with 1 GHz), the current waveguide transmission system needs to be replaced with a modern fiber-optics link. This will also permit future expansion to even wider bandwidths, and will allow inclusion of signals from other, more widely dispersed antennas. For the first stage, a fiber-optics link will replace the waveguide connection between VLA antennas and, in addition, it will connect the Pie Town VLBA antenna to the VLA.

Broad-Band Correlator

The VLA correlator provides a maximum bandwidth of 100 MHz (per polarization), obtained by a pair of separately tuned, 50 MHz wide bandwidths. These bandwidths were set by technological limitations current some fifteen years ago and cannot be greatly expanded. In conjunction with greatly improved IF transmission capability, a full 1 GHz bandwidth in each polarization can now be implemented by building a new correlator. A 2 GHz capability is also possible in the future.

Modern correlator design based on the FX approach, used successfully by the VLBA, is especially suited to arrays with large numbers of elements, such as the VLA. With an FX correlator and good spectral resolution, it should also be feasible to delete narrow-band RFI and thus exploit the full bandwidth of the IF system.

At the rate shown in Table IV-1, it will take 10-12 years to complete the VLA upgrades.

V. EQUIPMENT PLANS

1. Research Instruments

As a purely observational science, progress in radio astronomy is dependent on technological advances in all those areas that contribute to a successful observation. The experience at the NRAO and elsewhere has been that qualitative technical developments are soon reflected in qualitative, not incremental, scientific advances. The mosaic image on the cover of this Program Plan illustrates the point. Shown here is the distribution of neutral atomic hydrogen, HI, in the triple galaxy system M81-M82-NGC 3077. Prior to these VLA observations, HI emission had been observed in each of the three galaxies separately. But, as is evident in this mosaic image, the scientific interest in the M81-M82-NGC 3077 system is not the fact that each galaxy is rich in HI but rather that the gravitational tidal forces between each pair of galaxies is ripping the interstellar gas out from the disk of the galaxies. This could not have been seen before it was possible to make such a wide field mosaic, and the mosaic could not have been made without the sensitivity provided by the new HFET receivers. Improvement of the 21 cm receivers on the VLA has been a principal thrust of the NRAO Research Equipment plan for the past three years. The image on the cover and its implications are among the many rewards of the continuing effort to improve the NRAO observing equipment.

Each of the three major telescopes operated by the NRAO, as well as the newly completed VLBA, provides a unique service to astronomers, and each benefits by a scientifically considered and prioritized plan for improvements to its capabilities as enumerated below. To this end, an NRAO research and development program in electronics, instrumentation, and/or computing techniques is maintained at each observing site as well as the Central Development Laboratory in Charlottesville. Each of these locations is involved in design, development, and construction of auxiliary instrumentation for augmenting the research capabilities of the NRAO telescope system. However, it is a mistake to think of these instruments solely in terms of steel reflectors and cryogenic radiometers — as research instruments one must consider not only instrumentation but also data handling and the user interface. The purpose of the NRAO is to provide unique facilities to the researcher which he/she can use to maximum scientific profit. The typical user, in residence at the NRAO but a few times a year, thus needs to be provided with hardware and software interfaces to the instrumentation that are logical and comprehensible, yet which provide ready access to the full flexibility available from the instrument. The need for a suitable user interface has a considerable impact on NRAO plans for the design and utilization of astronomical instrumentation, which can be seen reflected in demands on the research equipment and budget.

The 1993 NRAO Program Plan includes $1600k for Research and Operating Equipment. A more detailed breakdown is shown in the table below.

Research and Operating Equipment

	1992 (est)	1993
Laboratory Test Equipment	$ 0	$ 100
Micellaneous Projects	80	
Very Large Array		
1.3-1.7GHz Improvement	190	100
23 GHz Repackage		80
RFI Shields	25	100
Array Computing	43	60
12 Meter Telescope		
SIS Receivers	35	90
Spectrometer Development	20	70
Control/Analysis Computing	50	40
140 Foot Telescope		
Cassegrain Receiver	10	0
Spec. Processor Upgrade	10	
GBT Prime Focus Receiver	30	30
GBT Gregorian Receiver	25	25
GBT Spectrometer		100
Analysis Computing	27	35
Common Development		
Millimeter Device Development	145	250
HFET Amplifier Development	30	100
Engineering Computing	35	30
Computational Imaging	30	90
Operations Equipment		300
Total	$785	$1600

2. Operating Equipment

Funding for Operating Equipment provides for the replacement, updating, and acquisition of equipment, including maintenance and shop equipment, office and library equipment, vehicles, living quarters furnishings, and building equipment. The lack of consistent funding over the past several years has resulted in delaying purchases that have a significant impact on the Observatory. Although the NRAO has been able to delay many of these purchases, the lack of funding has resulted in the measurable deterioration of the significant investment made in prior years by NRAO. Tractors, mowers, trucks, and other vehicles have been used well beyond their useful life. Over 56 percent of the rolling stock purchased by NRAO is at least ten years old. The replacement and acquisition of communications equipment, personal computers, and other major office equipment has been drastically reduced. Upgrading the living quarters and the replacement of household appliances and furnishings have been postponed indefinitely.

In 1991, a significant operating equipment purchase was the computer system for NRAO's business applications. This system replaced an old IBM System 34 which served the Observatory for over ten years. The new system represents a jump of four generations of computer technology, resulting in a substantial amount of training and education necessary to bring the employees utilizing this system up to speed with the latest hardware and software technology.

The NRAO has supplemented its effort to increase funding for the purchase of new equipment by obtaining a considerable amount of items from government surplus. In 1991 alone, the Observatory was able to secure two forklifts, a diesel truck, and an ambulance from other government agencies who declared these items as excess. Through July, 1992, the Observatory has additionally obtained a bucket loader, two dump trucks, a forklift, a utility truck, and a five-ton crane. These assets have a combined dollar value of $578k. Although we have stepped up our efforts to locate items through the government excess program, other agencies are experiencing similar budgetary restrictions and are also combining the excess property inventory in defense establishments.

The 1993 funding requirements are estimated at $300k. This level of funding will allow for the replacement of equipment critical to the ongoing operations of the NRAO. The majority of this allocation will go towards the purchase of machine shop equipment, heavy equipment (rolling stock), and building improvements. For the five-year period 1994-1998, an estimated total of $1.8M will be necessary to adequately fund the purchase of operating equipment.

VI. MAJOR CONSTRUCTION-THE GREEN BANK TELESCOPE

The Green Bank Telescope (GBT) project in the past year has advanced from concept development and design into a major construction project. CY 1992 has seen the telescope transformed from engineers' computer models of the structure to the construction beginnings of the actual structure itself. By midyear, the 5,000 cubic yard, monolithic, reinforced, concrete foundation was in place; the construction area had been graded and stabilized with a two-foot thick layer of gravel to support the upcoming heavy construction activity; and two additional, massive foundations were built, one for the 260-foot tall, 250-ton tower derrick and the other for assembly and construction of the reflector backup structure. Further, the contractor had installed the large pintle bearing on its center tower.

During the last quarter of CY 1992, the antenna contractor, Radiation Systems, Inc. (RSI) will present the completed design to NRAO for approval. The 90 percent design review is scheduled for mid-October, and the final design is scheduled for submission in December, 1992.

At the construction site during last quarter of CY 1992, the contractor will engage in the placement and grouting of the 48 splice plates and track sections, each set weighing approximately 17,500 pounds. The track will be leveled to within 0.020 inch and then grouted with 10,000 psi dry-pack grout. The contractor will also erect the derrick crane near the foundation to be used in hoisting the assembled telescope modules from the assembly pad to the erection area. In addition, the first three levels of the six-level alidade structure will be shipped to Green Bank during the last quarter of 1992 and alidade erection will begin. Current scheduling shows the alidade erection completed by mid-1993.

Major mechanical components, such as bearings, speed reducers, pinions and gear segments, are scheduled for procurement by RSI by mid-1993, in preparation for a late 1993 installation on the antenna structure. The feed arm is scheduled for trial assembly during late 1993 and final erection on the telescope during early 1994. The reflector back-up structure will be trial erected in late 1993 and assembled on the telescope during mid-1994. The main reflector panels and the subreflector will be installed on the antenna in mid- to late 1994.

Although the final design and fabrication schedule for the elevation structure and feed arm have slipped from RSI's original schedule, discussions and schedule reviews with the contractor have yielded commitments to recover the lost time by summer 1993 and deliver the antenna by the end of CY 1994. However, it should be noted that NRAO is not convinced that the contractor will be able to recover all the time and has begun contingency planning for an extension of the antenna construction of up to approximately six months.

During 1993, the electronics group will continue the hardware design and construction tasks started in 1992, and will initiate significant additional tasks. Testing on the receivers completed in 1992 will be done. In particular, the 18 - 26.5 GHz receiver will be used to evaluate the stability of HFET amplifiers for beam-switched systems. Additional receivers will be constructed, together with the associated feeds and converter modules. LO and test tone routers constructed in 1992 will be evaluated and utilized during receiver tests. Emphasis in the LO system design will shift to the subsystem needed for distribution of reference frequencies. Development of another important set of subsystems required for routing and distribution of IF signals will start in 1993, and construction should be well along by the end of the year. Both the LO reference and the IF distribution will rely on the use of analog fiber-optic links, and extensive selection and testing programs for these links will be required. Development of the turret cable wrap and feed rotator mechanisms which began in 1992 will be completed. By the end of 1993, it is planned that system tests will be underway, operating most of the major subsystems together to evaluate performance, and utilizing computerized monitor and control systems.

It is expected that a full-scale model of the active surface will be achieved by the end of CY 1992. After the successful demonstration of the full-scale model, NRAO will instrument a telescope with laser rangefinders to further evaluate the proposed pointing system. This will result in fully developed hardware that will be simply transferable to the

GBT. It is anticipated that this approach will minimize testing time on the GBT. A major task for 1993 will be refinement of the laser rangefinder system and the start of mass production of as many as twenty of the rangefinders.

Adjustments to the active surface will be made through the action of approximately 2200 actuator assemblies. The first shipment of approximately 800 actuator assemblies is expected at Green Bank in mid-November, 1992. The remaining units will be received by mid-1993. Receipt and acceptance of the full complement of units will represent a significant milestone to the project.

Additional tasks scheduled for 1993 for the open-loop, active surface include refinement of the control algorithm, development of the control software, development of miscellaneous control and monitor circuits, control panel wiring and tests, installation of RFI filtering, and power supply procurement. The wiring and testing of control panels and software development will continue into 1994. Wiring of the actuator control room on the telescope structure and system integration will occur in 1995.

Development of the autocollimator pointing system will continue, with the design and development of a gravity-stabilized platform being the main task for 1993.

Work on the GBT monitor and control system is broken into six modules: monitor, control, data, antenna, electronics and specifier. Early in 1993, design will begin on the monitor, control, electronics, and antenna modules. By the end of the year, design will be completed on antenna and electronics, and design and implementation will be completed on the control and monitor modules. These last two modules are infrastructure software modules which will serve as mechanism for the specific software used to interact with the antenna, electronics, and data acquisition.

Two interfaces are due to be specified by the end of CY 1993 as well. The first is to the precision pointing system which provides corrections to the commands to the servo systems for driving the antenna. The second is the telescope primitives which describe the interface between the core telescope system and the specifier. The specifier is the module which sets up each observation and houses the observer's user interface.

As currently scheduled, the telescope installation will be completed in late 1994. Outfitting and acceptance testing will occupy the latter part of 1994, looking toward final acceptance, operations, and first astronomical observations in 1995.

VII. MAJOR NEW INITIATIVES

1. The Millimeter Array

While the report of the Bahcall Committee, "The Decade of Discovery in Astronomy and Astrophysics," makes a number of prioritized recommendations, the overriding theme projected for the decade of the 1990's is the opportunity presented to us to exploit new technology for the exploration of the thermal sky. The three highest priority, large programs recommended by the Survey Committee — the Space Infrared Telescope Facility (SIRTF), the IR-optimized 8 meter telescope on Mauna Kea, and the Millimeter Array — address a common set of scientific questions and do so with comparable capabilities, especially sensitivity and angular resolution. Together these instruments will provide astronomers of the next decade with an appropriate suite of complementary facilities from which we can expect significant progress, discoveries, to be made in our understanding of the formation and evolution of stars, galaxies, and the large-scale structure of the universe.

The external peer review of the MMA proposal has been completed by the Foundation. This process involved both a mail review of the written proposal as well as a presentation made to an NSF site visit group. The proposal reviews were considered by the NSF Advisory Committee for Astronomical Sciences (ACAST) at their fall 1991 meeting. The Committee resolution records their excitement for "this bold and scientifically meritorious project." They recommended that the MMA research and development work proceed.

In September, 1992 the NRAO submitted to the Astronomy Division the Millimeter Array Design and Development Plan. This document describes a four-year plan for the development work that we intend to undertake for the MMA as a prelude to construction in 1997. The approach taken in this plan incorporates the following elements:

- Technical alternatives will be evaluated in detail before a choice is made;
- Prototypes will be constructed and thoroughly tested, so that reliability and functionality can be assessed. This includes both hardware and software prototypes;
- A single-baseline set of electronics will be constructed and tests will be made over a range of environmental conditions;
- A prototype antenna will be designed and constructed so that the special demands of MMA operations can be evaluated and the antenna design refined;
- Prototype software will be made available to users at an early stage so that it can evolve in response to informed criticism.

The Millimeter Array Joint Development Group (see Section IX) will participate in much of this work.

With the four years of effort described in the design and development plan having passed, design and prototyping of all the critical MMA technical components will have been competed. A prototype antenna will exist, instrumented with prototype receivers and ancillary instrumentation. Tests of the performance of the antenna under a variety of changing environmental conditions will have been made, and the operational modes demanded of the antenna (e.g.,beam switching, rapid positioning) will then be evaluated. The sensitivity, tunability, and flexibility of the receiving equipment will be assessed in light of the MMA requirements.

The prototype MMA hardware is the most visible "product" of the MMA design and development program. Less visible but equally important are the people available and trained in the construction of the MMA instrumentation through their work in fabricating the prototypes. In fact, a major rationale for constructing prototypes is that it provides us an opportunity to establish the fabrication and test facilities that will allow us to construct, reproducibly, the MMA instrumentation. In 1997 the technical design will exist, the prototype fabrication/test facilities will exist, the fabrication techniques will have been established, and experienced people responsible for MMA construction will be well prepared on the construction phase of the instrument.

2. VLA-VLBA Connection

A plan to bridge the gap in angular resolution between the maximum achievable by the VLA, $\sim 0''.1$, and the minimum provided by the VLBA, $\sim 0''.01$, was endorsed by the report of the Astronomy and Astrophysics Survey Committee as one of the recommended moderate programs. Connection of the two arrays will increase the resolution of the VLA at all frequencies; improve the dynamic range, field of view, and extended source sensitivity of the VLBA; and give a scaled array capability at $0''.1$ resolution for all frequencies from 300 MHz to 22 GHz.

The VLA/VLBA connection will be accomplished with a phased plan which includes the following three steps:

- Placing four VLBA recorders at the VLA so that the antennas at the ends of the wye arms can be used as independent VLBA telescopes;
- Constructing four new VLBA antennas (at Dusty, Bernardo, and Vaughn New Mexico and at Holbrook Arizona) for measurement of short VLBA spacings;
- Providing fiber-optic links from the VLA to the four new antennas as well as to the VLBA antennas at Pie Town and Los Alamos. These six outrigger antennas would then be used as part of the VLA. The VLA correlator will be expanded from 27 to 33 stations to accommodate the additional baselines.

Together, these improvements will provide a greatly enhanced imaging capability and brightness sensitivity over a wide range of frequency. The scientific applications will include observations of the sun and planets, radio emission from stars, novae, protoplanetary nebulae and stellar winds, as well as from star-forming regions, active galactic nuclei and quasars. The VLA/VLBA connection is a long-term goal — beyond the five-year budget and personnel schedule presented in Section XII.

3. Submillimeter Telescope

Recent initial results from the effort to develop a laser metrology system for the GBT have been very promising and, if they continue to be successful, they could form the basis for the construction of a large aperture, submillimeter telescope by employing an active surface. A national submillimeter facility that builds on the pioneering work of the Caltech Submillimeter Observatory and University of Arizona/MPI Submillimeter Telescope is a logical step in long-range national plans for this spectral region. Three requirements serve to define the characteristics of the national submillimeter telescope.

- Observations have to be made quickly. Because the atmospheric transparency and stability are so highly variable, even from the best ground-based sites, observations have to be accomplished in the favorable intervals as they occur.
- Submillimeter observations provide information on astronomical objects that is complementary to that obtained at other wavelengths. Astronomers will commonly combine millimeter-wave, submillimeter, and infrared observations to understand a single astronomical object. This means the submillimeter telescope must have angular resolution of a few arcseconds.
- Regions to be studied at submillimeter wavelengths often have an angular extent of several tens of arcseconds or more.

Given these three criteria, we see that the submillimeter telescope is an instrument with arcsecond angular resolution capable of imaging quickly a region many beamwidths in extent. The following technical developments are needed to achieve these capabilities.

- Demonstration that an active surface metrology system such as that being explored for the GBT will work in practice;
- Demonstration that it is possible to construct submillimeter receivers in quantity, reproducibly, and inexpensively;
- Development of an inexpensive and flexible spectrometer that can be reproduced in quantity;
- Development of a large-format heterodyne array receiver.

NRAO will keep abreast of developments in submillimeter astronomy, become involved in the technology required where possible, and appropriate, and foster opportunities for collaboration in submillimeter astronomy, with the long-term goal of establishing a national facility. We are particularly interested in following the developments in submillimeter astronomy occurring in the Antarctic.

VIII. NON-NSF RESEARCH

1. USNO Operations

In 1993, NRAO will continue to operate two telescope systems for the U.S. Naval Observatory in Green Bank. The primary system uses one 85-foot telescope (No. 3) as a VLBI station in the NAVNET system of stations. NAVNET determines the earth's (variable) rotation rate and, with less accuracy, the position of the pole. The observations are made of compact quasars simultaneously at 2.3 and 8.4 GHz. The data are now recorded on a VLBA data acquisition system, which provides an enhanced sensitivity because of the larger bandwidth recorded. The geodetic observations do not use all hours of every day. The time not used for VLBI on 85-3 is devoted to monitoring the time of arrival of pulses from a selected group of about 35 pulsars. These data are collected on behalf of a group at Princeton and Oberlin. The observations are conducted at 327 and 610 MHz. The observations provide fundamental data on the physics of neutron stars as well as on the turbulent structure in the electron component of the gas of the Milky Way.

The other 85-foot antennas (Nos. 1 and 2) are linked by fiber optics, thereby forming an interferometer also operating simultaneously at 2.3 and 8.4 GHz. It observes about 170 compact sources each day, with a view to identifying changes in the flux densities of these objects. Since many compact sources are continually changing, it is important to have a large sample so that the instrumental effects can better be identified. Flux changes may be either intrinsic to the source or extrinsic, arising because of changes in the path the radiation travels through the interstellar plasma of our own galaxy. A recent instance is the major and abrupt change in the flux density of the compact radio source 1741-038 which was observed beginning in late May, 1992. News of the event was sent to other observatories, and complementary observations were arranged on, for example, the 140 Foot Telescope and on the VLA.

In 1993 the activities on behalf of the USNO will undergo a significant expansion. First, construction will begin on the Ultra High Precision Time Reference System. This system will be comprised of ten hydrogen masers and twenty cesium standards, and will be synchronized with high accuracy with the clock system at the USNO. It will be integrated into the GPS. The system will be housed in a new clock building which will have very stable temperature and humidity and which will have the absolute minimum of traffic by persons. Second, work will begin on a new antenna system to replace the use of 85-3 in the NAVNET. The new antenna will have faster drive rates, in order to minimize time lost to telescope motion, and will be equipped with a new electronics system. Upon completion of the new antenna system, it and the 85-3 system will be run simultaneously for several months in order to explore any systematic differences between the two instruments.

The development of the new USNO station at Kokee Park, Hawaii will be completed. The antenna, a paraboloid of diameter 20 meters, was erected in 1992, and the outfitting was begun late in the year. The receiver system which was built in Green Bank will undergo tests, and some NRAO personnel will participate in the shakedown observations.

2. Green Bank OVLBI Earth Station

The Green Bank Orbiting VLBI Earth Station will be one of several such stations around the world that will provide communication links to and from the two orbiting VLBI satellites now scheduled for launch. These are Radioastron, to be launched by the USSR around July, 1995, and VSOP, to be launched by Japan in August 1995.

The Green Bank station is a NASA-funded project of the NRAO, started in 1990 and scheduled for completion of its implementation phase at the end of 1993. This will be followed by an operations phase which will last for the duration of the OVLBI missions, probably until about 1998. After that, the station will be available to support future OVLBI missions.

The two spacecraft are functionally similar. Radioastron carries a 10-meter diameter antenna and VSOP a 7-meter antenna. Each is equipped with front ends for several radio astronomy bands, commonly used for VLBI. The combination of either spacecraft and an appropriately equipped earth station constitutes a radio telescope for VLBI, very much like those on the ground. At ground VLBI stations, all major components are located in close proximity and are typically linked by fixed cables. In the orbiting case, important components must be located on the ground — in particular, the high-density recorders and high-stability oscillator —and linked to the orbiting components by a variable length radio path.

Each spacecraft is to be in a highly elliptical, high inclination orbit, but Radioastron will be at a much higher altitude than VSOP; the periods will be approximately 28 hours and 6 hours, respectively. Furthermore, Radioastron's apogee will remain over the northern hemisphere for most of its lifetime, with the result that it will be visible from Green Bank for the majority of nearly every orbit and sometimes for more than 80 percent of its orbit. VSOP's visibility from any fixed earth station will vary widely, from less than one hour to more than four hours. Especially for VSOP, a worldwide network of earth stations is needed. NASA is planning stations at Goldstone, Madrid, and Canberra (supporting both spacecraft); Japan at Kagoshima (VSOP only); and the USSR at Ussuriysk (Radioastron only).

The Green Bank earth station is built around a 13.7-meter diameter antenna which was formerly part of the NRAO radio-link interferometer. It has been restored to operation on the Green Bank site. The surface has been holographically measured and reset for operation at 15 GHz as required for OVLBI. In 1992, it was provided with two VLBA recorders built under contract by Signatron Corp, and the design was completed for the remainder of the hardware. A critical design review is scheduled with NASA in October, 1992. In 1993, the hardware will be constructed and integrated into the station. A staff of six engineers and technicians is involved in the 1993 implementation effort.

3. OVLBI Science Support

As one element of a synthesis telescope, the orbiting VLBI radio antenna is used in concert with ground antennas, all of which observe the same radio source simultaneously. After the data are taken and recorded, the data tapes are played back and correlated at a central facility. The scientific return from an OVLBI spacecraft therefore is contingent upon ground support in a number of ways — co-observations, correlation, data processing, and imaging. In return for access to the spacecraft by U.S.

scientists, NASA has negotiated with the foreign space agencies to provide the requisite ground support. Since the NRAO will operate the only dedicated VLBI array in the world at the time the spacecraft are launched, NASA has asked for NRAO involvement with the two space missions.

NRAO participation in OVLBI science support will consist of the following:

- Co-observation with the VLBA for as much as 30 percent of the scheduled VLBA time for an initial period;
- Correlation of all data taken when the VLBA is used for co-observations;
- Modification of the VLBA correlator to accommodate the higher fringe rates of OVLBI and the larger delays resulting from errors in the orbit determination;
- Modification of the VLBA software in AIPS++ to make it suitable for the special needs of OVLBI;
- Acquisition of four VLBA recorders for use with Radioastron and to be installed at radio telescopes and earth stations in Russia;
- Support of OVLBI users at the AOC in Socorro.

The 1993 NRAO OVLBI science support activities, planning, and operation will require four to six full-time staff. NASA funding passed through NSF by interagency transfer will bear the cost.

IX. COLLABORATIVE WORK

1. AIPS++

The consortium of radio astronomy organizations that is developing AIPS++, the successor to AIPS, consisted initially of the Australia Telescope, the Netherlands Foundation for Research in Astronomy, Jodrell Bank, the Canadian Herzberg Institute (JCMT and DRAO), the BIMA consortium, and the NRAO. By the end of 1991, the Tata Institute of India joined as well. The consortium is being governed by a steering committee in which each of the participants has one representative. The NRAO representative chairs the committee. It currently meets three times a year, although the meeting frequency is expected to decrease as AIPS++ nears completion.

As a first step in the development process, each of the participating organizations produced a document specifying the detailed requirements for the new software system from their point of view. These documents were received at the end of 1991. The participants also provided training for their staff in the special technique (object oriented programming) that would be used in the project.

In January, 1992 scientists and programmers from each participating organization got together in Charlottesville for six months of concentrated effort. First, the individual requirement documents were merged into a single document that serves as the foundation for the work. Then, an analysis was made of the most complicated area, that of the calibration of raw data and their use in the formation of images. The complications arose from the need to cover a wide range of instruments and hence to develop a comprehensive understanding of the problem domain. The first round of this work was finished by the end of February. It was followed by a period of one month in which the group built a working, albeit quite shallow, prototype covering calibration, imaging, image manipulation, and display.

The last three months of this period were spent on refining the original design and verifying its operability with regard to a few extreme, complicated cases. This work will continue throughout the remainder of the year and into 1993. In addition, various well-defined subsystems were defined, subsystems that form the basic building blocks out of which AIPS++ for the various telescopes will be built. These packages include a specialized but highly sophisticated database management system, a library of basic mathematical and utility routines, and a library of graphics routines. Many of these are derived or adapted from existing products. All the partners in the consortium (including the participating NRAO sites) have reviewed and accepted "software contracts." Each of these specifies well-defined pieces of software to be designed, coded, and tested, and to be delivered by that partner within a certain period of time.

With funding included in the present Program Plan and Long Range Plan, we intend to increase NRAO's contribution to the effort devoted to this product internationally and to participate in international workshops on AIPS++ design and development. As a result, we expect working, useful, but limited, prototypes of significant parts of AIPS++ to be available by the first quarter of 1993. We expect major applications for, say, VLBA and GBT data processing to become available from the middle of 1993 onwards. AIPS++ will also provide the basis for MMA data analysis, both on-line and off-line.

2. MMA Joint Development Group

Design of the Millimeter Array has been a cooperative venture between the NRAO and interested millimeter-wave astronomers for nearly a decade. The concept of the array as a fast imaging instrument capable of precision operation at frequencies as high as 360 GHz and capable of providing images of 0.1" angular resolution, equivalent to that achievable by the HST or SIRTF, was a result of a series of scientific workshops held at the NRAO. The realization of the concept — 40 transportable antennas of 8 meters diameter located on a high latitude site — was the instrument recommended by the 1991 report of the Astronomy and Astrophysics Survey Committee.

In September, 1992 a plan for the research and development phase of the MMA was submitted to the NSF Astronomy Division. The program covers the years 1993-1996 inclusive. In conducting the design and development program for the MMA, we intend to work closely with university groups through the MMA Joint Development Group

(JDG). In each of the areas of the plan the experience and expertise of these groups can be put to effective use. The primary contact between the NRAO and a particular university group is maintained at the working level, between the NRAO engineer and associate responsible for the development in an area and the individuals in a community group that are participating in the effort. Visits, exchanges of technical memoranda, and electronic mail are the means of communication. The current JDG membership and representatives are:

University of California, Berkeley	W. J. Welch
Caltech	J. E. Carlstrom
University of Illinois	L. E. Snyder
University of Maryland	L. Blitz
University of Massachusetts	[to be appointed]

The JDG concept is new to the NRAO. It has the potential to provide an efficient way to "recruit" experienced millimeter-wave astronomers and instrument builders to the MMA project without disrupting their personal lives or professional careers. If the JDG model is successful, it has a natural extension to the operational phase of the instrument. Working together with the university groups, we expect, during the MMA development phase, to define the role and guide the fruitful evolution of the JDG.

X. EDUCATION PROGRAMS

1. Overview

Although the distinction between research and education is somewhat hazy and perhaps artificial, nevertheless it is possible to point to a number of programs at the NRAO specifically designed to broaden and enhance the educational background of students. These include opportunities for undergraduate students to participate in on-going scientific, engineering, or computer science projects, opportunities for graduate students to conduct research under the direction of NRAO staff scientists, and opportunities for recent Ph.D. recipients to collaborate with scientists having mutual research interests at the NRAO. The scope and purpose of such programs are briefly outlined in this section as are programs designed to reach the public.

2. Postdoctoral Fellows

At the NRAO postdoctoral appointees are given Jansky Fellowships 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 postdoc position. In principle, Jansky Fellowships are available not only to those in radio astronomy but they are also available to recent Ph.D. recipients in engineering and computer science. In practice the stipend of a Jansky Fellowship, while very competitive with the stipend offered postdoctoral astronomy appointees at other observatories and universities, is nearly $20,000 less than the starting salary of Ph.D. engineers and computer science professionals. For this reason all recent Jansky Fellowships have gone to astronomers.

Jansky Fellows 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.

At the end of 1992, we expect six Jansky Fellows at the Observatory. Nearly ten postdoctoral positions were lost in the budget reductions of the last six years. This represents an unfortunate loss to young astronomers and to radio astronomy. In the period covered by the present Program Plan, the postdoctoral program will be restored to a level more appropriate to a national observatory.

3. Resident Ph.D. Thesis Students

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 those degrees 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 eight 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.

4. Non-Resident Ph.D. Thesis Students

More than one hundred twenty-five Ph.D. thesis students use the NRAO facilities each year for their research. While these 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.

5. Summer Students

For thirty years the NRAO has offered summer appointments to students interested in broadening their exposure to radio astronomy. Many of the former NRAO summer students are now established researchers. In this sense the summer student program has been very successful indeed.

One of the strengths of the early program was its emphasis on students who had made a commitment to radio astronomy: the only students admitted to the program were graduate students in radio astronomy, engineering, or computing. One of its weaknesses was that it was funded out of contract funds and, when funding was tight, the program was constrained. In 1982 there was no summer student program at all.

In 1987, the NSF funded a program for summer student research opportunities called Research Experiences for Undergraduates (REU). The NRAO has applied for REU funds every year since 1987 and has annually supported eighteen to twenty summer students from these funds. All these students are, of course, undergraduates and as such have not made a commitment to radio astronomy nor do they, usually, have the research skills of graduate students. Many students are exploring radio astronomy as a career option; others are simply looking for summer employment.

Each year since 1987 we have supplemented the REU funds with funds from the Cooperative Agreement to support a few graduate students, bringing the total number of summer students to nearly thirty. Approximately half this number are astronomy students; the remainder are interested in the engineering and computing aspects of radio astronomy. Through exposure to hands-on research, we hope to persuade the summer students to strengthen their commitment to careers in science.

6. Special Educational Programs

Secondary Science Teacher Institute.

In cooperation with the University of West Virginia, the NRAO sponsors two week-long workshops for science teachers in secondary schools. The workshops are held in Green Bank, two sessions each summer. In addition to lectures on radio astronomy research and instrumentation, the teachers are also given access to a radio telescope and encouraged to create their own observing program. The hope is that they will appreciate research, and later pass along its excitement to their students, by being involved in all aspects of observational research. Fifty teachers and ten returning teacher/mentors are accommodated in the program each summer. This program is funded by the NSF Education and Human Resources (EHR) Division.

Undergraduate Faculty Institute

A proposal has been submitted to the NSF EHR Division's program on undergraduate faculty enhancement to establish a summer institute at NRAO in Socorro, New Mexico which would draw faculty from two and four-year colleges to two-week sessions to learn the basic principles of image processing. Many of the graduates of these institutions would have careers in high-tech areas where image processing is used, medical technology being a prime example, if their interest were stimulated.

Young Scholars Program

The NRAO participated in an NSF-funded Young Scholars — Early Alert Program that was run by New Mexico Institute of Mining and Technology during June, 1992. The purpose of the program is to provide research experiences for selected minority math and science ninth grade students from around the State of New Mexico. Two students worked with NRAO electronics engineers for part of the summer. During the mentorship period, the students learned about the electronics research environment at the NRAO, and they helped develop and test instrumentation used for diagnostics on the MkII VLB correlator. In the next five years we expect to broaden the NRAO participation in The Young Scholars Program.

7. Workshops and Symposia

Green Bank Workshops

NRAO has traditionally hosted symposia and workshops on special topics of interest to research astronomers, those who develop new instrumentation, and their students. The series of Green Bank workshops are well-known: twenty workshops on topics from "Phases of the Interstellar Medium" to "Large Scale Surveys of the Sky" have been held to date. We anticipate a continuation of this series during the period of the present plan that will accompany bringing the GBT into operation.

Synthesis Imaging Workshops

One important measure of the success of the VLA is the number of scientists who use the telescope each year, that is, nearly six hundred. That so many people could use it speaks to its operational ease and convenience. This is surprising because the principles of aperture synthesis are subtle. Indeed, the VLA can and is used successfully by people lacking a thorough professional understanding of the instrument. At the same time users seeking to push the VLA to its limits recognize that one needs to understand its subtleties. We attempt to communicate this information to users, particularly student users, by workshops held in Socorro on synthesis imaging.

The fourth synthesis imaging workshop was held in June, 1991. More than 115 students (mostly graduate students) attended the workshop, the fourth in nine years. Fifteen NRAO staff scientists developed the theory and application of aperture synthesis in various lectures that were given over a ten-day period. Proceedings of three of the workshop have been published. The cost of the synthesis imaging workshops is paid from funds in the NSF Cooperative Agreement; no additional, special funds are provided by the Foundation. We expect this series to continue.

The 1993 VLBI School

In 1993, it will be twenty-six years since the technique of VLBI was first used in astronomy. Since the NRAO played a major role in the development of VLBI and we will see that effort culminate also in 1993 with the completion of the VLBA, the NRAO plans to commemorate the event by sponsoring a summer school on VLBI.

For over twenty-five years VLBI has been perceived as an arcane branch of radio astronomy capable of leading to considerable insight but the practice of which was limited to a few dedicated individuals. The VLBA promises to make VLBI readily accessible to the large number of users accustomed to observing with the VLA. In order to accelerate the process, the NRAO will encourage graduate students and others to attend a summer school on the theory and practice of VLBI, with specific reference to the capabilities of the VLBA. Nearly 100 graduate students are expected to attend for approximately ten days.

Tucson Remote Observing Workshop

In April of 1992 a workshop on remote observing was held in Tucson, Arizona, jointly sponsored by NRAO and the Royal Observatory Edinburgh. Ninety participants from eight countries discussed remote observing techniques, at one point controlling twelve of the world's millimeter wavelength telescopes from workstations at the meeting. We expect to continue to stimulate and foster discussion on this important topic.

8. Public Education

Images of Radio Astronomy

The NRAO maintains a collection of slides illustrating the telescopes, techniques, and research images of radio astronomy. These slides are made available to students, classroom teachers, professional colleagues, and the media. In 1993, we will expand this outreach program by issuing a compact disk of more than 3500 astronomical images called "Images from the Radio Universe." These images can be displayed on a PC computer screen and manipulated by students seeking to explore radio astronomy from their classroom. Each of the images is fully documented and calibrated — they are not "toys" or illustrations. These are research quality images in every respect.

Work will continue in the next year on a similar collection of radio images made of the complete third Cambridge catalog of radio sources. This collection will include images from the VLA, MERLIN, and the Westerbork synthesis telescope. As a collection meant for students as well as professional colleagues, all these images will again be complete, documented, and available as a compact disk for personal computers and workstations.

Green Bank

Approximately 13,000 - 14,000 tourists visit the Green Bank site during the summer months, taking the hourly tours via bus and viewing the displays in the Visitors Center. A smaller group of people take self-conducted walking tours outside of the summer months; roughly 2000 sign the guest book. In addition, two special tours are given on average each week to organized groups of typical size 30 persons. The total is close to 20,000 public visitors per year.

Socorro

The VLA site has a visitors center built by the State of New Mexico and opened in 1983. NRAO maintains and operates the Center, which is attended by roughly 15,000 tourists each year. They take a self-guided walking tour of the central area of the VLA and view displays and a slide show in the Center. A new slide show was installed in 1992. The VLA also hosts special tours, on average one per week, largely of student groups from junior high school through college.

Tucson

The 12 Meter Telescope is included in the special tours done by Kitt Peak National Observatory in connection with their monthly Public Nights. About 50 people visit the 12 Meter on each of these occasions. There are one or two other special tours each month, including the Smithsonian Seminars group who visit twice per year.

XI. 1993 PRELIMINARY FINANCIAL PLAN BY BUDGET CATEGORY
(NSF Funds, $ in Thousands)

	New Funds	Uncommitted Carryover of 1992 Funds	Total Available for Commitment	Commitments Carried Over From 1992 Funds	Total Available for Expenditures
OPERATIONS					
Personnel Compensation	$16,980		$16,980		$16,980
Personnel Benefits	5,094		5,094		5,094
Travel	738		738		738
Material & Supply	8,522		8,522		8,522
Management Fee	600		600		600
Common Cost Recovery/CDL Device Revenue	(819)		(819)		(819)
Advanced VLBA Operations (for 4th Quarter 1992)	1,000		1,000		1,000
TOTAL OPERATIONS	$32,115	$0	$32,115	$0	$32,115
DESIGN & CONSTRUCTION					
GBT	$0	$10,000	$10,000	$39,000	$49,000
TOTAL OPERATIONS AND DESIGN & CONSTRUCTION	$32,115	$10,000	$42,115	$39,000	$81,115
INFRASTRUCTURE					
Repairs & Maintenance	$ 2,385		$2,385		$2,385
Research & Operating Equipment	1,100		1,100		1,100
Computing Resources	700		700		700
VLA Upgrade	1,500		1,500		1,500
TOTAL INFRASTRUCTURE	$ 5,685	$0	$5,685	$0	$5,685
TOTAL NSF PLAN	$37,800	$10,000	$47,800	$39,000	$86,800

XI. 1993 PRELIMINARY FINANCIAL PLAN BY SITE/PROJECT
(NSF Funds, $ in Thousands)

	Personnel	Salaries, Wages, & Benefits	Materials, Supplies, & Services	Travel	Total
OPERATIONS					
General & Administrative	27	$ 1,534	$1,095	$120	$ 2,749
Research Support	58	4,372	1,349	230	5,951
Technical Development	22	1,291	126	17	1,434
Green Bank Operations	70	3,344	584	44	3,972
Tucson Operations	29	1,601	613	49	2,263
Socorro Operations	123	5,848	2,644	78	8,570
VLBA Operations	95	4,085	2,110	200	6,395
Management Fee			600		600
Advanced VLBA Operations (for 4th Quarter 1992)			1,000		1,000
Common Cost Recovery/CDL Device Revenue			(819)		(819)
TOTAL OPERATIONS	424	$22,075	$ 9,302	$738	$32,115
INFRASTRUCTURE					
Repairs & Maintenance	4	$ 260	$ 2,125		$ 2,385
Research & Operating Equipment			1,100		1,100
Computing Resources			700		700
VLA Upgrade			1,500		1,500
TOTAL INFRASTRUCTURE	4	$ 260	$ 5,425	$ 0	$ 5,685
TOTAL NSF	428	$22,335	$14,727	$738	$37,800

XII. LONG RANGE PLAN
(NSF Funds, $ in Millions)

	1993	1994	1995	1996	1997	1998
OPERATIONS						
Base Operations	$24,720	$33,500	$34,840	$36,930	$39,150	$41,500
VLBA Operations	6,395					
Advanced VLBA Operations (for 4th Quarter 1992)	1,000					
TOTAL OPERATIONS	$32,115	$33,500	$34,840	$36,930	$39,150	$41,500
INFRASTRUCTURE						
Repairs & Maintenance	$ 2,385	$ 1,625	$ 1,970	$ 1,680	$ 1,470	$ 1,300
Research & Operating Equipment	1,100	1,500	1,500	1,700	1,800	1,900
Computing Resources	700	1,000	1,050	1,100	1,150	1,200
VLA Upgrade	1,500	3,000	3,150	3,300	3,450	3,600
TOTAL INFRASTRUCTURE	$ 5,685	$ 7,125	$ 7,670	$ 7,780	$ 7,870	$ 8,000
TOTAL NSF OPERATIONS	$37,800	$40,625	$42,510	$44,710	$47,020	$49,500
NEW INITIATIVES						
VLA-VLBA Link ($31M)	-	-	-	-	$ 5,000	$ 5,000
Millimeter Array ($120M)	-	$ 6,200	$ 9,000	$10,500	25,000	25,000
TOTAL NEW INITIATIVES	$ 0	$ 6,200	$ 9,000	$10,500	$30,000	$30,000
TOTAL NSF PLAN	$37,800	$46,825	$51,510	$55,210	$77,020	$79,500

Personnel Projection (Full Time--Year End Ceiling)

	1993	1994	1995	1996	1997	1998
Base Operations	329	425	448	455	459	459
VLBA Operations	95					
Infrastructure	4	4	2	2	2	2
GB Telescope Construction	23	22	-	-	-	-
Millimeter Array	-	5	15	20	38	44
VLA-VLBA Link	-	-	-	-	5	5
Non-NSF Research*	15	20	20	20	20	20
PERSONNEL TOTAL	466	476	485	497	524	530

* Separately funded and not included in the above budget.

APPENDIX A

NRAO SCIENTIFIC STAFF ACTIVITIES IN 1993

The NRAO staff scientists will investigate a number of topics in a variety of areas in 1993, as described below. Visiting scientists will collaborate in some of this research.

1. The Sun

Studies of solar flares at radio wavelengths provide information about where and when electrons are heated and accelerated in the solar corona, and how the energy contained in energetic electrons is subsequently transported within the flaring volume. Furthermore, they provide constraints on the magnetic field topology in the solar corona. Work in this area will proceed along several lines.

First, the details of energy release during the course of a solar flare remains controversial; the question being whether or not the release is "fragmentary," with a flare being nothing more than a superposition of hundreds or even thousands of elementary acceleration events. Two observations will explore this issue. The first is to explore the smallest radio bursts detectable by the VLA, the so-called radio microbursts, in order to characterize their properties and their relation to hard X-ray microflares. The second experiment is to use the VLA to image decimetric bursts observed simultaneously with a broadband optical spectrometer.

Second, the earliest stages of the impulsive phase of solar flares remain unclear. Within a matter of seconds, enormous amounts of energy are liberated, a large fraction of which goes into heating and accelerating electrons. High-resolution imaging in microwaves offers a means of pin-pointing the energy release site and of following the evolution of the source in these critical early stages. Previously, the time resolution of available instrumentation was too low to accomplish this goal. Recent improvements to the VLA allow us to obtain snapshot images of solar flares in two bands (and in both senses of circular polarization) five times per second. The observations are ongoing.

Third, the question of what processes transport energy throughout the flaring volume is also unclear. While nonthermal electrons most often appear to carry the bulk of the energy, and are ultimately held responsible for the hard X-ray and microwave bursts observed, several flares have now been observed with the VLA which are dominated by thermal plasma. Rather complete data sets have been acquired for several of these flares at radio, optical, and X-ray wavelengths. Work is underway to understand the major transport processes in these flares.

One of the outstanding problems of solar physics has been a detailed understanding of the Sun's outer atmosphere. The VLA allows one to image radio emission from the corona, transition region, and upper chromosphere. Of particular interest is the structure of solar active regions, the site of enhanced magnetic field and of solar flares. During the coming year, multi-band data sets from the VLA, the soft X-ray telescope aboard the Japanese satellite, Solar-A, and a rocket-borne EUV spectrometer will be used to study the distribution of electron density, temperature, and magnetic field in solar active regions.

A second program is the study of coronal bright points, first discovered in soft X-rays. Bright points represent the coronal signature of compact magnetic bipoles which are either emerging or cancelling. Their importance lies in gaining an understanding of the distribution and evolution of magnetic flux through the Sun's surface. Work on joint radio/X-ray observations of bright points will continue during the coming year using data sets acquired recently.

A third program involves the use of millimeter/submillimeter single-dish observations to probe the low chromosphere, a region where non-radiative heating first begins to manifest itself. A first observing run at the Caltech Submillimeter Observatory produced maps at 850 and 1250 microns. Analysis is in progress and will continue into the coming year. A modeling effort is underway to account for the gross properties of the observations, including the center-to-limb brightness variation, the limb extension, and the distribution of brightness in active regions.

2. Stars and Stellar Remnants

Stellar Radio Emission

The presence of nonthermal radio emission is a discriminating characteristic of the collapsed remnant of evolved stars — pulsars and X-ray binaries, for example — while thermal radio emission, either in the continuum or in molecular spectral lines, is a signature of young stars or those shedding their outer envelope as they evolve along the giant branch. Both classes of objects will be studied.

The fundamental distance scale begins with the parallax of nearby stars. The VLBA will be used in order to determine the parallax and proper motions of nearby stars. These stars have already been observed with the VLA, and suitable calibrator sources within 5' have been found. Using differential VLBA techniques, the parallax can be determined to an accuracy of 0.0001 arcseconds.

The strong X-ray/radio source Sco X-1 has been monitored over the last ten years with the VLA. With new VLBA observations, the parallax, proper motion, and orbital motion of the binary system will be measured such that the distance to this important X-ray source can be determined.

The radio study of X-ray transients revealed by GRO/BATSE and Granat continues to provide surprises. These objects are now the prime candidates for black-hole components and have both initial, fast "synchrotron bubble" events and complex, second stage radio sources tied to the central binary systems. V404 Cyg, Nova Muscae 1991, and GRO J0422+32 are currently being observed and analyzed. Subsequent new objects will be studied on a target of opportunity basis.

The nature and origin of the nonthermal microwave emission from RS CVn will be probed using the VLBA to spatially resolve the emission from the systems. Preliminary results indicate a large halo morphology, difficult to understand using a solar analogy.

Pulsars

Pulsar observations will provide a rich field of research in 1992. Pulsars will be studied both to establish the physical nature of these stellar remnants and they will also be used to infer the properties of the supernova events which preceded their formation.

Pulsars are celestial lighthouses which have very precise rotation frequencies. The timing data obtained from these accurate clocks allow one to estimate physical properties of the star (e.g., pulsar age and magnetic field strength) from directly observable quantities (e.g.,pulsar period and period derivative). For pulsars in binary systems, the various orbital parameters measured with the timing data allow one to determine, among other things, the masses of the pulsar and its companion. Timing observations conducted at the VLA will be designed to measure the masses of stars in pulsar binary systems.

Estimates of pulsar birth rates are influenced by pulsar number counts and the distribution of their inclination angles (the angle between the pulsar's rotation and magnetic axes). The probability of detecting a pulsar is determined by its inclination angle. We are more likely to see a pulsar with an inclination angle of 90 degrees because its beam sweeps out more solid angle on the sky than the beam of a pulsar with a smaller value. Inclination angles are calculated from polarization data using an assumed emission beam geometry. Traditionally, pulsar researchers have assumed that pulsar emission beams are circular in cross section. However, recent considerations of the pulsar magnetic field structure suggest that the beams have elliptical cross sections. An entirely self-consistent analytical model will be developed which properly accounts for the pulsar beam ellipticity. The model will be applied to existing high-quality pulsar polarization data to test the elliptical beam hypothesis.

The position and proper motion of thirty pulsars have been determined using the VLA over the last seven years. Additional VLA and new VLBA observations will be used to improve the proper motions, and they will have the sensitivity to determine the parallaxes. The motion of pulsars with respect to the plane of the galaxy and their supernova remnant counterparts are important in establishing their age and formation.

In the past few years we have seen the discovery of the interaction zone between the relativistic winds of pulsars and their surrounding medium. This work continues at the VLA with follow-up observational and theoretical studies of the known nebulae. In addition, a large survey is planned to search for pulsar wind nebulae toward approximately fifty pulsars, identified as being likely candidates.

The small number of known pulsar-supernova remnant associations, and the problem this poses, is well known. If pulsars come from supernovae, why are so few pulsars seen in close proximity to supernova remnants? To address this question, a multi-wavelength campaign has begun to look into such issues as birth rates, beaming functions, luminosities, initial periods, and magnetic fields. Substantial progress has been made in some of these areas. In the coming year ROSAT data will be analyzed to attempt to find new associations. At the VLA, searches are planned in known supernova remnants to look for pulsars. In addition, a radio/infrared survey is being carried out toward all young pulsars in an attempt to characterize the interstellar medium surrounding these pulsars, particularly those with no known supernova remnant.

Supernova remnants themselves will be studied in the Galaxy and in distant galaxies. Changes observed in the spectral index across supernova remnants (SNR) in the Galaxy may help elucidate the mechanism of acceleration of cosmic rays. If the SNR is large, an interferometer will not faithfully reproduce the large-scale structure unless total power and/or mosaicing is used. Mosaic observations of two large SNR will be made with the VLA at 6 cm. Beam-switched total power data from the NRAO 140 Foot Telescope will be added. The mosaic algorithm must be altered to properly treat beam switched total power. Lower frequency VLA observations are planned so spectral index images can be formed.

A broad program of studying radio supernovae in external galaxies will continue. The radio emission from a supernova explosion gives information on the circumstellar environment of the supernova, and thus indirectly the mass loss rate and nature of the supernova progenitor. Older supernovae, ten to a hundred years of age, give information on the transition from a radio supernova to a supernova remnant where interaction with the interstellar medium dominates.

Emission Nebulae

Nebular emission lines may arise in material recently expelled from the atmosphere of an asymptotic giant star or they may arise in gas located near a stellar source of excitation. Both cases may be studied for information about the nature of interstellar gas.

The first naked eye nova since 1975, Nova Cygni 1992, is being studied with the VLA. Presently it is observed to be in a rising, optically thick phase of the light curve. In 1993, this should be the first nova where strong emission from resolved structure from the "shell" can be observed by the VLA, allowing resolution of the controversy over whether nova shells are largely spherical, Hubble flow shells, or are asymmetric equatorial rings and polar cap structures. A weaker nova, Puppis 1991, is having its radio light curve measured, and other bright new novae will be observed as they occur. Analysis of the multi-frequency light curves of three recent novae — Cygni 1986, Herculis 1987, and Herculis 1991 — is in progress.

There is now a good, general understanding of how the sharp filamentary shells are formed around massive O-stars and Wolf-Rayet stars. They result from the continued injection into the interstellar medium of material from the star by means of a massive, fast wind. What remains unresolved is the duration of the wind phase, since the visible shell is a complex amalgam of wind and ambient material. The advent of new, more sensitive receivers on the 12 Meter Telescope makes it profitable to try once again to identify the interstellar clouds into which the wind is expanding, for two or three of the most favorable cases. The study will entail observations primarily in CO, but it may be important to also try some observations of a transition characterist gas, such as SO.

The star MWC 349A is a particularly interesting stellar wind source. It appears to be surrounded by a disk, and the entire system is enclosed in an ionized stellar wind. At longer wavelengths, the radio recombination-lines are Gaussian and have ratios of line-to-continuum emission that are consistent with the stellar wind. However, at millimeter wavelengths, the lines are unexpectedly strong, have double-peaked line profiles, and allegedly are masing. Because this source may be undergoing an evolutionary phase common to massive stars, it may be important to understand the physical mechanisms underlying its emission. During the next year the mechanism for the "masing" lines seen at millimeter wavelengths will be investigated through both observations and theory.

Star Formation

Star formation is associated with clouds of heated dust that can be seen in the submillimeter and FIR wavelength regimes. In fact, heated dust serves as a signpost for star-forming activity. To investigate the nature of spatially extended star-forming regions, FIR maps of these regions will be compared with radio maps made at 1.3 mm and 0.8 mm. Comparison with existing molecular maps should show the relationship between the warm dust and the associated interstellar medium.

An interesting group of objects for the study of disk physics, and how low-mass stars might eventually form planetary systems, are young binary star systems. Recent observations revealed the first detections of submillimeter continuum emission from a spectroscopic, binary star system. Also detected were several other systems, and very strong upper limits were placed on several more. Currently several methods are being explored to model the emission which most likely arises from a circum-binary disk. During the next year work will continue on the analysis of these observations. Significant constraints will be placed on the dispersal time of circumstellar disks.

3. The Interstellar Medium

Radio observations provide an important tool for the investigation of both the low-density and high-density structure in the interstellar medium. Work continues on a long-term program to use pulsars as continuum sources to probe the diffuse Galactic HI gas on AU scales. Three epochs of observations covering two years reveal a wealth of structure on these small scales. Efforts in 1993 will concentrate on characterizing the nature of the opacity variations, determine the structure function, and compare these with other small-scale tracers of the neutral and ionized phases of the interstellar medium.

At present there exists only lower limits to the temperature of the ubiquitous HI gas known as the warm neutral medium. A high-spectral, dynamic-range experiment will be carried out at the VLA which should be capable of detecting any warm gas in absorption, and hence enabling a direct determination of its temperature for the first time.

Work continues on a well-established program at the VLA to probe the ionized gas layer using HI absorption measurements toward pulsars. The program will concentrate on high dispersion measure pulsars within the inner Galaxy. This will enhance the current space sampling in this region and allow an improvement of the electron density models at low galactocentric radii. All the HI absorption data will be used to globally model the cold atomic layer in much the same way as the electron layer has been modeled.

Dense interstellar clouds will be probed by an active investigation of massive star formation associated with ultracompact HII regions. Ultracompact HII regions are formed by massive stars deeply embedded in molecular clouds. Because they are present during the very early stages in the evolution of a massive star, ultracompact HII regions are an excellent probe of the conditions necessary for the formation of massive stars. Through their recombination-line emission and associated molecular-line emission, ultracompact HII regions also provide a means to study the kinematics of gas around young massive stars. Recently a high-resolution, H76α, VLA observation of G29.96-0.02 was used to reveal a remarkable flow in the ionized gas. This flow is consistent with the bow shock model of HII regions. In this model, the ionizing star moves supersonically through the surrounding molecular gas. In 1993, HII regions will be observed to see if they, too, are consistent with the bow-shock theory.

The remarkable massive star-formation region G5.89-0.39 is the most massive bipolar molecular outflow in the Galaxy. In 1993 ammonia observations will be used to demonstrate that a massive star drives an ionized flow from the inner edge of a thick molecular torus surrounding the star. The wind and thermal pressure of the expanding HII region drive this very massive flow. Future VLA observations will observe the recombination-line emission of the source with very high angular resolution. HI absorption experiments will be made with the VLA to see if the photodissociation region surrounding the HII region has the geometry and velocity structure that is predicted.

4. Molecules and Astrochemistry

Studies of dense cores of molecular clouds, both star-forming and devoid of stars, define the focus of much current research. An ammonia survey with the 43 meter telescope of the entire Rho Ophiuchi dense cloud complex can proceed over the coming year. Although the general location of a core is well-defined on arcminute spatial scales, even at this scale known mid-infrared sources clearly avoid the cores. Presumably, if the ammonia continues to trace the gas column density, new stars will form, or are forming, within the cores hidden from infrared scrutiny. Low-mass stars interact with their cores on scales of a few thousand astronomical units, so to locate and study the sites of star creation higher resolution is necessary. The next step will be to image specific cores at higher resolution with the VLA. Several cores have already been imaged; the remainder will be imaged in the 1993 D-configuration period. In most cores, only a single substructure can be seen, but in the unusually prolific Oph A core there are several substructures. The properties of these structures are being investigated: Are they the first signs of a forming subcluster or single multiple stellar system?

Several of the cores have unusual chemistry. Unusual enhancement of sulfur oxides near GSS30 have been described. Research during the coming year will attempt to continue the process of ruling out chemical explanations for the enhancement. The nearby VLA 1623 source remains enigmatic because, despite a well-developed CO outflow and ionized gas/cold dust continuum source, no molecules have been found to associate with the central object. The young star is so cold that most of the molecules appear to have frozen onto grains in its natal core. Attempts will continue to find emission from the object which will confirm whether or not it is that holy grail of star formation — a true protostar.

One observational problem with studying the formation of stars is finding molecular probes which uniquely trace the dense material close to stars. One approach being pursued is using high-frequency, high-excitation molecular transitions. These should only be excited in the hot, dense regions very close to the stars and therefore provide a probe to study the circumstellar regions of these stars. Two molecular transitions, with excitation energies about 50 K above ground-state have been detected in several sources using the Caltech Submillimeter Observatory (CSO) in Hawaii. During the coming year, observations will be made of lines from the more extended core material. It is hoped that the properties of the close circumstellar regions can be determined and any unique excitation or velocity signatures of the circumstellar environment identified.

The unique chemistry of circumstellar shells will be the focus of several investigations in 1993. The first project will attempt to measure nearly simultaneously the emission from up to six rotational states of the SiO maser in circumstellar envelopes. SiO maser pumping theories make specific predictions as to the inversion properties of the family of rotational transitions within given vibrational states. A measurement of the emission strengths and profile shapes for several transitions, observed at the same epoch, will help determine these models. The frequency coverage and flexibility of the 12 Meter Telescope will permit an observation of five of these transitions.

The identification of the interstellar molecule methylene (CH_2) should be secured in 1993. This is a molecule of some importance to interstellar chemistry since its primary formation mechanism is an alternative branch of the reaction producing the interstellar tracer molecule CH. In turn, CH_2 leads to the formation of HCO, a structural constituent of a number of well-known interstellar molecules. This molecule is difficult to observe because of the high-lying energy levels of its only accessible transitions. Previous observations have produced a tentative detection of this species. It should be confirmed in the coming year.

Finally, in pre-planetary nebulae, such as IRC+10216, molecules are created by chemical reactions in a distended stellar envelope where dissociation by ultraviolet light creates a reservoir of ions and radicals. VLA images of cyanoacetylene, cyanotriacetylene, and ammonia are in hand for comparison to Owens Valley interferometer images of cyanoacetylene. Cyanodiacetylene images will be obtained in two transitions with the VLA during the autumn 1992. The remarkable paradox unveiled by these observations is that the more complex molecules lie at successively larger radii, in regions of the envelope where large ultraviolet fluxes provide harsher conditions. During the remainder of the period existing radiative transfer models will be modified to treat stellar envelopes.

These models, plus the images, will provide accurate radial abundance profiles for confrontation with photochemical theories.

5. Studies of the Galaxy

In 1993, two studies will seek greater understanding of the distribution of gas far from the galactic plane. For several other studies, the center of the galaxy is the focus of attention

In an attempt to understand gas far from the plane, two general areas will be investigated. First will be observations at high latitudes where the ISM is relatively uncomplicated and detailed comparisons can be made between the emission seen in HI and CO, with other species such as soft X-ray emission (and absorption), and absorption lines from transitions in the optical and UV. Specific projects underway involve correlation of HI emission with soft X-ray emission (from ROSAT data) to try to determine the geometry and properties of the hot interstellar medium, and comparison of HI and UV spectra toward a set of QSOs to study the ionization state and elemental abundances of high-velocity galactic clouds.

The second area of study will be at fairly low latitudes where distant, large-scale, interstellar structures, like superbubbles, are seen emerging from the disk gas. The goal here will be to observe enough of these objects to determine which, if any, might be "chimneys" that are venting hot gas into the halo, and to get a general idea of the size, shape, and thickness of these regions.

Both neutral and ionized gas will be observed at the Galactic center. One of the most striking radio structures in the Galactic center is the arched filaments. The thermal nature is determined based on its continuum properties at a large range of radio wavelengths and on the detection of the radio recombination line. The kinematics of gas is characterized by negative velocities in a range between -50 to 0 km/s. A prominent molecular cloud has been observed also to be associated with the thermal ionized filaments. The 55 micron image shows a remarkable distribution of warm dust in this region. However, it appears controversial if the ionized gas has its origin in the photoionization by OB stellar populations or from magnetohydrodynamic processes. An additional controversial issue is if the forbidden negative velocity gas moves inward toward or outflows from the Galactic center. In order to understand these problems, images will be made of the fine structures of the velocity and other physical quantities which are derived from the VLA radio recombination-line observations.

Linearly polarization emission has been detected near the Galactic center along the radio arc (30 pc away from Sgr A*). Based on the existing observations, the depolarization appears to be increasing towards the Galactic center. There are several nonthermal sources in the central 10 pc (in size) region — Sgr A East (the nonthermal shell, perhaps an SNR), Sgr A* (a compact radio source at the dynamic center of the Galaxy), and the galactic center transient. No significant polarization has been detected from these nonthermal sources. Recent measurements with the VLA result in an extremely low limit of a degree of linear polarization from Sgr A* (e.g., $< 0.1\%$). The unusual low limits and previous negative detections of linear polarization from all the nonthermal sources within the central 10 pc can be explained if the radiation is severely depolarized by an extremely large Faraday screen. Observations have been proposed using the VLA to detect the putative Faraday screen.

6. Normal Galaxies

In 1993, observations are planned to investigate some of the most massive galaxies, the most energetic galaxies, and the relationship of one class of galaxy to another.

Several extragalactic studies aim toward a better understanding of the global properties of galaxies. Data are now extensive enough to evaluate such properties as total mass, HI content, linear dimension, and even specific angular momentum as a function of morphological type. As usual, sample bias is the principal uncertainty in such an effort, and much care must be employed to evaluate its effects. The goal is a set of values for these quantities, one that is consistent with a well-defined sample.

The study of high signal-to-noise HI velocity profiles has been very successful in uncovering high-velocity hydrogen clouds in galaxies other than our own. The initial filled aperture survey yielded a sample of close to twenty such galaxies. Several of these are now being or will be observed with synthesis array instruments in an attempt to better understand the origin of the high-velocity cloud phenomena.

Another as yet untapped diagnostic attainable from HI velocity profiles is an indication of galaxy interactions. There are several ongoing computer studies of such interactions, in part for their own sake but also to test the popular view that many, perhaps all, elliptical galaxies are the result of merges of gas-rich systems. The program to be undertaken here is to obtain a measure of the current frequency of such interactions, a quantity which would represent a zero point in the understanding of galaxy evolution.

The NRAO study of the interstellar medium within early-type galaxies is ongoing. An important catalog and several papers have resulted, and our understanding of this subject has broadened. And, as usual, new questions are posed. ROSAT observations have been or will be obtained to answer some of these. Others are amenable to ground-based observations, and work in this direction is planned. As an example of a specific problem that will be studied, there is the question of why do some Sa spiral galaxies appear to lack cool gas. The detection rate of cool gas is a strong function of galaxy type: near zero in elliptical galaxies, one-fourth in SO's, three-fourths in Sa's, and a sure thing in later type systems. The question posed here is why are there Sa galaxies with unambiguous disk and spiral features lacking in the cool gas that (we believe) makes these features. The first thing is to check and make sure that the older observations are correct and that no constraint, such as an unusually large velocity range, made its detection difficult. Both HI and CO observations will be necessary. A continued non-detection will then define further observations, e.g., stellar populations, environment, multicolor imaging, etc.

The hydrogen in galaxies in clusters forms the basis of two interesting investigations. For several years it has been recognized that galaxies in the cores of clusters differ from those in the field in their morphological type, stellar population, and gaseous content. By studying galaxies in clusters over a moderate range of redshifts, it might be possible to observe galaxies being transformed — from normal to gas-poor and old galaxies. As the beginning of a more systematic study of the HI properties of galaxies in clusters, VLA observations will be made of three clusters at redshifts of 0.04, 0.05, and 0.06. These clusters span a range in compactness, spiral richness, and X-ray luminosity, giving us a chance to study the evolution of galaxies under different circumstances. An HI mass as low as $\sim 10^8\ M_\odot$ can be detected, if present, in these galaxies from the observations. These observations will also be used to look for cooling flows in these clusters.

Several galaxies, thought to be isolated, are in fact accompanied by cloudlets of HI. The search for companion HI clouds near HII galaxies (also known as extragalactic HII regions or blue compact dwarf galaxies) has been extremely successful. HI companion cloudlets are found in VLA D-array HI maps in six out of nine galaxies. Follow-up C-array observations have been obtained as well as optical data (broadband CCD frame and Fabry-Perot $H\alpha$ images). They will form the basis of an article discussing the star-formation history in the dwarf galaxies and their companions. More importantly, twenty galaxies culled from a statistically significant subset have recently been observed in D-array. These data will be used to test the hypothesis that the companion clouds form the trigger of the violent, episodic bursts of star formation in HII galaxies.

The energetics of galaxies, including starbursts, supernovae, and black holes, are probed in other observations. One study will concentrate on the origin and propagation of cosmic rays, and the role magnetic fields and star formation play in this process. Radio continuum spectra will be used to determine the "thermal fraction," and hence give an unobscured picture of the distribution and rate of star formation across the disk of NGC 253. Multi-frequency polarization measurements will be used to determine the rotation measure distribution, and hence the magnetic field morphology and strength. These data will be combined with optical broad and narrow-band images, IRAS images, and proposed CO and HI observations, to obtain a "global" picture of the ionized, neutral, and molecular gas distributions, as well as of the dust and cosmic ray distributions and their relationship to galactic structure and star formation activity. This project presents a number of interesting observational challenges, involving three-dimensional imaging, high dynamic range mosaicing, and polarization mosaicing.

A related project is a proposed low-frequency survey with the VLA of a sample of edge-on spiral galaxies to determine whether "halos" of relativistic particles and magnetic fields of the kind observed in NGC 253 and a few other inclined spirals are a general property of spiral galaxies, or whether such halos are restricted to certain types of galaxies. These observations should also give insight into the physical mechanism driving such halos.

Some galaxies are dominated by supernovae which are significant sources of radio emission. Mkn 297A was discovered as a variable source in 1982. It was later identified as a single radio supernova with the highest peak radio luminosity ever observed. Further VLA observations will be made at 2, 3.5, 6, and 20 cm wavelengths for more complete light curves at its intermediate age and possible short-term variations from its long-term decline. With the new observations and the data from 1980-1992, it will be possible to study physical models for this subtype of very energetic supernovae (hypernovae).

A direct test can be made with the VLBA of the supernovae-driven starburst model for the Seyfert 1 nucleus of NGC 5548. If the supernova model is correct, a first-epoch VLBA image to be made in 1993 should show two or more radio supernovae in a region of diameter 0.1 arcseconds. A second epoch image several years later should also show supernovae but ones different from those seen at the first epoch. Phase referencing is necessary for observations at both epochs.

7. Radio Galaxies and QSO's

Observations of radio galaxies and QSOs in 1993 will concentrate on the physics of the radio emission process and on the relation of one class of radio source to another.

The physics of particle reacceleration in radio lobes will be investigated by means of a multi-wavelength, high-resolution VLA study of the filamentary lobes of the radio galaxy 3C 353. No satisfactory model exists for the origin of such large-scale filaments, yet their existence and prominence in sources such as 3C 353 calls into question the conventional assumptions about equipartition of energy, and about the isotrophy of magnetic fields and particle motions, in radio lobes. 3C 353 is nearby and a well-resolved example of a filament system that is particularly amenable to detailed study. The highest angular resolution possible will be used to quantify the spatial structure and power spectrum of its filamentation, and to clarify the relationship between apparently bright and apparently dark filamentary features. Multi-wavelength observations will also be used to determine whether the continuum radio spectra of the filaments differ systematically from each other or from those of the more diffuse lobe emission, and to map the magnetic structures in the filaments. The results will be compared with those of numerical models that presently suggest several different mechanisms that could lead to large-scale filamentation.

The internal structures of the jets and counterjets in the radio galaxies 3C 219 and 3C 353 will also be examined at high resolution using the VLA, for comparison with differing models of emissivity variations and symmetries in powerful sources.

A program to make VLA images of selected nearby bright QSOs will continue. These radio images will be compared with optical and IR images to look for signs that the host galaxies were once part of interacting systems. Already, optical images of one object, PG0052+251, shows a resolved active nucleus. In 1993, high sensitivity, multi-wavelength VLA images will be made of this object.

The VLA is being used to study the radio structure of optically selected quasars such as a sample of high-luminosity quasars and the Palomar Bright Quasar Survey. These data are being used to compare their radio structure with other optically selected and radio selected quasars and to search for examples of gravitational lensing.

Sources with steep spectra are of interest for many reasons: some are halos in clusters, some old radio galaxies, and others short-period pulsars. Observations at 90 and 20 cm using the VLA have been made of about a dozen sources chosen from the low-frequency survey at 34.5 MHz as they had steep spectra between 34.5 and 408 MHz. One of the sources, 0508-1842, has a core and two lobes. The lobes have a spectral index (α, where $S \propto \nu^{\alpha}$) steeper than -1.5 between 34.5 MHz and 5 GHz. Optically this source has been classified both as a quasar and a radio galaxy. Further VLA observations at a better resolution and optical observations will be made to understand the nature of these sources.

Attempts to synthesize the properties of classes of radio galaxies will take two forms in 1993. The prominence (relative to the extended lobes) of radio jets and counterjets in two complete samples of powerful radio galaxies and quasars have been determined. The results will be correlated with the detailed lobe morphologies to test predictions of "unified" models that identify radio-loud galaxies and quasars as members of the same population of strong radio emitters observed in systematically different orientations.

Tests will be made of the idea that FR I radio galaxies are the parent (unbeamed) population of BL Lac objects (beamed). The test involves measuring the size of the 4000 angstrom break in the spectra of radio galaxies in cluster sources and using the fact that the break amplitude is very constant in cluster ellipticals to infer the presence of a nonthermal nuclear source. The beaming picture predicts that there should be a range of core luminosities ranging from a true BL Lac luminosity down to zero depending on the beaming angle. So far, 50 galaxies have been observed. While nearly 20 percent of the radio galaxies have nonthermal components, they are very low luminosity and may not match the prediction of the model. In 1993, another 50 galaxies will be studied.

Spectroscopic observations are planned of the environment of cosmologically distant galaxies and QSOs. Recently radio recombination-line emission has been detected from four starburst nuclei — IC 694, NGC 3628, NGC 2146, and Arp 220. The radio recombination-line is a new tool to study the kinematics, with a high angular resolution (few tenths of arcsec), of starburst nuclei in which optical extinction due to dust is so high that study at optical wavelengths is impossible. A number of detailed models are being investigated to explain the new results. The VLA at 3.6 cm has proven capable of providing high spectral dynamic range (greater than 10000:1). Thus, it becomes possible to detect weak line signals from strong radio cores in active galactic nuclei. In 1993, the search will be extended to active galactic nuclei and radio quasars.

Radio-quiet quasars (and Seyfert galaxies) sometimes exhibit intense FIR emission. Recently, CO has been detected from seven of twelve such objects, which indicates that these objects have a cool interstellar medium. The presence of an ISM indicates that these objects are powered thermally by massive bursts of star formation rather than by nonthermal processes such as synchrotron emission. During the next season, the VLA will be used to search for radio recombination-lines from these objects, which if detected would indicate the presence of HII regions and thus clinch the case for the starburst hypothesis.

8. Parsec-Scale Radio Jets

The elliptical galaxy M84 hosts an FR-I radio continuum source. Its two VLA jets are initially asymmetric but symmetrize about 1 kpc from the nucleus. A nonrelativistic turbulent jet model can describe the brightness and spreading rate evolution of individual jets in FR-I sources, but cannot account for the trends in the symmetry properties of the jets seen in the VLA image of M84. Is the VLBI or parsec-scale brightness asymmetry an extrapolation of the asymmetry decline seen in the VLA jet? If so, this would imply a common physical origin for the symmetrization process between VLBI and VLA scales that can be studied with VLBI resolution. The first VLBA images of M84 will be used to evaluate the pc-scale brightness symmetry for comparison with the VLA symmetrization results. Brightness asymmetries on parsec scales could arise from Doppler boosting in relativistic flows. The VLBA images will be used to identify jet "knots" suitable for proper motion studies. The proximity of M84 means that such studies could distinguish between relativistic and subrelativistic apparent motions even in a side-on jet.

The parsec-scale structure of the flat-spectrum radio galaxy Mrk 501 apparently twists through a right angle. Recent VLBA and MERLIN images will be used to follow the details of the twist, and to interpret both the twist and other properties of Mrk 501 within the context of three possible models for the pronounced observed curvature: precession of mildly relativistic twin jets; deflection and brightening by strong dynamical interaction with clumped ambient gases; and expansion of a helically twisted light relativistic jet in response to an external ambient pressure gradient.

The VLBA will be used to continue studies of the structure of two radio galaxies: NGC 5128, the nearest galaxy with an AGN, and NGC 1275, a more luminous complex radio galaxy with subluminal motion. The high angular resolution of the VLBA at 7 mm will give a linear resolution at the distance of NGC 5128 of the order of one light day, or comparable with the accretion disk around the putative black hole at the center of the galaxy.

Between 1979 and 1988, the parsec-scale structure of 3C 120 was monitored with VLBI. Preliminary results show that new components appear about once per year and travel away from the core at about 2.5 milli-arcseconds per year, an apparent speed of about four times that of light. These data will provide a unique opportunity to study the evolutionary history of many superluminal components in a single source. It should help determine which characteristics are constant and which can vary from one component to another.

9. Radio Surveys

The Green Bank 4.85 GHz sky maps covering $0° < \delta < +75°$ and $-40° < \delta > +5°$, $0^h < \alpha < 20^h$ have been used to find radio identification candidates for extragalactic far-infrared (FIR) sources in the IRAS Faint Source Catalog, Version 2.0. These candidates are being confirmed or rejected with VLA maps and accurate optical positions. About 200 confirmed identifications powered by "monsters" in active galactic nuclei are expected plus over 200 sources powered by stars in normal or starburst galaxies. These samples are large enough to constrain the properties of FIR blazars and determine whether some hypothetical objects (optically quiet blazars, hidden Seyfert nuclei) exist. Joint FIR/radio luminosity functions will be constructed and used to compare the cosmological evolution of starbursts and AGN at radio and FIR wavelengths.

VLA A-array observations of all UGC galaxies with $\delta < +82°$ and $S > 150$ mJy at 1.4 GHz or $+5° < \delta < +75°$ and $S > 25$ mJy at 4.85 GHz have been obtained. Half of the ~ 400 maps have been made, and the remaining maps will be made in the next few months. These maps will be used to detect nearly all nearby compact nuclear radio sources in the northern hemisphere. The accurate radio positions of these sources will be compared with the optical centroids of their parent galaxies to test models that predict position offsets between "monsters" (supermassive black holes) and the stellar nuclei of active galaxies. The orientations of jets emerging from these radio cores will be compared with optical stellar isophotes on CCD images being obtained at Lick

Observatory. Emission-line spectra of those galaxies containing unresolved radio cores will also be obtained.

The VLA 20 cm survey of Abell clusters will be used to complete the first version of the radio H-R diagram and to study its consequences for radio source evolution. The diagram will be three dimensional and consist of radio luminosity, optical luminosity, and radio size for radio galaxies in rich cluster. The radio observations will be completed this fall with the VLA. The optical surface photometry, used to measure the galaxy magnitudes, is about 95 percent complete and should also be finished this fall.

10. Cosmological Studies

VLBI observations of the angular extent of compact radio sources show a dependence on redshift characteristic of Friedmann world models with $q_0 = 1/2$ corresponding to $\Omega = 1$. This is the first direct observational measurement of the expansion of the universe and is consistent with a "flat" universe having the critical mass density required by inflationary cosmologies. New observations planned with the VLBA will be used to determine how well compact radio sources define standard rods by studying possible variations of linear size with morphology and luminosity. In this way it will be possible to determine q_0 more accurately. Repeated VLBA observations will be used to determine the angular motion as a function of redshift in a large number of superluminal sources to give an independent determination of q_0 and to better understand the dynamics of superluminal motion.

Recent VLA observations of limits of CBR fluctuations with arcminute scale are among the most sensitive observations of the CBR fluctuations. With the detection of degree-scale fluctuations from COBE, it is now even more important to determine small-scale fluctuations which may be associated with galaxy formation and ionization at redshifts of about 5 to 10. Extensive VLA observations at 3.6 cm will be made in 1993 to continue these measurements.

Measurements will continue of the Sunyaev-Zel'dovich effect, a distortion of the spectrum of the microwave background due to Inverse-Compton scattering with the hot electrons that are present in dense clusters of galaxies. At a frequency of 20 GHz, the effect is a decrement in the temperature of the background radiation of about -1 mK in the direction of the densest and hottest clusters of galaxies. Due to the beam-switching schemes that must be used with single-dish telescopes at these levels of sensitivity, the measured decrements are about -0.4 mK as the reference beams are affected by the Sunyaev-Zel'dovich distortion. Such small signals have to be confirmed by observations at other frequencies, especially so due to the past history of the observations of this effect as observers have failed to reproduce other observers' results. The BIMA millimeter array will be used to observe the Sunyaev-Zel'dovich effect in the cluster 0016+16 at a frequency of 86 GHz. The observations will be made using a tessellating technique to measure the necessary short spacings.

The search for proto-clusters of galaxies will continue the technique involving the observation of their (redshifted) 21 cm emission at a frequency of 333 MHz, thus probing a redshift of about 3.3. 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 4×10^{12} $M_\odot$, somewhat dependent on the values of key cosmological parameters. One of the observed fields contains a protocluster with 3×10^{14} $M_\odot$ of neutral hydrogen which is seen in emission. Absorption at a redshift of $z = 3.4$ is seen towards a radio galaxy at about the same redshift. Observations of other fields are underway, searching over the entire P-band available to the VLA, a frequency range of 305 MHz to 335 MHz which corresponds to a probed redshift range, $3.7 > z > 3.2$.

11. Astrophysical Theory and Applied Studies

The evolution from asymptotic giant branch (AGB) star to planetary nebula (PN) and beyond is one of the least well understood phases of stellar evolution. An extended envelope is deposited around the star during a heavy mass-loss phase on the AGB. Because of the high densities and low temperatures in the stellar atmosphere, this envelope is predominantly molecular. As the star evolves off the AGB and the stellar core is exposed, a secondary wind — the "fast wind," which has much less mass but comparable momentum to the red giant wind — develops and begins to plow into the slower red giant wind. It has been proposed that the interaction of these winds is partly responsible for the shaping of planetary nebulae. In the earliest stage of this process, before the exposure of the stellar core, the envelope is still largely molecular. As the central star and nebula evolve, a photodissociation front moves through the gas and the circumstellar envelope changes from molecular to atomic to ionized. No detailed studies of the chemical evolution of PNe have as yet been completed.

During the coming year, several questions relating to AGB evolution will be studied. In particular, a detailed theoretical study into the time-dependent chemical evolution of planetary nebulae will be made. This project involves the integration of a complex chemical network (about 41 species and over 400 chemical reactions) throughout the lifetime of a simulated nebula. During most of the lifetime of a planetary nebula, the processes in the gas are dominated by photons. For this reason, photo-processes will be studied in detail. Modeling of molecular emission from spherical and non-spherical nebulae will be done at various epochs in the evolution of the PN. Simultaneously, an extensive observational program with the NRAO 12 Meter Telescope will be carried out. These observations will be used to test and refine the chemical models. This study will reveal the details of the evolution of planetary nebulae and will shed some light on the relative importance of time-varying gas density, radiation field, and interacting winds.

Two important imaging studies will begin in 1993. The possibility of ultra-high, angular-resolution imaging in the presence of strong scintillation will be investigated. In conditions of strong scintillation, information about both the scattering screen and the background object is present in the full mutual coherence function when measured completely and redundantly. By a process similar to self-calibration it is possible to extract both the actual form of the scattering screen and the brightness of the background object. In practice, however, interferometric arrays are not often constructed to sample completely and redundantly and so imaging must be performed from incomplete, non-redundant sampling. While full imaging is probably not possible, some limited form based upon model fitting may be possible. This work has ramifications in all situations of strong scattering, the most notable examples being optical speckle and interstellar scattering.

Investigations will continue of the limitations in radio-interferometric imaging due to deconvolution errors. It is well known that VLBI images are limited in dynamic range to a few thousand to one in many cases. While many have suspected that this is due to residual calibration errors, evidence has accumulated that this limitation can be ascribed to the CLEAN deconvolution algorithm used in many forms of radio-interferometry. Previously it had been suspected that CLEAN limited only the on-source signal-to-noise ratio whereas the current work shows that off-source errors are often due to so-called invisible distributions generated by CLEAN. The efficacy of various other deconvolution algorithms will be studied in this regime. If some countermeasures are possible, they will be applicable to VLA and VLBA imaging as well as to other radio and optical interferometers.

APPENDIX B

SCIENTIFIC STAFF

(Does not include Visiting Appointments)

D. S. Adler - Interstellar medium; molecular clouds; dynamics of spiral galaxies; star clusters; star formation

T. S. Bastian - Solar/stellar radiophysics; radiative processes; plasma astrophysics; particle acceleratrion; 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

J. A. Biretta - Active galaxies; quasars; VLBI techniques

A. H. Bridle - Extragalactic radio sources

E. Brinks - Interstellar medium in nearby galaxies; HI studies of galaxies; star-forming dwarf galaxies

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

W. R. Burns - Information theory and signal processing

C. Carilli - Extragalactic radio sources; formation of galaxies

B. G. Clark - VLBA control; software development

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

J. E. Conway - Extragalactic radio sources; jets in radio sources; VLBI observing techniques; extragalactic radio supernova and supernova remnants

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

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

G. A. Croes - Software architecture; software development

L. R. D'Addario - Theory of synthesis telescopes; superconducting electronics; millimeter wavelength receivers; radio astronomy from space

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

K. S. Dwarakanath - Clusters of galaxies; interstellar medium; aperture synthesis at low frequencies

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. 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

R. J. Havlen - Galactic structure; clusters of galaxies

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

P. R. Jewell - Circumstellar shells; interstellar molecules; cometary line emission

W. Junor - Extragalactic radio sources; VLBI

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

A. R. Kerr - Millimeter-wave development

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

W. B. Latter - Astrochemistry; interstellar medium; mass loss processes; planetary nebulae; magnetic white dwarfs

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

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

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

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

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

D. Puche - Kinematics of spiral galaxies; dark matter; groups and clusters dynamics

M. S. Roberts - Properties and kinematics of galaxies

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

M. P. Rupen - Interstellar medium of early type galaxies; galaxy dynamics through radio/millimeter observations; radio supernovae; steep spectrum radio sources

G. A. Seielstad - Quasars; active galaxies; VLBI

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

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

C. M. Wade - Astrometry; stellar radio emission; minor planets; extragalactic radio sources; VLBA development

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

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

D. S. Wood - Star formation; HII regions and the interstellar medium; radio and infrared astronomy; interferometry and infrared arrays; spectroscopy

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

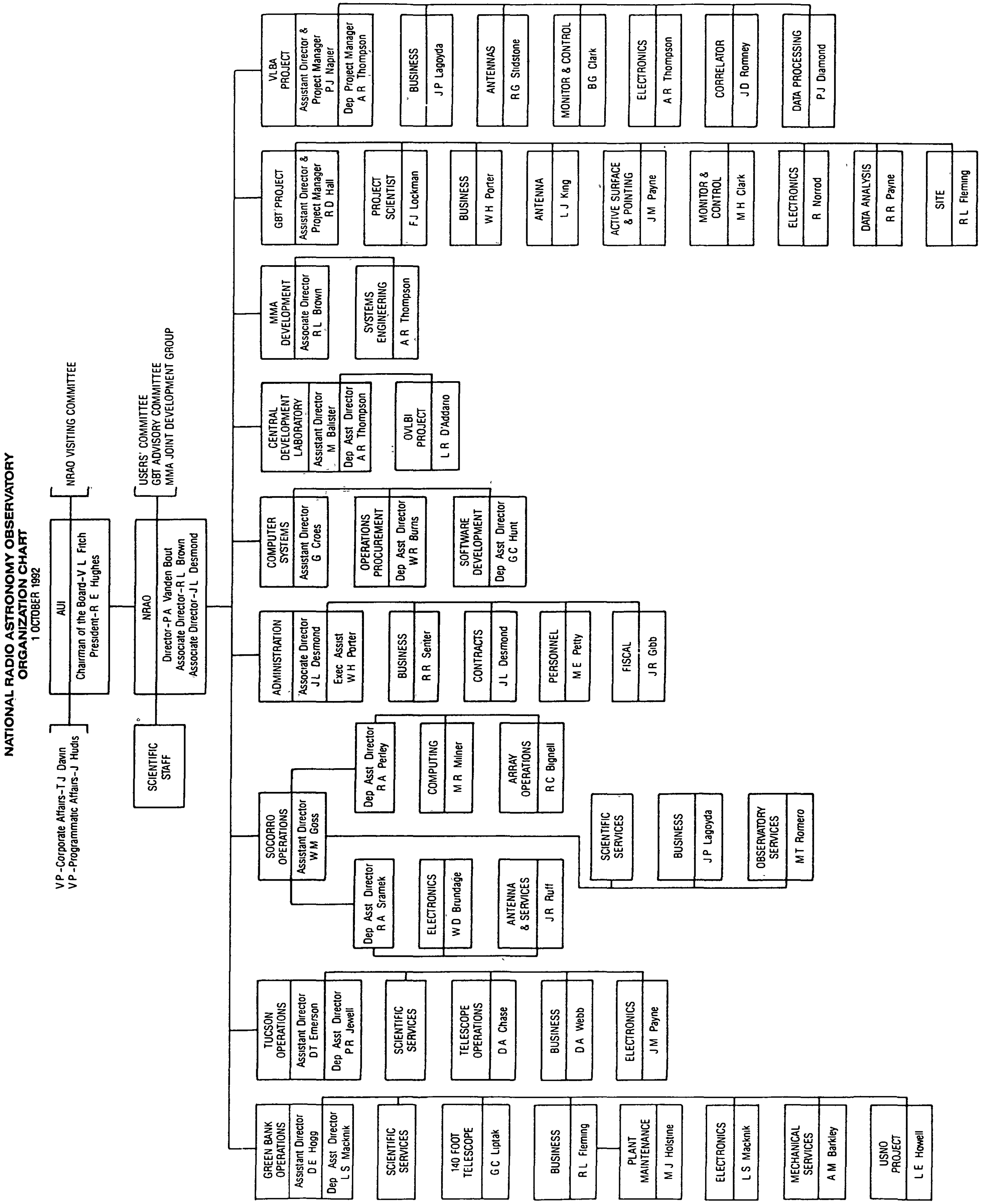
J. M. Wrobel - Normal galaxies; active galaxies; polarimetry

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

A. Zensus - VLBI observations of quasars and active galactic nuclei; compact radio jets and superluminal motion in compact radio sources

J.-H. Zhao - Radio jets; galactic center; interstellar medium; clusters of galaxies; recombination lines

APPENDIX C


NATIONAL RADIO ASTRONOMY OBSERVATORY
ORGANIZATION CHART
1 OCTOBER 1992
VP-Corporate Affairs-T J Davin
VP-Programmatic Affairs-J Hudis
AUI
Chairman of the Board-V L Fitch
President-R E Hughes
NRAO VISITING COMMITTEE
SCIENTIFIC STAFF
NRAO
Director-P A Vanden Bout
Associate Director-R L Brown
Associate Director-J L Desmond
USERS' COMMITTEE
GBT ADVISORY COMMITTEE
MMA JOINT DEVELOPMENT GROUP
GREEN BANK OPERATIONS
Assistant Director D E Hogg
Dep Asst Director L S Macknik
SCIENTIFIC SERVICES
140 FOOT TELESCOPE
G C Liptak
BUSINESS
R L Fleming
PLANT MAINTENANCE
M J Holstine
ELECTRONICS
L S Macknik
MECHANICAL SERVICES
A M Barkley
USNO PROJECT
L E Howell
TUCSON OPERATIONS
Assistant Director DT Emerson
Dep Asst Director P R Jewell
SCIENTIFIC SERVICES
TELESCOPE OPERATIONS
D A Chase
BUSINESS
D A Webb
ELECTRONICS
J M Payne
SOCORRO OPERATIONS
Assistant Director W M Goss
Dep Asst Director R A Sramek
ELECTRONICS
W D Brundage
ANTENNA & SERVICES
J R Ruff
Dep Asst Director R A Perley
COMPUTING
M R Milner
ARRAY OPERATIONS
R C Bignell
SCIENTIFIC SERVICES
BUSINESS
J P Lagoyda
OBSERVATORY SERVICES
M T Romero
ADMINISTRATION
Associate Director J L Desmond
Exec Assist W H Porter
BUSINESS
R R Senter
CONTRACTS
J L Desmond
PERSONNEL
M E Petty
FISCAL
J R Gibb
COMPUTER SYSTEMS
Assistant Director G Croes
OPERATIONS PROCUREMENT
Dep Asst Director W R Burns
SOFTWARE DEVELOPMENT
Dep Asst Director G C Hunt
CENTRAL DEVELOPMENT LABORATORY
Assistant Director M Balister
Dep Asst Director A R Thompson
OVLBI PROJECT
L R D'Addario
MMA DEVELOPMENT
Associate Director R L Brown
SYSTEMS ENGINEERING
A R Thompson
GBT PROJECT
Assistant Director & Project Manager R D Hall
PROJECT SCIENTIST
F J Lockman
BUSINESS
W H Porter
ANTENNA
L J King
ACTIVE SURFACE & POINTING
J M Payne
MONITOR & CONTROL
M H Clark
ELECTRONICS
R Norrod
DATA ANALYSIS
R R Payne
SITE
R L Fleming
VLBA PROJECT
Assistant Director & Project Manager P J Napier
Dep Project Manager A R Thompson
BUSINESS
J P Lagoyda
ANTENNAS
R G Stidstone
MONITOR & CONTROL
B G Clark
ELECTRONICS
A R Thompson
CORRELATOR
J D Romney
DATA PROCESSING
P J Diamond

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.

The current membership of the Committee is:

D. C. Backer	California, Berkeley
F. N. Bash	University of Texas
J. N. Hewitt	Massachusetts Institute of Technology
R. Hills	Cavendish Laboratory
F. J. Low	Steward Observatory
A. P. Marscher	Boston University
P. Thaddeus	Center for Astrophysics
J. A. Tyson	Bell Laboratories

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, which is appointed by the Director, meets annually in May or June.

The present membership is:

C. L. Bennett	Goddard Space Flight Center
J. H. Bieging	Univ. California, Berkeley
F. H. Briggs	University of Pittsburgh
E. B. Churchwell	University of Wisconsin
R. J. Dewey	Jet Propulsion Laboratory
G. A. Dulk	University of Colorado
N. Duric	University of New Mexico
A. S. Fruchter	University of California, Berkeley
R. A. Gaume	Naval Research Laboratory
C. R. Gwinn	University of California, Santa Barbara
J. N. Hewitt	Princeton University
A. P. Marscher	Boston University
C. R. Masson	Center for Astrophysics
K. M. Menten	Center for Astrophysics
L. G. Mundy	University of Maryland
M. J. Reid	Center for Astrophysics
L. J Rickard	Naval Research Laboratory
F. P. Schloerb	University of Massachusetts
D. B. Shaffer	Interferometrics, Inc.
R. Taylor	University of Calgary
J. Turner	University of California, Los Angeles
S. C. Unwin	California Institute of Technology
A. E. Wehrle	California Institute of Technology
J. M. Weisberg	Carleton College
D. Woody	California Institute of Technology
L. M. Ziurys	Arizona State University

3. Green Bank Telescope Advisory Committee

Appointed at the inception of the Green Bank Telescope (GBT) project in 1989, this committee reviews periodically the design planning for the GBT. Initially the committee advised the Director on critical design issues facing the GBT project. Construction review and proposed instrumentation are present areas of concern to the Committee.

The committee is appointed by the Director. It is composed of scientists and engineers representing the range of skills — structural, mechanical, electrical, computational, and scientific — needed for the telescope's design and construction.

Current membership is:

M. P. Haynes	Cornell University
C. Heiles	University of California, Berkeley
R. A. Jennings	University of Virginia
J. D. Nelson	University of California, Berkeley
V. Radhakrishnan	Raman Research Institute
S. von Hoerner	Independent Telescope Consultant
S. Weinreb	Martin Marietta Laboratories
R. W. Wilson	Bell Laboratories