NATIONAL RADIO ASTRONOMY OBSERVATORY

PROGRAM PLAN 1989

Cover: The Polarized Radio Emission from Fornax A

The cover photograph is a VLA image of the linearly polarized radio emission from the radio galaxy Fornax A. The two main radio emitting lobes are produced by radiating electrons in magnetic fields which have been transported hundreds of thousands of light years from the elliptical galaxy NGC 1316 which lies between the two regions. The isolated, dark features are caused by the obscuration of the polarized emission by foreground material. The small elliptical "shadow" on the right is associated with a foreground spiral galaxy which depolarizes the radiation passing through it. But the "ant-like" feature in the center of the right lobe and the long dark features which are particularly prominent in the left lobe are not associated with luminous material.

Observation details:

Observers: E. Fomalont and R. Ekers (NRAO), K. Ebneter and W. Van Breugel (U. Calif.)
Frequency of 1.384 GHz. Five hours of D-configuration and five hours of C-configuration
Resolution of 15"; field of view is 40' x 20'
Maximum polarized emission is 15 mJy; rms noise is 0.3 mJy

NATIONAL RADIO ASTRONOMY OBSERVATORY

CALENDAR YEAR 1989

PROVISIONAL PROGRAM PLAN

October 1, 1988

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I. INTRODUCTION

The National Radio Astronomy Observatory is funded by the National Science Foundation under a management contract with Associated Universities, Inc. The Observatory operates major telescope systems for research in radio astronomy and carries out research and development in related fields of advanced technology and image processing.

The four major telescope systems operated by the NRAO for scheduled astronomical observations are: the 27-element Very Large Array telescope (VLA) located on the Plains of San Agustin, near Socorro, New Mexico; the 12-meter millimeter wavelength telescope on Kitt Peak, Arizona; and the 140-foot telescope and the 300-foot meridian transit telescope in Green Bank, West Virginia. Additionally, in 1988 scheduled VLBI observations were conducted with the first completed antenna of the Very Long Baseline Array.

Allocated observing time remains at a premium as all NRAO telescopes continue to be heavily oversubscribed. Increasingly sophisticated astrophysical problems require the accumulation and comparison of large multi-wavelength databases across the electromagnetic spectrum: radio astronomical observations are an integral part of contemporary research programs. A major goal of the NRAO has been the continual development of state-of-the-art instrumentation so as to widen the accessibility of broad regimes of the radio spectrum while at the same time to increase the instrumental resolution, sensitivity, and dynamic range. New technologies are rapidly transformed to practical working receivers and operating systems which expand the observing potential of existing telescopes.

As the hardware evolves so must the software. The development of the Astronomical Image Processing System (AIPS) at the NRAO and its export to a wide range of machines at users' home institutions provides a computing environment sufficiently flexible to allow astronomers to exploit the scientific utility of the new technology.

Section II of this Program Plan summarizes the research that visiting investigators are planning to undertake with the NRAO telescopes during 1989. More than 70 percent of the available observing time will be used for the research programs of visiting astronomers. The remaining 30 percent is shared by the observing programs of staff scientists and scheduled maintenance and testing of the telescopes.

Section III of the Plan describes the continuing research instrumentation developments which will take place at the Observatory during 1989. These include instruments which are used directly as integral elements of the telescope-receiver-computer data acquisition chain or which are part of the off-line signal and image processing and data-analysis scheme. The instrumentation expenditures fall equally heavily on the electronics and computer hardware areas. A dynamic electronics research and development effort is one of the driving forces behind the application of technological advances to astronomical instrumentation and therefore is a vital part of the NRAO. Likewise, imaginative approaches to the optimal use of available computer resources are crucial to the total astronomical data acquisition and analysis process. Highlights of the 1989 effort in these areas will include implementation of multi-beam receivers, spectrometers, and control hardware for millimeter-wave observations at the 12-meter telescope; the rapid installation of low-noise, K-band HEMT amplifiers on the VLA antennas; and completion of an extremely versatile and efficient spectral processor for spectroscopic and pulsar observations at the 300-foot telescope.

Subsequent sections give the program of expenditures required for operations and maintenance of the Observatory and their breakdown according to geographic cost centers. Included are specific sections to describe the arrangements made through the National Science Foundation for the NRAO support of portions of the USNO and NASA programs in astronomy. Provision has been made for: (1) operation of the Green Bank three-element interferometer for the USNO (Section VI), and (2) completion and testing of the hardware needed for VLA support of the 1989 encounter of the NASA Voyager spacecraft with Neptune (Section VII).

Appendices to this Plan include a summary of the scientific programs of the NRAO permanent staff, a list of the staff and their principal research interests, an organizational chart for the NRAO, and a list of various committees that provide advice and assistance to the NRAO.

II. SCIENTIFIC PROGRAM

The following summary, by telescope, illustrates the diverse range of scientific topics that have been proposed for investigation during 1989 at the NRAO. Each of the programs has been designed to take advantage of the particular qualities of the NRAO instrument on which it is undertaken. The most important part of the NRAO mission is its obligation to provide forefront instrumentation to its user community. The demand for telescope time is now higher than at any time in the history of the NRAO--a clear demonstration of the impact of sensitive and versatile instrumentation.

The Very Large Array

The scientific productivity of the VLA without question surpasses that of any existing radio telescope. Results from the VLA dominate the radio science of almost every subdiscipline of astronomy from solar physics to cosmology. Hardware and software improvements continue to broaden the research capacity of the instrument. Furthermore, a growing number of first-time users find new scientific problems which require the power and flexibility of the VLA.

Radiophysical investigations of the sun and planets in 1989 will continue to rely heavily on new VLA observations that build solidly on recent VLA studies. Solar physicists will use the 90 cm capability of the telescope in order to clarify the properties and locations of Type I solar bursts with the aim of determining the mechanism for near-continuous acceleration of electrons to keV energies in these bursts. They will also attempt to make multiwavelength identifications of the fine spatial structures that populate solar active regions. Exciting new planetary investigations are on tap for 1989 as a result of recent instrumental improvements. The technique of synthetic aperture radar which was successfully demonstrated for mapping the radar echo from Saturn in 1988 will be applied to Mars in the current opposition. This technique provides a fresh new approach for the study of Martian surface features. Multi-wavelength, sensitive observations of Uranus will help in the study of its deep atmosphere. Maps of Uranus will be used to study latitudinal variations and variations with atmospheric depth of ammonia and water concentrations.

A significant fraction of the VLA research effort will continue to be directed toward the study of stellar physics. Pulsar observations will range from time-resolved polarimetry with the "phased array" to detailed astrometry of the newly discovered eclipsing millisecond pulsar. Both studies promise to break new ground in efforts to understand the structure and evolution of pulsars. The VLA will participate in a multi-wavelength campaign to observe the X-ray binary Cyg X-2 in order to investigate the role of binary mass transfer in the quasi-periodic oscillation activity that is seen in X-rays. For the binary Cyg X-3, monitor observations of large outbursts will be used to test propogation models. A sample of luminous O-stars that have strong excess X-ray emission will be searched for related nonthermal radio continuum emission that might explain both the X-ray and radio emission mechanisms in the stellar wind environment. Simultaneous radio and optical flare star observations will help to identify the source of the variable quiescent radio emission and its potential correlation with optically identifiable surface activity. Other flare star dynamic spectral observations of bursts will provide constraints on magnetic field strengths and electron densities in stellar coronae.

The VLA study of supernova remnants, planetary nebulae, and circumstellar shells will continue to provide a radio view of the advanced stages of stellar evolution. Identifications of new, very young supernova remnants will be a by-product of a multifrequency galactic plane survey. High-resolution VLA observations at 90 cm will be used to image the jet and filaments of the Crab Nebula and to investigate their origin. The investigation of extensive small-scale structures in other remnants will be used to probe the plasma turbulence and magnetic field environment and its universality among such remnants. For many remnants similar to the Crab, 90 cm observations are required in order to settle the nature of the interaction of the expanding shells with their surroundings. Multi-epoch observations of a number of planetary nebulae will measure angular expansion rates and allow much more reliable distance measurements to be made. Follow-up observations based on a general planetary nebulae survey will identify the most interesting candidates with compact, halo, or filamentary structures that might be characteristic of recent formation. A search for OH in the planetary IC 4997 will be undertaken in order to test the hypothesis that OH/IR stars are precursors of planetary nebulae. For samples of cool stars with circumstellar OH or H_2O masers, accurate astrometric observations of the masers are needed in order to specify envelope structures and the physics of mass loss and maser excitation. Advances in the VLA on-line data system will make possible polarization observations of OH masers and the identification of Zeeman pairs in late-type stellar atmospheres. Refined kinematic models for the circumstellar shells and evidence for global magnetic field structures will result.

Astrometric measurements with the VLA are being exploited in unique ways to provide accurate distances of radio-detectable stellar sources. The parallax of the radio sources associated with the star T Tau will be the first direct measurement of the distance to a nearby star formation region, the Taurus-Auriga complex. Comparisons between radio and optical positions of radio stars will be essential in order to establish the relationship between the extragalactic frame of reference and the FK4 optical frame.

Significant advances in the study of star-forming regions in the Galaxy have come about due to the application of VLA spectral line techniques. Future studies promise to bring further progress. High spatial resolution images and recombination line observations of ultracompact HII regions will facilitate dynamical studies on extremely small scales and allow competing theories of structural formation to be tested. Additional ultracompact HII regions will be sought on the basis of the infrared flux that is generated by O stars embedded in molecular clouds. Among the major star-forming regions to be studied, detailed maps of the W3 region in ammonia, water vapor, and hydroxyl will probe the evolution of the interstellar medium in an environment populated by molecular clouds, masers, and both compact and diffuse HII regions. New magnetic field strength measurements using OH masers will be done in the W49 region. In the NGC 6334 region, VLBI-detected H_2O and methanol maser regions will be compared with VLA maser observations in order to understand the kinematics and pumping mechanisms in the region. For a number of young stellar objects with CO outflows, VLA observations will be used to identify and measure the origins of the outflows. For well-studied young stellar objects such as Lynds 1551/IRS5 or HH 7-11 further observational probes of the inner structure of the circumstellar disk will be attempted. For HH 1-2, observations will be used to test the confined jet model and to detect the motion of new H_2O maser sources. Mosaiced VLA images of the Orion Nebula complex and the Sgr B complex of HII regions will be examined for the spectral and polarization properties of diffuse extended features.

Studies of the interstellar medium and galactic structure are also suited for VLA survey work. The extensive 327 MHz survey of the inner galactic plane, begun in 1988, will continue throughout 1989. Another survey aims to determine the nature of objects from Minkowski's list of emission nebulae which all have high $H\alpha$/continuum ratios and thus are physically unusual. VLA and MERLIN observations of a large sample of extragalactic sources will be used to probe the scattering properties of the interstellar medium. In another program, extreme scattering events--first detected at Green Bank--will be scrutinized by the VLA in an effort to identify and characterize their properties. Toward the galactic center numerous filamentary structures will be investigated for evidence of mutual interaction or indications of magnetic reconnection and particle acceleration.

Many studies of nearby galaxies will rely upon detailed VLA multi-configuration, multi-spectral radio observations to differentiate between emission mechanisms, kinematics, and evolutionary scenarios. Different samples of spiral galaxies will be surveyed for nuclei with compact, active radio sources; for individual supernovae and supernovae remnants in star-forming nuclear radio continuum complexes; and for anomalous spectral gradients that are critical diagnostics of cosmic ray transport models. For a sample of elliptical galaxies, the radio morphologies and dust-lane orientations will be examined as a clue to the origin of the radio emission. VLA data for a large sample of SO galaxies will be required to distinguish nuclear and disk radio components in a critical test of the correlation between radio continuum emission and far-infrared flux that is found in normal spirals. Optically selected samples of Seyfert galaxies will be examined with 90 cm observations for evidence of low-frequency cutoffs that would better define the energy, size, and age of the radio components. Other Seyfert galaxies which exhibit extended optical extra-nuclear and circumnuclear emitting regions require complementary radio study. Line and continuum radio observations of far-infrared emitting galaxies will play an important role in the investigation of possible relationships between galaxy interactions, star formation, and radio galaxy activity.

Multiwavelength, high-resolution observations of the H_2O maser regions of star formation in M33 will provide important information about the engines that power the maser sources. M82 is the focus of a high-resolution HI study which will provide an exhaustive look at HI shells and filaments and allow direct and detailed morphological and dynamical intercomparisons to be made between the HI and CO features.

The central bar of NGC 4258 will be the subject of high-resolution HI mapping for comparison with CO observations. Other individual galaxies, such as NGC 253, the interacting pair Arp 90, several multiple nucleus active galaxies, and a few classical Seyfert galaxies, will all be further investigated.

Classical radio galaxies continue to be a major subject for intensive VLA study in order to specify their observational characteristics, test source models, and probe distant source environments. Samples of ultra-steep spectrum radio sources will be surveyed for morphology and optical identification to study the properties and evolution of the most powerful and distant radio galaxies. Observations of the characteristics of giant radio sources will facilitate the study of their cosmic evolution out to $z \approx 1$. Suspected radio/optical relationships will be tested with the VLA for a wide range of high redshift galaxies as a function of radio power, morphology, and redshift. Another sample will be used to test model predictions for spectral aging as a function of luminosity and redshift. Detailed mapping of optically identified radio source hot spots in classical double sources will be carried out. High-quality polarization mapping of Hydra A will be obtained for comparison to previous Cygnus A maps and to look for evidence for the interaction between jets and the surrounding environment. Measured depolarization characteristics of one-sided radio sources will be used to investigate beaming models.

VLA studies of radio galaxies in clusters will serve to probe the effect that the cluster environment has on galaxy evolution. The rich cluster Abell 2256 will be the focus of an extensive high-resolution mapping survey in order to inter-compare X-ray, optical, and radio observations of the galaxies, the cluster halo, and anomalous cluster features. Abell 2052 and several other clusters will be observed in order to study possible mechanisms that produce central galaxy halos and to search for possible interactions between the radio sources and the known cooling flows in the clusters. A sample of small cluster radio galaxies will be investigated to determine what effect the cluster environment has had on their structure.

Studies of quasars continue to concentrate on the nature of their spectral evolution, their polarization properties, and the relationship of their environment, evolution, and morphology. Quasars which sample the complete IR luminosity/spectral index diagram will be observed for their radio properties. Further multifrequency observations are planned for those quasars which exhibit a high frequency excess. Polarization observations of a sample of quasars and BL Lac objects will be used to help discriminate between nuclear Faraday rotation effects and other frequency dependent structures in the core. High dynamic-range observations will be critical to observational tests of jet alignments and to the detection of sub-arcsecond jets and counterjets in several quasars that are under study. Under some circumstances the extension of VLBI structures will be detectable with high dynamic range, high resolution VLA maps.

The VLA will continue to extend surveys for new gravitational lens candidates. Snapshot observations of 400 sources from a re-observed strip of the MIT-Green Bank 300-foot telescope survey are planned. The second ring source found in the above survey will be observed in detail with the VLA in order to confirm its likely identification as a gravitational ring. A number of highly luminous quasars will be investigated as potential gravitational lens candidates.

The 12-meter Telescope

During 1989 a multifeed receiver for use in the study of the CO emission line at 230 GHz will be introduced. It is expected that the greatly increased speed for mapping programs offered by the new system will stimulate interest in a number of investigations, particularly in galactic research, that have been hampered by the difficulty of making large, high-resolution maps with existing equipment. The low-noise SIS receiver for 90-115 GHz has been outstandingly successful, particularly in extragalactic studies, and continues to be in heavy demand. The early results of studies made in the window between 330 and 360 GHz are now in the literature and will require extensive observations to follow up the new insights that have been gained.

Star-forming regions and protostars continue to be topics of high interest. The nature of these important regions has remained elusive, but several programs planned for the coming year offer innovative approaches which may lead to a better understanding of the phenomenon. For example, a number of small diameter sources in the Orion region have been identified using the IRAS database. These will be searched for CO emission in hopes of finding the high-velocity flows that characterize the early stages of star formation. If a number of flows are found, an attempt will be made to see if they are ordered in space by age, suggesting a progressive star formation process triggered by some as yet unidentified mechanism. In other cases, compact objects already known to exhibit large velocity gradients will be studied in the lines of a series of molecules that explore a range of densities and temperatures in an effort to characterize the physical conditions in these "protostars."

There will be a number of investigations dealing with the formation of molecules and dust grains in the interstellar medium and in molecular clouds. Recently a theory has been put forward which suggests that dissociative recombination of polyatomic ions may be an important process in interstellar chemistry. This theory can be tested by observation of certain critical molecules such as the ketyl radical HCCO and ketene (H_2CCO) itself. Translucent clouds, which have extinctions to visible light in the range of 2 to 5 magnitudes, offer certain advantages in the study of interstellar chemistry in that they can be probed at optical wavelengths using lines of CN and CH. These objects will be observed in a number of radio emission lines in order to explore the densities of some of the simplest molecules. Certain high latitude clouds, identified with the curious IRAS "cirrus," will be studied using lines arising in regions of relatively high density, in an effort to examine the present tentative and controversial suggestion that these objects may be deficient in the heavier elements, at least in their cores. Finally, an important study dealing with the emissivity properties of dust grains in regions of recent star formation will use high-resolution observations of CO and the continuum dust emission at 330 GHz.

Supernovae are an important source of the kinetic energy imparted to the gas clouds in the Milky Way and studies of line emission at millimeter wavelengths have been used to measure the physical conditions in the shock regions occurring at the point where the material ejected from the supernova runs into the surrounding interstellar medium. Now there is a tentative detection of emission from a highly ionized state of iron in the millimeter spectrum of a nearby supernova remnant. An attempt will be made to confirm this detection since the line is potentially an extremely important diagnostic of the high temperature regions in the expanding envelope.

It is now recognized that a number of galaxies show evidence that stars are being formed in them at a rate much higher than is commonly found in normal galaxies like the Milky Way or M31. The gas content has been measured in a few cases, using principally the CO emission at millimeter wavelengths, and it is found that frequently these objects are rich in molecular material. In an attempt to demonstrate this quantitatively, a group of interacting galaxies, some of which show evidence of rapid star formation, will be systematically surveyed for CO emission. The program will show if the amount of molecular gas correlates with the rate of star formation in this optically selected sample. Other programs will continue the study of some of the well-known objects, emphasizing the regions of high density by using the molecule CS as well as the relatively unexplored CO transition at 345 GHz. One promising study involves the search for molecular counterparts of the neutral hydrogen streamers that have been found in one of these objects.

Normal galaxies will, of course, not be ignored. The census of the CO content of nearby spiral galaxies is now nearing completion as a result of years of effort at many observatories, including the 12-meter. The survey of the few remaining objects will be undertaken. The high-density regions in the spirals showing strong CO emission will be studied using the CS line. A program to correlate the presence of dust in lenticular galaxies with the molecular gas content, as indicated by the strength of the CO emission, will be started.

Perhaps the most exciting recent advances in extragalactic studies with the 12-meter telescope have involved objects at very large redshift. The program began with the study of the counterparts of ultraluminous IRAS sources, culminating in the detection of CO in a galaxy whose velocity of recession is 48000 km/s. The picture that is slowly emerging is that the ultraluminous infrared galaxies may be dust-enshrouded quasars seen at an early stage before the dust and molecular material has been blown out of the nuclear region. Additional studies of the bright IRAS galaxies are in progress. It is now suggested that there may be some relation between the powerful radio galaxies and the IRAS galaxies, and that this possibility can best be explored by examining the gas content of radio galaxies. Indeed, this approach has lead to the detection of a number of the nearby classic radio galaxies in CO, and the search will be extended to objects having higher redshifts.

300-foot Telescope

This survey telescope provides the fundamental databases on which other radio astronomical investigations are based. In providing this vital information, the 300-foot telescope serves a unique function. Some examples of major investigations proposed in 1989 follow.

About 18,000 galaxies have redshifts measured from their HI emission. The three-dimensional structure of the universe, one of cosmology's most fundamental questions, is being determined from these data out to redshifts of about 12,000 kms^{-1}. The 300-foot telescope will continue to be one of the main contributors to this determination. Particularly significant will be a search for galaxies in the Zone of Avoidance, now recognized to be a crucial locale--the potential site of the "Great Attractor"--but it is inaccessible to optical study.

The same HI data have applicability to the question of galaxy formation and evolution. For example, the gas content of field and cluster galaxies will be compared, as will the gas content of galaxies of various types. These investigations will be improved when the spectral processor comes on line in late 1988/early 1989. But necessary improvements include the additions of a multibeam receiver for 21 cm observations and a low-noise receiver for the band 1000-1400 MHz. These receivers will, of course, be used on the 140-foot telescope as well.

The detailed parameterization of a few hundred pulsars using the 300-foot telescope and its nearly completed spectral processor is important to the research program of the Gamma Ray Observatory. In addition, a search for pulsars will continue. The focus will be on the anti-center region, largely unexplored to date. Since many pulsars found in the approximate direction of the galactic center are known to be nearby, one might expect to find several in the opposite direction as well. A few that can serve as accurate clocks are critically needed in that half of the sky, so that a set of reference standards can be connected through full 24-hour cycles.

The improvement most valuable for pulsar studies will be the construction of an adaptive array receiver for the range of frequencies 400-500 MHz. Such a receiver will permit the longer daily integrations (triple present ones) crucial for monitoring the behavior of individual pulsars.

The Milky Way's neutral ISM will be studied using a survey of HI emission. By illuminating only the unblocked portions of the 300-foot telescope (it has only two feedlegs plus guy wires in the orthogonal directions), galactic HI far from the main beam will not be scattered into the feed off feedlegs or other structures. These galactic HI data, uncontaminated by "stray radiation," are crucial to the future of X-ray astronomy: HI column densities limit the energies of extragalactic X-rays that can penetrate to the solar system.

The ionized ISM will be studied as well. Extreme Scattering Events (ESEs), pulsar scintillation, and low-frequency variables--phenomena all attributable to plasma effects--will continue to be monitored. This field has undergone a major revival as a result of the discovery of ESEs using the Green Bank interferometer and its confirmation using the 300-foot telescope. This research has spawned investigations using IRAS data and VLA and VLBI observations.

The magnetic field in the ISM will also be studied. A major survey of the galactic background polarization is proposed at three frequencies, enough so that the Faraday Rotation of the polarized radiation by the interstellar plasma and the intrinsic position angles of the polarized radiation can both be determined.

By searching for spectral lines, either emission or absorption, over the frequency range 500-1420 MHz and in the directions to known quasars, the intergalactic medium can be probed to great distances. The most likely agents causing such lines will be neutral hydrogen in intervening galaxies or perhaps protogalaxies, but searches for molecular features are also proposed.

The 300-foot telescope is conducting a sensitive continuum survey at 5 GHz aimed at cataloging the few hundred thousand sources expected to be present. These sources form the basis for comparison with the IRAS survey, with the new epoch Palomar Sky Survey, with the findings of the Hubble Space Telescope, and with future surveys at other spectral bands.

140-foot Telescope

New uses of this telescope arose in 1988 because of its improved sensitivity and further innovations are proposed in 1989. Several examples are noted below.

Long chain molecules (≈ 30 - 50 atoms) radiate their radio spectral signatures at centimeter wavelengths. Because the bonding of these chains is usually provided by carbon, they become biologically interesting, either as precursors of structures relevant to life or as actual biologically utilized molecules (urea and glycine, for example). Searches for these molecular species will continue, as will studies of the already known ones. The latter studies will aim at understanding the sequence of chemical reactions that produces the observed molecules and at using the existence of the molecules to delimit the physical conditions (temperature, pressure, density) in the regions where they originate.

Primordial nucleosynthesis will continue to be an area to which the spectroscopic capabilities of the 140-foot telescope are applied. Studies of $^3He^+$ continue, and they will be joined by searches for ^7Li. Both elements are believed to have been manufactured in the first few minutes following the Big Bang.

Research using the 140-foot telescope has added methanol to the molecules exhibiting maser emission. By combining investigations of CH_3OH with those of OH and H_2O, it is hoped that the pumping mechanism will be revealed. This discovery in Green Bank of a strong transition at 12 GHz illustrates the seminal role of the 140-foot telescope.

Masers will also be used to probe the interstellar medium. Because several masers usually occur in close proximity, and because each has a very small angular size, refractive scattering of these objects by the ISM provides a means to study the ISM.

Monitoring selected H_2O and OH masers will continue. Recent Green Bank observations have found emission features extending over some hundreds of kilometers per second. These features may be moving systematically apart in velocity, as if they were being pushed in opposite directions by bipolar outflows. The OH and H_2O features appear to arise in different regions of the outflows.

The 140-foot telescope will continue to augment surveys begun using the 300-foot telescope by observing the parts of the sky inaccessible to that telescope. One specific example of such a use is the three-dimensional mapping of the universe by measuring HI redshifts. Many of the structures--filaments, pancakes, voids, etc.--found are so large they continue into the southern sky. The 140-foot telescope will be used to determine the extent of these continuations.

A second example is the 5 GHz continuum source survey. Declinations between 0° and -45° will be surveyed with the 140-foot telescope and added to the northern hemisphere survey done with the 300-foot telescope.

Finally, in 1989 the 140-foot telescope will participate in all NUG and EVN VLBI observations for which it is requested. The VLBI demand on the 140-foot, which has averaged 25-30 percent of the total observing time over the past few years, is expected to remain at this level next year as well.

III. 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 VLA image of the radio galaxy Fornax A shown on the cover of this Program Plan is an appropriate illustration of this point. The image is not one of total intensity, radio brightness, but rather it is an image of the radio polarization, a quantity which reveals the large-scale organization of the magnetic field within this galaxy. The filamentary character of the emission shows us that the magntic field is itself filamentary and twisted. This conclusion, readily evident from the image, has an important bearing on the lifetime and evolution of the radio galaxy. In addition, those parts of the source where polarization appears to be absent are themselves interesting. Foreground objects having ionized gas will depolarize the background emission and therefore be "seen" as a polarization deficiency. The dark streaks evident on the left side of the image are foreground gas clouds; the elliptical "hole" on the right is a under-luminous spiral galaxy. Fundamental knowledge such as this is unobtainable without a concerted and continuous program of instrumental construction, evolution, and improvement.

Each of the four major telescopes operated by the NRAO as well as the partially 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 and computer hardware is maintained at each observing site as well as at 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 four telescope systems. 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 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 instruments. 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 plan and budget.

One of the more significant advances in radio astronomy in the last few years was spawned from the recognition that the quality of radio astronomical data could be markedly improved by more sophisticated data manipulation software. Here the most striking example is the use of self-calibration algorithms on VLA and VLBI data to correct the incoming wave-front for atmospheric (and instrumental) effects. This radio analog of the optical "adaptive optics" technique allows the VLA to achieve theoretical angular resolutions unencumbered by atmospheric smearing while at the same time reaching a dynamic range 100 times higher than expected in the design of the VLA. For the specific case of VLA data, the price of this improvement is an enormous computing burden that requires the astronomer to seek the resources of faster computers and greater data storage capacity. The NRAO, cognizant of these escalating demands, has sought additional computing facilities and personnel for algorithm development and user support through the proposed "Array Telescope Computing Plan" which has been submitted to the NSF. However, the single-dish telescopes, as well as the VLA, have also benefited by access to rapid data handling and manipulation hardware and software. The multi-feed receivers on the Green Bank telescopes and on the 12-meter telescope have led to a remarkable improvement in mapping large regions of the sky and in studying more numerous astronomical objects. But again the direct ramification is a need for faster, more flexible, and distributed computer power together with more sophisticated software in order to exploit properly these additional scientific opportunities.

The Research Equipment plan is designed to realize these opportunities. The following table shows the planned distribution of funds for the Research Equipment account as currently dictated by the anticipated funds and established scientific priorities in each of the NRAO operating divisions. The NRAO, in consultation with its users, continually updates this table as scientific priorities change. A brief narrative describing the various items in the Research Equipment plan follows the table. It is important to note that most of the RE projects extend over several years; those for which monies are allocated in 1989 are not necessarily planned for completion in 1989.

RESEARCH EQUIPMENT
($ in thousands)

	Expenditure 1988 (est)	Expenditure 1989 (plan)	Estimated Add'l Cost	Estimated Completion Date
1. Laboratory and Test Equip.	$ 0	$ 25	$100/yr	continuing
2. Miscellaneous Projects	62	50	200/yr	continuing
3. Very Large Array				
22-25 GHz Improvements	105		-	1989
1.3-1.7 GHz Improvements		10	150/yr	1992
RFI Improvements		15	60/yr	1992
Ant. Pointing Improvement - Active		10	25/yr	1991
75 MHz Receiver		15	50	1990
Correlator System Controller		10	20/yr	1992
Phased Array Processor	20	10	10	1990
Imaging Computer Additions		50		
4. 12-m Telescope				
Multi-beam 230 GHz Receiver	7	10	250	1992
Multi-band SIS Receiver	15	20	80	1990
70-115 GHz SIS Upgrade	10			1989
Hybrid Spectrometer	25	20	30	1989
Multi-beam Spectrometers		10	50	1990
Telescope Control Upgrade	35	25	50	1990
5. 300-foot Telescope				
Spectral Processor	55	20		1989
Adaptive Array Receiver		10		1989
Multibeam L-band Receiver		10	240	1991
6. 140-foot Telescope				
Spectrometer/Computer Dev.		10	175	1992
5-45 GHz HEMT Receiver	10	20	60	1991
LAN Interface		5	100	1991
7. Common Development				
Millimeter Device Development	70	70	150/yr	continuing
HEMT Amplifier Development		10	20/yr	continuing
Computational Imaging		20		
Single Dish Support	10	5		
TOTAL	$427	$450		

1. Laboratory Test Equipment

In order to improve existing and develop new telescope instrumentation, it is essential that NRAO upgrades its Laboratory Test Equipment. This area has been neglected in recent years due to very low Research Equipment budgets. There is a need to correct this as soon as possible. This budget line covers equipment for all sites and includes the Central Development Lab and also some computer diagnostic equipment. Included also are enhancements to existing test equipment.

2. Miscellaneous Projects

Numerous electronic and computer projects, limited in scope, are continually in progress throughout the Observatory. Although the budget for each project is generally considerably less than $20k, collectively the projects are vital to the ability of the Observatory to respond quickly to evolving technology and to the specific needs of visiting astronomers. Improvements to cryogenic systems, data record capacity or speed, and so forth are accounted for as miscellaneous projects.

3. Very Large Array: Electronics

The 327 MHz and 22 GHz receiver systems which have dominated the Electronics RE over the past years are complete, and we now wish to begin improvements of the L-band receiver system and to start construction on a dedicated phased-array processor for stellar and pulsar observations.

1.3-1.7 GHz Tsys Improvement - HI imaging is the most important class of spectral line project at the VLA. The observation of HI in emission (either galactic or extragalactic) is almost always sensitivity limited, either because the HI has to be followed to the faint outermost regions of galaxies, or because more angular or frequency resolution is desirable.

The current VLA 18-21 cm receiver has a system temperature of approximately 50-60 K. A significant fraction of this system temperature results from the arrangement of all front-ends in the same cryogenic dewar. This results in longer input waveguide runs than would usually be required and prevents the polarization splitters from being cooled.

An improved 18-21 cm receiver, using cryogenically-cooled GaAs FET amplifiers and a cooled polarizer, was designed for the VLBA. The prototype system has been installed on Antenna 23 at the VLA. It has a system temperature of 31 K. This receiver has undergone engineering tests in preparation for outfitting the full VLA with similar systems and a second system will allow for more complete engineering tests.

Another worthwhile area of investigation would be a modification to the 18-21 cm feed to improve its spillover performance.

<u>RFI Improvements</u> - The sensitivity of the 327 MHz and 75 MHz systems are limited by radio-frequency interference locally generated in the B-rack at each antenna. This problem is particularly severe for the more compact arrays. RFI shielding of the LO rack in the vertex room has proved effective and four antennas have been equipped. In order to improve the sensitivity of 327 MHz, the complete array will be required to be outfitted with these RFI shields.

<u>Antenna Pointing Improvements - Active</u> - With the antenna insulation completed, the next largest contribution to the pointing

errors is the tilts of up to 20 arcseconds in the azimuth axis of some antennas at certain azimuth angles. This effect is possibly caused by deformations or perturbations in the azimuth bearings. This and other problems such as an antenna tilt caused by a constant wind force could be corrected by an active correction scheme utilizing electronic tilt-meters mounted on the antenna structure. Two antennas are equipped with tilt-meters, and engineering studies indicate that improved tilt-meters are required. That design is complete and further testing is required.

75 MHz Receivers - As described in the "Low Frequency Radio Astronomy" Workshop (Green Bank, Nov. 84, ed. Erickson and Cove), we are increasing the low-frequency capability of the VLA by equipping VLA antennas with 75 MHz receivers. The installation of these receivers will be coordinated with the installation of B rack shields for RFI suppression. Four antennas were equipped with receivers and shields by mid-1987. We wish to add four more 75 MHz receivers, bringing the total to eight. We feel this is the minimum number which will allow tests of imaging at this wavelength.

Correlator System Controller - The future reliability of the system controller and its associated array processor is unknown as there has been an increase in the number of failures in the past years. A more up-to-date system would support a high-level language which would facilitate the implementation of more correlator modes, improve the data quality, and increase the dynamic range.

Phased Array Processor - Study of impulsive phenomena with the VLA is made possible not by the imaging capability of this instrument but simply by the large collecting area and instantaneous sensitivity afforded by the superb receiving systems. Here the desire is to measure rapidly all the Stokes parameters of the emission from flare stars and pulsars as a function of time. The positions are known and the objects are true point sources. For such an observation the signal from all the antennas needs to be added, in phase, in a special microprocessor and sampled rapidly. The phased array processor is designed to provide precisely this capability. In 1988 we began the design and prototyping of this instrument.

Imaging Computer Additions - Access to the full data rate of the VLA provided by the new on-line computers is a mixed blessing. Scientifically, it permits true spectro-polarimetry for the first time since the VLA was constructed; polarization images of OH masers (and similar science) are at last possible. But the price one pays for this information is a sustained data rate greater than can be accommodated by the DEC-10 calibration computer and by the downstream imaging computers. A very substantial enhancement in computing resources is needed and, indeed, such has been requested in the proposal "Array Telescope Computing Plan" submitted to the NSF. In the interim, and prior to the expected start of funding for this proposal in 1990, we will seek to begin replacement of the DEC-10 computer, and we plan some modest enhancement of the disk storage capacity, tape handling and interactive display for the CONVEX imaging computer. We wish to enlarge our meager workstation environment with the purchase of a small number of SUN workstations or an equivalent.

4. The 12-meter Telescope

During the past observing season, the performance of the telescope at high frequencies was improved dramatically by the installation of an error-correcting subreflector, made in collaboration with the University of Texas. The new subreflector reduced the effective surface error of the dish from 70 μm to 55 μm rms, which increased the aperture efficiency of the dish by some 60 percent at 345 GHz. A further iteration is planned for the 1988-1989 season in which a new subreflector, made with higher resolution holographic data, will be constructed. This second iteration is expected to produce even better high-frequency performance.

The increased emphasis on higher frequencies puts greater demands on the pointing accuracy. A major program has commenced which attacks this problem through continuous laser measurement of the focal point, an optical pointing capability, and thermal stabilization of the feedlegs. The focus-translation (Sterling) mount at the prime focus was not designed to have the precision required by such high-frequency operation, and should be redesigned and replaced. Replacement of the steel feedlegs with carbon fiber feedlegs is being investigated.

Multi-Beam 230 GHz Receiver - The 8-beam Schottky receiver for 230 GHz is already operational. In the next year we will develop multi-beam SIS receivers using some of the techniques developed for the 8-beam Schottky mixer receiver. Our aim is to produce a 32-beam spectral line system by 1993.

Multi-Band SIS Receiver - A long-term goal of the 12-meter telescope is to achieve complete frequency coverage at all usable wavebands between 70 and 360 GHz with highly sensitive, state-of-the-art, SIS receivers. Complete frequency coverage allows observers total flexibility in choosing the spectral-line transition that is most appropriate for their astrophysical research.

The present 90-115 GHz SIS receiver has been highly successful and has produced some of the world's most sensitive millimeter-wave detections. This receiver uses a hybrid cryostat that must be filled with liquid helium twice a week. This operation is expensive, both in helium costs and in manpower, and takes about one hour away from the observing schedule for each fill. This problem will be avoided in the next generation of SIS receiver, which will make use of 4.2 K niobium junctions cooled with a closed-cycle (i.e., low maintenance) refrigerator system.

Construction has begun on a 4.2 K "mini-dewar" system somewhat similar to that used in the 200-360 GHz Schottky mixer receiver. The first band, covering the 230 GHz CO frequency, should be completed in early 1989. Additional limited coverage in the range 200-360 GHz, may be available by the end of 1989. This same design principle will subsequently be used to construct receivers in the 70-115 GHz and 130-170 GHz bands.

<u>Hybrid Spectrometer</u> - In order to provide the greater instantaneous bandwidth needed by the higher frequency 12-meter telescope receivers, as well as to improve the spectral resolution at lower frequencies, a hybrid filter-bank autocorrelator is under construction. The 2.4 GHz total bandwidth and 1536 spectral channels to be incorporated in this device will benefit the present single-beam

receivers but, in addition, the spectrometer can be divided into as many as eight separate spectrometers for use with the existing 8-beam receiver. Due to a shortage of funds, the spectrometer will at first be a compromise system without the full frequency versatility intended in the original design. This compromise system will be taken to the telescope by the end of 1988. Budget permitting, the full system will be completed during 1989.

Multi-Beam Spectrometers - The development of multi-beam receivers will require the development of a new generation of spectral line backends. We have studied competing technologies (AOS, hybrid, digital, SAW devices, etc.) and have concluded that the acousto-optic spectrometer is the most promising technique for a multiple beam system. We hope to acquire, by an in-house development program or by an external contract, an AOS with a resolution of 1 MHz or better and an instantaneous bandwidth of 1 GHz. Such a device would be useful for multiple beam mapping applications up to a frequency of 365 GHz.

Telescope Control Upgrade - The existing control system for the 12-meter telescope has been stretched to the limit in supporting the current generation of instrumentation, and already imposes a severe limitation on the potential of the telescope and new data acquisition equipment. It is long overdue for replacement. The implementation of a new system must not necessitate any prolonged shutdown of the whole telescope, so the approach adopted involves a gradual off-loading of control tasks into a loosely coupled network of microprocessors, based upon a standard bus system. This greatly simplifies the eventual replacement of the control computer itself. During 1989 most of the

CPU-intensive control tasks will be implemented in satellite microprocessors. We hope to replace the main control computer itself with modern hardware, and to install a user-friendly software interface to the telescope operators and to the astronomer, during the normal summer shutdown of 1989. The new control system is being designed with a remote observing capability in mind.

5. <u>300-foot Telescope</u>

Since the 300-foot is a transit telescope, it is manifestly a survey instrument and, given the mesh construction of its surface panels, it operates effectively at the longer wavelengths, $\lambda > 6$ cm. For 25 years the enormous collecting area of the 300-foot telescope, together with the very sensitive receivers available at Green Bank, has provided astronomers with an opportunity for exceptional sensitivity in the OH and HI lines as well as in the continuum. These characteristics have been, and continue to be, exploited to the benefit of those astronomers interested in discovering new pulsars, extending knowledge of the gas content in galaxies to higher redshift, or attempting to determine the nature and distribution of weak radio sources. However, as a survey instrument the 300-foot telescope is limited by the capabilities of its backend instrumentation.

Enhancements to the 300-foot thus call for those improvements that will optimize the performance of the telescope as a survey instrument. The first pivotal step in this direction--replacement of the control computer--was completed in 1986. More than just a hardware replacement, the new computer includes modern user-interface software that dramatically increases the versatility of the telescope control.

The following items in the Research Equipment plan are needed now to exploit fully this versatility.

Spectral Processor - This is a pipelined, fast Fourier transform spectrometer, incorporating real-time interference excision and flexible time and frequency-merging capabilities. It improves on existing instrumentation in two major areas. Spectral-line observations will have greater resistance to interference since spectral estimates are produced once every 10 microseconds instead of once every 10 seconds as is the present case. It will also increase the available number of spectral channels, providing 2048 channels across 40 MHz as compared to 384 channels across 10 MHz in the present autocorrelator. Secondly, the spectral processor will greatly improve pulsar data-acquisition capabilities at the 300-foot telescope. It will provide 256 channels times 4 polarizations across a 20 MHz bandwidth with full dedispersing capabilities. The spectral processor will thus allow highly automated and accurate pulsar timing programs to be performed. One-half of the machine (1024 channels) should be completed in the first quarter of 1989, with the balance completed later in the year. The majority of component purchases will be completed in 1988. The money allocated for 1989 is primarily for external fabrication contracts and miscellaneous components.

Adaptive Array Receiver - Low-frequency receivers, frequencies less than 1 GHz, are mounted on a traveling carriage that briefly tracks the source in hour angle. Presently the beam degrades badly at hour angles greater than 10 minutes at 400 MHz. However, implementation of an array receiver together with a suitable combining network will permit sources to be tracked for more than an hour with near-maximum efficiency. This will facilitate pulsar observations, scintillation surveys, and searches for redshifted hydrogen lines in an astrophysically important band (400-500 MHz). This project was delayed in 1988 due to a shortage of manpower, but work will resume in 1989.

Multi-Beam L-Band Receiver - Observations of extragalactic hydrogen, as well as those galactic HI observations that have as their goal the mapping of HI column density with minimum contamination by "stray" radiation, benefit by a multi-beam capability. One receiver can benefit both programs. In the case of extragalactic studies, the telescope time can best be utilized by a receiver with seven or more independent feeds (two polarizations each) mounted in the focal plane. If the amplifiers are very low-noise, HEMT, L-band amplifiers giving 25 K or less system temperature, very large regions of the extragalactic sky may be surveyed with high sensitivity. With a somewhat different feed arrangement, the same receiver could be used to illuminate as many as four unblocked regions of the 300-foot telescope so as to provide a "clean" HI beam--essentially free of stray radiation--with a beam efficiency of greater than 98 percent. Such a receiver will provide the first reliable maps of the HI column density in the northern Milky Way.

6. The 140-Foot Telescope

The 140-foot, fully steerable, radio telescope incorporates great frequency flexibility through dual-polarization maser/upconverter receivers that provide exceptional sensitivity from 4.8 to 26 GHz. Longer wavelengths are observed with receivers mounted at the prime focus. With very few gaps, system temperatures lower than 50 K are available on the 140-foot telescope from 1 to 26 GHz. It is no surprise, therefore, that so many recent successful searches for molecular spectral lines in this frequency range have been made on the 140-foot telescope and not elsewhere.

During the last two years significant improvements have been made in the high-frequency sensitivity of the 140-foot. The sensitivity at most frequencies was improved by $\sqrt{2}$ by installation of a polarization beam splitter at the Cassegrain focus which allows both maser/upconverter receivers to be used simultaneously. One can choose either to observe at one frequency in two orthogonal polarizations or to observe with two receivers tuned independently anywhere in the range 4.8-25 GHz. A tilting, lateral focus mechanism for the subreflector was installed, resulting in an increase of a factor of two or more in K-band aperture efficiency at large hour angles. Finally, the surface panels were adjusted based on holographic surface maps, reducing the rms error from 1.0 mm to approximately 0.6 mm. The aperture efficiency at 25 GHz was improved by the surface adjustment from less than 20 percent to approximately 27 percent. These successful improvements have encouraged us to continue our program to instrument the 140-foot at higher frequencies.

Although the frequency flexibility and sensitivity of the 140-foot telescope are exceptional, the operational flexibility is limiting. The present control computer is an out-dated 16-bit machine which has limited capacity for expansion. It thus cannot make effective use of the dual receivers and the new data-taking procedures and data-processing algorithms that have the potential to greatly reduce the operational overhead as well as further improve the sensitivity, particularly the spectral sensitivity of the telescope. The Research Equipment plan in 1989 thus calls for a higher frequency capability and initiation of work on a new control system, spectrometer and digital hardware interface that, when complete, will permit a more versatile operation.

Spectrometer/Computer Development - There are three interrelated aspects to this project to improve the spectral sensitivity of the telescope by improving the backend performance. First, a concerted investigation of the cause of baseline ripple will be pursued which will involve extensive experimentation with reflection spoilers, absorbers and rapid switching techniques. Second, digital hardware interfaces between the telescope RF instrumentation and the control computer will be redesigned and built in anticipation of the next generation control computer. Finally, construction of a new spectrometer will be begun for the 140-foot telescope which will, as in the case of the 300-foot telescope, allow very rapid spectral estimates to be obtained, interference to be excised, and greater spectral resolution to be attained.

5-45 GHz Receiver: The accuracy of the individual surface panels of the 140-foot telescope is sufficient for useful observations to be made at frequencies as high as 45 GHz. There is considerable scientific motivation to observe at higher frequencies, driven principally by (a) spectroscopy, (b) cosmic background radiation studies, and (c) VLBI. Although there are many molecular lines between

25 and 43 GHz, the following species have transitions important for astrochemistry in this frequency band: methanol (maser lines), formaldehyde, silicon monoxide, cyanoacetylene, and cyclopropenylidene. A frequency band near 32 GHz is particularly interesting because the atmospheric transparency is greater than that at any frequency above the resonant water line at 22 GHz. Significant continuum research, especially on the microwave background, can take advantage of this window.

The present Cassegrain receiver systems use parametric up-converters to convert signals from 5 to 16 GHz into the 18-25 GHz frequency range of the ruby maser amplifiers. State-of-the-art HEMT amplifiers are now competitive or superior to the noise performance of the upconverter/maser system below 16 GHz. Conceptual work has been completed on a project to re-work the Cassegrain receivers to incorporate HEMT amplifiers for the 5-18 GHz range, and also above 25 GHz, but retaining the masers for the 18-25 GHz range. A small amount of 1988 RE money was allotted to this project, and significant progress can be accomplished with the money allocated for 1989.

LAN Interface - As with the 300-foot telescope, the astronomer at a workstation at the 140-foot telescope will benefit by access to a LAN connected via fiber optics to a network file server in the Jansky Lab. A coherent site-wide LAN is a necessity.

7. Common Development

Although the NRAO is distributed over the four operating sites, there nevertheless exist technical research programs that benefit all sites and which are carried out using the resources, where appropriate, of two or more sites. These programs often involve technical experimentation in innovative or even speculative technical areas. As such, they are not properly representative of any one particular site but rather they are the developments that may most rapidly improve the technical base of the whole Observatory.

Millimeter Device Development - Virtually all astrophysics done at millimeter wavelengths is sensitivity limited, because the emitting gas is both cold and spatially extended in most objects of interest. Thus, the spectral lines involved are both of low intensity and of narrow width, containing very little energy. There is accordingly a greater scientific need for continued improvements in receiver sensitivity at millimeter wavelengths than exists at centimeter wavelengths. To this end, millimeter-wave device development at the NRAO emphasizes both in-house work and a subcontract with the University of Virginia to supply superconducting circuits specialized to our millimeter-wave applications.

HEMT Amplifier Development - Development of cryogenic FET/HEMT (Field Effect Transistor/High-Electron-Mobility Transistor) devices represents a second important activity. This type of amplifier has become widely used for centimeter-wave radio astronomy receivers largely through the development work done at NRAO. The amplifiers are more reliable, stable, and have lower noise than parametric amplifiers. They are also used as IF amplifiers for millimeter-wave receivers; hence, the sensitivity of almost all observations performed at the NRAO is improved with the development of these amplifiers.

GaAs FET and HEMT amplifiers have been designed at 0.3, 1.5, 5.0, 8.3, 10.7, 15, and 23 GHz. Several hundred units have been constructed. Work in 1989 will focus on development of a 43 GHz amplifier for the VLBA project, and on the design of wideband amplifiers both for use as IF amplifiers and for use at the signal frequency on the 140-foot telescope.

Computational Imaging - This includes the support and development of the Charlottesville data processing facility, the AIPS development project and associated projects as, for example, the Class Vl computer evaluation. It also includes the support of the network infrastructure which provides the backbone of the Observatory's intersite digital communications.

Single Dish Support - Experimentation with hardware and software for analysis of single dish data takes place at all the Observatory sites. Algorithm development and the interface of the algorithm to new display hardware is given emphasis.

IV. OPERATING EQUIPMENT

The distribution of funds (in thousands of dollars) in the various equipment accounts is as follows:

1.	Maintenance, Shop, and Repair Equipment	$ 5
2.	Office and Library Equipment	80
3.	Living Quarters Furnishings	5
4.	Building Equipment	5
5.	Observatory Services	5
6.	USNO Related Services	37

1. <u>Maintenance, Shop, and Repair Equipment</u>

Funds planned in this account provide for the replacement and/or acquisition of items for the shops and maintenance divisions. Items included in this account are: tractors and mowers, replacement trucks and other vehicles, machine shop equipment, and auxiliary items and accessories to be used with existing equipment.

2. <u>Office and Library Equipment</u>

These funds normally provide for replacement, updating, and acquisition of communications equipment, typewriters, business data and text processing equipment, copying machines, and other major office equipment. In 1989 we will replace the IBM System 34, our primary computer mainframe for financial systems.

3. <u>Living Quarters Furnishings</u>

These funds provide for replacement of household appliances and furnishings used in site living quarters.

4. Building Equipment

These funds provide for items that are generally attached to and become a part of the buildings. Included are such items as small air conditioners, small heating units, water heaters, etc.

5. Observatory Services

These sums provide for small equipment additions in graphics arts and information services. Items such as cameras, film processing units, projectors, measuring equipment, etc., are included in this amount.

6. USNO Related Services

These funds are incorporated in USNO agreement with the NSF for support of the operation of the Green Bank interferometer.

V. OPERATIONS AND MAINTENANCE

The NRAO is administratively divided along functional lines into seven operating divisions. These units include both the individual operations at the three observing sites and the integrated operations which encompass all four geographic locations.

General and Administrative

Serving the needs of the entire Observatory, this unit is comprised of the Director's Office, Fiscal Office, and Business Office. Total Materials, Supplies, and Services (MS&S) funding will be $295k. Further major budget items, such as the rent and maintenance of the Charlottesville Edgemont Road building, communications, and utilities, will require $330k. The management fee paid to Associated Universities, Inc., is estimated to be $450k.

Research Support

The NRAO Scientific Staff group, composed of staff scientists and students (summer, co-operative, and Ph.D.), engages in independent research and competes for observing time on an equal basis with visiting scientists. They are expected to carry out research of the highest caliber while at the same time assisting visiting astronomers in effective utilization of NRAO instruments and facilities. Because they are at the forefront of research in their individual areas of expertise, they are a valuable asset to the NRAO in posing new problems and stimulating new approaches to observational problems. The staff advises the technical divisions about modifications to equipment or the design of new equipment and participates in the checkout and calibration of the instrumentation. They are distributed between the

Charlottesville and Socorro sites as 46 percent and 50 percent, respectively, with the remainder in Tucson or Green Bank.

In 1988 the NRAO summer student program was augmented by an award of $80,000 from the NSF Research Experiences for Undergraduates (REU) program to Associated Universities, Inc. Eighteen students were supported through this award. In 1989 a modest NRAO summer student program is planned, seven students. Once again, support for additional students will be sought through the REU program. With these two sources of support in 1989, the expectation is that the program will be restored as a vital element in NRAO's commitment to the training of future radio astronomers.

Over 33 percent of the overall NRAO travel budget will be expended in the Scientific Staff group primarily for travel by staff and visitors from U.S.-based institutions to carry out observing programs at NRAO telescopes or by visitors to travel to Socorro or Charlottesville data-analysis facilities ($150k). During 1989, $30k is planned for foreign travel by the staff, and $20k is available for qualifying U.S. scientists who need travel support to observe at unique foreign telescopes.

The Scientific Services group, in support of research and development throughout the entire Observatory, provides central library, technical illustrations and drafting services, and Observatory visual information services. In 1989, the MS&S budget of $495k for these areas is earmarked primarily for publication support (page charges) of papers based on data obtained with the NRAO telescopes as well as for the book and periodical expenses of the five NRAO libraries.

The computing group operates the NRAO central computer in Charlottesville and the VLB MKII processor and assists in the development of programs for computers at the telescopes. An astronomical image-processing team develops and maintains image processing and analysis software that is currently operating in Charlottesville and at the VLA as well as at more than 200 institutions world wide. As has been the case in previous years, a major portion of the MS&S for this Division will be used for computer-related expenses and maintenance. A CONVEX C1 mini-supercomputer, purchased with the University of Virginia on a cost-sharing basis, serves as a development computer for the NRAO image processing software system AIPS. It has been optimized to run this software for the benefit of visitors and staff. The last of four scheduled payments on the C1 will be made in 1989.

Technical Development

Observatory-wide technical research and development support are concentrated at the Central Development Laboratory. Work on radiometer improvements and the exploration of state-of-the-art techniques for expanding wavelength capabilities insures that the Observatory will have forefront instrumentation in the foreseeable future. A subgroup at the Central Lab is heavily involved in the development of new millimeter-wave devices for low-noise receivers. During 1989, $55k is budgeted for MS&S and $125k for rent of the Central Development Laboratory on Ivy Road.

Green Bank Operations

The five divisions at Green Bank are responsible for maintaining and operating the 300-foot telescope, the 140-foot telescope, and the interferometer (for the USNO). New instrumentation specifically for the single dishes is developed on site. Some workshops, electronics, and graphics support is also provided for Observatory-wide activities. These five divisions are: Telescope Services, Electronics, Plant Maintenance, Administrative Services,and Scientific Services. A total of $301k for MS&S is budgeted for these groups plus an additional $279k will be spent on communications and utilities. It is also estimated that food services and housing will bring in revenues of about $150k. The operation of the Green Bank telescope systems for the USNO is shown as a separate division in 1989, with a total cost of $757k (see Section VI).

Tucson Operations

Two divisions in Tucson are responsible for the maintenance and operation of the resurfaced 12-meter, millimeter wavelength telescope at Kitt Peak. The Electronics Division will be devoting a major portion of their 1989 effort to the installation of a new micro-processor based telescope control system together with its digital hardware, and testing of a new spectrometer and multi-beam receiver. The Operation and Maintenance group handles all visiting astronomer logistics and observing support, which for 1989 will include continued software development for improved telescope control and data acquisition. The two Tucson subgroups have the following MS&S budgets for 1989: Operations and Maintenance ($130k) and Electronics ($155k).

An additional $138k is programmed for building rent, communications, and utilities. Miscellaneous revenue will total about $19k.

Socorro Operations

Activities surrounding the VLA are coordinated through six divisions which differ in detail from those in Green Bank due to the special requirements of array operations and geographic isolation. The six divisions are: Scientific Services, Array Operations, Computer, Administrative Services, Electronics, and Antenna Services. The divisions are budgeted a total of $1080k for MS&S in 1989. In addition to this amount, $1120k is budgeted for communications and utilities, and $325k is required for computer rental and maintenance. With the move of most administrative, scientific, and array control personnel into the new Array Operations Center building, an amount of $105k is budgeted as the VLA's portion of the building rent and maintenance cost. Food services and housing will bring in an estimated $105k in revenue.

VLBA Operations

As the first three VLBA antennas become operational in 1989, the needs of VLBA operations grows appreciably. The total operations budget for VLBA will double over last year. In the long-term we anticipate a combined VLBA-VLA operations program, thus we categorize, initially, the VLBA operations into divisions similar to the existing VLA operations groups. The total MS&S budget for VLBA operations of $228k is comprised of $119k for communications and utilities, $12k for computer maintenance, $33k for building rent and manteinace, and $64k for other expenses.

A summary of the CY 1989 NRAO budget for the various sites is provided in the following table:

CY 1989 PRELIMINARY FINANCIAL PLAN
($ thousands)

	Personnel	Salaries, Wages & Benefits	Material, Supply, Service	Travel	Total
Operations					
General & Admr.	22	$ 1,018	$ 625	$109	$ 1,752
Research Support	43	2,408	505	171	3,084
Technical Develop.	15	696	180	15	891
Green Bank Oper.	73	3,032	535	29	3,596
Tucson Oper.	26	1,172	404	35	1,611
Socorro Oper.	115	4,083	2,525	40	6,668
VLBA Oper.	25	732	228	40	1,000
Management Fee			450		450
Common Cost Recovery			(195)		(195)
Total Operations	319	$13,141	$ 5,257	$459	$18,857
Equipment					
Research			-0-		-0-
Operating			-0-		-0-
Total Equipment			-0-		-0-
Design and Construction					
VLBA	60	$ 2,774	$ 8,974	$252	$12,000
NASA Voyager 2	1	255	138	25	418
USNO Additions			700		700
Total Design & Const.	61	$ 3,029	$ 9,812	$277	$13,118
TOTAL - ALL	380	$16,170	$15,069	$736	$31,975

Notes:
1. Green Bank Operations includes New Funds of $757 for operations and equipment in support of USNO telescope operations.
2. Green Bank Operations does not include anticipated funding from NSF for SSTI grant (approx. $273k).

VI. INTERFEROMETER OPERATIONS

In October 1978, the NSF entered into a Memorandum of Understanding (MOU) with the U.S. Naval Observatory (USNO) whereby the NRAO would operate the NRAO's Green Bank interferometer on a cost reimbursement basis as part of the USNO's fundamental astrometry program and basic time service functions.

In September 1988, a new Memorandum of Understanding between the USNO and the NSF was agreed upon for operation of the Green Bank interferometer. In the 1988 MOU, the scope of the USNO operation was changed from operation of a 4-element radio-linked interferometer to operation of a 2-element connected interferometer and, in addition, a dedicated VLBI telescope facility for USNO astrometric observations. The data acquired by the USNO will be used to further the USNO's fundamental astrometry program, including an attempt to improve the basic coordinate reference frame, continuing measurement of the earth's rotation, and understanding the variation in the strengths and structures of the radio sources from which these determinations are made.

Operating and maintenance costs and equipment replacements for the interferometer are planned at $757 in 1989. Funding for the interferometer program is provided to the NRAO through an interagency transfer between the USNO and the NSF for inclusion in AUI's contract with the Foundation. The 1989 allocation is shown in the following table.

USNO Expenditures and Funding Plan
($ in thousands)

	1987 Expended Actual	1988 Expended Estimated	1989 New Funds
Operations			
Personnel Compensation	$ 323.9	$ 298.0	$ 322.0
Personnel Benefit	85.1	82.0	81.0
Material & Supply	60.3	83.0	72.0
Communications & Utilities	41.3	40.0	32.0
Travel	0.0	4.0	4.0
Common Costs	216.0	192.0	209.0
Total Operations	$ 726.6	$ 699.0	$ 720.0
Equipment			
Shop	$ 0.0	$ 1.2	$ 0.0
Test Equipment	32.4	24.5	37.0
Computer Equipment	0.0	14.1	0.0
Total Equipment	$ 32.4	$ 39.8	$ 37.0
Design & Construction			
VLBI Upgrade	$ 0.0	$ 484.0	$ 700.0
Total Design & Construction	$ 0.0	$ 484.0	$ 0.0
TOTAL	$ 759.0	$1,222.8	$1,457.0

VII. VOYAGER 2 NEPTUNE PROJECT

In May 1985, the NSF and NASA entered into a Memorandum of Agreement (MOA) whereby the NRAO would develop, assemble, and install certain electronic equipment on the VLA antennas and then operate the VLA in conjunction with NASA's Voyager 2 Neptune mission. The utilization of the VLA for Voyager 2 data acquisition will commence on or about January 12, 1989, and end on or about September 28, 1989, with daily activity from August 7 through August 30, 1989. The spacecraft's closest approach to Neptune is August 24, 1989.

Under the terms of the MOA, the Observatory outfits each of the VLA antennas with front-end receivers (28 plus two spares) and feeds (the latter supplied by the Jet Propulsion Laboratory) to receive the Voyager 2 spacecraft frequency (8.4 GHz). The received signal will be combined with the identical signal that will be received by the NASA/JPL Goldstone antenna array and thus approximately double the total data return from Voyager 2.

Fabrication and installation of the receiver systems for the Voyager 2 program will be completed by the end of 1988. The projected Voyager 2 cost for 1989 is expected to run about $673k, of which about $255k is from 1988 funds carried over for commitment and expenditure in 1989.

Funding for the Voyager 2 program is provided to NRAO through an interagency transfer between NASA and NSF for inclusion in AUI's contract with the Foundation. The 1989 Voyager 2 program allocation is shown in the following table.

Voyager 2 Schedule
($ in thousands)

	1988	1989				
	Est. Exp.	New Funds	Carry-over	Available for Comm.	Comm. Fwd.	Available for Exp.
Personnel Compensation	$ 429.0	$ 200.0		$200.0		$200.0
Personnel Benefits	118.0	55.0		55.0		55.0
Material & Supply	349.0	(57.0)	$200.0	143.0	$55.0	198.0
Travel	10.0	25.0		25.0		25.0
Common Costs	389.0	195.0		195.0		195.0
TOTAL	$1295.0	$418.0	$200.0	$ 618.0	$55.0	$673.0

Total funding for NRAO's participation in the Voyager 2 programs is scheduled to be $6487k, as shown in the following table.

	1985	1986	1987	1988	1989	Total
Central Lab	$ 720.0	$ 925.0	$ 654.0	$ 143.0	$ 46.0	$2488.0
VLA Site	531.0	1114.0	965.0	$1017.0	372.0	3999.0
TOTAL	$1251.0	$2039.0	$1619.0	$1160.0	$418.0	$6487.0

At the completion of the program in 1989, the front-ends, feeds and other equipment acquired by the NRAO under the Voyager 2 program agreement will be retained by the Observatory, with title to all such property being transferred to the NSF.

VIII. VLBA DESIGN AND CONSTRUCTION

Revised Construction Plan and Budget for the VLBA

Included is NRAO's 1989 budget plan for VLBA construction, BD69N01, and associated overview schedule. This budget reflects the proposed $12M funding for 1989 with increases for inflation only in future years. It includes delays in many areas of the project because $12M in 1989 is approximately $4M less than the amount needed to construct the VLBA in the most efficient and cost effective way.

Among the delayed authorizations and their approximate dollar amounts are:

1. Construction of the Mauna Kea, HI and Hancock, NH control buildings from 1989 to 1990. $850k
2. Erection of the ninth antenna from 1989 to 1990. $350k
3. Construction of Focus/Rotation Mounts Nos. 7-10 from 1989 to 1990. $300k
4. Payment of approximately one-half the principal $3M to NMIMT for the Array Operations Center building from 1990 to 1991. $1.5M
5. Spare maser procurement delayed from 1989 to 1990. $150k
6. Construction of L-band feeds Nos. 6-11 from 1988 and 1989 to 1990. $100k
7. Payment of the infrastructure contribution to the Institute of Astronomy, University of Hawaii from 1990 to 1991. $300k
8. Tape recorder production from 1989 to 1990. $250k

Total 1989 Deferments = $2M

Total 1990 Deferments = $1.8M

For this plan to be effective, cooperation on the part of the NSF will be required. New 1990 funds will be needed in advance of NRAO's fiscal year (which is the calendar year) at the beginning of the Foundation's fiscal year (October of 1989) for the deferred 1989 items on the above list to continue orderly progress in the VLBA construction program.

Antennas and Sites

The schedule for manufacture and erection of antennas is essentially unchanged from the 1988 plan, with the completion of the tenth and last antenna still scheduled for 1990. Site selection for all sites has been completed. The current status of the antennas and sites follow:

Pie Town, NM - The antenna has been accepted except for correction of some punch list items. It is considered operational to the VLBI community and has participated in three NUG runs and a NASA crustal dynamics run. All receiver frequencies, except for the 43 GHz, have been utilized. Remote operation from Soccoro is now the normal mode of observation. Initial observational performance tests of primary parameters yield values within specifications.

Kitt Peak, AZ - The antenna is accepted except for punch list items. Phase I NRAO outfitting was completed in early 1988. Outfitting equipment dependent on the focus/rotation mount and subreflector is scheduled for October 1988. Assuming adequate funding, Kitt Peak is scheduled to be operational in early 1989.

Los Alamos, NM - Has the same status as the Kitt Peak site. Final outfitting is scheduled for February 1989. The expected operational date is also the same: early 1989.

Fort Davis, TX - The antenna is accepted. At the request of the VLBI community, North Liberty outfitting will take precedence over this site, delaying Fort Davis operation until early 1990.

North Liberty, IA - Antenna erection is underway and expected to be completed in November 1988. Operation is scheduled for late 1989, or early 1990, depending on operations funding.

Brewster, WA - The site work, antenna foundation, and control building are complete. Start of antenna erection is scheduled for October 1988.

Owens Valley, CA - Has the same status as the Brewster site. Antenna erection is scheduled to start in January 1989.

St. Croix, VI - Construction drawings are complete. Request for construction bids awaits final local government approval of the site lease. If such approval is delayed beyond October 1988, the eighth antenna erection will likely be authorized for the Hancock, NH site.

Mauna Kea, HI - The environmental approval process is on schedule. Access to the site for survey and soil tests is scheduled for January 1989. Start of site construction is scheduled for spring, 1989.

Hancock, NH - Lease approval by Boston University is expected by October 1989. Site survey is complete. Start of this site construction is also scheduled for spring 1989, but is likely to be completed much quicker than at the 12,000 foot altitude of Mauna Kea.

Additionally, work continues on the manufacture of focus rotation mounts, subreflectors, and feed cones for the array.

Array Operations Center (AOC)

Construction was initiated in August 1987 for the AOC building by the firm of Bradbury Stamm. Occupancy is now expected in November 1988.

Electronics

Generally speaking, production of the three electronic rack sets required for each site, plus the front ends for each first round installation, are continuing to keep pace with antenna outfitting schedule. The fifth electronics set is ready, and the sixth scheduled for December 1988 completion. Two more (7 & 8) are scheduled for 1989 construction.

The first round front ends for 1.5, 4.8, and 23 GHz bands are on the same schedule. The initial production of the second round front ends for the 2.3 GHz (two each) and 8.4 GHz (five each) bands is scheduled for 1989. Development of the 43 GHz front end system addition will continue, with production scheduled in 1990 and 1991.

The first six hydrogen maser clocks were delivered by Sigma Tau Standards Corporation. Serial Nos. 7 - 9 are scheduled for delivery through 1989.

Data Recording

The first prototype VLBA Recording and Data Acquisition System (No. 1) was delivered in April 1988. The second prototype (No. 3) is virtually complete and undergoing tests at Haystack Observatory, as are Data Acqusition Racks Nos. 3 and 4. Preproduction Recorder System (No. 3) is in the circuit board and parts procurement phase, as are Playback Drives Nos. 1 and 2 at Haystack. Haystack is scheduled to deliver Recorders Nos. 4, 5 and 6 and Playback Drives Nos. 3 and 4 in 1989. Haystack is scheduled to be funded for five more units in 1989: Recorders Nos. 7 and 8 and Playback Drives Nos. 5, 6 and 7, for delivery in 1990.

At NRAO Charlottesville, the first Playback Interfaces, Nos. 1 and 2, are in design phase; and production Data Acquisition Racks Nos. 5 and 6 are in board acquisition phase. Production of two more Data Acquisition Racks in 1989 (four in 1990), and four Playback Interfaces for each of the next three years are also scheduled for Charlottesville.

Monitoring and Control

The prototype monitor and control hardware and firmware are operating at Pie Town. These include the standard interface boards for the receiving system, data acquisition system, and antenna control system; the utility monitoring system of the control building; the focus/rotation control for the subreflector mount; the weather station; and the station monitor and control computer hardware and software. These systems allowed the unattended remote control of the Pie Town antenna during the September 1988 NUG run.

Serial versions of many of these systems are in an advanced stage of test and fabrication, with additions and modifications in firmware being added to correct bugs as they are uncovered by the observations and tests performed at Pie Town. The debug and improvement of these systems, with fabrication of hardware for the remaining sites will continue in 1989. Much of the programming of the Array Control Computer remains to be completed and tested. This could not be done until the delivery of Motorola's X.25 communication package for its VME computers, expected in October 1988, which is necessary for efficient multi-station monitor and control.

Correlator

A major milestone was achieved in August with the selection of a vendor for the "FX chip." Purchase orders for the chip design and development, and the delivery of production quantities with spares are imminent. Final correlator circuit board design and procurement, other hardware procurement, design of playback interfaces, and correlator control computer software development are underway with full staffing.

Post Processing

Programming work continued to add to the AIPS package the programs necessary to process VLBA data.

Project Management

The project office will move to the Array Control Center this fall. The electronics, correlator, and data processing activities will continue primarily in Charlottesville in 1989.

15-Sep-88

1989 Financial Plan VLBA Constant'88	Effort	Salaries & Wages	Benefits (@ 27.5%)	Materials & Services	Travel	Contract Charges	Total
Sub-project	Man-months	$k	$k	$k	$k	$k	$k
Sites	24	108	29	129	40	1330	1636
Antennas	84	233	64	88	60	4286	4731
Electronics	264	676	186	803	55	0	1720
Data Recording	36	99	27	322	10	168	626
Monitor & Control	60	182	50	187	10	105	534
Correlator	120	388	106	398	22	0	914
Data Processing	36	95	26	20	16	0	157
System Engineering	0	0	0	0	0	0	0
Array Oper. Center	0	0	0	228	0	0	228
Spares	0	0	0	206	0	0	206
Project Management	115	313	86	140	30	0	569
Operations Training	0	0	0	0	0	0	0
Planned Commitments	739	2094	574	2521	243	5889	11321
New Funds, 1989							11538
Carryover from prior years							126
Net Contingency, $K							343

File: FIN09
15-Sep-88

1989 Financial Plan VLBA Current '89	Effort	Salaries & Wages	Benefits (@ 27.5%)	Materials Services	Travel	Contract Charges	Totals
Sub-project	Man-months	$k	$k	$k	$k	$K	$K
Sites	24	112	30	134	42	1383	1701
Antennas	84	242	67	92	62	4457	4920
Electronics	264	703	193	835	57	0	1788
Data Recording	36	103	28	335	10	175	651
Monitor & Control	60	189	52	194	10	109	554
Correlator	120	404	110	414	23	0	951
Data Processing	36	99	27	21	17	0	164
System Engineering	0	0	0	0	0	0	0
Array Oper. Center	0	0	0	237	0	0	237
Spares	0	0	0	214	0	0	214
Project Management	115	326	89	146	31	0	592
Operations Training	0	0	0	0	0	0	0
Planned Expenditures	739	2178	596	2622	252	6124	11772
New Funds, 1989							12000
Carryover from prior years							126
Net Contingency							354

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VLBA BUDGET AND COST ESTIMATE (Constant $)

	1983,4	1985	1986	1987	1988	1989	1990	1991	1992	TOTALS
ANT STARTS/INSTLS		1/1	3/1	2/2	2/3	2/1	0/2			
SITES	32	194	2,204	1,605	1,832	1,636	1,144	502	10	9,159
ARRAY OPNS CTR			33	19	46	228	1,607	1,542	19	3,494
ANTENNAS	1,088	2,460	6,540	5,180	5,715	4,731	1,340	0		27,054
ELECTRONICS	533	1,573	1,652	2,045	1,422	1,720	2,255	1,804	124	13,128
DATA RECORDING	290	424	4	906	708	626	1,489	1,192	1,776	7,415
MONITOR, CONTROL	63	94	316	549	473	534	216	10		2,255
CORRELATOR	322	133	196	370	1,038	914	464	170		3,607
POST PROCESSING	0	0	0	75	63	157	1,454	2,035		3,784
SYST ENGINEERING	54	86	76	24	0	0	0	0		240
MISC & SPARES	0	0	0	16	134	206	665	1,626		2,647
PROJ MGT& SUPPORT	272	374	606	657	649	569	564	529		4,220
OPNS TRAINING	0	12	49	26	0	0	0	0		87
EXPENDITURES	2,655	5,350	11,676	11,472	12,080	11,321	11,198	9,410	1,929	77,090
CONTINGENCY	N/A	N/A	N/A	N/A	126	343	340	2,128	588	3,401
PERCENT CONT.	0.0	0.0	0.0	0.0	1.0	3.0	3.0	22.6	30.5	4.4
NEW FUNDS (1988 $)	2,806	9,000	8,552	11,400	11,600	11,538	11,538	11,538	2,517	80,491
CARRYOVER from prior years					606					
PROJECTED carryover from prior years						126				
OPERATIONS (1988 $)				143	500	961	2,300	3,600	5,013	6,255 ('93)

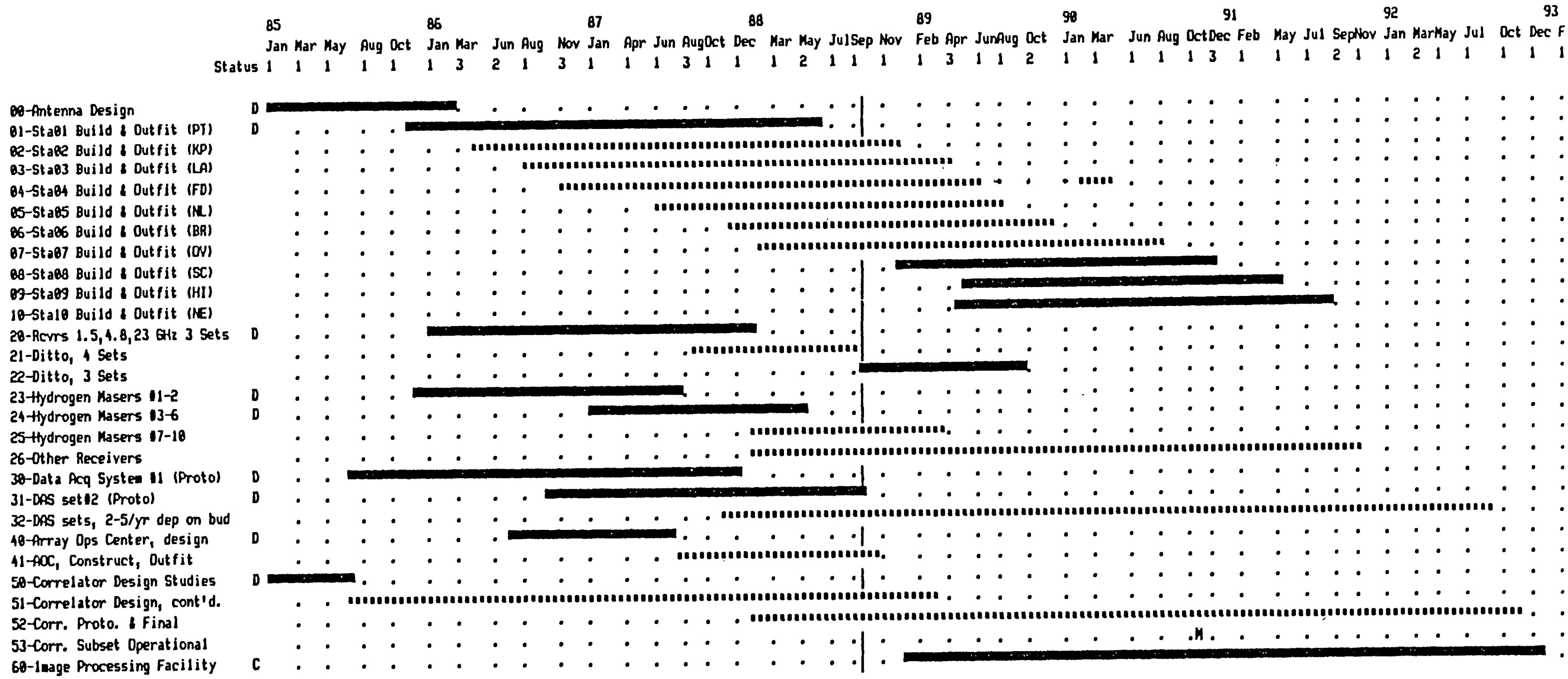
BD69N01 880915
15-Sep-88

VLBA BUDGET AND COST ESTIMATE (Current $)

	1983,4	1985	1986	1987	1988	1989	1990	1991	1992	TOTALS
INFLATION (%)	0	0	0	0	0	4	4	4	4	4
ANT STARTS/INSTLS		1/1	3/1	2/2	2/3	2/1	0/2			
SITES	32	194	2,204	1,605	1,832	1,701	1,237	565	12	9,382
ARRAY OPNS CTR	0	0	33	19	46	237	1,738	1,735	22	3,830
ANTENNAS	1,088	2,460	6,540	5,180	5,715	4,920	1,449	0	0	27,353
ELECTRONICS	533	1,573	1,652	2,045	1,422	1,789	2,439	2,029	145	13,628
DATA RECORDING	290	424	4	906	708	651	1,611	1,341	2,078	8,012
MONITOR, CONTROL	63	94	316	549	473	555	234	11	0	2,295
CORRELATOR	322	133	196	370	1,038	951	502	191	0	3,703
POST PROCESSING	0	0	0	75	63	163	1,573	2,289	0	4,163
SYST ENGINEERING	54	86	76	24	0	0	0	0	0	240
MISC & SPARES	0	0	0	16	134	214	719	1,829	0	2,913
PROJ MGT& SUPPORT	272	374	606	657	649	592	610	595	0	4,355
OPNS TRAINING	0	12	49	26	0	0	0	0	0	87
EXPENDITURES	2,655	5,350	11,676	11,472	12,080	11,774	12,112	10,585	2,257	79,959
CONTINGENCY	N/A	N/A	N/A	N/A	126	352	368	2,394	688	3,803
PERCENT CONT.	0.0	0.0	0.0	0.0	1.0	3.0	3.0	22.6	30.5	4.8
NEW FUNDS, Current $	2,806	9,000	8,552	11,400	11,600	12,000	12,480	12,979	2,945	83,762
CARRYOVER from prior years					606					
PROJECTED carryover from prior years						126				
OPERATIONS, Current $				143	500	1,000	2,500	4,090	5,865	7,610 ('93)

Schedule Name: VLBA SCHEDULE OVERVIEW
Project Manager: Peter Napier
As of date: 8-Sep-88 3:10pm Schedule File: C:\TLDATA\VLBAOV8

An approximate bar chart keyed to Budget BD69N01



D Done
C Critical
R Resource conflict
r Rescheduled to avoid resource conflict
Scale: Each character equals 12 days

■ Task
▪▪▪ Started task
M Milestone

- Slack time (■—), or
Resource delay (—■)
) Conflict
p Partial dependency

TIME LINE Gantt Chart Report

Strip 1

IX. NATIONAL RADIO ASTRONOMY OBSERVATORY
CY 1989 PRELIMINARY FINANCIAL PLAN
($ in thousands)

	1989 New Funds*	1989 Uncomm. Funds Carried Over from 1988	1989 Total Avail. for Commit.	1989 Commitments Carried Over from 1988	Total Available for Expend.
I. OPERATIONS					
Personnel Comp.	$10,311.0		$10,311.0		$10,311.0
Personnel Benefits	2,830.0		2,830.0		2,830.0
Travel	455.0		455.0		455.0
Material & Supply	5,006.0		5,006.0	$ 100.0	5,106.0
Management Fee	450.0		450.0		450.0
Common Cost Recovery	(195.0)		(195.0)		(195.0)
Total Operations	$18,857.0		$18,857.0	$ 100.0	$18,957.0
II. EQUIPMENT					
Research Equipment	$ 0.0	$ 450.0	$ 450.0	$ 50.0	$ 500.0
Operating Equipment	0.0	100.0	100.0	0.0	100.0
Total Equipment	$ 0.0	$ 550.0	$ 550.0	$ 50.0	$ 600.0
Total: Oper. & Equip.	$18,857.0	$ 550.0	$19,407.0	$ 150.0	$19,557.0
III. DESIGN & CONST.					
VLBA Project	$12,000.0	$ 126.0	$12,126.0	$4,000.0	$16,126.0
NASA Voyager 2 Project	418.0	200.0	618.0	55.0	673.0
USNO Interferometer Addn.	$ 700.0	276.0	976.0	40.0	1,016.0
Total: Design & Const.	$13,118.0	$ 602.0	$13,720.0	$4,095.0	$17,815.0
TOTAL PLAN	$31,975.0	$1,152.0	$33,127.0	$4,245.0	$37,372.0

* Includes USNO Funds $1,457k; NASA funds $418k; NSF funds $30,100k.

APPENDIX A

The NRAO permanent staff will investigate a number of topics in a variety of research areas during 1989, as described below. Visiting scientists will collaborate in some of this research.

A. GALACTIC STUDIES

The Sun and the Solar System

With the approach of the next solar maximum, the level of solar activity has increased dramatically, offering renewed opportunities to study active solar phenomena (e.g., flare precursors, microwave bursts, filament eruptions, and coronal transients). The many problems posed by synthesis imaging of the Sun, including sparse uv imaging and time variability, for example, have led to the exploration of innovative synthesis imaging techniques designed to overcome or circumvent these problems. One promising means to improve the uv coverage over short time scales employs bandwidth synthesis. This technique has been used very effectively to image solar active regions on short time scales, and it will be exploited to study the temporal evolution of solar active regions, particularly during the flare precursor phase.

A long-standing discrepancy exists between radio and extreme ultraviolet (EUV) wavelength solar observations: all models derived to date from EUV line intensities predict brightness at radio wavelengths which are much larger than observed. An observational program will continue at the VLA whereby images of the Sun are obtained contemporaneously with EUV images to study the problem. The problem is particularly acute in coronal holes. The observational program is designed to image coronal holes in both wavelength regimes with degrees of angular resolution which were previously unobtainable.

Certain parameters of the solar wind within one degree of the Sun will be measured. The properties include the distribution of refractive index variations with radius and position angle, and the wind velocity. By making average images of the scattering-broadened image of radio sources at different distances and position angles from the Sun, the anisotropy of the Solar wind as a function of position near the Sun will be measured. A novel, fast (40 msec) integration mode employing a correlator gating technique will be employed, in addition to conventional long time integration modes.

At the other end of the solar system, Pluto will be observed. Competing models for the surface and atmospheric conditions of Pluto can be distinguished by observations which will be made with the sensitive 3.7 cm receivers at the VLA. These observations will measure the equivalent surface temperature of Pluto, an important discriminator between these models.

Astrometric measurements of the largest planets will yield a refined location of the vernal equinox and an absolute calibration of the VLA in right ascension.

Stars and their Environment

From juvenile single stars, where thermal radio jets are observed, to flares on young stars, through the mass loss/planetary nebula phase of red giants to the emission from neutron stars, this field provides a growing source of interest to radio astronomers. Research projects of staff members and their collaborators cover a cross section of these areas.

Stellar dynamic spectroscopy will be used to explore outbursts such as the intense one observed in UV Ceti using the VLA spectral-line system in 1986. Such decimetric outbursts on flare stars have been observed periodically since then, using the 140-foot telescope at Green Bank and the Arecibo telescope. Such observations place important constraints on the coherent emission mechanisms believed to be responsible for the outbursts. In the coming year, new instrumental developments will be exploited to further this work, including the use of a broadband acousto-optical spectrometer developed by a French group to obtain spectra of large relative bandwidth.

A number of flare stars were detected in a survey of the nearest stars to be completed this year, but no stars with continuous radio emission above 0.5 mJy were detected. The statistics of the detected sources are consistent with the number expected for flare stars in the sample.

Fundamental new astronomical data on the masses and distance of galactic stars may be obtained through their gravitational lensing of background radio sources. VLA observations have already produced several candidates for anticipated VLBI observations. The high-resolution lensed image will be analyzed to deduce the parameters of the stellar lens.

The general properties of the radio emission from nearby Wolf-Rayet stars are now well-documented as a consequence of the extensive observations with the VLA. Progress in the understanding of the Wolf-Rayet envelopes however has been slow because of the inherent difficulty in solving the radiative transfer problem in the massive high-velocity wind. Recently Hillier has developed a new model that requires that the wind will have cooled significantly by the time it reaches the distance characteristic of the radio emitting region. The VLA will be used to measure the effective temperature in the radio regions of the atmospheres of two Wolf-Rayet stars in order to test the main predictions of this very important theory.

Astrometric observations of selected radio-binary stars should lead to well determined parallaxes and proper motions.

Neutral material around planetary nebulae and their progenitors has been known for some time from optical spectra. Collisionally excited lines of CO and H_2 demonstrate that some of this material is molecular, and it is believed to originate in the shocked interface between a neutral remnant of the circumstellar shell of the progenitor red giant and the expanding HII region which the exposed core of the red giant excites. CO provides a sensitive tool with which to measure even hundredths of solar masses of this molecular gas, as it is sensitive to cool gas whereas H_2 samples only hot gas. The velocity field of the neutral gas is traced by CO emission where it is resolved, indicating evidence of the possible source of the bipolar structures dominating many planetaries. A survey of CO emission of southern planetary nebulae will be carried out, with some emphasis on structures which can be resolved.

In one bright planetary with a double nucleus, mass transfer between the central stars is thought to have occurred. Isotopic observations in the neutral material surrounding the planetary will be made to gauge the degree of nuclear processing in that material, originating in the surface of one of the stars only a few thousand years ago. In another, VLA observations of the ionized gas will provide a detailed description of the nebular density distribution; a comparison with a similar description from optical data will be made.

Earlier in the red giant stage, when the star's envelope is expelled, poorly understood processes deep in the envelope create molecules and dust and accelerate them into space. The profiles of vibrationally excited SIS and CS lines indicate that they are located within the zone where full acceleration has not yet occurred. Hence they explore the critical region where dust is being formed and where the products of thermochemical equilibrium are being frozen in. Their angular size is important in determining the nature of the IR radiation field, the size of the acceleration zone, and the critical radius at which dust condenses out. Using the OVRO interferometer, images will be made at 1.3 mm of vibrationally excited SIS and CS species in the circumstellar envelope of IRC 10216. Because of their unusual excitation, these species are powerful diagnostics of the innermost region of this circumstellar shell.

VLA and VLBI studies of the X-ray binary SS 433 will continue. A study of the coupling between radio emission and the X-ray emission environment in X-ray binaries is also planned during this period. This will include comparison between observations and models for SS 433, Cyg X-1, Cyg X-2, Cyg X-3, Sco X-1, GX17+2, and LSI +61d 303. The special sub-category of soft X-ray transients will receive special attention with extensive modeling of the evolution of X-ray emission in these systems, with re-analysis of light curve and spectrum information in accessible data archives.

The flux density and position of the two radio lobes and radio core of Sco X-1, the X-ray galactic binary system, will be monitored with VLA and VLBI observations. This is the only radio double for which proper motion within the source can be observed.

An exploratory project to formulate a non-linear equation to describe the state transitions and chaotic behavior in low-mass X-ray binaries will be carried out. The objective is to formulate a theory for the behavior of these systems in terms of a strange attractor and the quantification of chaos.

The study of new (Nova Her 1987 and Nova Cyg 1986) and old (HR Del 1967, FH Ser 1970, V1500 Cyg 1975) classical novae, and the recurrent nova RS Oph, will be concluded during this period with joint interpretation of optical and radio light curves in a unified model.

<u>Studies of the Galaxy</u>

Radio astronomical studies by the NRAO staff of the Galaxy and processes shaping it cover the structure of the interstellar medium from the galactic center to the halo, star formation and dense cloud properties, and the chemistry of the interstellar gas.

The structure of the interstellar medium in the vicinity of the galactic center continues to provide grist for a broad range of studies. Dense molecular material is best probed through observations of CO. High velocity (|V|> 100 km/s) features within 10 pc of Sgr A will be used to locate forces interacting with molecular clouds. Maps of the Sgr C complex will be made to confirm preliminary suggestions of the existence of the sort of "non-thermal filament related to molecular cloud" situation already seen in Sgr A. From localized regions in the galactic center arise maser emission from both ammonia and water molecules. These emissions will be used as probes of the region's physical and kinematic properties. Non-thermal components related to the Sgr A sources can be well-delineated with the new 327 MHz receivers on the VLA. High dynamic range maps of the center at this frequency will be obtained which will help to distinguish these components from the substantial component of ionized gas present in the halo surrounding both Sgr A East and West. The thermal component should have recombination line emission associated with it. Maps at 20 cm are planned which should reveal the kinematics of this ionized gas halo. The Zeeman effect in recombination lines will allow us to verify the high magnetic fields postulated in the central region.

Radio recombination line emission may be detectable from ionized filaments in the fluxful remnants Cas A and the Crab. Very broad velocity coverage observations are necessary to detect such turbulent gas, but, if detected, recombination lines could provide another tool for studying the kinematics of gas in distant supernova remnants which are optically obscured. Toward Cas A, carbon recombination line emission can be measured at 327 MHz and compared with the HI distribution, providing an understanding of the ionization and thermal balance in the cold clouds along this line of sight. Other lines may be measured with the 140-foot telescope to test models of this emission, and, if detectable at 20 cm, provide a direct comparison with the HI emission.

Radio recombination lines in the millimeter and submillimeter spectrum tend to show less severe effects of departures from thermodynamic equilibrium than those at low frequencies. The effect of the Lyman discontinuity in the atmospheres of early-type stars will be studied through comparison of alpha and beta recombination lines at high frequency. These results are expected to lend insight into the effects of the metallicity of the interstellar gas upon the excitation of atomic hydrogen in HII regions.

Imaging of extended regions with interferometers like the VLA presents numerous problems which will become more acute as interferometric imaging is extended to higher frequencies. Detailed images of several galactic HII regions (W43 and the Rosette) are being constructed which are expected to provide high dynamic range maps of 20" resolution which extend over several degrees. The vexing problem of addition of long-spacing data to the filtered images is currently under attack. When complete, the images will form one portion of a substantial database incorporating optical and infrared (IRAS) images as well as CO datacubes.

Toward the low-latitude, inner-galaxy, HII region W43 the line of sight passes through a copious amount of HI. Unique insight into the structure of this inner galactic plane gas will result from the analysis of the HI absorption line maps recently obtained at the VLA. This very large database will also provide a test for new spectral-line and data-calibration procedures in AIPS.

Towards a number of galactic HII regions, HI absorption is observed at forbidden velocities. The origin of these non-circular velocities is unclear, and a synthesis study of these features will be initiated to explore their causes.

In the Orion region, in contrast to the inner galaxy, most of the HI seen in emission in some direction is associated with the cloud. A survey of this emission will be undertaken to help determine the interactions and interrelationship of this atomic gas with molecular gas. Two filamentary molecular clouds in Orion are of particular interest owing to their bizarre properties, which are unlike other known molecular clouds.

The structure of the dense star-forming core of OMC1 has been explored via the 2 cm lines of H_2CO, revealing an unexpected abundance of this fragile molecule in the energetic hot core region. An appealing hypothesis for the source of formaldehyde holds that it is liberated from grain surfaces onto which it was frozen during a colder epoch in the cloud's history. This hypothesis will be tested through interferometric observations of the millimeter lines near 72 GHz, using the BIMA array. Preliminary data shows the emission to be quite strong, and serendipitously demonstrates that the DCN, and possibly DCO+ lines, can also be mapped. Combination of three interferometer maps, in differing formaldehyde transitions, should lead to separation of the effects of temperature, density, and abundance in this complex region.

Maps of the DR21(OH) regions, made with the OVRO interferometer in the continuum and the $C^{18}O$ lines at 2.6 and 1.3 mm, show a complex region with at least four centers of star-forming activity. Like OMC1, this cloud does not appear to harbor embedded HII regions; unlike OMC1 it does not contain known bipolar flow sources. It may represent a region of massive star formation viewed at a younger age than OMC1. These maps will be combined with maps of NH_3 emission to be obtained at the VLA to paint a complete picture of the structure of a cloud which apparently forms many massive stars in separate cores nearly simultaneously.

At an even earlier epoch in its star-forming career is the IRAS 16293 object in the Rho Ophiuchi molecular cloud. A small, rotating disk-like core contains a protobinary system, one component of which is the source of high-velocity outflow, which excites a compact, thermal radio continuum source. The second component, located by a weak radio source, may be in an even earlier stage of formation. Although it is encompassed by a large column density of dust, that dust is quite cool and the molecules associated with it are relatively unexcited. Curiously, in the disk immediately surrounding the brighter object there is a pronounced lack of ammonia, apparently because it was frozen onto grains during an earlier period when gas and dust were colder, and has not been liberated by the warming of the core subsequent to star formation. However, sulfur oxides usually associated with warm shock chemistry have been located in the warm core, and maps of their distribution will be obtained at BIMA to gauge the size of the warm core (if the chemical expectation is correct) and to probe the velocity field of the disk close to the central object. Very close to the central object, a number of water masers lie. Their intensities are quite variable and will be monitored as part of a continuing program to follow variations in velocity and intensity of water and ammonia masers in star-forming regions.

Other dense cores in the prolific Rho Oph cloud will be further explored, in particular to investigate the cause of a bright isolated source of SO_2 emission near the bipolar infrared reflection nebula GSS30. This source, though it has very strong emission lines of sulfur dioxide, is unrecognizable in maps of emission from any other molecule mapped there. The character of this source will be further explored through interferometry and maps in other molecules during the coming year.

The energy transfer between interstellar dust clouds and the protostars embedded within them will be studied. At millimeter wavelengths, dust emission is weak, and the ultrasensitive combination of the MPIfR/Bonn bolometer and the IRAM 30-meter telescope will be used to measure cooling radiation from the dust. An aim of these studies will be to use the dust emission as a diagnostic of stellar conditions within them, and to attempt to get insight into the characteristics of the interstellar dust itself.

The role of magnetism in star formation has always been difficult to investigate. Several recently detected molecules may provide magnetic field probes through their sensitivity to the Zeeman effect. Recently a Zeeman experiment was performed at the 140-foot on the molecule C_4H in the dense core of the cold TMC-1 molecular cloud. A limit of 60 μG was achieved, indicating that the field is at least partly, if not completely, expelled during gravitational contraction, and thus may play little or no role in the process of star formation. Unfortunately C_4H emission was not strong enough to repeat this experiment in other objects, so the negative result could be attributed to an unfavorable geometry, with a larger field perpendicular to the line of sight. The only other molecule suitable for such Zeeman experiments is C_2S. This species is known to radiate strongly enough in several cloud cores. The C_2S Zeeman experiment will be conducted on several of these cores in the coming year.

C_2S is also a good probe of the chemistry of cloud cores. This topic, in cirrus cores in particular, will be further assessed by searches for C_2S and C_3S. These species are formed directly from acetylene and will thus determine its abundance. If acetylene is found to be underabundant as are the other species which have been studied, then very likely all organic chemistry in these objects must be depleted, suggesting that the cirrus have a large O/C ratio.

Other studies of these cirrus cores will measure ammonia emission in them to establish gas temperatures. Previous studies of 6 and 2 cm H_2CO, HC_3N, and C_3H_2 established the densities of these objects and the fact that they are chemically deficient, each of these species being of order 10 times less abundant fractionally than they are in galactic plane clouds. A lower metallicity seems the only plausible explanation at present. The temperatures determined by NH_3 observations will not affect the derived abundances, but will tell us how well the grains and gas are coupled, and bear on the question of the existence of Polycyclic Aromatic Hydrocarbons or of a small stochastically heated grain population postulated to explain certain characteristics of the grains as seen by IRAS.

Combined optical, radio, and ultraviolet studies will probe further out in the galactic halo. A growing appreciation of the symbiotic relationship between the halo region and the disk drives this work, but the faint, elusive halo HI signal is frequently masked by the strong signal from local hydrogen in telescope sidelobes. Hence, a new very low-sidelobe receiving system is under development at Green Bank, a prototype for a multi-beam system. The prototype receiver will be used for HI studies of the halo in the coming year.

Interstellar Molecules

Interstellar lithium (Li) has so far only been seen via its optical resonance lines along nearby lines of sight. However, atomic Li has a spin flip hyperfine transition at 803 MHz which will be sought in the galactic center. According to some nucleo-synthesis theories involving major explosive events in the galactic center, Li may be 1000 times overabundant there, and thus easily detectable. Another source of lithium in the interstellar medium may be mass loss from super Li-rich stars. To see whether such stars can significantly enrich the Li content of the ISM, they will be studied by searching for CO in their circumstellar envelopes in order to determine their mass-loss rates.

Together with the Herzberg group, a spectral scan of Sgr B2 and IRC 10216 covering the range 220-280 GHz and of Orion covering 330-360 GHz will be undertaken at the James Clark Maxwell Telescope (JCMT). This survey will be interpreted in the light of comparisons with a similar survey of Orion taken last winter with the 12-meter telescope. Such comprehensive surveys will allow the reassessment of the chemistry in these very dissimilar regions.

In a continuing quest to understand how interstellar and circumstellar cyanopolyynes (HC_nN) are formed, a search is planned for protonated methyl cyanide (CH_3CNH^+), based on recently measured frequencies. This continues a program of searches for protonated species. (The failure to detect HC_3NH^+ last year has posed serious problems for existing theories of HC_nN chemistry.)

Vinoxy (CH_2CHO) will be searched as a second test of Bates' theory of dissociative electron recombination of polyatomic ions which holds that one and only one H atom will be detached. Observations last year of the ketyl radical (HCCO) were consistent with Bates' theory.

Studies of interstellar Chlorine chemistry are hampered by the difficulty of observing the only known species, $HC\ell$, at 626 GHz. A search for $H_2C\ell^+$, its immediate progenitor, is planned, not only to test ion molecular schemes for chlorine chemistry but, if detected, to provide a much more convenient $C\ell$ species for study since $H_2C\ell^+$ has a suitable transition at 271 GHz where routine ground-based observations can be made.

The acetylene dimer $(C_2H_2)_2$ will be searched. Acetylene is a cornerstone of all gas phase astrochemistry, but cannot be directly observed because it lacks a permanent dipole moment. Its dimer may form in appreciable quantities on grains, has a dipole moment, and may explain the dilemma of why C_2H_2 is unexpectedly low in abundance in circumstellar envelopes.

The cornerstone molecule in interstellar carbon chemistry is CH_3^+. Unfortunately it is symmetric and so lacks rotational lines and cannot be observed. Its deuterated form, however, possesses a small dipole moment, and its rotational lines should be detectable in interstellar clouds. Calculated frequencies will be replaced by measured ones soon, and a search for the appropriate lines will commence. The resonance line lies in a particularly auspicious region below 300 GHz where the sky is transparent and the performance of the 12-meter excellent.

An irritating problem to interstellar chemists has been the high observed abundance of interstellar atomic carbon. Unfortunately, however, abundance determinations for this species rely on complex interpretation of its only two lines, at 492 and 808 GHz. The atmosphere is clear at neither of these frequencies, hence the observations are both very difficult to obtain and require very different instruments. Comparison of line shapes and intensities in the few places both lines have been observed indicate low optical depths, but are subject to severe calibration uncertainties. In a few sources, such as in the Rho Oph cloud, apparent absorption by optically thick foreground gas indicates high optical depth. An independent assessment of optical depth would be possible if the ^{13}CI line, lying only a little over 1 km/s from the main line, could be measured. An optically dim rim has been identified in the Rho Oph clouds in which an extremely strong but unusually narrow CO line occurs. Measurement of CI at this position should reveal the intensity ratio of the isotopic lines in a single spectrum, immune to calibration uncertainties, and provide a good measurement of optical depth in a region where other molecular abundances are well understood.

H_3O^+ is nearly as important to oxygen chemistry as $CH_3{}^+$ is to carbon chemistry. Emission at the frequency of one of its lines has been detected, but remaining lines are in atmospherically extremely difficult regions. However, three lines lie between 364 and 396 GHz and should be observed in the coming year, securing the identification of H_3O^+ and placing limits on the abundance of water. Further observations of the ^{18}O isotope of water, tentatively detected during the past season, are also planned.

The theory of the interstellar chemistry of ammonia has encountered serious problems, accounting for the observed high ammonia abundance in warm sources. In addition to excessive ammonia, these sources also have excessively high levels of deuterium enhancement if standard nitrogen chemistry applies. Together, the observations suggest that there exists a source of ammonia capable of concentrating deuterium in warm sources. A survey of deuterium fractionation levels will be conducted in order to characterize the temperature dependence of deuterium fractionation in interstellar clouds, a key to the identification of the second source.

Unsuccessful searches for CaOH and for several phosphorus compounds (HCP, HPO, PH_3) have been made. CaOH is predicted to be even more highly abundant in circumstellar envelopes than the recently detected refractory compounds NaCℓ, AlCℓ, KCℓ, AℓF. Models carried out to explain the recently detected species PN predict that HPO should be only slightly less abundant in interstellar clouds. Other models predict that HCP should be highly abundant in circumstellar envelopes. Analyses to explain the negative results in light of these models will be carried out.

B. EXTRAGALACTIC STUDIES

Normal Galaxies

From the final maps of the 6 cm sky survey made with the 7-feed receiver, all UGC galaxies brighter than 25 mJy will be identified. This sample of radio identifications should contain a significant population of flat-spectrum sources, allowing further studies of currently "active" radio galaxies out to a distance of about 200 Mpc. The identified galaxies can then be used to determine for the first time the local radio luminosity function at 6 cm for both flat-spectrum and steep-spectrum sources. Then the local luminosity function and counts of both strong and faint (much less than 1 mJy) sources can be modeled to see if flat-spectrum sources evolve in the same way as steep-spectrum sources and if the flattening of the faint source counts found at 20 cm also appears at 6 cm.

Maps of the entire IRAS bright galaxy sample made with the VLA at 20 cm will be completed. This sample of 324 galaxies with 60 micron brightness above 5.4 Jy is the infrared counterpart of the radio 3CR and optical Shapley-Ames samples. It represents the best sample for investigating the processes responsible for infrared emission from galaxies. There is a tight correlation between the far-infrared and radio continuum fluxes of infrared-selected galaxies. The VLA maps will be used to test its physical significance and limitations (e.g., is there a detailed spatial correlation within each galaxy?). The VLA maps may also provide the best means for establishing the brightness distributions of the vast majority of Bright Galaxy Sample sources that are unresolved in the IRAS survey at 60 microns.

Work is continuing on a description of those basic integral properties of spiral galaxies derivable from the two parameters of size and maximum rotational velocity. Such data are available for some 2000 systems and define an R-V plane (radius rotational-velocity) in which known spirals occupy only a small region. The integral properties include mass, density, angular momentum, and surface brightness. The research effort is directed toward an understanding of why galaxies avoid certain regions of the R-V plane. Thus, large, slowly rotating spiral galaxies are essentially unknown. Similarly, spirals with a total (visible) mass greater than $\sim 10^{12}$ $M_{\odot}$ are also unknown.

Studies of a complete sample of E/S0 galaxies are continuing. VLA observations will be made at additional wavelengths to give information about their radio spectra. Selected properties of the sample will be subjected to statistical analysis during the coming year.

A large research effort is directed towards describing the interstellar component within early-type systems, i.e., elliptical galaxies and the earliest disk (spiral) systems, S0's and Sa's. There is interstellar material in all forms: hot (10^7 K), warm (10^4 K), and cool (10-100 K) gas as well as dust in representatives of these various galaxy classes. A broad trend relating interstellar content and galaxy morphology has long been recognized, but a detailed and statistically meaningful sample has not been studied. A sample of approximately 500 early-type galaxies in which the assignment of morphological type is consistent and for which the selection bias is understood is in preparation. It will, among other things, serve as a basis for future observations. At radio wavelengths, pilot studies are planned or underway at Arecibo, Green Bank, Kitt Peak, and Pico Veleta.

Ultraviolet imaging is a sensitive probe of interstellar matter and a very sensitive detector of low surface brightness hot sources. These sources may populate part of the currently vacant R-V plane. The ultraviolet imaging experiment of the Astro Spacelab mission is scheduled for launch in the coming year and some of its experiments address these topics. Observations of a large sample of irregular galaxies with ultraviolet excess will be made with the VLA, in part to try to increase the number of recognized clumpy irregular galaxies available for study. These galaxies may represent extreme examples of star formation activity.

Among the many emission-line galaxies which show evidence of having had a recent episode of star formation is a small group of galaxies whose spectra are characterized by a feature identified as arising in a large population of Wolf-Rayet stars. The implication is that these stars result from an intense yet short-lived burst of star formation that occurred within the last ten million years. The burst of star formation was perhaps triggered by the interaction between two galaxies, leading to the optically complex object which is now seen.

To develop this thesis further, it is of importance to make a census of the interstellar material remaining after the episode of star formation. This will enable an estimate of the star-forming efficiency to be made. In addition, maps of the distribution of such material may show direct evidence that a merging of two galaxies has taken place. For example, some merger theories predict that there will be plumes or streamers of gas torn from the interacting systems.

During the next year studies of two objects (He2-10 and NGC 3125) will be completed. The recent VLA observations of He2-10 in which neutral hydrogen was detected will be reduced and the distribution of hydrogen will be mapped. The 12-meter will be used to confirm a tentative detection of CO in this object as well as to measure the total mass of CO and by inference, the total molecular gas content. An attempt will be made to detect CO and hydrogen in NGC 3125.

How does interaction affect nuclear activity? A representative sample of galaxies with double nuclei will be mapped at the VLA. These maps will be compared with an extensive spectroscopic and photometric set of observations of these galaxies to gain insight into this question.

The HI and CO distributions in several Seyfert galaxies have been mapped. These interesting results detail neutral gas distributions in the disks but have no discernible relationship to the Seyfert phenomenon. The most important result concerns the large-scale disk structure of NGC 1068, whose rings are clearly seen to be spiral arms winding out from the bright central bar. These results will be interpreted and published in the coming year.

Pilot observations for a large-scale CO survey of M31 using a novel observational technique have been obtained, and analysis and interpretation will continue. Global parameters of the molecular gas in that large nearby spiral will be obtained.

The linear polarization and Faraday rotation of the central radio source in M31 will be studied. This is a part of a larger study of resolved sources and outflowing synchrotron-emitting plasma which dominates radio emission from them.

Numerous studies are devoted to mapping thermal radio emission or hydrogen in normal galaxies, such as M51. A detailed comparison of the distribution of ionized and neutral material has led to increased understanding of the role of the spiral shock in star formation and the history of dense clouds in galaxies. In some galaxies, such as the very active nearby galaxy NGC 253, recombination line emission from ionized gas, particularly in the turbulent nuclear region, can be mapped. Multifrequency maps will provide key data on the kinematics and physical condition in this gas and in the plume which has been found emanating from the nucleus.

One surprising result of the study of neutral hydrogen in M31 has been the recognition that the maximum observed brightness temperature of HI in emission, while fairly uniform within individual galaxies, varies dramatically between different galaxies. Thus, while our own Galaxy is observed to have peak brightness temperatures of about 135 K, M33 has peaks of only 95 K and M31 has peaks in excess of 200 K, all measured with the same physical resolution. It seems likely that this quantity is indicative of some general condition of the galaxy's ISM. Current models for the heating and cooling of the ISM predict stable phases at 10^4 K and along a line from some tens to hundreds Kelvin, depending primarily on the overall ISM pressure. It may be that the peak HI brightness offers fairly direct access to this important global quantity. To explore this possibility, a study has begun of ten of the nearest galaxies using the VLA in A/B, B, and D configurations to obtain 5" resolution in HI corresponding to 50 pc at a distance of 2 Mpc. The sample contains a wide range of Hubble galaxy types, which are well-suited to optical follow-up work. This study should make clear what the range of HI properties at high physical resolution are, and how they are related to the galaxy type.

Radio Galaxies and Quasars

The study of B3 classical double radio sources in the radio and optical will continue. This study will attempt to extend the knowledge gained from the extensive studies of the 3CR sample to lower flux density levels. In the radio, mapping of the sample will be extended to 8 GHz in order to confirm the structural types of the sample and to detect the central components. Using the central component positions more optical identifications will be made employing deep CCD images from Lowell Observatory and KPNO. The long-range goal of the project is to test whether the correlation of radio structure with absolute radio and optical luminosity holds at high redshift and whether the redshift cutoff around $z = 2$-3 holds for these fainter sources.

Studies of radio variability of extragalactic objects, particularly BL Lac objects and quasars, continues, on time scales ranging from minutes to years using the VLA, 140-foot, 300-foot, and 100-meter telescopes. Present emphasis includes both very short (minutes to hours) and very long (greater than five years) times scales.

In the interesting source Fornax A, depolarization data at 1.5 GHz suggests the presence of dense material in front of the radio lobes, well outside of the galaxy. These clouds are suspected of being the remains of the infall of galaxies cannibalized by the host galaxy NGC 1316. Recently, optical observations were obtained of these remains in hydrogen lines; however, no optical emission was detected from them.

A detailed interpretation of the glorious radio galaxy Cygnus A should be complete late this year. Strong evidence has been found for bow shocks surrounding one of the hotspots in this source. This observation lends strong evidence to the current models of radio source structure which involve propagation of supersonic beams through the radio lobes. These beams then impact the undisturbed intergalactic medium at the observed hotspots.

The radio galaxy NGC 326 has been mapped at four frequencies between 1.5 and 15 GHz, and the final stages of analysis of the total intensity and linear-polarized intensity distribution have begun. Several symmetries in the maps indicate the importance of precession of the nuclear source, buoyancy, and ram pressure.

The study of M87 with the VLA continues. A new set of observations at 2 cm is planned in order to improve the limits on the proper motion of bright features in the jet. These observations should allow an improved accuracy on the velocity limits of the jet, narrowing them from 60,000 km/sec (0.2 c) down to 10,000 km/sec. Observations at 8 GHz are also planned in order to improve the resolution and sensitivity of the images of the filaments in the 2 kpc radio lobes. The velocity and density structure of Hα filaments in M87 will be further investigated using new observations at Kitt Peak National Observatory.

Certain observational signatures may be expected to indicate the presence of magnetized jets in large radio galaxies. The search for these signatures will continue. In particular, the radio galaxy PKS 0634-206 will be scrutinized to determine if the bright region terminating a dark tube locates the "chamber" of a magnetized jet.

In some radio galaxies the central engine may have been driven out of the nucleus by the action of the rocket effect. Candidates are being searched for examples of this phenomenon.

Several studies will center on detailed polarization maps. The distributions of spectral index, rotation measure, depolarization, and magnetic field will be mapped in a number of galaxies using five frequencies in the decade between 1.4 and 14 GHz. Particularly interesting jet and hot spot features have been noted in the well-resolved lobes of the double sources 3C 98, 3C 288 and 3C 353 which will be examined in the coming year. The B3 catalog imaging experiment mentioned above has also revealed several new "giant" radio galaxies similar to NGC 6251, with very extended structures which will be included in the study. In a sample of powerful extragalactic 3CR radio sources, statistics of jet, counterjet, hot spot, and lobe sidedness will be analyzed and interpreted. The goal of this study is to provide new constraints for relativistic jet models of the asymmetries in such powerful sources.

Images will be made of the structure of hotspots in about 10 very nearby classical double radio sources, with a linear resolution of 100-300 pc. These images should be sufficiently detailed that they can be meaningfully compared with the results of numerical simulations of jets, and with models of particle acceleration in hotspots, which make predictions about the spatial structure of the emission near shocks, and in particular predict differences between optical/IR and radio morphology. The project will be supplemented by optical, especially near-IR, imaging of the program sources.

The addition of the new VLBA antenna at Pie Town will bring new resolving power to the VLA. For example, using the Pietown antenna with the VLA at 8 GHz doubles the resolution of the VLA at that frequency and provides a resolution identical to that obtained with the VLA alone in the "A" configuration at 15 GHz. Hot spots in extragalactic double sources will be observed to provide data on spectral index distributions at the 0.1" level. Such data will help us understand the mechanisms of electron acceleration and energy loss in the neighborhood of the hot spots. This work will also explore joint VLA-VLBA imaging methods.

Jet features in the galaxy M84 will be measured in another joint VLA-VLBI experiment. A pronounced dust lane in this galaxy demonstrates that the jets lie in the plane of the sky. Hence, projection effects should not confuse the interpretation of measured velocities as they do for superluminal sources. VLBI observations will reveal parsec scale structure and motions while the VLA will measure motions on kiloparsec scales, such as those recently seen in 3C 120.

VLBI observations of 3C 120, made about three times per year over the past several years, have produced invaluable data on the motions of the superluminal components. Preliminary results show that new components appear about once per year and travel away from the core at about 2.5 milliarcseconds per year, an apparent speed about four times that of light. Continued monitoring will provide a unique opportunity to study the evolutionary history of many superluminal components in one source. With such abundant data, the character of each component can be established for comparison to other components, hopefully resulting in interesting constraints on the nature of the superluminal motion phenomenon. Analysis of this data will be completed in the coming year.

A series of VLBI observations of the N galaxy 3C 371 will be completed, including a new epoch of data. New data-analysis techniques will help us to model accurately the low-level emission from the milliarcsecond jet which underlies the bright knots and to determine whether there is real but non-classical motion associated with the jet. Such data may help uncover the basic nature of parsec-scale jets. Structural variations in the unusual active galaxy NGC 1275 will be monitored in a continuing long-term VLBI program. The complex source in the nucleus of this object exhibits one-sided core-jet structure typical of sources in which apparent superluminal motions are observed, but in this relatively nearby galaxy features moving subluminally have been detected. These two circumstances are inconsistent with the standard "unified model" in which one-sided structure and superluminal motion are both consequences of bulk relativistic motion. In NGC 1275 there is an opportunity to study in some detail the physics of one-sided jet ejection and to test whether the standard model truly unifies the observed phenomena. Seven epochs of structural monitoring covering a decade are in hand, and a new observation set at 2.8 cm is well matched to the spectra of the several compact emission regions. The global array at this wavelength has developed sufficiently to permit truly excellent maps for the three most recent epochs. These excellent maps will allow simultaneous study of the core, the somewhat extended features in the jet, and the diffuse emission along the jet.

Finally, very accurate positions will be determined for a large number of unresolved extragalactic sources. The objective is to establish a precise inertial reference frame for the VLA.

Clusters of Galaxies

Developing a greater understanding of the cooling flow phenomenon in elliptical galaxies and clusters of galaxies is the focus of a major theoretical and observational effort. Nearly all clusters of galaxies for which good X-ray images exist show the presence of gas at $3\text{-}10 \times 10^7$ K whose mass is either comparable to or greater than the sum of the masses of the cluster galaxies. In many cases, the radiative cooling time is significantly less than a Hubble time in the central regions of the cluster (typically the inner 200 kpc). From X-ray observations, it is estimated that the rate at which the hot gas is evolving into cool gas, dM/dt, is 10-1000 solar masses per year. Individual elliptical galaxies not in rich clusters also contain hot gas and are a miniature version of the cluster cooling flows, with a few important differences. Both the ellipticals and the clusters are the subjects of parallel studies.

The greatest difficulty in this cooling flow picture is the eventual fate of the cooled gas. At estimated cooling rates, more than 10^{12} solar masses of gas should have cooled during a Hubble time in several relatively nearby clusters and 10^{10} solar masses in elliptical galaxies. Because this amount of gas is not apparent in either ionized or neutral form, it is suggested that the repository for the cooled gas is low mass stars and, in fact, some evidence for star formation exists. If stars form, the cooled gas must pass through a neutral stage and be visible through the 21 cm HI line, either in emission or absorption, and through CO line emission.

During the past year, HI was detected in the cooling flow elliptical NGC 4406, with the properties expected from theory in contrast to the HI in more ordinary galaxies. The HI was centrally peaked and extended but not rotationally supported. In another cooling flow elliptical, NGC 4472, CO was detected at a location away from the nucleus. In the coming year, a series of projects will be carried out to provide a better understanding of the connection between the cold gas and the cooling flows. VLA observations of NGC 4406 may shed some light on the unusual nature of the HI gas in this galaxy. A survey of HI in all known cooling flow ellipticals will also be carried out at Arecibo. Lastly, the CO distribution in NGC 4472 will be mapped using the IRAM telescope at Pico Veleta.

In cluster cooling flows, HI absorption was detected in two new cases, raising the total to three, and HI absorption was detected in one system, currently unique. Each object in which the HI was detected has an especially vigorous cooling flow, which would be in keeping with theoretical expectations. To investigate this trend further, a variety of clusters with both weak and strong cooling flows will be observed. In addition, the cluster with the unique HI emission line will be mapped at the VLA.

Theoretical activity has centered around understanding thermal instabilities, which is how the gas is believed to cool, and in searching for alternative cooling flow models in which a much smaller amount of cool gas is produced. This is motivated by there being one-tenth the amount of blue light expected if stars form at the nominal rate with a normal initial mass function. Although reheating of the cooling gas will reduce the net cooling rate, it was found that conductive cooling and reheating by galaxy motions would not lead to a generally viable alternative model. Perhaps bursts of star formation following periods of cooling can provide the necessary reheating process; this will be investigated in 1989. Such a model would lead to long periods in which dM/dt is small, along with brief periods when dM/dt, the star formation rate, and the associated supernova rate, are large. Existing data will be contrasted with the expected observational consequences of this model.

In nearby ($z = 0.06$) dense clusters of galaxies diffuse optical light may be detected, as indeed it already has in Abell 2029 in the R band. The program which led to this detection uses a tesselating technique in order to produce a mosaic of frames covering about a square degree, centered on the cluster. These difficult measurements must achieve a sensitivity of $3x10^{-4}$ of the night sky level, now accomplished.

Previous work has measured the decrement in the microwave background radiation, the Sunyaev Zel'dovich effect, toward a few dense clusters of galaxies. The measured decrements (at a level of -0.4 to -0.5 mK) show that these clusters are among the hottest known, with derived temperatures between 11 keV and 25 keV depending upon the value adopted for Hubble's constant. The small size of the Sunyaev-Zel'dovich effect has led to quite some controversy about its extent and reality since it was first discovered in 1972--observers have disagreed with each other and sometimes even with themselves. It therefore seems important to confirm these detections by repeating the experiment using a different technique and at a different frequency. The BIMA interferometer will be employed to measure the decrement at 3 mm toward three clusters. A tesselating technique will be used to recover the necessary short spacing information. It is not yet clear what will be the main limitations to this project.

Remarkable rotation measures and gradients in the rotation measures toward luminous galaxies embedded in clusters of galaxies have been published for 3C 405, and similar findings will be reported for 3C 295 and Hydra A in the coming year.

A very deep integration, involving 100 hours at 5 GHz on the VLA, has revealed sources as weak as 15 μJy at 6" resolution. This resolution is sufficiently good that optical identification of the sources may be made, using very deep images from the Palomar Four-

Shooter instrument. The density and other properties of these very weak sources will be determined.

At a redshift of $z = 3.3$, the 21 cm line of HI is shifted to 333 MHz. Efforts to detect proto-clusters of galaxies at this frequency will continue at the VLA. The key to success of this experiment is to locate sources of interference--several were removed and others were dealt with by modification of the data acquisition method and subsequent analysis. The sensitivity at this frequency has been pushed to better than 3 mJy/beam for spectral line channels of 200 kHz width. To achieve a 100 percent probability of locating one protocluster in the volume surveyed, six independent fields must be surveyed, requiring about 250 hours of observations in the D configuration. Because of the time requirements, this experiment will continue through the coming year.

C. Miscellaneous

A magnetohydrodynamic code for simulating jets in radio galaxies is under development. During the coming year the effects of gravity, angular momentum and poloidal magnetic fields will be incorporated into the code, and the results will be verified. Several key problems may be investigated with this code, such as the behavior of helically magnetized jets, the collimation of magnetized winds from disks, and the interaction of jets with the ambient medium, and cooling flows.

Techniques of radio astronomical imaging will be further developed. A recently developed technique in which the coherence function of scattered radiation is measured using a radio-interferometric array offers potential for high angular resolution imaging. By reconstructing the coherence function at the scattering screen, it is possible to determine the properties of the background object and hopefully to image it.

What are the optimal imaging algorithms for low-signal levels in the presence of an atmosphere which corrupts the phase of the incoming signal? This question has applications in both radio and optical interferometry. A solution is being investigated, based upon the concept of closure phase/bi-spectrum, which will have equal applicability in both fields. At the moment, the most promising approach seems to be based upon a deconvolution algorithm which treats the observed averaged bi-spectra as constraints.

APPENDIX B

SCIENTIFIC STAFF

(Does not include Research Associates or Visiting Appointments)

W. Batrla	GB	Interstellar masers; molecular clouds; star formation
J. M. Benson	CV	Extragalactic radio sources; VLBI image processing
R. C. Bignell	SO	Polarization and mapping of extragalactic radio sources; planetary nebulae; supernovae remnants
R. Braun	SO	Interstellar medium; supernova remnants; HII region complexes; nearby galaxies; data acquisition and analysis techniques
J. N. Bregman	CV	Theoretical astrophysics; interstellar medium; cooling flows; quasars
A. H. Bridle	CV	Extragalactic radio sources
R. L. Brown	CV	Theoretical astrophysics; interstellar medium; quasar absorption lines
B. G. Clark	SO	VLBA control; software development
J. J. Condon	CV	QSOs; normal galaxies; extragalactic radio sources
T. J. Cornwell	SO	Interferometry; image construction methods; the maximum entropy principle; spectral analysis; coherence theory
W. D. Cotton	CV	Extragalactic radio sources; interferometry, computational techniques for data analysis
P. C. Crane	SO	Normal galaxies; radio interferometry and aperture synthesis; radio frequency interference
L. R. D'Addario	CV	Theory of synthesis telescopes; superconducting electronics; millimeter wavelength receivers; radio astronomy from space

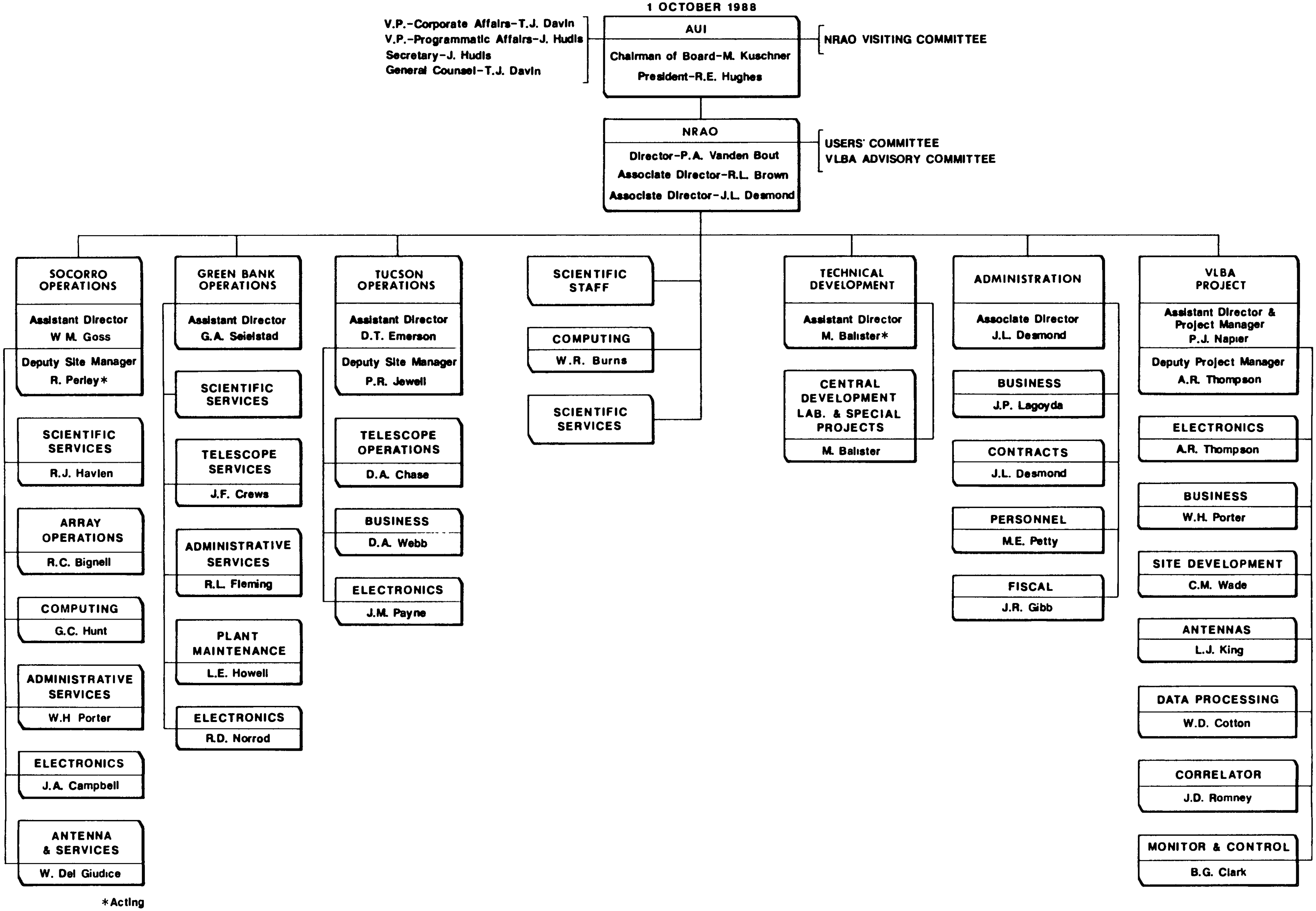
P. J. Diamond	CV	Spectral line interferometry; VLBI; software development
*R. D. Ekers	SO	Synthesis techniques; galactic center; radio continuum properties of normal galaxies; cosmology
D. T. Emerson	TU	Nearby galaxies; star formation regions; millimeter wave instrumentation
J. R. Fisher	GB	Cosmology; signal processing; antenna design
E. B. Fomalont	CV	Interferometry; extragalactic radio sources; relativity tests
F. D. Ghigo	GB	Interacting galaxies; extended structure of galaxies and QSOs
*M. A. Gordon	TU	CO; galactic structure; interstellar medium
E. W. Greisen	CV	Structure of the interstellar medium; computer analysis of astronomical data
W. M. Goss	SO	Galactic line studies; pulsars; nearby galaxies
R. J. Havlen	CV	Galactic structure; clusters of galaxies
D. S. Heeschen	CV	Variable radio sources; normal galaxies; QSOs
R. M. Hjellming	SO	Radio stars; theoretical astrophysics; VLA development
D. E. Hogg	TU	Radio stars and stellar winds; extragalactic radio sources
P. R. Jewell	TU	Circumstellar shells; interstellar molecules; cometary line emission
K. I. Kellermann	CV	Radio galaxies; quasars; VLBI
A. R. Kerr	CV	Millimeter wave development
H. S. Liszt	CV	Molecular lines; galactic structure
F. J. Lockman	CV	Galactic structure; interstellar medium; HII regions
R. J. Maddalena	GB	Molecular clouds; galactic structure; interstellar medium

F. N. Owen	SO	Clusters of galaxies; QSOs; radio stars
P. J. Napier	SO	VLBA development
J. M. Payne	TU	Telescope optics; millimeter-wave receivers; cryogenic systems
R. A. Perley	SO	Radio galaxies; QSOs; interferometer techniques
M. S. Roberts	CV	Properties and kinematics of galaxies
J. D. Romney	CV	Active extragalactic radio sources; VLBI; interferometer imaging
A. H. Rots	SO	Nearby galaxies; spectral line interferometry; data display techniques
G. A. Seielstad	GB	Quasars; active galaxies; VLBI
*R. A. Sramek	SO	Normal galaxies; quasars; astrometry
A. R. Thompson	CV	Interferometry; frequency coordination and atmospheric effects; distant extragalactic sources
B. E. Turner	CV	Galactic and extragalactic interstellar molecules; interstellar chemistry; galactic structure
J. M. Uson	SO	Clusters of galaxies; cosmology
P. A. Vanden Bout	CV	Interstellar medium; molecular clouds; star formation
J. H. van Gorkom	SO	Galactic center; nearby galaxies; clusters of galaxies; spectral line interferometry
C. M. Wade	SO	Astrometry; stellar radio emission; minor planets; extragalactic radio sources; VLBA development
R. C. Walker	SO	Extragalactic radio sources; VLBI; VLBA development
*S. Weinreb	CV	Millimeter wave development
D. C. Wells	CV	Digital imaging processing; extragalactic research

D. Westpfhal	GB	Pattern speeds of spirals and bars in disk galaxies; mass-to-light ratios in disks
A. H. Wootten	CV	Structure; spectroscopy and chemistry of the interstellar medium in galaxies; star formation; circumstellar material

* Sabbatical or Leave of Absence

NATIONAL RADIO ASTRONOMY OBSERVATORY ORGANIZATION CHART
1 OCTOBER 1988



APPENDIX D

NRAO COMMITTEES

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 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:

R. J. Allen (chairman)	University of Illinois
J. A. Baldwin	Cavendish Laboratory
A. Dalgarno	Harvard University
J. S. Gallagher	Lowell Observatory
M. H. Haynes	Cornell University
K. J. Johnston	Naval Research Laboratory
R. M. Price	University of New Mexico
A.C.S. Readhead	California Inst. of Technology

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.

The present membership is:

W. A. Baan	Arecibo Observatory
J. Bally	AT&T Bell Laboratories
T. M. Bania	Boston University
J. A. Bookbinder	JILA/University of Colorado
J. O. Burns	University of New Mexico
F. O. Clark	University of Kentucky
B. K. Dennison	VPI & SU
I. de Pater	University of California
P. E. Dewdney	Dominion Radio Astrophysical Obs.
J. W. Dreher	Massachusetts Inst. of Technology
S. T. Gottesman	University of Florida
P. C. Gregory	University of British Columbia
M. P. Haynes	Cornell University
L. A. Higgs	Dominion Radio Astrophysical Obs.
P. T. P. Ho	Harvard College Observatory
J. M. Hollis	Goddard Space Flight Center
G. J. Hurford	California Institute of Technology
S. Kulkarni	California Institute of Technology
M. L. Kutner	Rensselaer Polytechnic Institute
R. N. Martin	University of Arizona
G. K. Miley	Space Telescope Science Institute
R. L. Mutel	University of Iowa

D. B. Sanders	California Institute of Technology
S. M. Simkin	Michigan State University
R. S. Simon	Naval Research Lab
D. R. Stinebring	Princeton University
J. S. Ulvestad	Jet Propulsion Laboratory

VLBA Advisory Committee

The VLBA Advisory Committee will periodically review the status and progress of the VLBA. Its particular concern is with the broad elements of the Project and especially those that directly influence the scientific capabilities and performance characteristics of the instrument. It will advise on broad aspects of design, scientific emphasis, and priorities as well as on general progress, to assist the Director and the Project staff in assuring that the scientific and technical specifications are met and that the VLBA will be as responsive to the needs of radio astronomy as is possible.

The Committee is appointed by the Director. It is composed of scientists and specialists whose interests encompass all areas of radio astronomy and technology of concern to the VLBA. An attempt is also made to maintain in the membership reasonable geographic distribution and representation of the major radio astronomy centers and foreign VLBA projects. The Committee generally meets annually, but the exact meeting frequency will depend on the nature of current project activities and the rate of progress.

The current membership of the Committee is:

D. C. Backer	California, Berkeley

R. S. Booth	Onsala Space Observatory
B. F. Burke	Massachusetts Institute of Technology
Y. Chikada	Nobeyama Radio Observatory
R. D. Ekers	Australia Telescope
D. Fort	California Institute of Technology
K. J. Johnston	Naval Research Lab
R. Porcas	Max-Planck-Institut fur Radioastronomie
M. J. Reid	Center for Astrophysics