NATIONAL RADIO ASTRONOMY OBSERVATORY

PROGRAM PLAN 1985

N A T I O N A L R A D I O A S T R O N O M Y O B S E R V A T O R Y

CALENDAR YEAR 1985 PROGRAM PLAN

NATIONAL RADIO ASTRONOMY OBSERVATORY

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I. INTRODUCTION

NATIONAL RADIO ASTRONOMY OBSERVATORY

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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 data processing.

The four major telescope systems operated by the NRAO are: the 27-element Very Large Array telescope (VLA) located on the Plains of San Augustin, near Socorro, New Mexico, the 12-m millimeter wavelength telescope on Kitt Peak, Arizona, and the 140-ft telescope, and the 300-ft meridian transit telescope in Green Bank, West Virginia.

All telescopes continue to receive requests for more observing time than is available for allocation. In part, this is due to an expanding base of users in the astronomical community, where more than just the "traditional radio astronomer" is demanding radio wavelength data to complement a larger multiwavelength database to attack increasingly sophisticated astrophysical problems. Equally stimulating to the growing demand for observing time is the NRAO policy of continually exploiting new technologies as they are available and translating them to practical working receivers and operating systems. New receiver developments and operating system retrofits continually improve the observing potential of all of the telescopes. The resultant demand for telescope time by the NRAO user community speaks for itself as the number of active users has doubled since 1980 and increased by more than a factor of three in the

past decade. Section II of this Program Plan summarizes the research that visiting investigators are planning to undertake with the NRAO telescopes during 1985. More than 70% of the available observing time will be used for this purpose.

Section III of the Plan describes the continuing research instrumentation developments which will take place at the Observatory during 1985. 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 acquisiton and analysis process. Highlights of the 1985 NRAO effort in these areas will include continuing development of millimeter-wave receivers in order to better exploit the new 12-m telescope surface, the continued expansion of the VLA to new, low-frequency domains, and the development of an extremely versatile and efficient spectral processor for the 300-ft. Especially advantageous upgrades to VLA computing systems, both synchronous and asynchronous, are also planned in order to fully utilize the enormous capabilities of the instrument. In 1985, computer expenditures will reflect the implementation of the NRAO integrated computer plan for the following five-year period.

Subsequent sections give the detail of the expenditures required for operations and maintenance of the Observatory and their breakdown according to geographic cost centers.

Appendices to this Plan include a summary of the scientific program 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 associated with the NRAO, and the 1985 VLBA Program Plan.

II. SCIENTIFIC PROGRAM

II. SCIENTIFIC PROGRAM

A wide variety of scientific programs will be carried out with the NRAO telescopes during 1985. Each program individually has specific goals and requirements which depend in a complicated way upon the availability of instrumentation and the results of prior observations and those underway at NRAO or other observatories world-wide. Although it is impossible to currently specify or anticipate the details of the majority of the 1985 proposals yet to be submitted, the existing proposal backlog represents a general sample of the current areas of scientific interest that will be under investigation at the NRAO in 1985. The following summary, by telescope, illustrates the science that will be accomplished during the year.

The VLA - The demand for VLA time continues unabated as the instrument makes forefront observations at a rapid pace. Recent technical improvements have increased the observing efficiency and at the same time expanded the areas of its potential application. The availability of more spectral-line channels, the doubling of the number of available I.F. bands, and the increased 2-cm sensitivity have all greatly impacted the versatility of the most productive of the NRAO instruments. The VLA has experienced a dramatic increase in the number of proposal submissions and yet the high through-put has meant that only a small fraction do not receive some observing time. Although this increased speed has been somewhat of a burden on the data-processing capabilities of the instrument, more efficient data-handling procedures have been invoked where possible. Remote observing via data link to the asynchronous computer and absentee observing, where the VLA staff edits and

calibrates the data, have been operating successfully and have slowly increased in popularity as more astronomers become familiar with the VLA system. Additionally, longer-term solutions for processing the enormous flow of data through the VLA are being investigated.

For objects within the solar system, the VLA has proven to be a powerful addition to coordinated multiwavelength studies involving other ground-based and satellite observatories. For the sun a complete understanding of the physics of the solar atmosphere is critically dependent on the analysis of transient events. Simultaneous VLA and balloon observations of solar hard x-ray microbursts will be attempted and observations of solar magnetic structures have been proposed for coordinated studies with Spacelab 2. Other coordinated solar studies where simultaneous multiwavelength data is essential will concentrate on the inner corona.

Proposed planetary studies include observations of the emissivity of several of the minor planets as well as of the surfaces of Mars and Venus. Observations of the major asteroids have the potential of determining properties of their regoliths while data from Venus would corroborate radar studies of the surface composition and extend the surface map coverage of the planet. The VLA will also participate in the International Halley Watch campaign in coordination with many observatories world-wide.

The VLA continues to be an extremely powerful new tool for researchers interested in stellar astronomy. The proper motion of several pulsars will be astrometrically measured to confirm the high radial velocities implied by scintillation studies, thereby determining their

space velocities and potentially constraining their evolutionary histories. An extensive survey of very compact planetary nebulae aims to learn more about the mass-radius relationship which can lead to an improved distance scale and thereby information on the galactic distribution of old stars and their death rate in the Galaxy. Radio recombination-line studies of planetaries, now facilitated by the improved sensitivity of the VLA, will provide heretofore unattainable statistics on the physical parameters of numerous planetaries. A search for protoplanetary nebulae among OH/IR candidate stars has been proposed that would confirm increasing evidence that the copious mass-loss phase seen in OH/IR stars immediately precedes the formation of planetary nebulae. Studies continue of the circumstellar environment of luminous early-type stars where the comparison of observations with model calculations can determine mass loss rates and the thermodynamics of the stellar wind. The surprising prevalance of nonthermal radio emission for some luminous stars will be thoroughly investigated in an attempt to understand both stellar wind emission objects as well as stars which exhibit only surface nonthermal emission. Improved statistics could reveal potentially important characteristics of the evolutionary state of the two types of stars. High-resolution studies of x-ray stars, such as Sco X-1, Cyg X-1, and Cyg X-3, will continue to follow their suspected radio periodicities and morphological changes. Simultaneous x-ray, UV, and VLA observations of selected flaring RS CVn binaries have been proposed as a powerful diagnostic of the currently favored models for coherent maser emission in these objects. These and many other proposed studies of non-traditional stellar radio sources, such as

peculiar B stars, cool giant stars, Algol binaries, and T Tauri stars, have given great impetus to the use of the VLA as a major new tool to provide the spectral information and occasional morphological clues necessary to understand the physics and evolutionary status of these stellar sources.

High-resolution, VLA observations have proven invaluable for detailed morphological studies of molecular cloud star-formation regions in the Galaxy. Bipolar outflows represent an unusual and previously unsuspected stage of star formation where proposed VLA observations could significantly improve our understanding of the physical mechanisms which power the flows. Multifrequency continuum observations of the prototype source, L1551, are planned to study the radial dependence of the flow collimation. OH spectral-line observations of this source and others will be attempted as a sensitive probe of the physics of the flow region, including details of the strength and orientation of the magnetic field. Additional collimated flows will be sought toward regions containing Herbig-Haro knots similar to the L1551 region. The VLA will also further probe the physics of compact HII regions, such as G10.6-04, where 2-cm H_2CO observations which suggest the existence of a rotating massive disk will be followed up. In the Orion Molecular Cloud previously unknown, deeply imbedded, compact HII regions are expected to be found near newly discovered strong sources of ammonia emission. A survey of several compact HII regions has been proposed to test the circumstantial evidence for the association of "cometary" HII regions around newly formed O stars and nearby supernova remnants.

Other, important galactic sources that will receive concentrated attention include nearby supernova remnants and particularly enigmatic sources near the galactic center. Secular changes in the structure and emission characteristics of the young SNR Cas A will be monitored by direct comparison with high-resolution VLA maps of the complex extended source made in 1983. The observations hope to distinguish between the evolution of the energy spectrum of relativistic electrons and thereby test the widespread belief that some particular acceleration mechanism is operating throughout the nebula at the present epoch. An astrometric investigation of the proper motion of the galactic center source Sgr A will continue in an attempt to place limits on the mass of the object. If Sgr A is a massive object accreting stellar debris in the gravitational center of the galaxy, it should appear at rest in contrast to the space motion expected if it were a stellar object traversing the region and radiating as a consequence of relativistic outflow. Follow-up observations of the continuum near the galactic center will be made to enhance the resolution of the unexpected filamentary radio structure seen in the region. The implications of the extended features on our understanding of the magnetic field environment and the dynamics of the region are not clear. Other, similar features apparently associated with Sgr C, over one-half degree away from Sgr A, will also be studied in order to investigate the positional uniqueness of the Sgr A features at the center of the Milky Way.

Extragalactic research with the VLA will continue to include the detailed study of previously known powerful radio sources as well as the investigation of the spectral and morphological characteristics of

numerous classes of less powerful galaxies. Radio galaxies will come under increasing scrutiny as investigators attempt to learn more about the physical mechanisms that power, direct, and collimate the energy flows that extend from their nuclear regions to the extended radio lobes. For the nearby radio galaxy M87, precise multi-epoch positional measurements have been proposed which could potentially determine the velocities of knots in the jet. The very high dynamic range observations of both jet and lobes will also enhance the visibility of features that are only poorly seen in current maps. High-quality images, spectral gradients, and polarizations will supply critical tests for models of the source. Very high spatial resolution observations are also planned for the hotspot regions in the extended lobes of a few nearby sources. Direct comparison with the parameters of the Cyg A hotspots will test the universality of the phenomenon and its interpretation as shock compression at the termination of the jet. Continued VLA studies of the radio jet and tail distortions of cluster radio galaxies will be used to probe the dynamics of radio source-intracluster medium interactions. Radio source morphologies in a sample of interacting or very close binary galaxies in poor clusters will be examined in an attempt to discriminate between thermal and nonthermal emission mechanisms.

The high angular resolution and sensitivity of the VLA will be required to study low-luminosity features that have been discovered in the nuclear regions of several nearby, bright spiral galaxies. In M51, for example, existing evidence suggests that the energetics of the two nuclear bubble-like features may be up to a thousand times greater than those of galactic supernova remnants. It is hoped that further

observations detailing their formation mechanism may have implications for the understanding of the narrow emission-line regions in more distant and powerful Seyfert galaxies, radio galaxies, and quasars. A sample of edge-on, nearby spiral galaxies will be searched to determine whether the curious "vertical" morphology (perpendicular to the galactic plane) of the continuum arc of our own galactic nucleus is a common phenomenon, and if so, how it correlates with the characteristics of galaxies such as nuclear gas content or morphological class. A program to study the detailed HI properties of a number of dwarf, irregular galaxies has been proposed in order to obtain morphologies, rotation curves, and mass-to-light ratios. Several studies of galaxies found by IRAS to be strong infrared emitters will be carried out. The radio, optical, and infrared fluxes, spectra, and morphologies are needed in order to determine the responsible emission mechanisms.

The extension of a distance-limited survey of Seyfert galaxies has been proposed in order to improve the statistical analysis of differences in optical and radio orientations and to better test a ram pressure bending model for jet morphologies in spiral galaxies. The study also hopes to improve the distinction between Seyfert galaxies and starburst galaxies by investigating the incidence of circumnuclear starburst characteristics in the sample galaxies. Observations of a sample of nearby starburst galaxies will be otained to supplement ongoing CO observations which hope to differentiate proposed thermal and nonthermal emission mechanisms in these active nuclei. A small number of starburst galaxies will be monitored for the appearance of new compact radio sources which indicate the presence of frequent radio supernova and thereby prove a crucial test of the starburst hypothesis.

Numerous surveys of differently selected samples of quasars are planned. The extended emission around a large sample of core-dominated quasars will be mapped. In an attempt to test the validity of relativistic beaming schemes that make use of the same fundamental models to explain the occurrence of both core-dominated and lobe-dominated quasars, sensitive, high-resolution maps of a few compact, high-redshift quasars will be compared with maps of their less extreme low-redshift counterparts to investigate the possibility that their structures may be constrained by the interstellar medium of their parent galaxies at earlier epochs. A large sample of radio-selected quasar candidates will be studied in order to obtain radio morphologies of quasars that are much fainter than those quasars selected from strong radio-source catalogues. The sample will considerably expand the previous investigations of the luminosities, spectral properties and morphologies of samples of optically selected quasars. An extensive search for new gravitational lens candidates has been suggestd which will provide additional tools for the study of the distribution of dark matter in galaxies and clusters.

The 12-m Telescope - At the NRAO millimeter-wave facility improved telescope pointing stability and the increased aperture efficiency of the new surface have added a new outlook to the research impact of the instrument. The successful, new, 1-mm coherent receiver provides the needed capability to make spectral-line observations in the 195-270 GHz frequency range during periods of excellent atmospheric transparency. Demand for telescope time is very high for both the 1-mm and 3-mm receivers. Capability at 2 mm has been temporarily curtailed while the receiver is being rebuilt.

Of major interest to numerous users of the 12-m telescope will be extragalactic observations at the higher resolutions allowed by the 1-mm receiver. Observations of extragalacatic molecular clouds in the J = 2-1 line of CO are expected to reveal much about the physical parameters of star-formation regions in a variety of galaxy classes. For three nearby spirals, CO observations will investigate the availability and possible inflow of molecular material to supply fuel for existing bursts of star formation at the nuclear cores of the galaxies. A sample of dwarf galaxies will be explored in order to test the effects of star-formation rate on CO emission and destruction. Ongoing investigations of the classical spirals M31, M33, and M51 seek to compare the giant molecular cloud environment with that of the Galaxy and should significantly constrain theories of cloud formation.

The chemistry of the interstellar and circumstellar media will also be the subject of several planned molecular-line observations. Comparative measurements of the spectral-line characteristics of the species SiO, SiS, and CN throughout the envelope of IRC+10216 will investigate the excitation and chemical structure of the envelope. An intercomparison of TMC1 and IRC+10216, both similarly rich in long-chain, carbon molecules, will determine why methyl group substitutions are more prevalent in TMC1 and what the implications are for interstellar chemistry. Additional circumstellar shell regions will be surveyed for their degree of Si depletion and to determine the systematic variation of CO mass loss with dust mass loss.

Also continuing as a dominant subject of study in the Galaxy are the molecular, bipolar outflows found in young, star-forming regions. It is

hoped that the higher spatial resolution observations of CO (2→1) lines will provide additional physical insight into the collimation mechanisms involved and into the prevalence and morphology of the suspected dense molecular disks from which the flows emanate.

The 140-ft Telescope - Many of the programs planned for 1985 will be taking advantage of the proven capability of new, sensitive receivers to detect faint spectral features within reasonable integration times. In particular, the 5-26 GHz upconverter maser receiver will be heavily in demand for continued searches for and studies of new molecular species in the interstellar environment. Several investigations hope to add to the known inventory of long, carbon-chain molecules in the interstellar medium and to study their intermediate reaction products under conditions which are not adequately reproducible on earth. Understanding the chemistry of the ISM should improve our view of how molecules interact. A search for silicon-containing molecular species has been proposed in order to test the theory that grain mantles are the source of the known silicon-bearing molecules, SiO and SiS.

Sensitive molecular-line observations will sample the physical conditions of star-formation regions in the Galaxy and in external galaxies. OH intensity and polarization measurements of bipolar outflow regions will test cooling conditions in the flows. An H_2O maser emission survey of external galaxies with star-formation characteristics will attempt to find masers that are much more powerful than the typical masers found in our own Galaxy. Newly detected, high latitude, molecular clouds will be observed in HI and OH to intercompare their relative molecular abundances with the results of previous CO observations and to

evaluate the feasibility of future Zeeman splitting observations of magnetic fields in their filamentary structures.

Extragalactic HI observations of a sample of active galaxies have been proposed which will more fully specify their HI masses, spin temperatures, and kinematic environment. Understanding the properties of the neutral gas, which is the fuel supply for the central engine, may shed light on the nature of the nuclear activity of these galaxies and possibly on the nature of such activity in the more powerful quasars. An HI survey of dwarf galaxies will be extended to the southern limit of the telescope. The complete body of redshift data thus assembled will permit a thorough study of the local velocity field and the local, mean matter density as well as the clustering properties of dwarf galaxies and their morphological differences within clusters versus the general field.

Experiments dealing with the large-scale properties of the universe and its early evolutionary history continue to challenge the limits of the 140-ft system. A new, sensitive search for interstellar deuterium will provide a more sensitive measure of the role played by baryons in constraining the expansion of the universe. The search for anisotropy of the microwave background radiation will be carried to more sensitive limits than previously attainable. Finally, an attempt will be made to confirm the attenuation of the background radiation toward clusters of galaxies in order to learn more about the intracluster gas and to make a model-independent test of the value of Hubble's constant.

The 140-ft telescope will continue to participate heavily in VLBI experiments, partly in coordination with other VLBI Network antennas, partly with European VLB stations, and partly in independent VLB

experiments. VLB extragalactic programs will focus on the smallest size-scale features in quasars and the nuclei of galaxies in order to understand the mechanisms of energy generation and transport in these sources. A subset of these programs will continue to monitor superluminal sources. Within the Galaxy, VLB experiments will probe regions of maser activity in circumstellar shells and star-formation regions for direct dynamical clues to the evolution of these objects. VLB experiments for terrestrial applications, including precision geodesy, crustal dynamics and polar-motion studies, will also continue.

The 300-ft Telescope - Even taking into consideration the limitations imposed by its transit configuration, the 300-ft telescope is still one of the world's largest single dishes. Its enormous collecting area in combination with newly engineered, sensitive, receiver systems still places the instrument in high demand for specific survey and long-term variability studies for which it is ideally suited.

The telescope continues to serve as the work horse for pulsar survey programs outside of the declination ranges accessible from Arecibo. Newly discovered, suspected pulsars will have to be thoroughly checked before they are included in later statistical studies. The implications for theories of pulsar formation and evolution of the extremely sensitive survey will be significant if preliminary indications of a deficiency in low-luminosity pulsars holds up.

Variability programs will occupy a significant fraction of the observing time during 1985 as efforts intensify to improve the identification of and to delineate the characteristics of several classes of variable sources. The study of low-frequency variability which has

been carried out over several years has successfully identified distinct types of spectral behavior. In some sources high-frequency bursts propagate to lower frequencies with reduced amplitude. The features of the dynamic spectra could be explainable in terms of intrinsic changes in synchrotron opacity or refractive scintillations in the interstellar medium. Further monitoring will be required to detect additional spectral variations and to analyze their statistical occurrence in order to substantiate the theoretical interpretation. At a longer wavelength (9 cm), a systematic variability study will be extended to include time scales ranging up to six years in length. The apparent differences in time scale and amplitude seen over a range of optical classes and spectral criteria could be valuable diagnostics of the evolutionary processes at work in these sources.

Invaluable HI observations of a sample of galaxies between the Local supercluster and the Hydra/Centaurus supercluster will yield accurate radial velocities and global parameters of the individual galaxies and will initiate a study of the probable link between the two groups. Confirmation of the cell-like, large-scale structure of the universe where filamentary bridges connect superclusters is anticipated. Other, similar observations will trace the extent of nearby superclusters and also determine the HI characteristics of specific x-ray clusters in order to intercompare the properties of cluster galaxies and the intergalactic medium.

III. RESEARCH INSTRUMENTS

Four major telescope systems form the core of the primary research instrumentation at the National Radio Astronomy Observatory: (1) the 140-ft telescope; (2) the 300-ft telescope; (3) the 12-m telescope; and (4) the Very Large Array (VLA). The commitment of NRAO to its user community and its obligation to operate first-rate observing instruments have provided for continuous evaluation of these systems as measured by the scientific needs of the radio astronomical community. Significant performance improvements have come about for each of these instruments following recommended physical modifications and/or upgrades which have primarily reflected technological advances since the era when these telescopes were conceived, designed, and constructed. Reevaluations in this area have resulted in such changes as: telescope resurfacing to improve higher frequency response, improvements in pointing control and stability, modifications to feed designs, and upgrades to the control and data acquisiton computers.

An NRAO research and development program in electronic and computer hardware is maintained at each observing site as well as in 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. Technological advances and a commitment to forefront radio astronomical capability are the driving forces behind these efforts.

In this way the NRAO maintains the flexibility to respond to scientific innovations and new astronomical discoveries that are made in

wavebands outside of the radio regime. Auxiliary instrumentation in the form of new or modified receivers, spectrometers, correlators, refrigeration systems, etc., are some of the major products of the NRAO electronic research effort. Major computer systems which are critical to the off-line analysis of astronomical data, the correlation of VLBI observations and image processing of aperture synthesis observations are an integral part of the data collection and analysis chain, and are also budgeted in the Research Equipment account.

The NRAO strives to maintain as much flexibility as possible within this general area of the program because of the rapid and unpredictable changes in "state-of-the-art" electronics and computer hardware and unforseen short-notice requirements of the scientific community. The following table shows the planned distribution of funds for the "Research Equipment" account as currently dictated by limited available monies and established scientific priorities in each of the NRAO operating areas. The NRAO continually updates this table as scientific priorities change.

Following the table is a brief discussion of the projects which will receive the highest priority consideration during 1985. The project justifications and descriptions refer to items to be purchased or work to be done over the course of several years and do not reflect the 1985 budgeted monies alone. Many of the projects which were already begun in 1984 will still not be completed in 1985. Within the limited 1985 Research Equipment funds, no new development is foreseen in 1985.

Research Equipment (in thousands of dollars)

	1984 Plan	1985 Plan	Estimated $Need to Complete	Estimated Completion Date
1. General Laboratory and Test	$ 300	$200	$ 325/yr	Ongoing
2. 140-ft Telescope				
New Receivers	35	-	-	-
Subreflector	30	-	-	-
Lateral Focus	20	-	-	-
3. 300-ft Telescope				
7-feed 5-GHz Receiver	40	20	30	1986
Spectral Processor	80	50	135	1986
Control Computer Upgrade	30	-	100	1986
Lateral Focus	25	-	-	
4. 12-m Telescope				
Millimeter Device Development	90	50	100/yr	Ongoing
New Receivers	60	20	130	1987
Control Computer Upgrade	150	-	70	1986
Hybrid Correlator	10	-	80	1986
5. VLA Electronics				
300 MHz Receivers	70	30	30	1986
Antenna Pointing Improvement	15	25	-	1985
Modules	60	-	30/yr	Ongoing
Water Vapor Receivers	60	40	50	1986
75 MHz Array	10		1000	1990
44 GHz Receiver	15	-	-	
6. VLA Computing				
Synchronous Computer	82	200	150	1986
Pipeline	20	25	381	1987
Phased Array Processor	65	-	-	
AIPS	145	15	545	1986
7. Other				
Miscellaneous	210	50	60/yr	Ongoing
Total	$1,622	$725		

GENERAL LABORATORY AND TEST EQUIPMENT

Description

Many small electronics and computer projects too numerous to itemize are continually in progress at each of the four NRAO geographic locations. Although the budget for each project is generally considerably less than $20 k, collectively the projects are vital to the ability of the Observatory to respond to the changing technological environment. Ongoing electronics research projects deal primarily with the application of digital engineering, modifications to existing front-ends, developments in the cryogenic systems, telescope surface measurements, and improvements in interference detection and excision. At the VLA, electronics research efforts are directed to VLBI observing techniques and tests and improvements of the electronics subsystems. A wide diversity of critical test equipment, from oscilloscopes to network analyzers, is indispensible to carry out the above tasks.

7-FEED, 5-GHZ CONTINUUM RECEIVER FOR THE 300-FT TELESCOPE

Justification

The purpose of the 7-beam, 14-channel receiver is to make 6-cm maps of the entire sky visible from Green Bank. With this receiver, the 91-m telescope could cover the declination range 0° to 75° in 90 days, resolving the sky into 10^7 beam areas and detecting about 2×10^5 sources stronger than 10 mJy. Such a map would be a radio analog of the Palomar Sky Survey (in the form of contour maps plotted on the PSS scale, the beam would be a 2.7-mm diameter circle; and there would be over 300 sources on each 6°x6° "plate") to be used by any astronomer to make radio "identifications" or set upper limits to the flux densities of any class

of objects. Each map is also a historical record of the sky, so successive maps will reveal all variable sources. For example, the 42-m telescope could be used with this receiver to cover the entire galactic plane out to $|b| = 5°$, with an rms noise of 10 mJy in only one day.

Description

The proposed receiver consists of 7 dual-polarization feeds followed by 14 FET amplifiers, all mounted in a single dewar. The expected system temperature is 40 K; the bandwidth, 500 MHz.

SPECTRAL PROCESSOR FOR THE 300-FT TELESCOPE

Justification

The spectral processor is a combination spectrometer and signal processor, designed to replace the Mark III autocorrelator and the Nicolet signal averager at the 300-ft telescope. 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 in the autocorrelator. This allows spectral estimates contaminated by broadband or narrowband interference to be excluded from the accumulated spectrum. The spectral processor will also increase the available number of spectral channels, providing 2048 across 40 MHz as compared to 384 across 10 MHz in the Mark III autocorrelator. Secondly, the spectral processor will greatly improve data acquisition capabilities at the 300 ft. As a dedisperser, it will allow high time-resolution studies of average waveforms and single pulses, with full polarization information. Scintillation studies will be possible that employ a wide range of bandwidths, with spectral windows centered on different pulse components.

The spectral processor will also allow highly automated and accurate pulsar timing programs to be performed.

Description

The spectral processor is a pipelined, fast Fourier transform spectrometer, incorporating real-time interference excision and flexible time and frequency merging capabilities. As a spectrometer it will provide up to 1024 channels x 2 polarizations across a 20-MHz bandwidth, with the accumulation of up to eight independent spectra. As a pulsar processor, it will provide 256 channels x 4 polarizations across a 20-MHz bandwidth with full dedispersing capabilities. In either configuration the bandwidth can be reduced to 1/1024 of the maximum in binary steps. Maximum time-resolution will be 12.8 microseconds and interference excision will take place on intervals as short as this. The ability to display spectra and pulsar profiles in real-time will be provided as well as the capabilty of monitoring the interference excision process.

MILLIMETER-WAVE DEVICE DEVELOPMENT

Justification

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. This will be especially true when future millimeter-wavelength array observations are made. Current experience suggests that significant improvements are to be expected

using both cooled Schottky-barrier diodes and SIS junctions. At the longer millimeter wavelengths (~3 mm), recent improvements in SIS mixers, especially at Goddard Institute for Space Studies, have resulted in $T_{sys} \simeq 400$ K (SSB) in a full receiver.

Description

Millimeter-wave receiver design work will continue to make use of Schottky diodes supplied to NRAO under a subcontract with a group at the University of Virginia. Theoretical considerations and developmental work on SIS junctions hold the promise of eventually producing junctions and corresponding millimeter devices that are inherently superior to Schottky diode mixers at the shortest millimeter wavelengths. SIS junctions fabricated by NRAO at NBS have not matched in performance the junctions in use at Bell Labs. The current plan will therefore include the development of niobium SIS junctions at the University of Virginia. Niobium junctions should be more durable and require less refrigeration than those junctions currently in use.

NEW RECEIVERS FOR THE 12-M TELESCOPE

Justification

With the expanded capability of the resurfaced 12-m, millimeter-wave telescope, there is a need to improve and modernize some of the existing 1, 2, and 3-mm receivers. A number of technical developments potentially leading to substantially lower noise temperatures have occurred since the existing receivers were constructed. Observing pressure in these three atmospheric windows is expected to rise as researchers seek to take advantage of the increase in sensitivity at the 12-m telescope at the shortest wavelengths and improved pointing characteristics. Of

fundamental interest will be the study of the J = 2→1 line of molecular CO in a wide variety of objects, including circumstellar shells, regions of molecular outflow, and external galaxies where the increased spatial resolution is critical.

Description

The new 1-mm receiver will consist of a number of mixers, each in its own dewar, covering the range 200-345 GHz. This receiver will use an I.F. frequency of 1.5 GHz to make use of the new, cooled FET amplifiers developed by the NRAO Central Development Laboratory. The new 2-mm receiver will use similar technology. The new 3-mm receiver will cover the 3-mm atmospheric window in two separate ranges. A cooled Schottky mixer will cover the range 70-95 GHz. The frequency range 95-120 GHz, important for observations of CO in distant galaxies, will make use of an SIS mixer. These receivers will also make use of the new, L-band I.F. system.

300-MHz RECEIVERS FOR THE VLA

Justification

Observations of a large number of astronomical objects would benefit from a lower observing frequency than 1.35 GHz, the lowest frequency currently supported on the VLA. Giant radio galaxies and large galactic sources are specific classes of sources where low-frequency, spectral gradient information clearly is necessary to fully understand and model the source parameters and evolutionary characteristics.

Description

The receivers will be designed so that observations in the range 300-350 MHz can be made with an instantaneous bandwidth of approximately

5 MHz. At this low frequency, the VLA 25-m diameter antennas can only be used in prime focus mode. If the off-axis aberrations are not too large, it is expected that the feed can be permanently located at the end of the subreflector to minimize the time it takes to change to this frequency. It is known that radio-frequency interference, both locally generated at the VLA and from external sources, will be a significant problem.

VLA ANTENNA POINTING IMPROVEMENTS

Justification

When the VLA antennas are illuminated by the sun at a low-elevation angle, differential temperatures of up to 5° C have been observed across the antenna structure. Under these conditions the pedestal and yoke of the antenna can bend significantly and cause pointing errors of up to one arcminute. These are critical for observations in the 1.3-cm waveband where the potential shifts are comparable in size to the primary antenna beam width. Lesser pointing problems, with tilts up to 20 arcseconds, occur in the azimuth axis of a few antennas at certain azimuth angles, presumably caused by deformations or perturbations in the azimuth bearings.

Description

Thermal insulation is being added to the critical parts of each antenna as it comes in turn to the maintenance shed for its periodic inspection and overhaul. The reinsulation program will take until 1986 to complete for all 28 antennas. An active correction scheme, utilizing electronic tilt meters mounted on the antenna structure, is being investigated for potentially solving the azimuth bearing problem and the problem of antenna tilts caused by constant wind forces.

WATER-VAPOR RADIOMETERS AT THE VLA

Justification

The development of a system to measure the total precipitable water in a path through the atmosphere will serve three purposes. First, the radiometer developed in this project can be used as a prototype of the device which is required at each VLBA station. Second, the radiometer can be used at the VLA to provide estimates of the extinction, giving corrections for observations at 1.3 cm and serving as an historical record of the quality of the VLA site. Finally, if reliable systems can be built at sufficiently low cost, it would be attractive to add them to the VLA itself.

Description

The device will consist of two radiometers; one operating at about 20.5 GHz, the other at about 31 GHz. The radiometers will probably be built around room-temperature mixers, with system temperature of ~600 K. The system will be mounted so that it can cover the full range of elevation and probably the full range in azimuth as well. The concept is straightforward. The engineering effort will concentrate on the problem of achieving high-gain stability at a reasonable cost.

VLA SYNCHRONOUS COMPUTER UPGRADE

Justification

Most of the hardware in the VLA on-line system was purchased in 1974, and although the Modcomp computers should continue to be reliable, some peripherals are, or will soon become, obsolete. Increased maintenance and higher downtime will result. Bottlenecks in the two main computers of the system are caused by memory that is completely used up

or nearly full. Any additional demands for space will require very careful memory management or major redesigning of data storage algorithms. CPU capacity is insufficient to handle the additional displays required for array operation, and I/O bandwidth is lacking in the capacity necessary to allow the addition of faster devices. Additionally, the operating system is not optimal for efficient program development and debugging.

Description

Although there are several stop-gap measures that could be taken, none address all of the above problems and all represent substantial software and hardware effort. A single upgrade that has been proposed is the replacement of four of the current Modcomp computers (BOSS, MONTY, and CORA/CORBIN) by three new Modcomp Classic models and to obtain a fourth for software development and as a repository for spares. This recognizes the existing software investment in Modcomps and minimizes hardware development costs.

VLA PIPELINE COMPUTER MAPPING HARDWARE

Justification

The VLA Pipeline System generates maps from VLA observations with significantly more capacity than any of the other VLA computer systems. Its main objective is to provide the mapping through-put that is necessary to operate the VLA at full efficiency in the spectral-line mode. Although the system does not lack for computer capacity, its impact as a convenient tool for astronomers has been limited by its lack of interactive display devices. Visual inspection of the data in the map plane is necessary in order to provide effective quality control,

database reduction, limited map analysis, and production of hard copy. In the visibility plane, rapid display would promote effective editing and control of the data processing and be a useful diagnostic tool throughout the mapping procedure. Rapid response to the data stream and the ability to change mapping strategy will avoid potential slow downs and data overloads in the pipeline system.

Description

The Pipeline currently uses one I^2S TV-type interactive display system and a gray-scale, hard-copy device. At least one more image display system will be required in order to make the Pipeline truly a multi-user system. Other necessary hardware units include: an image storage device for storing 128, 512x512 maps with film loop playback capability, control panel, dot matrix printer, and Dicomed color image recording devices.

AIPS: ASTRONOMICAL IMAGE PROCESSING SYSTEM

Justification

The AIPS software package handles virtually all VLA postprocessing, both within the NRAO (on four systems) and in the university community (on approximately twenty systems). It is extensively supported by a full-time applications group at the NRAO whose clientele have recently included the VLBI community.

The evolving needs of aperture synthesis map processing have imposed increasing demands on AIPS for handling larger maps and spectral-line data. When added to the already large demand for disk space that this type of processing requires, several gigabytes of disk space for a heavily used system is not unusual. The current NRAO systems need

additional disk capacity to keep pace with increasing demand and system complexity.

The cost of a VAX-based AIPS system is prohibitively high for a small university department. While still preserving its scientific power, AIPS must be developed for use on less expensive hardware if its use is to continue expanding outside of the large astronomical centers.

Description

Additional disk capacity will be acquired and made available for the NRAO-supported large processing systems. Better inter-processor communications are planned which will more effectively share disk capacity between systems.

The NRAO will purchase a UNIX-based super-microprocessor (probably 68000-based) and array processor in order to develop a small AIPS system that is affordable by small university departments (approximately $150 k.) Software development and support is planned to the same extent that VAX-based software is supported on the more expensive systems.

OTHER PROJECTS

COOLED GaAs FET AMPLIFIER DEVELOPMENT

Justification

Cooled GaAs FET amplifiers are more reliable, stable, and have lower noise than parametric amplifiers. They have become widely used for centimeter wavelength observations because their improved characteristics allow for reduction in observing integration times as well as more reliable detections of weak signals and less cumbersome and unreliable calibration procedures. These amplifiers are also used as I.F.

amplifiers for millimeter-wave receivers and thereby improve the sensitivity of nearly all observations performed at the NRAO.

Description

Amplifiers have been designed at 1.5, 5.0, 10.7, and 15.0 GHz, and over 200 units have been constructed; the majority are already in use at observatories around the world. Future work will include designs at 0.3, 8.3, and 23.0 GHz. Investigations will also be directed at improving the FET device itself. The NRAO expects to participate contractually with another development laboratory to produce and test prototype High Electron Mobility Transistor (HEMT) devices which promise to significantly lower noise temperatures at elevated operating temperatures (~100 K).

IV. EQUIPMENT

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

Item	
1. Maintenance, Shop and Repair Equipment	$ 23.0
2. Office and Library Furnishings and Equipment	54.0
3. Living Quarters Furniture	2.0
4. Building Equipment	5.0
5. Scientific Services and Engineering Equipment	16.0
	$100.0

1. Maintenance, Shop, and Repair Equipment

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. Office and Library Furnishings and Equipment

These funds provide for replacement, updating and acquisition of communications equipment, typewriters, business data and text processing equipment, copying machines, and other major office furnishings.

3. Living Quarters Furnishings

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. Scientific Services and Engineering Equipment

These sums provide for small equipment additions in the darkroom, Public Education, and Engineering Divisions. Items such as cameras, film processing units, projectors, measuring equipment, etc., are included in this amount.

V. OPERATIONS AND MAINTENANCE

The activities at the NRAO group naturally into six operations units which reflect both the individual operations at its three observing sites and the integrated operations which encompass all four geographic locations. The geographic distribution of personnel in these six units is given in §VIII.

A. General and Administration

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 $185 k. Further major budget items, such as the rent and maintenance of the Charlottesville buildings, communications, and utilities, will require $480 k. The management fee paid to Associated Universities, Inc., will be $350 k.

B. Research Support

The NRAO scientific research staff, 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 calibre while at the same time assisting visiting astronomers in gaining familiarity with the NRAO instruments and facilities. Because they are at the forefront of research in their individual areas of expertise, they are an invaluable 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.

In 1985, the NRAO summer student program will continue in full force as a vital element in NRAO's commitment to the training of future radio astronomers.

The Research Support unit also includes the Charlottesville support persons who maintain the central library and the technical illustration and drafting services for the entire Observatory. In 1985, Material, Services and Supply (MS&S) budget of $133 k for this group 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 three major NRAO libraries.

Over 40% of the overall NRAO travel budget will be expended in the Research Support group ($270 k) primarily for travel by all staff and visitors from U.S.-based institutions to carry out observing programs at NRAO telescopes or to use Charlottesville's data analysis facilities. During 1985, $50 k is planned for foreign travel by the staff and $20 k is available for qualifying U.S. scientists who need travel support to observe at unique foreign telescopes.

C. Technical Support

Several groups providing Observatory-wide technical research and development support are concentrated in Charlottesville. Work at the Central Development Laboratory 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 VLBI techniques and correlator improvements. The Computer Division operates the NRAO IBM 4341 central

computer and the VLB MKII processor and assists in the development of programs for computers at the telescopes. A major responsibility of the Computer Division is the development and maintenance of an astronomical image processing capability, which is currently operating in Charlottesville and at the VLA as well as at a number of institutions world-wide. The Engineering Division provides engineering assistance for the design of new facilities and telescopes. During 1985, $440 k is budgeted for MS&S for the above three groups. The major portion of this sum ($285 k) will be used for computer rental and maintenance.

D. Green Bank Operations

The five divisions at Green Bank are responsible for maintaining and operating the 300-ft telescope, the 140-ft 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 and their 1985 budgets for MS&S are: Telescope Services ($168 k), Electronics ($175 k), Plant Maintenance ($128 k), Administrative Services ($105 k), and Scientific Services ($44 k). An additional $320 k will be spent on communications and utilities. It is also estimated that food services and housing will bring in revenues of about $112 k. The operation of the Green Bank interferometer for the USNO affects the Green Bank Operations budget as a credit of $680 k (see §VI).

E. Tucson Operations

Two divisions in Tucson are responsible for the maintenance and operation of the newly resurfaced 12-m millimeter wavelength telescope at

Kitt Peak. The Electronics Division will be devoting a major portion of their 1985 effort to packaging new receivers which will take full advantage of the improved short wavelength potential of the new surface. The Operations and Maintenance group handles all visiting astronomer logistics and observing support, which for 1985 will include continued software development for improved data acquisition. The two Tucson subgroups will require the following MS&S budgets for 1985: Operations and Maintenance ($238 k) and Electronics ($175 k). An additional $78 k is programmed for communications and utilities. Miscellaneous revenue will total about $14 k.

F. 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 VLA Scientific Services group will require a MS&S budget of $111 k. The Computer Division (including several Systems Scientists), Electronics Division, and Array Operations Division, which are most critical to the mechanical functioning and data collecting capabilities of the telescope, will require MS&S budgets of $419 k, $122 k, and $10 k, respectively. Other services related to the efficient functioning of the operation and their MS&S budgets are: Engineering and Services Division ($239 k), and Administative Services ($326 k). Communications, utilities, and building rent (in Socorro) will amount to $796 k, while miscellaneous revenue of $100 k is expected. Included in the above sums is $304 k for computer rent and maintenance, more than $600 k for electric power costs, a substantial increase over 1984, and the cost of visiting observer

transport from Albuquerque to the site. A significant part of the communications expenditures will be devoted to remote observing costs.

A summary of the CY 1985 budget for these operations units is provided in the following table:

CY 1985 Budget - Operation Units
($ thousands)

Operation Unit	Personnel Ceiling	Salaries, Wages & Benefits	Material, Supply, Service	Travel	Total
Operations					
A. General & Admr.	27	$ 1,003.0	$1,015.0	$ 83.0	$ 2,101.0
B. Research Support	42	1,818.0	133.0	363.0	2,314.0
C. Technical Support	38	1,667.0	440.0	68.0	2,175.0
D. Green Bank Operations	96	3,092.0	828.0	37.0	3,957.0
E. Tucson Operations	24	961.0	477.0	52.0	1,490.0
F. Socorro Operations	114	3,639.0	1,923.0	102.0	5,664.0
Total Operations	341	$12,180.0	$4,816.0	$705.0	$17,701.0
Design and Construction					
VLBA: January-March		$ 175.0	$ 99.0	$ 26.0	$ 300.0
April-December	52	1,493.0	7,292.0	215.0	9,000.0
Total Design and Construction	52	$ 1,668.0	$ 7,391.0	$241.0	$ 9,300.0
Total	393	$13,848.0	$12,207.0	$946.0	$27,001.0

Notes 1. Does not include commitments carried forward from 1984.
2. General and Administrative includes $350 k for management fee.
3. Green Bank Operations includes $680.2 k for USNO interferometer support.

VI. INTERFEROMETER OPERATIONS

The NRAO operates the Green Bank Interferometer for the U.S. Naval Observatory as part of USNO's fundamental astronomy program under a cost reimbursement arrangement between the NSF and the Naval Research Laboratory. During 1982/83 a 14.2-meter telescope was acquired by NRAO for the Interferometer system and was installed some 25 miles west of the Green Bank site and thus provided an east-west baseline link to the existing north-south baseline. Discussions are currently underway between NRAO and USNO regarding the replacement of the main Interferometer system computer at Green Bank during 1985. Should the NRAO undertake this work for USNO the total installation is expected to be in the neighborhood of $1,000,000. The funding status of the interferometer program is shown in the tables below.

Interferometer Financial Status @ 09/31/84

	Allocation thru 09/30/84	Est. Expended & Committed	Balance @ 09/30/84
Operations	$3,034,614	$2,976,288	$ 58,326
Construction	1,627,561	1,350,631	276,930
Total thru 09/30/84	$4,662,175	$4,326,919	$335,256

Interferometer Funding Plan 1985

	Funds Carried Over from 1984	1985 New Funds	Total Available for Commitment
Operations	$ 58,326	$ 680,200	$ 738,526
Construction	276,930	325,000	601,930
Total, 1985	$333,256	$1,005,200	$1,340,456

VII. DESIGN AND CONSTRUCTION

The Astronomy Survey Committee of the National Academy of Sciences ranked the Very Long Baseline Array as the highest priority for major, new ground-based instrumentation during the decade of the 1980s. In May 1982, the NRAO submitted a proposal to the NSF requesting financial support for the construction of a VLBA. Much preliminary design work has already been carried out by NRAO and other centers of VLBI activity, and the general array configuration has been specified. During 1985, the NRAO will continue to refine the design of the instrument with monies to be spent on design and protyping of the electronics system for receiving and recording of data and in the areas of telescope monitor and control, data correlation, and data processing. Monies will also be spent on antenna engineering, manufacture of the first antenna, and the completion of design specifications for site facilities and the Array Operations Center. The planned activities for 1985 are outlined in more detail in Appendix E.

VIII. PERSONNEL

The following table compares the Personnel Services and Benefits (level = full time at December 31) at the Observatory according to employment classification for 1984 and 1985.

Category	1984			1985		
		($ thousands)				
	Est. Level	Salaries	Benefits	Est. Level	Salaries	Benefits
Operations*						
Scientific and Engineering	108	$3,675.6	$ 870.0	105	$ 3,981.6	$ 956.9
Technical	117	2,635.6	623.8	116	2,777.8	667.6
Administrative and Clerical	68	2,005.1	474.6	69	2,088.8	502.0
Operations and Maintenance	51	938.3	222.1	51	971.8	233.5
Total Operations	344	$9,254.6	$ 2,190.5	341	9,820.0	$2,360.0
Design and Construction	34	$ 414.2	$ 99.5	52	$ 1,344.2	$ 322.6
Total Personnel	378	$9,668.8	$ 2,290.0	393	$11,164.2	$2,682.6

* Includes approximately 10 man years charged to Interferometer Operations

The following table shows the geographic distribution of NRAO personnel according to job function.

The following table shows the geographic distribution of NRAO personnel according to job function.

Full-Time Employment by Location

	Estimated Distribution				
	GB	CV	TUC	SOC	Ceiling
General and Administration					
Director's Office		6			6
Fiscal Office	8			5	13
Business Management		8			8
Subtotal	8	14		5	27
Research Support					
Basic Research	2	24	1	9	36
Scientific Services		6			6
Subtotal	2	30	1	9	42
Technical Support					
Central Lab		16			16
Computer		19			19
Engineering	3				3
Subtotal	3	35			38
Green Bank Operations					
Telescope Services	32				32
Electronics	22				22
Plant Maintenance	17				17
Administrative Services	13				13
Scientific Services	12				12
Subtotal	96				96
Tucson Operations					
Operations/Maintenance			14		14
Electronics			10		10
Subtotal			24		24
Socorro Operations					
Scientific Services				8	8
Engineering and Services				28	28
Computer				17	17
Electronics				30	30
Array Operations				11	11
Administrative Services				20	20
Subtotal				114	114
Total NRAO	109	79	25	128	341

IX. 1985 PROVISIONAL FINANCIAL PLAN
Expenditures and Commitments by Classification
($ thousands)

	Prior Years		1985 Plan				
	1983 Actual Expend.	1984 Est. Expend.	New Funds 1985	Carryover Funds From 1984	Avail. for Comm. 1985	Est. Comm. From 1984	Avail. for Exp. 1985
1. Operations							
Personnel Compensation	$ 8,354.5	$ 9,254.6	$ 9,820.0		$ 9,820.0		$ 9,820.0
Personnel Benefits	1,979.3	2,190.6	2,360.0		2,360.0		2,360.0
Travel - Domestic	499.9	646.6	635.0		635.0		635.0
Travel - Foreign	43.6	50.0	70.0		70.0		70.0
Material, Supplies, & Services	3,925.8	4,201.3	4,466.0		4,466.0	$ 270.3	4,736.3
Subtotal	$14,803.1	$16,343.1	17,351.0		$17,351.0	$ 270.3	$17,621.3
Management Fee	$ 315.0	$ 330.0	$ 350.0		$ 350.0		$ 350.0
Total Operations	$15,118.1	$16,673.1	$17,701.0		$17,701.0	$ 270.3	$17,971.3
2. Equipment							
Research Equipment	$ 1,215.5	$ 1,854.4	$ 579.0	$144.7	$ 723.7	$ 321.1	$ 1,044.8
Operating Equipment	148.5	280.0	100.0		100.0	11.9	111.9
Total Equipment	$ 1,364.0	$ 2,134.4	$ 679.0	$144.7	$ 823.7	$ 333.0	$ 1,156.7
3. Design and Construction							
VLA Additions	$ 106.1	$ 23.1					
Interferometer Additions	347.3	81.9	$ 325.0	$276.9	$ 601.9	$ 9.3	$ 611.2
VLBA Design	55.2	1,305.7	300.0		300.0	1,139.1	1,439.1
VLBA Construction	-		9,000.0		9,000.0		9,000.0
Total Design & Construction	$ 508.6	$ 1,410.7	$ 9,625.0	$276.9	$ 9,901.9	$1,148.4	$11,050.3
Total	$16,990.7	$20,218.2	$28,005.0*	$421.6	$28,426.6	$1,751.7	$30,178.3

* Includes $1,005.0 USNO Funds for Interferometer Operations and Additions

1985 PROVISIONAL FINANCIAL PLAN
Expenditures and Commitments by Major Function
($ thousands)

	Prior Years		1985 Plan				
	1983 Actual Expend.	1984 Est. Exp.	New Funds 1985	Carryover from From 1984	Avail. for Comm. 1985	Est. Comm. from 1984	Avail. for Exp. 1985
1. Operations							
General & Administrative	$ 1,548.8	$ 1,681.3	$ 1,751.0		$ 1,751.0	$ 14.5	$ 1,765.5
Research Support	1,768.4	2,110.3	2,314.0		2,314.0	18.0	2,332.0
Technical Support	2,134.9	2,340.4	2,175.0		2,175.0	6.4	2,181.4
Green Bank Operations	3,289.0	3,683.6	3,957.0		3,957.0	75.7	4,032.7
Tucson Operations	1,147.9	1,339.0	1,490.0		1,490.0	29.7	1,519.7
Socorro Operations	4,914.1	5,188.5	5,664.0		5,664.0	126.0	5,790.0
Subtotal	$14,803.1	$16,343.1	$17,351.0		$17,351.0	$ 270.3	$17,621.3
Management Fee	315.0	330.0	350.0		350.0		350.0
Total Operations	$15,118.1	$ 16,673.1	$17,701.0	-	$17,701.0	$ 270.3	$17,971.3
2. Equipment							
Research Equipment	$ 1,215.5	$ 1,854.4	$ 579.0	$144.7	723.7	$ 321.1	$ 1,044.8
Operating Equipment	148.5	280.0	100.0		100.0	11.9	111.9
Total Equipment	$ 1,364.0	$ 2,134.4	$ 679.0	$144.7	$ 823.7	$ 333.0	$ 1,156.7
3. Design & Construction							
VLA Additions	$ 106.1	$ 23.1					
Interferometer Additions	347.3	81.9	$ 325.0	$276.9	$ 601.9	$ 9.3	$ 611.2
VLBA Design	55.2	1,305.7	300.0		300.0	1,139.1	1,439.1
VLBA Construction	-	-	9,000.0		9,000.0		9,000.0
Total Construction	$ 508.6	$ 1,410.7	$ 9,625.0	$276.9	$ 9,901.9	$1,148.4	$11,050.3
Total	$16,990.7	$ 20,218.2	$28,005.0*	$421.6	$28,426.6	$1,751.7	$30,178.3

* Includes USNO Funds $1,005.0

APPENDIX A

RESEARCH PROGRAMS FOR THE NRAO SCIENTIFIC STAFF

During 1985 the permanent staff of the NRAO will be working in a number of research areas as described below. Some of the research will be carried out in collaboration with visiting scientists.

A. STUDIES WITHIN THE GALAXY

1. Stars and the Stellar Environment

Further observations of the red supergiants Betelgeuse and Antares will attempt to confirm preliminary measurements that resolve their angular diameters at the hightest VLA resolutions for 2 cm and 1.3 cm. Power-law spectra due to the optically thick thermal emission in their extended chromospheres already provide sufficient information to determine the radial dependences of the electron-density distributions in their atmospheres. A confirmed determination of the diameter of the radio disk at any wavelength provides the necessary scaling constant for the electron-density distribution, which then combines directly with the inverse squared radial fall-off in gas density to determine the changing fractional ionization of the gas. The measurement is thus expected to constrain models and strengthen our understanding of energy transport processes in these extended chromospheres.

Recent theoretical work on the evolution of planetary nebulae suggests that the rate of mass loss from the central star remains high even after the ejection of the major part of the shell. By studying compact or "stellar" planetary nebulae with the VLA, and using the visibility function to separate the contributions of the nebula and the

star, it may be possible to measure the rate of mass loss and the temperature of the stellar wind directly.

The study of planetary nebulae will also be extended to the infrared where observations of the vibration-rotation lines of molecular hydrogen will be undertaken in an attempt to detect massive, circumnebular shells. For the more massive shells in which H_2 lines are seen, a search for neutral atomic hydrogen will be carried out with the VLA. Although it has historically been assumed that all PN central stars had masses in the range of 0.5 to 0.8 solar masses, having come from solar-sized progenitors, there is recent evidence that this may not be the case. Some stars which are thought to be predecessors of planetaries have quite massive envelopes of primarily molecular material, possibly exceeding 5 solar masses. Type I planetaries have the higher He/H and N/O abundance ratios which theory predicts will result from more massive progenitors. It has been thus suggested that the bulk of the mass of the progenitors, which is not now visible in the nucleus or the ionized shell of the Type I PN, resides in a neutral circumnebular shell and should therefore be accountable with the proposed H_2 and HI observations.

Analysis of a large data base of VLA observations of 30 compact HII regions with sizes under 2 arcseconds is expected to reveal the nature of the mechanism which creates the shell-like morphology in large numbers of these objects. The highest resolution observations were made with the outstanding sensitivity of the upgraded VLA 2-cm receivers. Preliminary analysis favors a stellar-wind mechanism of shell formation. Their derived lifetimes may be short enough to seriously call into question the current estimated birth rate of massive O stars. In addition, VLA

observations of the OH molecule have been made toward several of the compact shell structures to determine whether bipolar molecular flows may originate from these objects. Such flows may decide whether the structures are toroids.

A multifrequency attack is planned which will investigate mass loss rates in S stars as a function of the C/O abundance in their circumstellar shells. Line profiles of the primarily collisionally excited CO line probe the density in the shell while the total CO emission flux is an appropriate measure of the gas cooling rate. Heating occurs through collisions with radiatively accelerated dust grains, whose composition is derived from infrared spectra. Maps from the IRAS satellite provide a measure of the dust cooling rate. Models of the density and temperature profiles of the circumstellar shells will be constructed from the data, which will accurately measure mass-loss rates for the S-star sample. For shells with a known range in C/O, it is hoped to be able to correlate stellar composition with mass-loss rate and to constrain the nature of the unknown engine responsible for the mass loss.

In the circumstellar shell of the Mira variable, IRC+10216, the lower rotational lines of the SiS molecule vary with the light cycle of the star and the weak masing of these lines arises from unknown sources. Pumping of the infrared vibration-rotation lines arises either from the continuum or from an overlap of some SiS lines with certain HeN lines in the 14.3-micron band. A monitoring program to follow closely the variation of several SiS lines through the approach of the light cycle to maximum light will help to distinguish between these pumping sources.

Additional observations of the twin jet, stellar radio source, SS 433, will provide a critical test of the currently favored model to explain both radio and optical data. High-resolution, full synthesis, VLA maps of the source at 2 cm suggest that the radio emission is "limb brightened." This would be expected if the emission originates in a sheath around the expanding jets similar in concept to the radio emission originating in an expanding supernova shell. Further, high-quality maps at several epochs are needed to confirm this cylindrical, "supernova"-like model. The observations are further needed to confirm suspected period changes and to determine the polarization and hence magnetic field structure of the jets. The details of this nearby stellar source should provide clues to the mechanisms operating in extragalactic radio jets.

Astrometric observations of selected radio binary stars continue with the VLA in an effort to measure their absolute parallaxes and proper motions.

2. The Interstellar Medium

A 140-ft telescope survey of the OH spectra of bipolar flows around young stars will be followed up with OH maps with the VLA. Preliminary results of the survey suggest that OH may trace the flows over a wide range of velocities and may give clues to physical conditions in them through the OH excitation mechanism. These galactic jets are examples of supersonic outflows in a background medium whose density, temperature, etc., can be measured by many methods. This may, therefore, provide a "laboratory" in which to test flow models used in extragalactic sources.

In the bipolar flow source L1551, optically thin, OH absorption has been detected against the 3 K background. Some explanations of this refrigeration of the 18-cm OH lines involve highly anisotropic particle streams within the bipolar cavity and predict that the OH absorption will be linearly polarized. Observations of the polarization properties of the absorption lines are planned to test the predictions of this model.

The exceptional star-formation rate in the nearby Rho Ophiuchus molecular cloud will be the subject of a spectral-line survey of the cloud. One of the most interesting aspects of the cloud is a very cold and extremely dense clump which has apparently not yet formed stars. A gradient in the characteristics of the spectrum of this cloud from one edge to the other apparently suggests that a low-velocity shock is interacting with it on one edge. The cloud is well resolved, and one emphasis of its study will be to understand exactly what physical processes are responsible for this spectral change and to understand how star formation may proceed in the clump.

Several puzzling, 3-mm continuum sources detected in recent years toward cold, dark molecular clouds will be confirmed with bolometric observations on the 12-m telescope. The source of the emission is probably not thermal bremsstrahlung since the gas is not known to be heated. The most likely source of the radiation is from very slightly heated dust grains (about 10 K). If this is the case, the regions must be very dense and could represent the final phase of collapse into protostars before the heat sources are generated. The observations at wavelengths between 1 and 3 mm are intended to clarify the situation.

Measurements of the J = 3→2 HCO^+ emission from the gas in the molecular clouds associated with the Sgr A source at the galactic center will be obtained in order to investigate its abnormally elevated temperature. Measurements of [OI] and [CII] emission have shown the temperature to be unusually high, and the planned observations should test the suggestion that an enhanced flux of cosmic rays permeate the cloud and elevate the temperature.

High-resolution, VLA absorption-line maps will be used to study the internal structure of interstellar diffuse and molecular clouds in greater detail than otherwise available. The HI absorption, which arises primarily in the optically thick, cooler constituents of the interstellar medium, has been mapped in great detail across the faces of three extragalactic continuum sources, 3C 111, 3C 161, and 3C 348. Other techniques involving HI emission profiles cannot easily segregate the effects of other, hotter, optically thin regions along the line of sight. Likewise, optical absorption studies rely too heavily on the random presence of bright background stars and do not facilitate cloud mapping. For diffuse clouds, the results bear more or less directly on models of the heating, cooling, and overall equilibrium of the interstellar medium.

A new program will be initiated which will combine both sensitive observations of millimeter-wave recombination lines in HII regions and theoretical modeling of the line strengths in terms of the temperature and density of the ionized region. Only recently have advances in millimeter-wave telescopes and detectors made the observations feasible. The millimeter-wave recombination lines provide a sensitive diagnostic

of the thermodynamics of HII regions. The millimeter-wave lines overcome the limitations encountered by the analysis of either radio or optical recombination lines. The bright, collisionally excited, optical emission lines are sensitive to the gas density alone, while the faint radio wavelength lines are primarily temperature sensitive. It is hoped that the millimeter recombination-line observations will enable a more complete analysis of the HII region environment.

Several searches for new molecular species are planned, including $HCNH^+$, NH_2, vibrationally excited diacetylene, and SiH. These are all based on new laboratory work and all are fundamental to an understanding of interstellar chemistry. A previous search for MgO, based on newly available laboratory results, provided very sensitive upper limits which will have to be carefully analyzed. Current models of interstellar grain chemistry predict significant amounts of MgO which the observations apparently do not confirm.

It is presumed that in chemically young interstellar clouds the carbon chemistry has not yet reached equilibrium and there may still exist significant quantities of complex, carbon-chain molecules. To test this hypothesis, a program has been developed to search for the complex, carbon-chain molecules CH_3C_6H and CH_3C_5N. A similar intercomparison of the molecular composition of physically different clouds will look at the CH_3C_4H/CH_3C_2H ratio in a number of hot, massive clouds which presumably have a very evolved chemistry. The cold, small TMC1 cloud has already been detected in CH_3C_4H emission and should presumably have a different abundance ratio than the massive clouds to be sampled.

The study of deuterated molecules can provide estimates for the abundances of unobservable species in interstellar clouds, such as electrons and diatomic nitrogen. The deuterium enhancement ratio in various sources and in various molecules is also important for the determination of the chemical ancestry of some species. An observational program will therefore undertake to probe more thoroughly the situation with respect to the DCN molecule. HCN and DCN may originate in two major reaction sequences in molecular clouds, and temperature behavior of the deuterium enhancement should indicate the degree to which each reaction chain contributes to the HCN and DCN production. If DCN is created primarily by a chemistry involving H_3^+, the deuteration enhancement temperature dependence should follow that observed for DCO^+. If DCN is created, on the other hand, through a reaction chain originating from CH_3^+ and atomic nitrogen, the enhancement temperature dependence should be significantly different. The observational program will measure several transitions of HCN, DCN, and $H^{13}CN$ in molecular clouds spanning a range of temperatures in an attempt to separate these effects and thereby clarify the chemical history of these species.

3. Galactic Studies

Recent VLA observations of the extended filamentary structures near the Sgr A region at the galactic center have stimulated further studies of the region. Data combining observations with all four VLA arrays will be used to produce a spectral-index map of the region extending from the Sgr A nuclear source outward to the northernmost filamentary feature. Also, with the help of recombination-line observations, an attempt will be made to separate the thermal and non-thermal emission. At the nucleus

itself, the relationship between the ultra-compact source and the other components of the galactic center region is still being studied. Included are several components which cover a broad range of angular scales.

A galactic survey for very young supernova remnants will be continued with the VLA. Although the galactic supernova rate is thought to be approximately one every twenty years, most would be optically obscured and only detectable by the radio emission. Recent radio detections of extragalactic supernova soon after outburst indicates that a radio search for galactic supernova remnants is feasible. The ongoing radio survey selects from a well-catalogued sample of known, unresolved radio sources in the galactic plane. With the highest VLA resolution brought to bear on the strongest of these catalogued sources, it is expected that the circular morphology of a small percentage of them will actually identify them as supernova remnants. The detection (or even lack of detection) of these young supernovae will provide important constraints on the supernovae rate in the galaxy and clues about star formation, stellar evolution, mass loss rates, and the interstellar medium.

The results of an extensive VLA, 20-cm, continuum survey of the inner 3 degrees of longitude around the galactic center will be consolidated and analyzed. The survey concentrates on sources away from the nuclear source, Sgr A. Most of the surveyed sources are long-known objects but their detailed morphologies are just being revealed. Among the more interesting objects is the strong infrared source Sgr C, which shows a remarkable similarity to the heavily studied Sgr A source.

High-resolution observations of Sgr C are planned to determine its small-scale structure and spectral-index distribution.

If there is a hot corona of gas around the Galaxy, the soft x-rays produced by the gas would only be observable if the intervening interstellar medium is transparent. Over most of the sky, however, the amount of HI is too great and there is not enough clumping to allow a significant number of soft x-rays to penetrate the galactic layer. Some directions, however, are apparently quite free of intervening HI and could allow the passage of hot coronal, soft x-rays. In order to determine if these regions might be the source of some part of the soft x-ray background, sensitive HI maps of these "holes" will be obtained for comparison with rocket and satellite x-ray measurements.

UV, optical, and 21-cm measurements toward distant, high latitude stars will be combined in a continuing effort to probe the neutral halo of the Galaxy.

Kinematic HI distance estimates above the plane are unreliable since the assumption of cylindrical, rotational symmetry is probably not valid. Radio, HI, total-column density measurements corrected by UV Lyman-alpha column densities in front of candidate stars can greatly improve our knowledge of the distribution of distant HI as mapped over the sky. The technique, however, is extremely sensitive to corrections for stray 21-cm radiation from telescope sidelobes, and the correction method will be further developed and applied to a large sample of stars. This study, and a parallel one to investigate the rotation of galactic gas far from the plane, will add to our knowledge of the extent and kinematics of the neutral halo.

B. EXTRAGALACTIC STUDIES

1. Normal Galaxies

A low-resolution, VLA survey of all 308 spiral galaxies brighter than $B_T = +12$ mag north of $\delta = -45°$ will be made at $\lambda = 20$ cm. Fewer than 30% of these galaxies have ever been detected, but the new observations will be an order of magnitude more sensitive than previous ones and should produce maps of at least 90% of these bright spirals.

For several nearby spiral galaxies, including M51, M82, NGC 253, NGC 6946, and IC 342, high-resolution millimeter-wave observations have been obtained with the NRAO 12-m telescope and the Japanese Nobeyama telescope. These results will be analyzed to try to determine (1) whether giant molecular clouds are confined to spiral arms; (2) whether any other galaxies have an "inner Lindblad resonance" such as does the Milky Way; (3) whether large-scale trends--dimly suggested in current low-resolution studies--can be confirmed, such as temperature or sizes of GMCs with galactocentric radius in M31, or large-scale ejection of gas out of the plane in M82.

Other VLA observations are in hand which sample the OH distribution in NGC 253, M82, NGC 3628, and NGC 3079. The observations were sensitive to absorption features against the central continuum sources rather than to the broad, weak emission that would characterize spiral or other global structures. Evidence of molecular rings, ~1 kpc in size, is seen in NGC 253 and M82, as well as evidence of ejection plumes of masering OH gas. Analaysis of the data for other significant structural features will continue.

A number of emission-line galaxies have a feature in their optical spectra that is characteristic of a large population of Wolf-Rayet stars, and indeed the ratio of WR stars to OB stars inferred is near unity. Such a high ratio implies that a sudden burst of star formation occurred very recently. Radio maps made with the VLA of two of these objects will be used to separate the thermal and nonthermal components, giving improved estimates of the number of early stars in these galaxies.

The HI emission from a number of galaxies detected by IRAS will be observed in order to measure their velocities and estimate gas masses. A sample will also be selected for CO emission studies in order to derive their H_2 masses. The IRAS-selected galaxies of interest have exceptionally high infrared-to-blue luminosity ratios and are thus expected to be extremely dusty. HI emission should be present in a sizeable fraction of these galaxies and the relative measures of HI and CO should reveal much about the star-formation, molecular-cloud environment of these newly surveyed galaxies.

The Giant Molecular Clouds of M31 will be surveyed in the peculiar 1720-MHz satellite line of OH in order to establish whether or not they are primarily confined to the spiral arms. The 1720-MHz line has been shown to trace out spiral structure in the Milky Way. Confirmation of the same effect in M31 would strengthen the interpretation of the pseudo-linear features in our own galaxy as spiral arm features and would support the notion that GMCs are found only in spiral arms.

Several studies of the kinematics of galaxies will be undertaken. Global velocity profiles of galaxies will be reanalyzed using new, very high signal-to-noise ratio HI data. Comparison and analysis will be made

of global velocity profiles derived from 21-cm observations and from optically derived rotation curves. Synthesis maps of hydrogen in dwarf ellipticals, polar-ring galaxies, and radio galaxies will be used to study the kinematics and mass distribution of ellipticals in general and to address the question of ongoing disk formation in these galaxies.

An analysis of data on low-luminosity, gas-rich galaxies promises to result in a better determination of the faint end of the galaxian luminosity function and the role played by late-type systems. Preliminary results have already indicated that the early/late ratio for low-luminosity galaxies is much larger than one.

For Seyfert galaxies of different morphological types the gravitational potentials and mass-to-light ratios will be derived as a function of distance from the galactic nuclei. Faint, optical, photometric measurements of several nearby Seyferts will be combined with detailed VLA hydrogen spectral-line maps in order to probe the kinematic properties of these galaxies in this manner. The observations of three particular Seyfert galaxies (NGC 4051, 4151, and 6814) do not seem to indicate that there is any obvious connection between the kinematics of the disks and the characteristic nuclear phenomena seen in Seyferts. NGC 1068, the most extreme of the Seyferts studied, requires further examination. Higher resolution CO studies of the innermost few kiloparsecs of the galaxies are expected to improve our understanding of the gas kinematics.

Galaxies in clusters have come under intense scrutiny over the past few years in order to determine the extent to which their kinematics, morphology and evolution are influenced by their unqiue environment. The

VLA hydrogen study of the Virgo cluster of galaxies has already shown that the most central galaxies exhibit strong morphological distortions and assymetries as a possible result of their proximity to the powerful central x-ray galaxy M87. The effects of the cluster environment, such as hot intergalactic gas and an anisotropic gravitational potential, should influence the evolution of additional spiral galaxies in the cluster, and the continuing VLA study will intercompare the hydrogen distribution within galaxies at different positions in the cluster.

2. Radio Galaxies and Quasars

The close galaxy pair NGC 4782/4783 associated with the radio source 3C 278 will be the focus of a detailed multifrequency study of the structure in total intensity and polarization. This is a tightly bound system in which at least one member is a radio galaxy with prominent radio jets. If the other galaxy proves to possess radio jets, then it may be possible to estimate the jet velocities. Also, the collimation and stability of the jets may prove useful in deducing the presence of dark matter around the system, which in some models is required to account for the apparently fast orbit.

Multiple VLA arrays and frequencies have been used for a detailed study of the individual radio galaxies, M87, 3C 75, and 3C 465. In each source the observations are being analyzed for the complete distribution of polarization and spectral index which are the primary diagnostic indicators of the properties of the thermal and nonthermal gas as well as the magnetic field configuration. For M87 it is hoped that second epoch, 2-cm observations will be sufficient to allow the determination of the proper motion of its brightest jet features relative to the nucleus. A

detectable proper motion would indicate that the jet is moving relativistically and a follow-up measurement in 1988 could place velocity limits of about 15,000 km/s on its motion.

Long-slit, optical spectra are planned for a small sample of radio galaxies in rich clusters. Spectra will be taken with the Cryo camera on the Kitt Peak 4-m telescope to search for faint emission lines produced by cool clouds which may be deflecting jets in Wide Angle Tail sources. Similar observations for Narrow Angle Tail sources should reveal the hotter medium which is predicted by theory. Other optical observations are planned with the AAT and MMT to obtain higher resolution, long-slit spectra for the determination of the mass distribution for each galaxy in the sample. These observations should allow the most complete specification of the environment of low-luminosity jets and should provide good tests for the current set of models.

Follow-up CCD optical imaging observations of several 3CR radio galaxies are planned using the KPNO telescopes. Partial results from earlier observations suggest a strong correlation between the extent of the optical and radio morphologies of these systems. CCD observations of a sample of compact, weak radio sources with steep spectra are planned in combination with VLBI observations in order to test predictions of inverse Compton emission from these sources. Another sample of faint, flat-spectrum radio sources will be the subject of a multi-wavelength study designed to compare radio and optical morphologies and kinematic properties.

The detailed investigation of a sample of kiloparsec-scale, extragalactic radio jets will continue. Multifrequency VLA data on knot

structures, jet spreading rates, and magnetic configurations will be compared with theoretical models of pressure-matched supersonic flows in order to refine our understanding of energy transport processes in large extragalactic sources. Theoretical descriptions of analytic models of mildly supersonic decelerating turbulent flows will be directly compared with the data on the brightness distributions and magnetic configurations in the rapidly spreading jets in several weak radio galaxies. Other, more sophisticated theoretical models of the hydrodynamics of hypersonic flows not appreciably decelerated by interactions with ambient gas will be compared with the detailed VLA observations of narrow jets in strong radio sources.

New, VLA observations of fine structure in radio jets at 2 cm are planned, preparatory to work at similar resolution with the Space Telescope. The goal of the observations will be to identify, and then map, bright knots in several radio jets, ultimately determining their radio morphology, magnetic structures and optical-radio synchrotron spectra for comparison with shock- and turbulence-driven particle acceleration mechanisms.

A variety of observations will continue, using the VLA to study the radio structures of QSOs. Particularly interesting will be continued observations of a sample of the physically largest radio QSOs which are being found to have strong nuclear components and one-sided jets, results which contradict naive relativistic beaming models. High-resolution observations (0.1 arcsec) of one-sided quasar jets will also be processed further to give the best constraints on magnetic confinement of these sources. For the unique quasar, PKS 2300-189, the orientation of its

non-relativistic precessing jet is known such that it should be possible to interpret the structure of its core and inner jet unambiguously. Hopefully, intercontinental baseline, 3.8-cm observations will resolve the core structure.

A search for λ = 21-cm HI emission from nine of the brightest quasars with $z < 0.1$ will be made at Arecibo. If these nearby, optically selected quasars lie in spiral galaxies, it may be possible to detect line and continuum emission from their disks. Disk continuum-emission will also be searched for the 20-cm VLA maps of six other low-redshift quasars which do not contain nuclear radio sources.

The structure and dynamics of compact radio sources will be studied with further VLBI observations of the superluminal source 3C 454.3, the non-superluminal source 3C 84, and the quasar 3C 147, which has shown large variations in flux density at long wavelengths but no corresponding motion. The VLA will be used to extend the observations of optically selected quasar samples. A particular aim of these studies will be to evaluate the role of relativistic beaming in quasars and active nuclei.

The VLA will be used to extend the 6-cm radio source count to less than 25 μJy. This will provide valuable new data on the low end of the radio galaxy/quasar-luminosity function as well as the spatial distribution and evolution of radio sources out to large red shifts. The same data will be used to search for fluctuations in the cosmic background radiation down to a level $\Delta T/T < 10^{-4}$ on a scale of 1 arcminute, corresponding to the angular scale associated with mass fluctuations which may occur in the formation of galaxies and clusters.

We have obtained deep CCD images of part of the survey area, and hope to use this material, as well as new material, to identify the sources found in the radio survey.

The program, begun in 1979, to investigate the global properties of the variability of a large sample of quasars and radio galaxies will be continued. The study of variability on time scales of one day to 20 days has now been completed and has led to recognition of a new phenomenon called flickering. In 1985 the time-scale range will be extended to include 30 sec to 2 days with observations with the VLA and with the 100-m telescope at Effelsberg, and to 6 years with further observations with the 92-m telescope at Green Bank. Additional observations with the Arecibo telescope will also be undertaken to extend the frequency coverage. In addition, observations will be made with the new 30-m telescope at Pico Veleta to determine the spectra of the objects down into the millimeter-wavelength region for comparison of spectral and variability characteristics and to search for variability at those wavelengths.

Stimulated radio-recombination lines toward quasars and radio galaxies will be investigated from both the observational and theoretical viewpoint. Whether or not such lines are detectable is dependent on the particular physical conditions surrounding individual sources.

The program to monitor a complete sample of low-frequency variable sources at 318, 430, 606, 880, and 1400 MHz will be completed and the full data set will be reduced and interpreted. Some of the variations seen are clearly intrinsic, but others may be caused by refractive scintillations in the interstellar medium of our galaxy. The

characteristics of refractive scintillations are being determined by another program which monitors the flux densities of pulsars at 310, 420, and 750 MHz.

Higher resolution maps of the deep survey fields centered on $\alpha = 08^h\ 52^m\ 15^s$, $\delta = +17°\ 16'$ and $\alpha = 13^h\ 00^m\ 37^s$, $\delta = +30°\ 34'$ will be made to determine the angular-size distribution of faint ($S < 1$ mJy) radio sources. This angular-size distribution will be compared with predictions of models in which most faint radio sources are produced by spiral galaxies. Deep optical photographs in three colors will be taken with the CFHT to improve the identification rate and classifications of the radio galaxies in these three fields. Spectra of the brighter galaxies will be obtained with the Palomar 5-m telescope.

C. MISCELLANEOUS

Development will continue of a method of extending the wide field imaging capabilities of radio synthesis arrays, such as the VLA and the VLBA. This method, called broad-band imaging, utilizes the change in resolution with observing frequency to fill in missing samples of the source visibility function. Crucial to the method is the correction of spectral-index gradients in the object which could otherwise corrupt the synthesized image. An iterative scheme to remove such spectral effects, based upon the Maximum Entropy method of image deconvolution, will be tested on VLA and MERLIN data. It is believed that this method will considerably enhance the imaging capabilities of the VLBA and other systems with a relatively small number of antennas.

The theory of optimal designs for radio synthesis arrays will be studied further with special emphasis upon small arrays for which both

complete sampling of the u,v plane and high surface brightness sensitivity are required. A sophisticated optimization technique for finding global minima of functions with many local minima, simulated annealing, has proven very fruitful in this area and has revealed a number of unexpected results. The scope of current work will be expanded to include specific consideration of both sensitivity and sidelobe level.

Investigation and development of new image deconvolution algorithms will continue. The Maximum Entropy approach to image deconvolution has proved to be quite powerful and suggestive, and it is intended that extensions will be made to include polarization imaging and processing of spectral-line data. In addition, other, more ad hoc algorithms show considerable promise and will be studied in detail.

Measurements to establish very accurate positions for a large number of unresolved extragalactic sources continue. The main objective is to determine a precise inertial reference frame from the VLA. Secondary objectives include refinement of precessional, nutational, and geophysical constants.

APPENDIX B

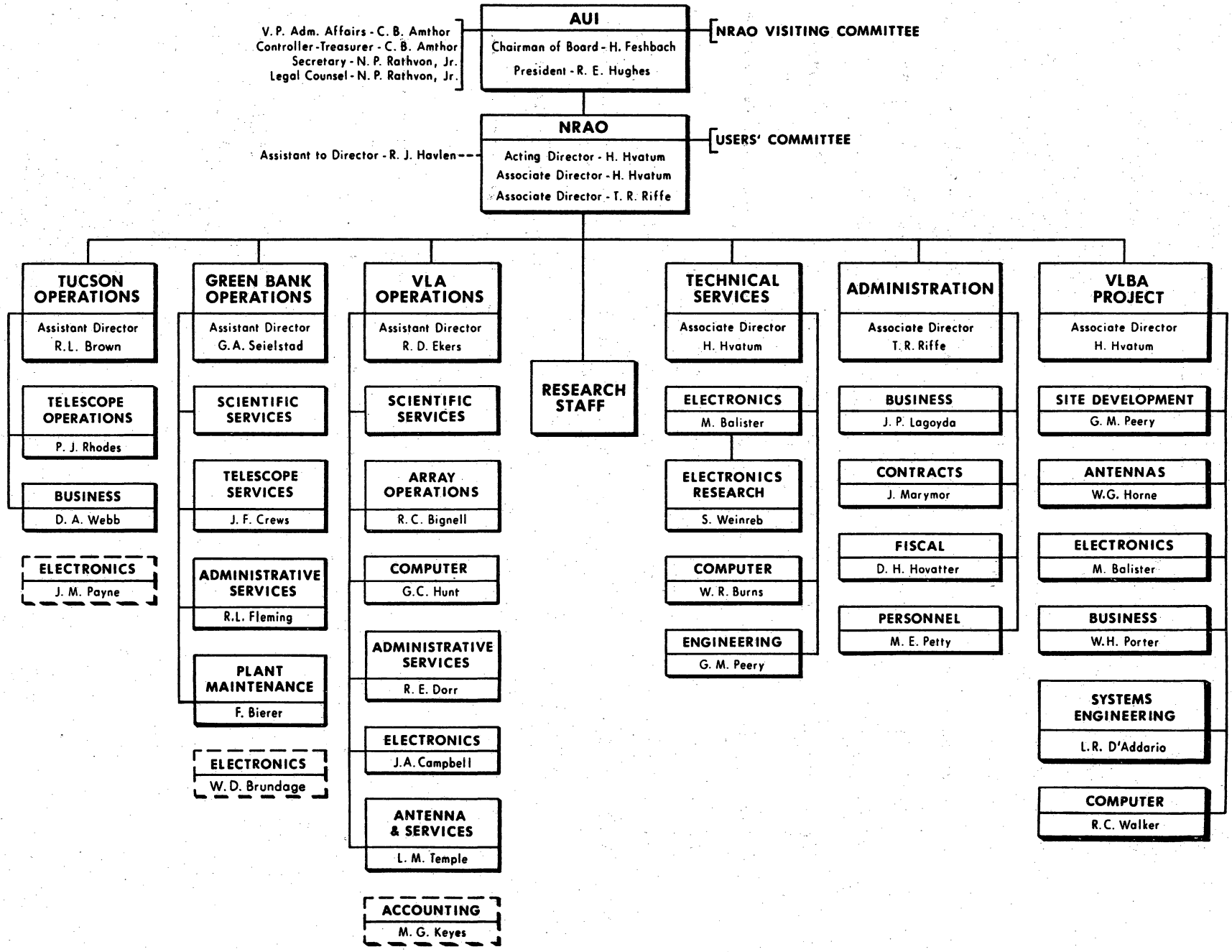
NRAO PERMANENT SCIENTIIC STAFF, WITH MAJOR SCIENTIFIC INTERESTS

J. M. Benson	Stellar OH Masers; Compact Galactic Sources
R. C. Bignell	Polarization and Mapping of Extragalactic Radio Sources; Planetary Nebulae; Supernova Remnants
J. N. Bregman	Theoretical Astrophysics; Interstellar Medium; Quasars
A. H. Bridle	Continuum Radio Radiation; Extragalactic Radio Sources; Radio Jets
R. L. Brown	Theoretical Astrophysics; Interstellar Medium
B. G. Clark	VLA Development; VLB; Interferometry
J. J. Condon	QSOs; Normal Galaxies; Extragalactic Radio Sources
T. J. Cornwell	Extragalactic Radio Sources
W. D. Cotton	Extragalactic Radio Sources; VLBI; VLA Development
P. C. Crane	Normal Galaxies; Interferometry
R. D. Ekers	Synthesis Techniques; Galactic Center; Normal and Radio Galaxies; Cosmology
J. W. Findlay	Absolute Flux Density Measurements; Telescope Design; Surface Measuring Techniques
E. B. Fomalont	Interferometry; Extragalactic Radio Sources; Relativity Tests
M. A. Gordon	CO; Stellar Structure
E. W. Greisen	Structure of Interstellar Medium; Computer Analysis of Astronomical Data
R. J. Havlen	Galactic Structure; Clusters of Galaxies
D. S. Heeschen	Variable Radio Sourcxes; Normal Galaxies; QSOs
R. M. Hjellming	Radio Stars; Theoretical Astrophysics; VLA Development
D. E. Hogg	Radio Stars and Stellar Winds; Extragalactic Radio Sources

H. Hvatum	Electronics and Instrumentation for Radio Astronomy
K. I. Kellermann	Extragalactic Astronomy; VLBI Instrumentation
H. S. Liszt	Molecular Lines; Galactic Structure
F. J. Lockman	Galactic Structure; Interstellar Medium; HII Regions
F. N. Owen	Clusters of Galaxies; QSOs; Radio Stars
H. E. Payne	Interstellar Medium; Low Frequency Variables
R. A. Perley	Radio Galaxies; QSOs; Interferometric Techniques
M. S. Roberts	Properties and Kinematics of Galaxies
J. D. Romney	VLBA; Phenomenon of Active Nuclei in Radio Galaxies and Quasistellar Objects
A. H. Rots	Extragalactic Research; Spectral Line Interferometry
G. A. Seielstad	Quasars; Active Galaxies; VLBI
R. A. Sramek	Normal Galaxies; Quasars; Astrometry
B. E. Turner	Galactic and Extragalactic Interstellar Molecules; Interstellar Chemistry; Galactic Structure
C. M. Wade	Astrometry; Stellar Radio Emission; Minor Planets
R. C. Walker	VLBI Studies of Galactic and Extragalactic Sources
S. Weinreb	Millimeter Wave Development
D. C. Wells	Digital Imaging Processing; Extragalactic Research
A. Wootten	Molecular Clouds; Circumstellar Shells

NATIONAL RADIO ASTRONOMY OBSERVATORY
ORGANIZATION CHART

October 1, 1984



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:

G. A. Dulk	University of Colorado
J. V. Evans	Comsat Laboratories
A. Hewish	University of Cambridge, England (Cavendish Laboratory)
P. L. Richards	University of California, Berkeley
E. Seaquist	University of Toronto
I. I. Shapiro	Harvard University (Ctr. for Astrophys.)
P. Strittmatter	University of Arizona (Steward Obs.)
P. Vanden Bout	University of Texas

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 twice a year.

The present membership is:

M. F. Aller	University of Michigan
M. Bell	Herzberg Institute of Astrophysics
J. H. Bieging	University of California, Berkeley
J. J. Broderick	VPI & SU
F. O. Clark	University of Kentucky
R. M. Crutcher	University of Illinois
G. A. Dulk	University of Colorado
E. D. Feigelson	Pennsylvania State University
B. J. Geldzahler	Naval Research Laboratory
R. Giovanelli	Arecibo Observatory
S. J. Goldstein	University of Virignia
S. T. Gottesman	University of Florida
D. J. Helfand	Columbia University
P.T.P. Ho	Harvard College Observatory
P. J. Huggins	New York University
K. Y. Lo	California Institute of Technology
A. P. Marscher	Boston University
D. O. Muhleman	California Institute of Technology
R. B. Phillips	Haystack Observatory
M. J. Reid	Smithsonian Center for Astrophysics
D. H. Roberts	Brandeis University
L. F. Rodriguez	Observatorio Astronomico Nacional
L. Rudnick	University of Minnesota

E. R. Seaquist	University of Toronto
R. L. Snell	University of Massachusetts
J. Weisberg	Carleton College
W. J. Welch	University of California
A. S. Wilson	University of Maryland

1985 VERY LONG BASELINE ARRAY (VLBA) PROGRAM

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VERY LONG BASELINE ARRAY

VERY LONG BASELINE ARRAY.....($9,000,000)

During 1985, the VLBA group will continue to refine the system design and oversee the start of construction. The major tasks and activities for 1985 are briefly described by project group in the following paragraphs.

In compliance with the Congressional funding action, no part of the $9,000,000 appropriation will be obligated before April 1, 1985, and no Request for Proposal will be issued before the allowable date of obligation of the funds.

Site Acquisition

The first antenna is to be constructed near Pie Town, New Mexico. The exact site location was determined in 1984, and the process was begun to acquire the site from the Bureau of Land Management. Acquisition of the Pie Town site by the NSF is expected by early 1985. Also, during 1985 further refinements will be made in the exact locations of the remaining antennas, including RFI checks where possible. The NSF will be asked to acquire these sites as they individually become known during the year.

Site Development and Site Facilities

During 1985, the Architect-Engineer (A/E) firm (selected in late 1984) will continue the VLBA site design tasks. A principal task for the A/E in 1985 will be to complete the design drawings and specifications for a typical site control building, which later will be adapted to each antenna site. Final construction documents for the site control building will be completed in 1985 for the Pie Town, New Mexico site. In

late 1985, preliminary site planning for the Kitt Peak, Arizona; Los Alamos, New Mexico; and North Liberty, Iowa sites will begin.

During 1985 the A/E will also assist in the collection and analysis of soil conditions and help to adapt the antenna subcontractor's typical foundation design to the site-specific conditions at Pie Town.

The design of the Array Operations Center (AOC) has been delayed due to changes in the anticipated funding schedule; however, the A/E will begin preliminary planning for the AOC in 1985.

It is assumed that federal environmental impact statements (EIS) will not be necessary for the VLBA antenna sites. In the event that any local or state EIS are required, the A/E will assist in their preparation.

Antenna System

The antenna subcontractor, brought under subcontract in the last quarter of 1984, will continue the antenna design into 1985. His tasks during 1985 will, in general, include completion of the antenna engineering and manufacturing plans as well as final development of plans for the installation, alignment, and testing of the VLBA antennas.

Also, following a final design approval from NRAO, the subcontractor will begin to procure materials for the manufacture of the antennas. It is anticipated that by the end of 1985 the manufacture of the first antenna will be nearing completion, so that it may be shipped to the first antenna site (Pie Town, New Mexico).

In the third quarter of 1985 contracts will be let for the manufacture of various NRAO-supplied mechanical equipment for the VLBA antennas, including the focusing feed mounts, secondary reflectors, and the feed cones.

In compliance with the Congressional VLBA funding action, no construction or procurement of construction materials will occur prior to April 1, 1985.

Electronics

The principal aim of the Electronics Division during 1985 is to design and prototype the electronics system for five of the receiving bands and to construct as much as possible of the ancillary electronics for one antenna. The resulting system will be installed on the first antenna, which is scheduled to become available in the second half of 1986. The frequency bands to be included in the initial installation are 330 MHz, 610 MHz, 1.5 GHz, 4.8 GHz, and 15 GHz. In addition to the feeds and low-noise front ends, the local oscillator system, the frequency converters, and the I.F. stages must be included. Racks, mounting bins, power supplies, and helium and vacuum systems for the cryogenically cooled front ends are also required.

The purchase of two hydrogen maser frequency standards is planned for 1985. With the present construction plan, funds for purchasing all of the masers required will not be available until 1987-88, and it is necessary to obtain at least two units for test operations with the first four antennas that will be completed during 1986-87. Purchase of two masers in 1985 will allow time for laboratory testing of these units. The masers may be moved between different antennas to allow observational testing of all four antennas.

Because of the widely distributed locations of the VLBA antennas across the U.S., reliability of operation becomes especially important. The reliability of the cryogenic cooling systems for the front ends is of

particular concern, and a life-test system of six refrigerators being set up at Green Bank during 1984 will be operated through 1985. Two test front ends of the VLBA type will also be in operation on VLA antennas during 1985. The total electronics effort during 1985 will be limited by the available funds. However, as a start on the main procurement it is planned to build a total of two or three front-end units for each of the bands 1.5, 4.8, and 15 GHz.

Data Recording

In 1984, a contract was signed between AUI/NRAO and the Northeast Radio Observatory Corporation (NEROC) for the design, development, manufacture, and testing of the VLBA data-acquisition and playback system.

Phase I of the contract is scheduled to be completed by March 31, 1985. Phase I includes an evaluation of the Mark IIIA longitudinal recording system versus a video cassette recording system for the VLBA; the design of I.F. to baseband converters, digitizers, recorder interfaces, and playback interfaces for the chosen recorder system; and the preparation of cost estimates and schedules for the production of the data recording system.

The remainder of 1985 will be devoted to the Phase II contract work, which includes the construction and testing of a prototype data-recording system in compliance with the design agreed to in Phase I.

Monitor and Control

In the area of software planning in 1985, the Monitor and Control group will start the year with a division of the required programs into

modules, and a mechanism of communication between modules. The year will be spent in refining the internal structures of all models and in producing code, testing and documenting a selected subset of these modules. The modules picked for early implementation will be those required to remotely operate a single antenna with absolutely minimal facilities for remote diagnosis or nice interface facilities for the astronomer-user.

The second priority for the software effort is (1) the development of a spartan command/monitor program for use in hardware module design and development and (2) the development of command-monitor programs for use in the laboratory for debugging of newly built hardware modules.

In the area of hardware planning, by early 1985 the system level design of the VLBA equipment should have progressed far enough so that the number and types of device interfaces becomes known. As soon as the numbers are available the Monitor and Control group will begin to order parts and to set up a production facility. Further production will be coordinated with the needs of the various equipment fabrication groups.

Correlator

A contract with the California Institute of Technology (Caltech) for the design, construction, and testing of the VLBA correlator system was in preparation at the time of this 1985 Program development. It is anticipated the contract with Caltech will be signed in October 1984.

Under the contract, the work to be performed in 1985 includes the definition and specification of the overall VLBA correlator system hardware and software architecture. In addition, Caltech will proceed with the design, characterization, and testing of a Very Large Scale

Integrated (VLSI) chip for use in the correlator, as well as the development of all the required electronic modules.

Detailed cost and schedule plans for the full VLBA correlator, including prototypes, will also be developed during 1985.

Data Processing

In 1985, the primary work of the Data Processing group will be directed toward developing and refining the necessary calibration and editing software for VLBA astronomy data. Some effort will be made towards preserving the geometric information in the data.

System Engineering

The major thrust of the System Engineering group in 1985 will include the finalization of specifications for interfaces between major subsystems, the establishment of signal processing design from the receivers through the correlator, and the development of methods for handling certain special observations (e.g., solar observations).

Project Management

During 1985 the project staff will continue its work of directing and coordinating the project; updating and maintaining detailed time and cost schedules; purchasing and subcontract administration; and implementing project management guidelines. All general management and operating procedures adapted for the VLBA will be consistent with existing Observatory practices and procedures.

Funding Schedule

A funding schedule (in current-year dollars) for the VLBA of $2.8 M; $9.0 M; $16.3 M; $17.1 M; $17.95 M; $7.55 M for 1984-89 is currently anticipated by NRAO. The $2.8 M shown for 1984 includes $2.5 M

originally funded for 1984 plus $0.3 M added by NSF to carry the VLBA to April 1, 1985 due to a Congressional limitation on the 1985 funding.

VLBA Project Staffing Plan

The following table represents the projected staffing for VLBA construction covering the six years from 1984 to 1989. Peak staffing, as shown, will occur in 1986-1987. No operations positions are shown in this table.

Project Staffing Plan
(Number Employees @ 12/31)

	1984	1985	1986	1987	1988	1989
Sites	0	3	3	3	2	0
Antennas	1	6	8	9	8	0
Electronics	8	22	23	19	9	0
Data Recording	0	1	1	1	1	0
Monitor and Control	2	4	6	6	5	0
Correlator	1	2	2	2	2	0
Data Processing	0	1	3	4	3	0
System Engineering	1	2	2	2	3	0
Project Management	7	11	11	10	8	0
Total	20	52	59	56	39	0
Estimated Man Years	16	41	59	58	43	8

VLBA Financial Plan - 1985

The distribution of planned commitments and expenditures for VLBA activities for the $9.0 M authorized for April 1-December 31 are shown in the following table. A brief explanation of each category follows.

	Man Months	Salaries & Wages	Employee Benefits (24% wages)	Material, Supplies & Services	Travel	Contract Charges	Total
		($ thousands)					
Sites	24	$ 92.2	$ 22.1	$ 100.7	$ 20.0	$ 265.0	$ 500.0
Antennas	48	155.1	37.2	772.7	35.0	2,500.0	3,500.0
Electronics	189	485.9	116.6	937.5	60.0	-	1,600.0
Data Recording	9	32.1	7.7	45.2	10.0	305.0	400.0
Monitor & Control	36	96.5	23.2	370.3	10.0	-	500.0
Correlator	18	50.5	12.1	66.4	25.0	846.0	1,000.0
Data Processing	3	8.2	2.0	1.8	8.0	-	20.0
System Engineering	18	58.7	14.1	7.2	20.0	-	100.0
Project Management	87	224.4	53.9	194.7	27.0	-	500.0
Subtotal	432	$1,203.6	$288.9	$2,496.5	$215.0	$3,916.0	$8,120.0
Other:							
Spare Parts	-	-	-	-	-	-	0.0
Contingency	-	-	-	880.0	-	-	880.0
Total	432	$1,203.6	$288.9	$3,376.5	$215.0	$3,916.0	$9,000.0

Salaries and Wages.....$1,203,600

The VLBA project in calendar year 1985 will incur approximately 41 man-years of direct in-house labor costs. Of these, 41 man-years of effort, 36 man-years (432 man months) will be incurred during the period April 1-December 31, which is covered by the 1985, $9.0 M appropriation.

These costs cover salaries and wages of VLBA employees who have been hired directly into the project or transferred into the project from other Observatory operations, as the funds become available in the second quarter 1985 and as construction gets underway.

Employee Benefits.....$288,900

Benefits are computed at 24% of salaries for the NRAO for 1985. All NRAO cost centers bear the same benefit rate.

Material, Supplies, and Services.....$2,496,500

The majority of material, supplies and services expenditures for the VLBA in 1985 will be in the antenna, electronics, and monitor and control areas.

Major expenditures will include NRAO supplied equipment for the antennas, such as the feed cone, focusing mount, cabling equipment, cryogenic supports, special tools and additional mechanical equipment. In addition, the VLBA will purchase two hydrogen-maser frequency standards in 1985, as well as a monitor and control computer.

Travel.....$215,000

Travel costs incurred in 1985 will include moving and relocation expenses of new VLBA project emloyees. In addition, travel will be necessary in the areas of site review and acquisition, contract progress and review meetings, design review meetings, and construction site inspections.

Contract Charges.....$3,916,000

The major contract work to be performed on the VLBA during the April 1-December 31, 1985 period includes the following:

(a) Site development: Site development work is estimated at $265,000. Of this amount, $225,000 is estimated for site construction at the Pie Town site. The remaining $40,000 is allocated for A/E contract services for site and foundation design.

(b) Antennas: $2,500,000 is estimated for the antenna manufacturing, final development and procurement.

(c) Data recording: $305,000 is required to support the prototype development and testing of the VLBA data recording system by NEROC (MIT).

(d) Correlator: Caltech's efforts to design, develop and construct a prototype of the VLBA correlator will require $846,000.

Preliminary Antenna Design and Delivery Schedule
(Revised from 1984 Program Plan)

Antenna Design and Engineering	Start	Complete
Initial Design	Nov. 16, 1984	Feb. 15, 1985
AUI Review	Feb. 16, 1985	Mar. 15, 1985
Final Design	Mar. 16, 1985	June 15, 1985

Antenna Authorization* Dates and Delivery Schedules

	Authorization	Delivery
Prototype		
Antenna No. 1	June 1, 1985	Apr. 15, 1986
Group I		
Antenna No. 2	Jan. 1, 1986	Nov. 31, 1986
Antenna No. 3	Jan. 1, 1986	Feb. 28, 1987
Antenna No. 4	Jan. 1, 1986	May 31, 1987
Group II		
Antenna No. 5	Jan. 1, 1987	Nov. 31, 1987
Antenna No. 6	Jan. 1, 1987	Feb. 28, 1988
Antenna No. 7	Jan. 1, 1987	May 31, 1988
Group III		
Antenna No. 8	Jan. 1, 1988	Oct. 30, 1988
Antenna No. 9	Jan. 1, 1988	Jan. 31, 1989
Antenna No. 10	Jan. 1, 1988	Apr. 30, 1989

Antenna Contract Term	
Design Start	Nov. 16, 1984
Construction Completed	Apr. 30, 1989
Total Term	53.5 months

* Equals commitment date

VLBA ORGANIZATION CHART