NATIONAL RADIO ASTRONOMY OBSERVATORY

PROGRAM PLAN 1984

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 1984 PROGRAM PLAN

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I. INTRODUCTION

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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. Demand for observing time remains high at all telescopes. As new technology is exploited, new receiver developments and operating systems retrofits will continually improve the observing potential of all of the telescopes. No fall off in demand is foreseen. The size of the NRAO user community has increased by 60% since 1980 and by nearly threefold in the last decade as more and more non-traditional radio astronomers exploit the available opportunities. During 1984, approximately 70% of the observing time that is available on the NRAO telescopes will be used by visiting investigators, and their planned research is summarized in Section II of this Program Plan.

Section III of the Plan presents a program for the development of new research instrumentation for use on the telescopes, for computer upgrades to keep pace with advancing technology, and for computing software to

handle the increasing demands for telescope control, data acquisition, signal and image processing, and data analysis. 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. Highlights of this effort will include continuing development of millimeter-wave receivers in order to better exploit the new 12-m telescope surface, the expansion of the VLA to a new low-frequency domain, and improvements in VLB recording and processing techniques. During 1984, the NRAO will begin to implement an 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. A summary of the allocations of funds is given in §IX, the Financial Plan.

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, a list of various committees associated with the NRAO, and the 1984 VLBA Program Plan.

II. SCIENTIFIC PROGRAM

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The following summary, by telescope, is meant to be illustrative of the science that will be accomplished during the course of 1984. The detailed character of these programs will obviously change continuously during the year as new proposals are received and old ones are dispatched. The overall emphasis and the major thrusts by the integrated radio astronomical community will probably not deviate from those described below, however, since the proposal scheduling delay after receipt can range from three to nine months as a result of the peer review process, the proposal backlog, and the availability of required instrumentation.

The VLA--By every measure the VLA continues to be the most powerful and the most scientifically productive instrument that the NRAO has constructed and operated. Since its first use in 1976, in excess of 2000 projects have been proposed and over three-fourths of them have received observing time. Several recent improvements to the instrument assure that this trend will continue through 1984 and beyond. Antenna pointing errors are being systematically reduced as thermal insulation is added at the rate of one antenna every six weeks. Cooled GaAsFET amplifiers have been retrofitted to the 18-21 cm and 2-cm wavelength band receivers; at 2 cm the sensitivity has improved by a factor of three. The addition of two 50-MHz wide IF bands has essentially doubled the data rate. On-line spectral-line capacity has been increased to over 10,000 baseline channels. Prototype 300-350 MHz band receivers have been installed and tested as an initial phase in a program to expand the frequency capabilities of the VLA. Close to twenty percent of the programs are run in absentee observing mode where all or part of the data editing and

calibration is done by NRAO staff. Remote observing via data link to the asynchronous computer has also proven to be a successful procedure for preparing observing files or monitoring the progress of the observations.

The VLA has made significant contributions to the study of solar system objects, and 1984 promises more of the same as previous discoveries are followed up and new experiments are proposed. Simultaneous VLA and VLBI observations are planned of high brightness temperature microwave solar flare emission. Multifrequency observations of dark H-alpha filaments on the sun should lead to an explanation of the origin of the filament depressions seen on millimeter and centimeter-wavelength solar maps. Observations of the brightness temperature and polarization of Titan will help determine the fraction of the radio emission generated at the surface and better test the present model of Titan's atmosphere. The thermal physical characteristics of the four Galilean satellites will also be studied. Further observations of Saturn's rings are necessary to fully understand the scattering properties and sizes of the ring particles and to complete a study of the planet's atmosphere. Uranus will be monitored for rotation and to interpret previously observed brightness temperature increases. Target of opportunity occultation experiments will probe the number-density and spatial distribution of electrons in comets' tails.

The increased sensitivity and resolution of the VLA has proven to be especially attractive for researchers interested in stellar astronomy. Fully 25% of the observing requests deal with stars or the immediate stellar environment. Observations of pulsars will attempt to isolate potential short-period candidates, provide dynamical data via scintillation measures, and improve polarization knowledge of the Crab

pulsar. High-resolution studies of X-ray stars, such as Sco X-1, Cyg X-1, and Cyg X-3, will search for radio periodicities and morphological changes. Planetary nebulae, mass losing stars, and supernovae continue to receive much attention, especially as the VLA observations are directly comparable with similar resolution observations from other spectral regimes. This is also true for stellar objects which have not traditionally been of radio interest, such as T Tauri stars, normal A stars, red giants, and symbiotic stars. The VLA provides new radio spectral information for these objects and occasional morphological clues which improve our understanding of the interaction with their environment.

Most of the galactic studies that will be undertaken with the VLA are concerned with detailed dynamical and morphological interactions in star formation regions and molecular clouds. Regions of energetic outflow will be extensively sampled with spectral-line observations at higher resolution than ever before. Likewise, HII regions provide important laboratories in which to probe the physical conditions of the interstellar material. The structure of compact and ultracompact HII regions and the investigation of OH and H_2O maser sources promises to reveal much about small-scale star-formation phenomena throughout the Galaxy.

Many studies of extragalactic objects have taken advantage of the VLA's ability to provide equivalent angular resolutions over a broad wavelength range as it is used in its various standard configurations. Programs requiring this capability are on the increase as the instrument spends greater amounts of time on in-depth studies of individual objects. Spectral-index distributions, polarization properties and source

variability parameters are all important quantities which require multiple observations if we are to fully investigate the physics of normal galaxies, active galaxies, radio galaxies, and quasars. For many of these objects the proposed VLA observations will be supplemented with multi-wavelength data from the optical, X-ray, ultraviolet, and infrared spectral regions. The VLA is heavily involved in programs to investigate clusters and groups of galaxies, including an attempt to detect the effect of clusters on the microwave background radiation.

The 12-m Telescope--With the telescope out of service for most of 1983 as a result of the installation and testing of the new surface of the upgraded telescope, a large number of very excellent programs have backlogged in anticipation of greater sensitivity and resolution at the shortest millimeter wavelengths. Most of the projects described below were already on hand at the end of 1982.

Although a number of requests are in hand to continue spectral observations in the J = 1-0 CO lines at 3 mm, the attraction of twice the angular resolution in the J = 2-1 lines has given rise to a number of requests to observe extragalactic molecules in a wide variety of galaxy classes, ranging from spirals to irregulars to Seyfert galaxies. The distribution of molecular gas is expected to reveal much concerning the star-formation regions of these galaxies.

Many spectral-line studies are planned which focus on nearby star-formation regions and molecular clouds in our own Galaxy. The energetics of bipolar mass outflow will be a particularly noteworthy area of investigation which promises to reveal much about critical phases of stellar formation and evolution. Prospects are also quite good for

improving our understanding of the chemistry of the interstellar medium in regions as diverse as dark clouds, circumstellar shells around evolved stars, or in young star-formation regions.

The stability and improved sensitivity of the 12-m telescope are also critical for a number of proposed continuum studies of a variety of objects. Several investigators intend to make a concerted effort to observe the local variation in the character of the cosmic background radiation seen through clusters of galaxies. Several programs aim to establish the short-wavelength spectral character of specific classes of extragalactic objects as well as to monitor designated sources for variability. Limited availability of large sensitive instruments in the 1 to 3-mm range has restricted such programs in the past. A direct improvement in models for energy generation and propagation in quasars and galactic nuclei is the ultimate goal of these spectral studies. Other continuum programs will explore the character of circumstellar dust emission, the heating mechanisms in dark clouds and globules, and the surface properties of solar system planets, satellites, and asteroids.

The 140-ft Telescope--More than half of the outstanding proposals to use NRAO's most versatile single-dish instrument request the use of the recently available 5-26 GHz range upconverter maser receiver. This receiver provides performance at or very close to the present state-of-the-art, and the completion of its second channel in late 1983 will make demand for its use even heavier. The second channel will improve the signal-to-noise for sensitivity-limited spectral-line experiments as well as permit simultaneous dual-frequency observations and the acquisition of both orthogonal polarizations. Sensitive searches will

be carried out for $^3He^+$ hyperfine transitions in several galactic HII regions and planetary nebulae as an accurate probe of the $^3He^+$ to $^4He^+$ ratio which sets important limits on models of the Universe. The detection of numerous molecules in specific galactic environments will not only lead to valuable information about interstellar chemistry but will improve our understanding of the physical conditions in these unusual environments. Other experiments in this frequency range will search for polarization of the microwave background radiation, improve the limits previously set on small-scale anisotropy of this background, and search for the dimunition of the background in the vicinity of clusters of galaxies.

In the lower frequency ranges recent improvements in the L-band receiver system noise temperature make extragalactic, neutral hydrogen-line observations very attractive. Continued observations of hydrogen in the Magellanic Stream are planned, and it is hoped that an HI study of active galaxies will shed clues on the relationship between normal galaxies and quasars. OH-line observations are planned as part of an international campaign to monitor the gas production rate and coma kinematics of the periodic comet Crommelin and as a "trial run" for the upcoming visit of Halley's Comet in 1985/86. H_2CO and OH studies of a star-formation region in Taurus are planned which will carefully evaluate the effects of stellar winds from low-mass stars and the evolution of gas clouds and young star rotation rates.

About 25% of the observing time on the 140-ft telescope will be devoted to VLBI experiments, partly in concert with the VLBI Network, 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 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--Continuous integration times are necessarily limited for most observations with the 300-ft transit telescope, and the telescope is most efficiently used for observing many sources per day as they cross the antenna's meridian. Many observing sessions are usually necessary to build up adequate signal to noise on individual sources. Large survey programs are able to make the most efficient use of these instrumental limitations and as a result the type of program that it carries out does not change much from year to year. In addition, some work on individual sources can be accomplished with the help of the travelling feed.

Programs, which are primarily extensions from prior years, include the monitor programs being run by groups from VPI&SU, Massachusetts, and Michigan to establish source variability characteristics as a function of time and spectral range. These are extremely time-consuming programs which are critically dependent on calibration procedures and long-time baselines. The resulting correlations will provide strong constraints on our understanding of the physical mechanisms and evolutionary processes at

work in these sources. In several cases, the 300-ft programs are matched by auxiliary monitoring programs at other wavelengths by other non-NRAO telescopes. Preliminary results, which will be further evaluated, seem to favor the existence of two distinct types of low-frequency variables which may possibly be caused by intrinsic synchrotron opacity changes within each source or by slow refractive scintillations in the interstellar medium.

The 1983 pulsar survey which yielded 37 new pulsar discoveries will be extended to some potentially fertile, low-latitude regions with a new technique designed to improve the sensitivity for very short period pulsars. The recent discovery of two millisecond pulsars accentuates the need for an extensive survey sensitive to pulsar periods less than 0.1 sec. It is felt that the new data gathering and handling techniques will be able to surmount the limitations of previous surveys.

There are several galaxy survey programs for which the 300-ft telescope is particularly well suited. A new survey of nearby ($\lesssim$ 20 Mpc) E and SO galaxies for 21-cm emission is appropriate due to the increased sensitivity afforded by the new, cooled 21-cm FET receiver. Recent catalogs of radial velocities and morphological types allow the selection of an improved sample over a wider range of luminosity than previously available. In another set of galaxies, which primarily contain known dust lanes, a search for HI and OH absorption will be concentrated in order to better elucidate the dynamical properties of the galaxies. A study of long-term variability of active galactic nuclei at 1.5 GHz will be correlated with ongoing studies at higher frequencies.

III. RESEARCH INSTRUMENTS

The primary research instruments at the National Radio Astronomy Observatory are in its four basic telescope systems: (1) the 140-ft telescope, (2) the 300-ft telescope, (3) the 12-m telescope, and (4) the Very Large Array (VLA). Each of these telescopes was conceived, designed, and constructed in response to specific scientific needs of the radio astronomical community and with the most current technologies then available. A major part of the NRAO program deals with sustaining the forefront capabilities of these telescopes in fulfillment of the NRAO obligation to operate first-rate observing instruments. On many occasions during the operating lives of each of the telescopes, modifications and upgrades have been performed which have significantly improved their performance. Items in this area have included resurfacing, improved pointing control, modified feed designs, and upgraded control and acquisition computers.

Additionally, auxiliary instrumentation in the form of new or modified receivers, spectrometers, correlators, refrigeration systems, etc., are continually required to maintain and improve the capabilities of the telescopes. To this end, the NRAO maintains an active research and development program in electronic and computer hardware at each observing site as well as in the Central Development Laboratory in Charlottesville. As the nation's principal center for research in radio astronomy, it is essential that the Observatory set a leading pace in most instrumentation areas.

Because of rapid and unpredictable changes in "state-of-the-art" electronics hardware and unforeseen short notice requirements of the

scientific community, it is desirable that flexibility within the general area of the program be maintained. The table shows the planned distribution of funds for the "Research Equipment" account. The NRAO continually updates this table as scientific priorities change. These estimates provide funds for the completion of already started projects, items of continuing and general development, and funds for new development.

A general description of most of the projects in the Research Equipment account follows:

Item 1. Research Equipment (in thousands of dollars)

	1983 Plan	1984 Plan			1984 Total Estimate	Cost to Complete	Year of Completion
		Est. to Complete	Est. Cont. Development	Est. New Development			
1. Research & Test	$ 275.0		$ 325.0		$ 325.0		Ongoing
2. 140-ft Telescope							
5-26 GHz Rx	50.0	$ 10.0			10.0		1984
New Subreflector				$30.0	30.0		1984
3. 300-ft Telescope							
2-5 GHz Rx	20.0	65.0			65.0		1984
Spectral Processor	20.0		100.0		100.0	$ 95.0	1986
300-ft Computer	25.0	60.0			60.0	80.0	1984
Lateral Focusing Device				40.0	40.0		1984
4. 12-m Telescope							
mmλ Device Development	70.0		140.0		140.0		Ongoing
New Receivers	40.0		100.0		100.0		Ongoing
Computer Upgrade	75.0		145.0		145.0		Ongoing
5. VLA Electronics							
300 MHz Rx	30.0		70.0		70.0	60.0	1986
FET Amplifiers	150.0				0.0		1984
Antenna Pointing Improv.	25.0		15.0		15.0	15.0	1985
Modules	25.0		30.0		30.0		Ongoing
Water Vapor Rx	30.0		30.0		30.0	120.0	1986
6. VLA Computing							
Sync. Computer	230.0		315.0		315.0	300.0	1986
DEC 10 System			100.0		100.0	40.0	1986
Pipeline			170.0		170.0	170.0	1986
AIPS	130.0		282.0		282.0	1000.0	1986
7. VLBI							
Miscellaneous	140.0		50.0		50.0		Ongoing
8. Other							
Miscellaneous	193.0		140.0		140.0		Ongoing
Total	$1,528.0	$135.0	$2,012.0	$70.0	$2,217.0		

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	1983 Plan	1984 Plan			1984 Total Estimate
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Spectral Processor	20.0		100.0		100.0
300-ft Computer	25.0	60.0			60.0
Lateral Focusing Device				40.0	40.0
4. 12-m Telescope					
mmλ Device Development	70.0		140.0		140.0
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Computer Upgrade	75.0		145.0		145.0
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Total	$1,528.0	$135.0	$2,012.0	$70.0	$2,217.0

A. ITEMS TO COMPLETE IN 1984

5-26 GHz RECEIVER

Justification

The recently completed first channel of the 5-26 GHz receiver is in very high demand at the 140-ft telescope. Many spectral-line experiments, however, are sensitivity-limited and would benefit significantly with a second channel capability. A second channel on the receiver will improve signal-to-noise, allow redundancy checks between the two independent front ends, and allow simultaneous dual-frequency observations of, for example, different transitions of a given molecular species. Experiments which require the detection of both orthogonal polarizations would also be possible with the addition of a second channel. Current requests include the study of circular polarization in maser sources and the search for small-scale polarization of the microwave background. Currently VLBI polarization studies of compact radio sources make use of the 6/25-cm prime focus receiver which has an elevated system temperature and generally compromises the sensitivity of all of the experiments during 6-cm network sessions.

Description

The second channel of the receiver will be completed and is expected to perform as well as the first channel. After initial installation and testing to confirm the system parameters, the receiver's two channels will not be simultaneously usable until completion of a new reflector/feed system.

2-5 GHz RECEIVER

Justification

The region of the electromagnetic spectrum from 2 to 5 GHz is primarily of interest due to the presence of spectral lines. Radio recombination lines of hydrogen and dielectronic recombination lines of heavy elements both originate in regions of ionized hydrogen and are valuable probes of the dynamics and physical conditions in young star-forming regions. The molecular lines of CH are very weak (few tenths degree Kelvin) and originate in tenuous clouds which are quite widespread throughout the Galaxy. Just as the 3-mm transitions of CO have contributed to the study of dense molecular clouds, the 9-cm CH lines should prove invaluable to the study of diffuse molecular clouds. Improvements in this waveband would also greatly affect continuum observations--the principal beneficiaries being VLBI continuum studies of compact sources.

Description

The 2-5 GHz receiver will be used on both the 300-ft and 140-ft telescopes and consolidate and improve the performance of several existing receivers which were designed mainly for continuum work and do not have sufficient sensitivity requirements for spectral-line work. The receiver design is similar to the existing 1-2 GHz receiver, and orthomode junction feeds will be constructed to optimize performance around specific spectral-line regions. The design goal at the 9-cm CH lines is a system temperature of 30 K.

300-FT CONTROL COMPUTER

Justification

The present 300-ft telescope control computer is severely constrained in its capacity to handle new observing procedures and improved instrumentation. Currently the DDP-116 computer lacks sufficient space to allow an increase in the sampling rate for multichannel receivers or to expand the storage of card images by the data-taking programs. Additional requirements for on-line observing, file editing, remote observing, or the ability to handle spectra from the proposed new spectral processor are completely beyond its means. The basic requirements for a new telescope control computer are modest real-time speed, sufficient capacity to handle advances in data-taking, software friendliness, and reliability.

Description

The old DP-116 computer will be replaced with a new computer, probably either a VAX or a 68000-based MSC 500.

B. ITEMS FOR CONTINUING DEVELOPMENT IN 1984

RESEARCH 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 $20k, collectively the projects are vital to the Observatory's ability 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.

SPECTRAL PROCESSOR

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 capability of monitoring the interference excision process.

MILLIMETER-WAVELENGTH 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 $T_{sys} \simeq$ 75 K (SSB), a factor of nearly two better than previously achieved. Similar sizable improvements continue at shorter (1.3 mm) wavelengths with Schottky mixers, where NRAO has now achieved $T_{sys} \simeq$ 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 atmosphere windows is expected to rise as researchers seek to take advantage of the 12-m telescope's increase in sensitivity 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 IF frequency of 1.5 GHz to make use of the new cooled FET amplifiers developed by NRAO's 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 IF system.

12-M TELESCOPE CONTROL COMPUTER UPGRADE

Justification

Currently the millimeter-wave telescope is controlled by means of a FORTH control program installed in a PDP-11/40 computer. Data acquisition is handled by a separate PDP 11/40 which was installed several years ago. The FORTH control program has approximately 1000 words of memory available for program expansion, and this is already seen as inadequate for handling telescope and instrumentation hardware modifications which have already

been planned as logical follow-ups to the 12-m surface upgrade. Inductosyns, for example, will increase the data load for the determination of telescope pointing corrections and new receivers will demand more sophisticated control software if full advantage is to be made of the higher angular resolution afforded by shorter wavelength operations.

Description

Extensive software and hardware investment in the existing UNIBUS data system dictates the DEC VAX 32-bit processor series as the computer of choice for the next generation telescope control computer system. Over the course of the next two or three years, the existing PD 11/40 will be replaced by a PDP 11/44 with expanded memory (already existing downtown). This SERVO computer for all hardware except the data taking devices would be slaved to a VAX 11-750 which would in turn function as the CONTROL/ ANALYSIS computer. The VAX 11-750 would control the PDP 11/44, collect data from the data taking devices, as well as provide operator interface and observer analysis. An almost identical system downtown will optimize program preparation and hardware tests. System duplication will also effectively reduce the required spare part inventory.

300 MHZ RECEIVER 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 receiver 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 beamwidth. 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.

VLA MODULE IMPROVEMENTS

Description

Many of the various VLA electronics modules which perform critical tasks in governing the flow of data or signals in the VLA receiver channels need to be replaced by more modern elements. Replacement of the older technology components will have the net affect of significantly reducing system noise temperature and improving the system phase stability. Some of the modules have been functioning, essentially unimproved, for more than six years.

WATER VAPOR RADIOMETERS

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 temperatures 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 system's two main computers 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 stopgap 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 DEC-10 SYSTEM UPGRADE

Justification

The asynchronous DEC-10 computer system is the only computer used for interactive calibration and editing of VLA data. Currently, it is heavily oversubscribed for computing and disk storage and remains the major bottleneck in the VLA data reduction chain. Even though the "pipeline" will ultimately remove much of the burden from the DEC-10, the calibration software will continue to be run there. The ease of upgrading this system is effectively limited by its 36-bit architecture and the fact that most of the application software is written in the SAIL language. The TOPS-10 operating system currently in use on the DEC-10 will also not support DECNET, the networking system that will provide friendly user interaction for the pipeline system. The disks currently employed on the DEC-10 system are also old and costly to maintain.

Description

The DEC-10 operating system will be upgraded to TOPS-20, which does not have the limitations of the older TOPS-10 operating system, supports SAIL, and probably will provide better allocation of the DEC-10's scarce resources. A Winchester disk system will replace the existing disks.

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 throughput 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 grey scale, hard-copy device. At least one more image display system will be acquired 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 device.

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 $150k). Software development and support is planned to the same extent that VAX-based software is supported on the more expensive systems.

IMPROVEMENTS TO MK III VLBI RECORDING EQUIPMENT

Justification

Current wide-band MK III VLBI experiments consume enormous quantities of magnetic tape as they are recorded with fixed, relatively wide track heads at both Green Bank and the VLA. This has put severe limitations on the operational ease of the MK III system and the type of experiment which has been able to take advantage of its wide-band capabilities. Especially inconvenienced have been spectral-line experiments which demand high resolution and velocity range. The lack of a substantial tape inventory has also imposed an artificial limit to the science done with the system. Furthermore, the VLA formatter differs from all other formatters now in use as well as being marginally designed and poorly documented. It also is unreliable at the highest MK III sampling rate.

Description

It is planned to purchase movable, narrow track heads which will record at least a factor of twelve more information on one tape by stacking multiple record strips across the tape. In addition to this high-density recording mode, the recorder electronics will be upgraded to augment the system's bandwidth capabilities. Operational reliability at the VLA will be improved by purchasing a new formatter.

OTHER PROJECTS

COOLED GASFET 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 IF 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).

C. NEW DEVELOPMENT ITEMS STARTING IN 1984

NEW 140-FT SUBREFLECTOR

Justification

The use of the deformable subreflector system is in great demand. As a method of removing atmospheric fluctuations at the high frequencies, nutating has proved extremely successful. However, the nearly constant use of the nutation and deforming mechanisms put significant structural stress on the subreflector. Frequent removal and installation of the subreflector (because of its great demand) also have resulted in some minor damage to the subreflector, and it shows sign of plastic creep as

well. One section of the subreflector is now misshaped, and the best fit rms is measured to be 0.012 inches, degraded from an original 0.009 inches.

Description

A new deformable subreflector will be constructed which will include design modifications which have been suggested in the light of experience with the existing subreflector. It will, for example, have a somewhat slower nutation and larger beam throw built into it for operation at lower frequencies. The new subreflector will have a somewhat different figure and will be built to accommodate future modifications in lateral focusing schemes on the 140-ft telescope.

LATERAL FOCUSING DEVICE FOR THE 300-FT TELESCOPE

Justification

At the 300-ft telescope, there is a significant N-S displacement of the focal point as the telescope is moved away from the zenith. Both defocusing and astigmatism cause a sharp dropoff in the aperture efficiency of the 300-ft at zenith angles greater than about 20° for centimeter-wave observations. The demand for high performance of the 300-ft at these frequencies is growing as the instrument is used for wide sky surveys.

Description

A N-S focusing mechanism and astigmatic lens are being designed which could potentially improve the existing peak efficiency level and extend the range of high efficiency by 10° to 15° at high and low declinations. Tests at 4.75 GHz have indicated a 0.75/degree motion of the optimum focus location as a function of zenith angle. When the

antenna moves South, the optimum feed location moves North. Tests with an offset feed scheme show that the aperture efficiency at 20° zenith angle might rise from about 0.28 to about 0.38 if such a solution were adopted. An astigmatic lens would primarily benefit higher zenith angle observations.

IV. EQUIPMENT

IV. EQUIPMENT

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

1.	Maintenance, Shop and Repair Equipment.....	$ 32.0
2.	Office and Library Furnishings and Equipment.....	46.0
3.	Living Quarters Furniture.....	2.0
4.	Building Equipment.....	5.0
5.	Scientific Services and Engineering Equipment....	20.0
6.	Other Equipment.....	145.0
		$250.0

Item

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 funds 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.

6. Other Equipment

An amount of $145k is required to replace one of the passenger buses at the VLA.

V. OPERATIONS AND MAINTENANCE

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 $185k. Further major budget items, such as the rent and maintenance of the Charlottesville buildings, communications, and utilities, will require $420k. The management fee paid to Associated Universities, Inc., will be $330k.

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 1984, 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 1984, Material and Supply (M&S) budget of $141k 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.

More than one-third of the overall NRAO travel budget will be expended in the Research Support group ($225k) 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 1984, $45k is planned for foreign travel by the staff and $20k is available for qualifying U.S. scientists who need travel support to observe at unique foreign telescopes.

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 1983, $470k is budgeted for MS&S for the above three groups. The major portion of this sum ($340k) will be used for computer rental.

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 1984 budgets for MS&S are: Telescope Services* ($197k), Electronics ($120k), Plant Maintenance ($120k), Administrative Services ($115k), and Scientific Services ($32k). An additional $310k will be spent on communications and utilities. It is also estimated that food services and housing will bring in revenues of about $90k. The operation of the Green Bank interferometer for the USNO affects the Green Bank Operations budget as a credit of $621k (see §VI).

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* Telescope Operations and Central Shops are combined to be the Telescope Services Division.

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 1984 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 1984 will include continued software development for improved data acquisition. The two Tucson subgroups will require the following M&S budgets for 1984: Operations and Maintenance ($203k) and Electronics ($160k). An additional $60k is programmed for communications and utilities. Miscellaneous revenue will total about $12k.

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 Site Management group will require a M&S budget of $85k. 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 M&S budgets of $385k, $126k, and $10k, respectively. Other services related to the efficient functioning of the operation and their M&S budgets are: Engineering and Services Division ($367k), Administative Services ($300k), communications, utilities, and building rent (in Socorro) will amount to $750k, while miscellaneous revenue of $90k is

expected. Included in the above sums is $280k for computer rent and maintenance. A significant part of the communications expenditures will be devoted to remote observing costs.

A summary of the CY 1984 budget for these operations units is provided in the following table:

CY 1984 Budget - Operation Units
($ thousands)

Operation Unit	Personnel Ceiling	Salaries, Wages & Benefits	Material, Supply, Service	Travel	Total
Operations					
A. General & Admr.	27	$ 927.0	$ 935.0	$ 78.0	$ 1,940.0
B. Research Support	42	1,784.0	141.0	318.0	2,243.0
C. Technical Support	45	1,721.0	470.0	58.0	2,249.0
D. Green Bank Operations	97	2,821.0	804.0	38.0	3,663.0
E. Tucson Operations	23	839.0	411.0	38.0	1,288.0
F. Socorro Operations	114	3,389.0	1,933.0	92.0	5,414.0
Total Operations	348	$11,481.0	$4,694.0	$622.0	$16,797.0
Design and Construction					
Very Long Baseline Array	34	$ 752.0	$1,676.0	$ 72.0	$ 2,500.0
Total Design and Construction	34	$ 752.0	$1,676.0	$ 72.0	$ 2,500.0
Total	382	$12,233.0	$6,370.0	$694.0	$19,297.0

Notes 1. Does not include commitments carried forward from 1983.
2. General and Administrative includes $330k for management fee.
3. Green Bank Operations includes $621.1k for USNO interferometer support.

VI. INTERFEROMETER OPERATIONS

VI. INTERFEROMETER OPERATION

Since October 1978, the NRAO has operated and maintained the Green Bank 4-element interferometer for the U.S. Naval Observatory under a cost-reimbursement arrangement (Memorandum of Understanding) between the NSF and the Office of Naval Research. In 1981, the MOU was amended by NRL to authorize funds for the NRAO to design and construct a 14.2-m telescope to be erected some 25 miles west of the Green Bank site in order to provide an east-west baseline link with the existing north-south baseline. In late 1983, construction and installation of the telescope was completed and the connecting east-west microwave link installed, with the only scheduled (construction) work remaining in 1984 being upgrading of the microwave link on the north-south baseline. The funding status of the interferometer program is given in the following table.

A. Interferometer Financial Status @ 09/30/83

	Allocation thru 09/30/83	Expended & Committed	Balance @ 09/30/83
Operations	$2,413,523	$2,348,273	$ 65,250
Construction	1,627,561	1,210,463	417,098
Total Thru 09/30/83	$4,041,084	$3,558,736	$482,348

B. Interferometer Funding Plan 1984

	Funds Carried Over from 1983	1984* New Funds	Total Available for Commitment
Operations	$ 65,250	$621,100	$ 686,350
Construction	417,098	-	417,098
Total, 1984	$482,348	$621,100	$1,103,448

* Authorized in letter dated 08/31/83 from Capt. C. K. Roberts (USNO) to Dr. L. P. Bautz (NSF)

VII. DESIGN AND CONSTRUCTION

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 1984, the NRAO will initiate the design phase of the instrument with monies to be spent on engineering design of the antenna elements and for the design and prototyping of the various electronic subsystems. The planned activities for 1984 are outlined in more detail in Appendix E.

VIII. PERSONNEL

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 1983 and 1984:

Category	1983			1984		
	Est. Level	Salaries	Benefits	Est. Level	Salaries	Benefits
Operations*						
Scientific and Engineering	94	3,264.9	$ 724.4	110	$ 3,829.6	$ 861.8
Technical	114	2,374.7	526.8	118	2,599.7	585.0
Administrative and Clerical	67	1,794.6	398.2	68	1,971.6	443.7
Operations and Maintenance	52	881.8	195.6	52	971.1	218.5
Total Operations	327	$8,316.0	$1,845.0	348	$9,372.0	$2,109.0
Design and Construction	-	-	-	34	$ 614.0	$ 138.0
Total Personnel	327	$8,316.0	$1,845.0	382	$9,986.0	$2,247.0

* Includes approximately 10 man years charged to Interferometer Operations.

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	3	23		11	37
Scientific Services		5			5
Subtotal	3	28		11	42
Technical Support					
Central Lab		18			18
Computer		21			21
Engineering	4	1		1	6
Subtotal	4	40		1	45
Green Bank Operations					
Telescope Services	32				32
Electronics	24				24
Plant Maintenance	17				17
Administrative Services	13				13
Scientific Services	11				11
Subtotal	97				97
Tucson Operations					
Operations/Maintenance			12		12
Electronics			11		11
Subtotal			23		23
Socorro Operations					
Site Management				7	7
Engineering and Services				28	28
Computer				17	17
Electronics				31	31
Array Operations				11	11
Administrative Services				20	20
Subtotal				114	114
Total NRAO	112	82	23	131	348

IX. FINANCIAL PLAN

IX. 1984 PROVISIONAL FINANCIAL PLAN

Expenditures and Commitments by Classification

	1982 Actual Expend.	1983 Est. Expend.	New Funds 1984	Uncomm. Funds From 1983	Avail. for Comm. 1984	Est. Comm. From 1983	Avail. for Exp. 1984
1. Operations							
Personnel Compensation	$ 7,684.6	$ 8,316.0	$ 9,372.0		$ 9,372.0		$ 9,372.0
Personnel Benefits	1,697.5	1,845.1	2,109.0		2,109.0		2,109.0
Travel	458.7	498.9	622.0		622.0		622.0
Material & Supply	3,577.0	3,609.9	4,364.0		4,364.0	$317.3	4,681.3
Subtotal	$13,417.8	$14,269.9	$16,467.0		$16,467.0	$317.3	$16,784.3
Management Fee	$ 295.0	$ 315.0	$ 330.0		330.0		$ 330.0
Special Severance Payment	9.1	68.5					
Total Operations	$13,721.9	$14,653.4	$16,797.0		$16,797.0	$317.3	$17,114.3
2. Equipment							
Research Equipment	$ 1,173.0	$ 1,300.0	$ 1,674.1	$ 542.5	$ 2,216.6	$564.9	$ 2,781.5
12-m Resurface	365.8	43.5				2.0	2.0
Operating Equipment	189.9	97.4	250.0		250.0	49.7	299.7
Total Equipment	$ 1,728.7	$ 1,440.9	$ 1,924.1	$ 542.5	$ 2,466.6	$616.6	$ 3,083.2
3. Design and Construction							
Very Large Array	$ 221.5	$ 122.5					
USNO Interferometer	872.3	275.0		$ 544.0[1]	$ 544.0[1]	$ 61.4	$ 605.4
VLBA			$ 2,500.0		2,500.0		2,500.0
Total Construction	$ 1,093.8	$ 397.5	$ 2,500.0	$ 544.0	$ 3,044.0	$ 61.4	$ 3,105.4
Total NRAO	$16,544.4	$16,491.8	$21,221.1[2]	$1,086.5	$22,307.6	$995.3	$23,302.9

Notes: 1. Includes $165k from USNO Operations
2. NSF Funds $20,600.0k; USNO Funds $621.1k.

1984 Provisional Financial Plan

Operating Expenses by Major Function

	1982 Actual Exp.	1983 Est. Exp.	New Funds 1984	Uncomm. Funds From 1983	Avail. for Commitment 1984	Est. Comm. From 1983	Avail. for Exp. 1984
Operations							
General & Administrative	$ 1,392.7	$ 1,488.9	$ 1,610.0		$ 1,610.0	$ 40.1	$ 1,650.1
Research Support	1,598.6	1,781.7	2,243.0		2,243.0	21.4	2,264.4
Technical Support	1,976.6	2,039.1	2,249.0		2,249.0	62.7	2,311.7
Green Bank Operations	3,002.8	3,150.9	3,663.0		3,663.0	34.8	3,697.8
Tucson Operations	991.2	1,111.3	1,288.0		1,288.0	41.1	1,329.1
Socorro Operations	4,465.0	4,766.5	5,414.0		5,414.0	117.2	5,531.2
Subtotal	$13,426.9	$14,338.4	$16,467.0		$16,467.0	$317.3	$16,784.3
Management Fee	$ 295.0	$ 315.0	$ 330.0		$ 330.0		$ 330.0
Total Operations	$13,721.9	$14,653.4	$16,797.0		$16,797.0	$317.3	$17,114.3

APPENDIX A

RESEARCH PROGRAMS FOR THE NRAO SCIENTIFIC STAFF

APPENDIX A

RESEARCH PROGRAMS FOR THE NRAO SCIENTIFIC STAFF

During 1984 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. PLANETARY STUDIES

The new sensitive VLA 21-cm system will be used to measure the brightness distribution of the thermal radio emission from the planet Pluto. In combination with 1-mm measurements obtained with the bolometer on the 12-m telescope, the surface temperature of the planet will be determined. Previous attempts to detect Pluto's thermal radio emission have proven unsuccessful. Given the current best estimates of the planet's size and albedo, the predicted radio emission should be well within the range of these instruments. Unexpectedly low values of the radio flux could have implications for the solar heating models of the planet's surface. The measurements will also be used to refine the planet's orbit and possibly to detect radio emission from Charon, Pluto's only moon.

Efforts, so far unsuccessful, will continue to detect continuum radiation from comets. Continuum cometary radio emission may in principle arise either as thermal emission from solid particles in the coma (ice or dust) or as nonthermal emission produced by plasma effects. Confirmation and study of the radio continuum emission would provide important basic data on the nature, spatial distribution, and temporal behavior of particulate matter, including the hypothesis of an icy grain halo and on the poorly understood plasma processes in comets.

The long-term program of astromeric measurements of the largest minor planets will continue. Not only does the study reveal physical properties of the asteroids, but its main objectives are a refined location of the vernal equinox and an absolute calibration of the VLA in right ascension without reference to any optically determined standards.

B. GALACTIC STUDIES

1. Stars and the Stellar Environment

Follow-up observations with the VLA will be made of ultra-compact HII regions (diameters 0.5 to 2 arcseconds). Earlier observations which discovered a high proportion of shell or ring-like structures amongst these objects will be tested with the more sensitive new 2-cm VLA receivers. The large number of such compact objects being found, when considered along with their very short ages, suggests revision of the estimated birth rate of massive O stars. Detection of more such objects will also help decide whether stellar winds, currently favored, form the shells. Other confirming observations of the six known shell structures will be made in the OH line at 1667 MHz in order to test for the potential presence of bipolar molecular outflows, which may be produced by the suspected stellar wind sources.

The role of turbulence in the star formation process will be analyzed more thoroughly in an attempt to derive a more comprehensive picture of how both small and large mass stars form out of molecular clouds. Turbulence, which is fed into clouds to support them against free fall collapse, is decoupled when stars form. The roles of massive accretion and of shocks will be assessed in the formation of massive stars.

The program of monitoring the flux density and of measuring the spectral indices of the emission from the winds of six Wolf-Rayet stars will be completed. The search for radio emission will be extended to other evolved stars which show evidence in the infrared for significant rates of mass loss. Continued observations of the highly variable star HM Sagittae, using the VLA, will be used to study stellar wind phenomena in more detail.

The availability of the new 21-cm system, with its greatly improved sensitivity and stability, makes it attractive to repeat the earlier attempt to detect a neutral hydrogen shell associated with the wind-blown bubbles which surround a number of Wolf-Rayet stars. In the intervening time, improved optical velocities of the bubbles are available, so that a smaller velocity range need be searched. Analysis of the dynamics and energy of these shells represents the best opportunity to measure the total mass lost and the rate of energy input to the interstellar medium by Wolf-Rayet stars.

Four years of high-resolution, multi-frequency maps of the evolving SS 433 radio sources will be analyzed in order to study the time-dependent evolution of the radio jets in the context of existing models. Further modelling will be needed before the relationships between different source structures are understood. It is hoped that scaled-up models of this nearby stellar source in our own Galaxy will provide clues to the mechanisms operating in extragalactic radio jets. Similar regular observations of the triple source Sco X-1 should greatly improve our knowledge of how it evolves with time.

A selected group of radio binary stars continues to be monitored with the VLA in an effort to measure their absolute parallaxes and proper motions.

Measurements of the angular diameters of the apparent radio disks of Betelgeuse and Antares will be made at high frequencies and coupled with centimeter, millimeter, and infrared observations to study the extended chromospheric regions around these red supergiants. In some of these cool stellar wind environments, hot companion stars have been discovered which ionize a sub-region of the circumstellar wind and produce typical cavity nebulae. Additional high-resolution observations, as well as theoretical studies and modelling, are planned to better understand the physics of these systems.

Special attention will be paid to planetary nebulae, the peculiar products of advanced stellar evolution. The proto-planetary CL618 will be mapped at 1 and 2 cm with the VLA in order to follow its known temporal changes. Its gradual expansion and transition from optically thick in the radio to optically thin will be monitored for structure changes. Other planetaries will be the subjects of detailed radio-optical comparisons which will strive to obtain temperature, electron density, and extinction distributions throughout the nebulae.

A model of the embedded star IRC+10216 predicts the behavior of the SiS maser throughout the stellar light cycle. Observations are planned which will test that model near maximum light. A number of other circumstellar shells will be modelled and tested with observations of CO, 10 micron SiC emission, and other infrared radiation (from IRAS). The fate of circumstellar shells as planetary nebulae form within them will also be

investigated, using the IUE and the VLA to probe atomic lines in the circumnebular shell, and H_2 emission at the shocked interface of that shell with the expanding nebula.

2. The Interstellar Medium

The physical conditions in star-forming clouds can readily be monitored by observing high excitation transitions in the one millimeter region of the spectrum. The transitions are specific to the dense, warm, active regions of the clouds and their emission is relatively unaffected by absorption from cool, intervening material. Using the high resolution of the 12-m telescope in combination with Onsala observations, a program will be carried out to investigate the velocity-radius structure of several bipolar molecular flows. Since the highest velocity material is limited to the smallest radial distances from a flow source, and therefore has the shortest time scale, the history of a flow can be investigated from a set of data at suitable resolution. The relatively nearby sources GL490, Cep A, and NGC 2071 are most suitable for this analysis. VLA observations will be made to detect enhanced OH emission from shocks in the outflow. The origin of H_2CO in the OMC1 cloud bipolar flow will be investigated with planned simultaneous detection of a set of lines at 291 GHz.

Further observations will be pursued of a newly discovered ensemble of molecular clouds at the galactic center. The clouds appear to be molecular counterparts to clouds which were previously seen in [OI] and thought to be exclusively atomic. These clouds occur in a significant density maximum within a few parsecs of the galactic nucleus, and their total mass is unknown.

VLA maps of nearly 50 bright galactic HII regions will be used to establish the distribution of gas density within these nebulae. From these same nebulae, radio recombination lines have been observed which are sensitive to the distribution of nebular temperature and density. The two types of observations, in combination with a theoretical model of the physical parameters, will be employed in an iterative scheme to evaluate the models of the nebula.

The VLA will be used to map HI absorption toward four extragalactic continuum sources in an attempt to determine the small-scale structure of interstellar clouds. The HI absorption arises primarily in the optically thick cooler constituents of the interstellar medium and provides an unambiguous method for sampling internal cloud structures. 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.

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.

Observations are planned with the 12-m telescope of emission from molecular oxygen in interstellar clouds. Observations of relatively high-frequency lines of the weak $^{16}O^{18}O$ isotope are necessitated by the very strong telluric absorption of the main isotope. O_2 is expected to be an abundant constituent of molecular clouds, and as density increases an increasing fraction of the gas-phase oxygen nuclei are bound up in the molecule. O_2 emission would provide crucial information on the most critical free parameters of interstellar chemistry, the O/C ratio, and the relative abundance of oxygen (relative to hydrogen).

Detection of the ^{13}C line at 492 GHz in a particularly narrow-lined cloud will be sought in order to establish the optical thickness of these lines or to place limits on that and the $^{12}C/^{13}C$ ratio. It may also be possible to establish a correlation of electron abundance with neutral carbon if, like other metals, neutral carbon is an electron donor and must be depleted in regions of exceptionally low ionization.

A confirmation of vibrationally-excited HCO^+ and a search for vibrationally-excited HCN and HNC is planned. Recent laboratory measurements of the rotation constants for the (1,0,0), (0,0,1), and (0,2°,0) states of HCO^+, HCN, and HNC have been made elsewhere. In the case of HCO^+, coincidence of the J = 1-0 transitions in both the (1,0,0) and (0,0,1) states occurs with the two U-lines seen in the NRAO survey toward Ori (KL). The search to confirm the identification for HCO^+ and to seek vibrationally-excited transitions of HCN and HNC will feature the J = 2-1 lines in the 1.2-mm wavelength region.

A search is planned for the exclusive NH_2 radical, of considerable importance in models of gas-phase ion-molecule chemistry of interstellar

clouds. NH_2 has no suitable transitions at wavelengths longer than ~1.3-mm wavelength but has two highly suitable groups of transitions (the $2_{20} - 3_{13}$, J = 3/2 → 5/2 and J = 5/2 → 7/2 transitions) which recently have been accurately measured in the laboratory and lie at ~229 and 242 GHz, respectively. Some preliminary evidence for a signal at the 242 GHz lines has already been obtained, but may be spurious.

Searches for the lowest lying excited rotational states of CH ($\pi_{3/2}$, J = 3/2 and $\pi_{1/2}$, J = 3/2) have recently been made, and detection of the $\pi_{3/2}$ states appears to have been made at Arecibo at 725 MHz. A tentative detection of one of the four lines of the $\pi_{1/2}$, J = 3/2 state has been made at 7375 MHz with the 140-ft telescope. Follow-up studies will be carried out. Detection of such excited states will go far toward helping to understand the universally anomalous pumping of the ground state of CH which has prevented an accurate determination of the abundance of this most fundamental of organic molecules in space.

3. Galactic Studies

The Sgr A region at the galactic center will be further studied in an effort to better understand the relationship of the ultra-compact source with respect to other galactic center features. There is not a one-to-one correspondence between radio and infrared compact features within the core of the spiral-shaped thermal source. Even lower frequency observations are required to help sort out the spectral character of the various components. Further observations of the nonthermal shell-shaped source, Sgr A East, will also be undertaken. The true physical association of the Sgr A West compact thermal source with the superposed nonthermal source has not yet been explained. More extensive observations of both sources in conjunction

with recombination-line velocities should discriminate between competing dynamical models of the region.

Previous large angular scale (1.5°) CO mapping efforts and high resolution (12") HI absorption measurements of the inner region of the Galaxy have led to a better understanding of the kinematics of neutral atomic and molecular gas in these regions. The continuum morphology surrounding Sgr A on a 40-pc scale suggests that some energetic event has caused ionization to occur along the periphery of the single massive neutral gas cloud. On a much smaller scale, a 3-pc rotating gas ring appears heated and morphologically distorted by sources near the galactic center while exhibiting gas infall toward the center. Further delineation of these features and their kinematics will be undertaken with higher resolution VLA HI absorption studies.

The question of how far HI extends out of the galactic plane will be addressed in a combination radio-uv observational sampling of a large number of stars. 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.

Although it is well known that the HI interior to the sun lies in a thin layer that is not perfectly flat, potential large-scale patterns in the known ripples or corrugations remain to be investigated. A study of

possible relationships between the HI ripples, their large-scale patterns, if any, and other large-scale galactic features--such as the outer Galaxy warp or the tilted structures in the galactic nucleus--is planned.

C. EXTRAGALACTIC STUDIES

1. Normal Galaxies

The new, extremely sensitive OH receiver at Green Bank now facilitates an investigation of the confinement of Giant Molecular Clouds to spiral arms in M31. The peculiar 1720-MHz transition of OH traces out large-scale, pseudo-linear structures in our own Galaxy which are most easily interpreted as spiral arms. A spiral pattern in the 1720-MHz line in M31 would not only confirm the notion of confinement of GMCs to spiral arms, of central importance to all star formation theories, but would help confirm that the patterns seen in our own Galaxy are indeed spiral arms.

Several problems which are fundamental to the structure of galaxies have been proposed for investigation with the new Nobeyama millimeter-wave telescope in Japan. 115-GHz CO-line observations of external galaxies could reasonably address the following topics: (1) Are Giant Molecular Clouds confined to spiral arms? (2) Do any nearby galaxies exhibit inner Lindblad resonances similar to that in our Galaxy? (3) What large-scale kinematic and/or radial morphological correlations confirm currently suggested trends which have been determined from low-resolution studies (i.e., radial dependence of temperature and size of GMCs in M31, large-scale ejection of molecular gas out of the plane of M82, the variation with galactocentric radius of isotopic abundances of C and O)?

Analysis will continue of previous observations of the OH distribution in NGC 253, M82, NGC 3628, and NGC 3079 made with the VLA. 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.

VLA maps of the low-inclination "starburst" spirals NGC 1569, NGC 1961, NGC 2207/IC 2163, and NGC 2276 will be made with 2" resolution and compared with Hα + [NII] maps to be obtained at the KPNO 2.1-m telescope. Tens of individual giant HII regions will be isolated and resolved, making it possible to (1) find the fraction of the integrated radio flux in such spiral galaxies which can be spatially associated with a young stellar population, (2) determine whether the (dominant) nonthermal radiation is generated within the HII regions or in shells surrounding them, and (3) model rates of star formation and supernova production.

Studies of clumpy irregular galaxies which may be regions of extreme star formation will continue at radio and uv wavelengths. Twenty-one centimeter-line VLA observations will be made to determine the hydrogen contents of several of the galaxies. One, Mkn 297, has been found to be variable at 6 cm, and will be monitored to better determine the nature of the variability. IUE spectra obtained in 1983 will be analyzed and additional IUE observations obtained. Comparison of the radio and uv emission of clumps in these galaxies should be especially interesting in helping to establish the nature of the phenomena involved.

A program to monitor the supernova remnant in the galaxy NGC 4449 will continue. Observations at 6 and 20-cm are being obtained regularly with the VLA. All of the available optical (spectrum), radio (luminosity), and X-ray data suggest that the object is very young and yet there is no known confirming historical record of the outburst. Marginal evidence for radio variability has led to the current program which should provide definitive information on the validity and degree of the variability of the radiation and therefore provide a proper test of its age.

A large sample of galaxies in many clusters will be observed with the Medusa multiple aperture spectrograph on the Steward Observatory 90-in telescope. The radial velocities thus obtained will provide a basis for dynamical studies of these clusters, most of which also contain radio sources. A parallel program will continue the VLA Abell cluster survey in the B and C configurations in order to obtain a more complete morphological picture of cluster radio emission and its role in cluster evolution.

2. Radio Galaxies and Quasars

Investigations into the complicated polarization distribution of the radio galaxy 3C 449 will continue. The radio jets in this source show extremely complicated depolarization indicating clumping of depolarizing thermal matter on arcsecond scales. It is expected that careful mapping of the depolarization will shed some light upon the location of this thermal material, and, in particular, whether it lies within or just outside the radio jet. In either case the classical arguments concerning the jet density and momentum may need revision.

Thermally unstable cooling flow onto NGC 4696, the dominant galaxy in the Centaurus cluster, may result in $\approx 10^{12}$ solar masses of star formation

per Hubble time. A medium resolution radio map shows a "stepped" jet structure, suggesting that nonthermal energy flow from NGC 4696 promotes the thermal instability, a hypothesis which will be tested by mapping the jet structure at higher resolution and comparing the new map with optical emission-line data.

Studies of the internal structures of kiloparsec-scale radio jets in galaxies using the VLA will be continued, emphasizing the relations between jet collimation, transverse and longitudinal intensity profiles, and magnetic field uniformity and orientation. The goal of this work is to constrain models of confinement, particle acceleration and magnetic field structures in the energy transport "pipelines" within extragalactic radio sources. As an example, the geometrical and brightness symmetries of the parsec and kiloparsec scale jet and counterjet in the radio galaxy NGC 6251 will be examined using both the VLA and an ad hoc VLB array. This work will help to discriminate between relativistic-jet and intrinsic interpretations of asymmetries in extragalactic jets.

Higher resolution VLA observations of four luminous jet sources are expected to resolve the jets in a direction transverse to their major axes for the first time. Lower resolution observations will be necessary for studies of the magnetic field structure surrounding the jets. In another sample, a combined radio and optical study of binary galaxy cores is underway to investigate radio jet kinematics in a reasonably well understood dynamical system. A further goal of the study is to learn more about the distribution of dark matter in such systems. The sources M87, 3C 75, and 3C 465 will be subject to detailed scrutiny since complete data

sets in VLA configuration and frequency space will optimize the analysis of the polarization and spectral index distributions in each source.

Multifrequency observations of the lobes of several extended radio galaxies will be used to derive synchrotron emissivity and magnetic field distributions across these structures for comparison with models of particle transport from the ends of the jet "pipelines." Existing NRAO Astronomical Image Processing Systems (AIPS) software will be modified to determine spatial power spectra of individual lobes for comparison with theoretical predictions. AIPS will also be employed in the direct comparison of VLA images with theoretical brightness and polarization distributions that are a direct outgrowth of a numerical model for synchrotron emission of relativistic eletrons moving in various three-dimensional magnetic field configurations.

VLBI observations will be made to help further understand the dynamics of compact radio sources, including the superluminal sources 3C 453.3 and 3C 273 and the non-superluminal sources 3C 84 and 4C 39.25. Particular attention will be paid to the nucleus of Cygnus A, which is thought to lie in the plane of the sky and therefore is not expected to show superluminal motion. Further study of the radio emission from optically selected quasars, including their angular size distribution, will be used along with the VLBI observations to test relativistic beaming models.

Various statistical studies of radio sources are underway. Eleven hundred extragalactic sources selected in an unbiased manner at 408 MHz (the B3 catalog) are being systematically observed to provide a large, complete sample for eventual statistical analysis. For a large group of

southern radio galaxies, the existing radio data will be analyzed for correlations between the observed radio parameters as well as intercompared with existing quantitative optical spectroscopic information.

Optical studies of several radio galaxies are planned which require observational data from very sensitive, digital response, CCD array detectors. Both radio galaxies in clusters and a sample of 3CR galaxies with moderate redshifts will be imaged in order to detect and analyze the large-scale optical halos that are present in these systems. For a much weaker sample of flat spectrum radio sources, the optical program will search for optical counterparts and possibly detect extended emission and provide color information as well.

The Seyfert galaxies NGC 1068, 4051, 5151, and 6814 have been mapped in HI emission at 35 to 50 arcsecond resolution in an attempt to associate the Seyfert phenomenon in their nuclei with the behavior of the external gas of their galactic disks. The four disk morphologies range from negligibly to highly (e.g., NGC 1068) distorted; three disks have annular gas distributions, three are apparently barred, and two show strong non-rotational motions. With the exception of NGC 1068, which is chaotic in its morphology, the Seyfert galaxy disks do not appear unusual compared with the run of normal spirals. Analysis is only in the preliminary stages, however.

A continuing search is underway for stimulated radio lines toward distant, active galaxies and quasars. Distant radio continuum objects will stimulate the radio lines from any ionized gas that is located along the line of sight to those objects. The strength of the line emission is directly proportional to the intensity of the continuum radiation. Further

detections will assist in determining the physical parameters (density and temperature) of the gas that gives rise to such recombination lines.

Extremely sensitive observations for CO absorption in the spectrum of the distant object AO 0235+164 have been proposed for the 45-m Nobeyama millimeter-wave telescope. Previous 21-cm and optical measurements of this object's absorption system have shown that certain fundamental atomic constants, the fine-structure constant, and the ratio of electron to proton masses have not varied over the past history of the universe. Detection of CO absorption at the previously observed redshift would show that the proton mass has also maintained constancy and, by inference, that the electron mass has remained constant.

The long-term program of investigation of variability in a sample of quasars and radio galaxies begun in 1979 will be continued. In 1984 the effort will be primarily directed to a detailed analysis of the data already obtained. In addition, observations will be made at Arecibo to complement those already made with the 300-ft. For a small sample of D2-candidate quasars, total and polarized intensity maps will be made with the VLA to determine structural classifications and to add to the growing body of data on the systematics of quasar radio structures.

The program to monitor a complete sample of low-frequency variable sources at 318, 430, 606, 880, and 1400 MHz is continuing. The recent suggestion that a large part of low-frequency variability is caused by refractive scintillation in the interstellar medium will be tested by observations of the long-term (days) fading of pulsars. These observations should also settle the question of whether long-term changes in pulsar luminosities are intrinsic or extrinsic.

A confusion-limited survey of the northern sky ($-5° < \delta < +80°$), using the rebuilt 1400 MHz four-feed receiver on the 300-ft telescope, is half complete, although the data is not yet full reduced. Adequate gain and baseline stability have been obtained so far to show structures as large as the galactic plane. The remaining 12^h of right ascension will be mapped, and the entire survey will be put into the form of an AIPS processable map. As an historical record of the 1400-MHz sky at the time of observation, it is expected that the survey will be universally useful for source identification and variability studies.

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. The results of an intermediate survey over ~100 VLA fields will be followed up by optical work on the ~500 sources detected with flux densities in the range 350 μJy to 5 mJy. At 1465 MHz, a deep VLA survey has resulted in counts of sources as faint as 84 μJy. The counts will be modeled to constrain the evolution of faint radio sources. The sources will be observed with somewhat higher resolution so that their angular-size distribution can be determined.

D. MISCELLANEOUS

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.

Investigations of the optimum methods of VLA data processing are planned. Particular attention will be paid to two areas: firstly, the general problem of image reconstruction from incomplete and noisy data; and, secondly, the extension of the selfcalibration technique to weak sources and to large, non-isoplanatic fields of view. These research areas reflect a need for new numerical techniques to enhance the capabilities of the VLA and other synthesis instruments.

Observations are in progress with a two-channel radiometer which will give an indication of the usefulness of Puerto Rico as a VLBA site. The observations will also be useful in the study of the general problem of the accuracy with which delays arising in the water vapor in the atmosphere can be estimated.

APPENDIX B

NRAO PERMANENT SCIENTIFIC STAFF WITH MAJOR SCIENTIFIC INTERESTS

APPENDIX B

NRAO PERMANENT SCIENTIFIC STAFF, WITH MAJOR SCIENTIFIC INTERESTS

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

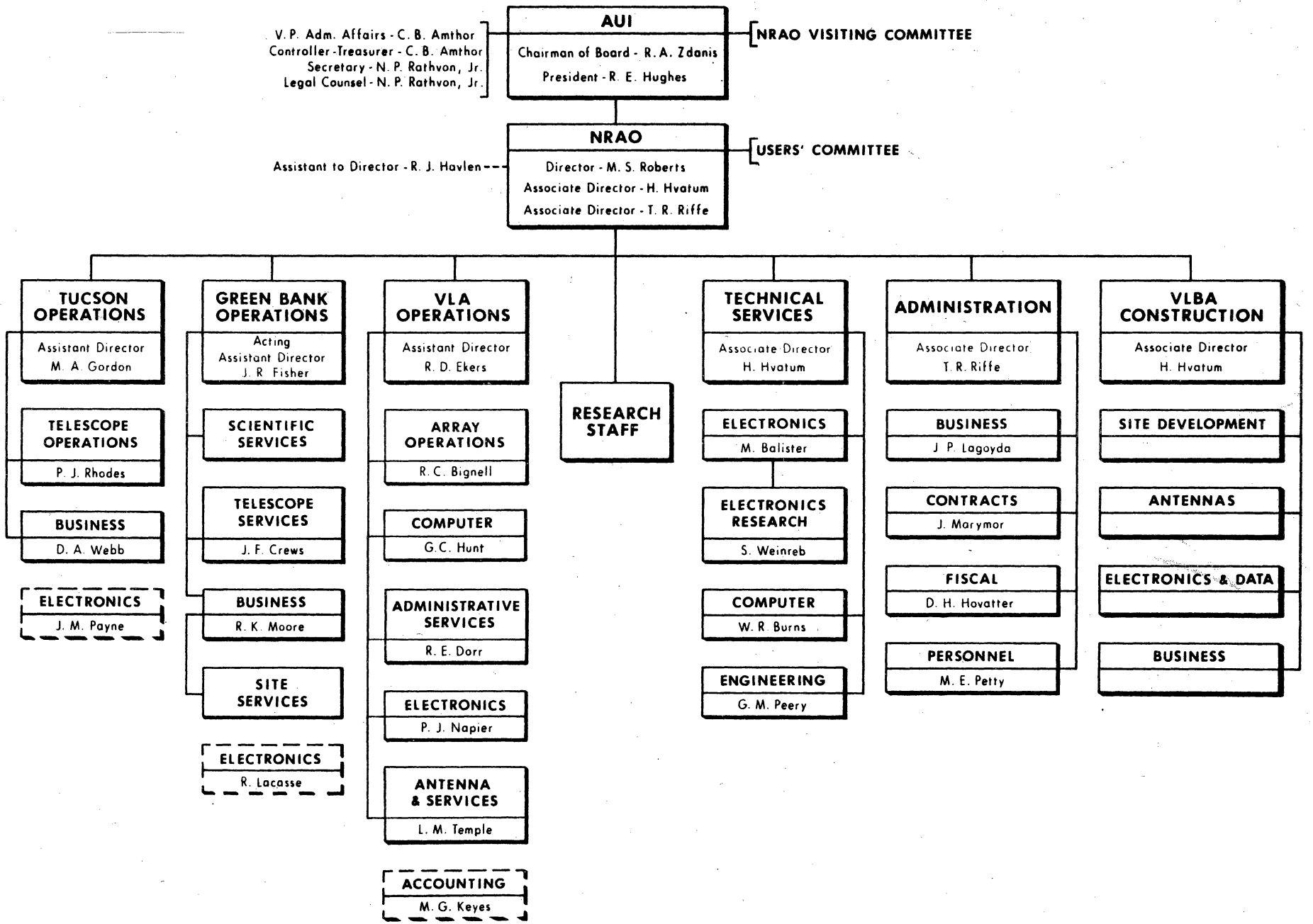
Liszt, H. S.	Molecular Lines; Galactic Structure
Lockman, F. J.	Galactic Structure; Interstellar Medium; HII Regions
Owen, F. N.	Clusters of Galaxies; QSOs; Radio Stars
Payne, H. E.	Interstellar Medium; Low Frequency Variables
Perley, R. A.	Radio Galaxies; QSOs; Interferometric Techniques
Roberts, M. S.	Properties and Kinematics of Galaxies
Rots, A. H.	Extragalactic Research; Spectral Line Interferometry
Sramek, R. A.	Normal Galaxies; Quasars; Astrometry
Turner, B. E.	Galactic and Extragalactic Interstellar Molecules; Interstellar Chemistry; Galactic Structure
Wade, C. M.	Astrometry; Stellar Radio Emission; Minor Planets
Weinreb, S.	Millimeter Wave Development
Wells, D. C.	Digital Imaging Processing; Extragalactic Research
Wootten, A.	Molecular Clouds; Circumstellar Shells

APPENDIX C

NRAO ORGANIZATIONAL CHART

NATIONAL RADIO ASTRONOMY OBSERVATORY
ORGANIZATION CHART

October 1, 1983



APPENDIX D

NRAO COMMITTEES

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:

Dulk, G. A.	University of Colorado
Evans, J. V.	COMSAT Laboratories
Hewish, A.	University of Cambridge, England
Richards, P. L.	University of California, Berkeley
Seaquist, E.	University of Toronto
Shapiro, I. I.	Harvard University (Center for Astrophys.)
Strittmatter, P.	University of Arizona (Steward Obs.)
Vanden Bout, P. A.	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, appointed by the Director, meets twice a year.

The present membership of this Committee is:

Bell, M.	Herzberg Institute of Astrophysics
Berge, G. L.	California Institute of Technology
Bieging, J. H.	University of California, Berkeley
Blitz, L.	University of Maryland
Briggs, F. H.	University of Pittsburgh
Dennison, B. K.	Virginia Polytechnic Institute and State University
Dulk, G. A.	University of Colorado
Giovanelli, R.	Arecibo Observatory
Goldstein, S. J.	University of Virginia
Gottesman, S. T.	University of Florida
Helfand, D. J.	Columbia University
Ho, P. T. P.	Harvard University
Lo, K-Y.	California Institute of Technology
Lovas, F. J.	National Bureau of Standards
Marscher, A. P.	Boston University
Mutel, R. L.	University of Iowa
Myers, P. C.	Center for Astrophysics
Partridge, R. B.	Haverford College
Phillips, R. B.	Haystack Observatory
Price, R. M.	University of New Mexico
Reid, M. J.	Smithsonian Center for Astrophysics
Rodriguez, L.	Observatorio Astronomico Nacional
Rudnick, L.	University of Minnesota
Seaquist, E. R.	University of Toronto

Stark, A. A.	Bell Laboratories
Weisberg, J. M.	Princeton University
Welch, W. J.	University of California, Berkeley
Wilson, A. S.	University of Maryland

APPENDIX E

THE VERY LONG BASELINE ARRAY PROGRAM

NATIONAL RADIO ASTRONOMY OBSERVATORY

1984 VERY LONG BASELINE ARRAY (VLBA) PROGRAM

VLBA

PART 1. DISCUSSION OF 1984 ACTIVITIES

VERY LONG BASELINE ARRAY (VLBA).....($2,500,000)

During 1984, the NRAO's VLBA efforts will be concerned primarily with taking existing VLBA concepts and preliminary designs and turning them into purchasable designs with schedules and detailed cost estimates for each element of the project. The major VLBA activities to be undertaken in 1984 are set out below.

Antenna System

Early in 1984 the contract work proposed for the VLBA antennas will be advertised in Commerce Business Daily and an RFP issued to qualified companies. The RFP will call for the design of the antenna with unilateral options to be exercised by AUI for the manufacture and delivery of ten such antennas under terms and conditions to be prescribed in the RFP. Detailed design of the antennas will commence immediately upon contract award.

The preliminary schedule for selecting the antenna contractor is:

VLBA Antenna Contract Selection Schedule

December 20, 1983 - Advertisement for Commerce Business Daily submitted to NSF for approval.

January 5, 1984 - Approved advertisement runs in Commerce Business Daily.

February 1, 1984 - Request for proposals issued to qualified companies.

March 1, 1984 - Preproposal conference held in Charlottesville.

May 1, 1984 - Proposals due at NRAO.

July 15, 1984 - Recommendation for award of contract forwarded to NSF for approval.

August 1, 1984 - Contract awarded to successful firm.

An Antenna Contract Selection Committee composed of NRAO scientists, engineers, and senior business and fiscal personnel has been designated by the Director to assist in the selection and award of the antenna contract. This committee is set out below.

VLBA Antenna Contract Selection Committee

Contract Selection Committee

Chairman: H. Hvatum, Associate Director
T. R. Riffe, Associate Director
K. I. Kellermann, Senior Scientist

Technical Evaluation Committee

Chairman: J. W. Findlay, Senior Scientist
W. G. Horne, Antenna Engineer
L. J. King, Structural Engineer
L. Temple, Head, VLA Antenna Division

Business Evaluation Subcommittee*

Chairman: J. Marymor, Contracts Manager
D. H. Hovatter, Fiscal Officer
M. E. Petty, Personnel Officer
_____, VLBA Business Manager

* Will be assisted by AUI Internal Audit group as necessary

Site Acquisition

In early 1984, the location for the VLBA Control Center will be determined and the Foundation will be requested to proceed with acquiring the site. By mid-1984 the ten VLBA antenna sites will be fixed and their ownership determined. Requests to have NSF acquire these sites will be forwarded to the Foundation as they (individually) become known during the year.

Site Development and Site Facilities

During late 1983, the NRAO will begin the process of selecting an Architect-Engineer (A/E) firm for the site(s) work. The anticipated contract award date for the A/E is May 1984. The principal tasks for the A/E in 1984 will be to complete the general plot and lay-out for a typical antenna station, assist in completing detailed cost estimates for all site work, complete the preliminary design of the Operations Control Center by December 1984, and assist in preparation of local and/or state environmental impact statements if and when necessary. (Note: It is assumed that federal environmental impact statements will not be necessary for the VLBA antenna sites.) A preliminary schedule for the selection of an Architect-Engineer firm is:

VLBA A/E Contract Selection Schedule

October-November 1983 - Scope of work to be performed by the A/E defined.

December 1983 - Solicitation letters sent to several A/E firms; ad placed in Commerce Business Daily.

January 1984 - Process of reducing the number of respondents to a workable number begun by the NRAO Contract Selection Committee.

February 1984 - Interviews with a small number of interested A/E's (7-8).

March 1984 - Final selection and recommendation of award forwarded to NSF.

April 1984 - Approval to negotiate with the successful A/E given by NSF.

May 1984 - Contract awarded.

The following committee has been established by the Director to assist in the selection of an architect-engineer for the VLBA project:

VLBA Architect-Engineer Contract Selection Committee

Contract Selection Committee

Chairman: H. Hvatum, Associate Director
T. R. Riffe, Associate Director
K. I. Kellermann, Senior Scientist

A/E Evaluation Subcommittee

Chairman: G. M. Peery, Head, Engineering Division
R. C. Walker, Systems Scientist
S. C. Smith, Civil Engineer
J. Marymor, Contracts Manager
J. P. Lagoyda, Business Officer
_____, VLBA Business Manager

Electronics System

In 1984, the VLBA front-end and feed system design will begin and some prototype feed development will be undertaken. There will be no major electronic procurements during 1984.

Data Recording System

In late 1983, the Massachusetts Institute of Technology (MIT) is expected to offer a proposal whereby MIT will design and build the VLBA recording system under a contract with NRAO. Preliminary discussions between NRAO/MIT should be completed in November 1983 and the scope of work and a contract price for the data system agreed upon by January 1984.

Monitor and Control System

The design of the electronics part of the antenna control system will be undertaken in 1984 and the software development for the antenna computers will begin. There will be no major monitor and control procurement during 1984.

Processor System

In late 1983, the California Institute of Technology (CIT) is expected to offer a proposal whereby CIT will design and build the VLBA processor system under a contract with NRAO. The processor design, which is currently being developed at CIT, is tentatively scheduled to be adopted as the VLBA processor system. The scope of the work and a contract price for the processor system will be agreed on by NRAO/CIT in early 1984.

Project Management

The VLBA project management staff will be assembled in Charlottesville during 1984 and quartered in NRAO rented office facilities on Ivy Road. The project management staff will be headed by a Project Manager who will have general direction of VLBA construction activities. The NRAO is currently seeking a project manager for the VLBA construction program, and it is anticipated that the position will be filled in 1984. Dr. Hein Hvatum, Associate Director for Technical Services, is currently holding this position.

During 1984, the VLBA project staff will be concerned with developing detailed time and cost schedules for the project; purchasing and subcontract administration; and developing field construction and management guidelines for the project to cover local administrative and logistical requirements for the various VLBA sites. All general management and operating procedures adopted for the VLBA project will be consistent with existing Observatory practices and procedures.

Part 2 shows the projected staffing for VLBA construction covering the five-year period 1984-1988. Peak staffing for the project will occur in 1986-87, although it could change somewhat depending on the project funding schedule finally adopted by the NSF. (A funding schedule of $2.5M, $20.0M; $20.0M; $20.0M for 1984-87 is presently contemplated by NRAO.)

VLBA

PART 2. PROJECT STAFFING PLAN

Very Long Baseline Array

Project Staffing Plan
(Number Employees @ 12/31)

	1984	1985	1986	1987	1988
Site Development	2	4	4	4	3
Antenna System	1	8	8	8	6
Electronics System	14	20	21	19	13
Data Recording System	2	2	2	2	-
Monitor and Control	4	4	7	7	6
Processor	1	1	1	1	-
Post Processing	-	2	3	4	1
Project Management	10	10	10	10	10
Total	34	51	56	55	39
Estimated Man Years	23	48	56	54	34

VLBA

PART 3. 1984 FINANCIAL PLAN

VLBA Financial Plan - 1984

The distribution of planned commitments and expenditures for VLBA activities in 1984 are given in the following table:

	Man Months	Salaries and Wages	Employee Benefits (22.5%/wage)	Material and Supply	Travel	Contract Charges	Total
				(thousands)			
1. Site Development	9	$ 30.0	$ 7.0	$ 2.0	$15.0	$ 81.0	$ 135.0
2. Antenna Syst.	9	20.0	5.0	5.0	8.0	785.0	823.0
3. Electronics Syst.	98	211.0	47.0	132.0	10.0	-	400.0
4. Data Recording Syst.	24	56.0	13.0	1.0	8.0	295.0	373.0
5. Monitor and Control	36	84.0	19.0	40.0	8.0	-	151.0
6. Processor Syst.	12	24.0	5.0	2.0	4.0	290.0	325.0
7. Post Processor	-	-	-	-	-	-	-
8. Project Management	86	189.0	42.0	10.0	19.0	-	260.0
Subtotal	274	$614.0	$138.0	$192.0	$72.0	$1,451.0	$2,467.0
Other:							
9. Spare Parts	-	-	-	-	-	-	-
10. Contingency	-	-	-	$ 33.0	-	-	$ 33.0
Total	274	$614.0	$138.0	$225.0	$72.0	$1,451.0	$2,500.0

1. Salaries and Wages.....$614,000

In 1984, approximately 23-man years of direct in-house labor costs will be incurred by the VLBA project. These costs cover the salaries and wages of VLBA employees who have been hired directly into the project or transferred into the project from other Observatory operations. In addition to those employees whose wages are charged directly to the

project, other non-direct NRAO employees will be involved in overall planning, design and procurement activities for VLBA during 1984. Certain of these latter employees will be transferred full-time into the project in 1985 as construction gets underway.

2. Employee Benefits.....$138,000

Benefits are computed at 22.5% of salaries for the NRAO during 1984. All NRAO cost centers (e.g., VLBA) bear the same benefit rate.

3. Material and Supply.....$192,000

The majority of Material and Supply expenditures for the VLBA in 1984 is expected to be in the electronics and monitor and control areas of the project. Considerable prototype work in feed systems and front-end development in 1984 will require the early procurement of both current shop material and laboratory bench stocks.

4. Travel.....$ 72,000

Travel costs are expected to be relatively high in 1984 due to moving costs of new employees hired for the project and the relocation expenses of NRAO employees who are expected to transfer to the project. In addition, it is anticipated that considerable travel expenses will be incurred in the area of site evaluation, acquisition, and development and in the selection of an antenna contractor.

5. Contract Charges.....$1,451,000

Almost 60% of the $2,500,000 VLBA allocation in 1984 is earmarked for contract work, primarily design activities.

(a) Site development: $81,000 is the amount estimated for the first phase A/E work in 1984, which is expected to include the design of an

antenna control building that can be adapted to all antenna sites; a typical site layout, including the telescope foundation, utilities, roads, etc.; and completion of the preliminary design of the Array Operations Center (AOE).

(b) Antenna system: $785,000 is the amount estimated for the contract for antenna design and for engineering consultants for pre-contract award design work.

(c) Data recording system: $295,000 will be required to support the design and development work by MIT on the data-recording system during 1984.

(d) Processor system: $290,000 is the amount Caltech has estimated will be required to support its development efforts on the VLBA processor during 1984.

VLBA

PART 4. CONTRACTOR SELECTION PROCEDURE

PART 4(A)

PROCEDURE FOR SELECTION OF THE ANTENNA SUBCONTRACTOR

The following procedures will be adhered to in the selection of a subcontractor to design, manufacture, deliver, erect, align and test the 10 radio telescopes required for the Very Long Baseline Array Telescope System.

1. Preparation of the Request for Proposals

This document will be prepared by the NRAO staff and consultants, reviewed by AUI, and submitted to the National Science Foundation. An agreed upon version will be the basis for the procurement action.

2. Qualification of Potential Subcontractors

Qualification will be accomplished by the following methods:

(a) Solicitation of known concerns - There are several concerns in the United States who have designed and erected large steerable antennas. The interest of these firms will be solicited directly by letter.

(b) Publication of notice in the Commerce Business Daily - A notice will be placed in the Commerce Business Daily setting forth information on the project and requesting interested concerns to contact the VLA Project Manager.

(c) Qualification of concerns - Interested concerns will be requested to furnish Form 251 or other data to show that they are generally qualified. Should it be found that a firm is not qualified, it will be so notified. Should an impasse result where the concern states that it is qualified and insists on receiving the RFP, copies will be forwarded.

3. Issuance of the Request for Proposals

Two copies of the RFP will be sent to each concern. Transmittal letter will be brief and will not repeat data which is contained within the body of the RFP. Twelve weeks will be allowed for the preparation of the proposals.

4. Pre-Proposal Conference

A pre-proposal conference of all interested parties will be held at Charlottesville, Virginia, about four weeks after issuance of the RFP.

5. Requests for Interpretation of Documents

Efforts will be made to have concerns submit their questions in writing. All answers will be in the form of written addenda to the RFP.

6. Contents of Proposal

Proposals will contain the following sections:

General Summary of the Proposal

Technical Proposal Based on AUI Design Concept

Alternate Technical Proposal

Business Proposal

Master Summary Schedules

Subcontract Price

Price and cost data will be received in separate sealed envelopes.

7. Review of Proposals

The Director of NRAO will name the following:

Contract Selection Committee which will have overall responsibility for selection of the successful concern and making the recommendation of award to the Director of NRAO. The Committee will be assisted by the following two subcommittees.

Technical Evaluation Subcommittee which will have the responsibility of delving deeply into all technical aspects of the proposals to ensure that the proposed designs are feasible and will meet the requirements of the RFP.

Business Evaluation Subcommittee which will have the responsibility of ensuring that the concerns have the resources, financial strength, and management capability to properly execute the work covered under the RFP.

The Contract Selection Committee shall direct the priorities and activities of the two Evaluation Subcommittees. Price information will not be divulged to any outside person or organization until the selection has been made.

As the selection process proceeds, it is expected that each Evaluation Subcommittee will review the entire proposal of the key concerns.

Each Evaluation Subcommittee shall prepare its own "Criteria for Evaluation" and shall file them with the Contract Selection Committee prior to the receipt of proposals.

Written reports will be furnished by the Subcommittees on the concerns as requested by the Selection Committee.

It is expected that one or more technical and management conferences will be held with key concerns during the selection process and requests for additional data sent out.

8. Selection of the Subcontractor

After full consideration of all facets, the Contract Selection Committee will make a selection and recommendation to the Director of NRAO setting forth in writing the basis for the selection. After approval by the NRAO Director, the selection will be forwarded to the NSF for approval. Public announcement and the notice to unsuccessful proposers will not be given until the NSF has approved the selection.

9. Liaison with the National Science Foundation

NSF will be kept fully informed as to the selection process to the extent that NSF requests.

10. Negotiating Committee

The Director of NRAO shall name a Negotiating Committee to negotiate the terms of the contract with the successful concern.

PART 4(B)

PROCEDURE FOR SELECTION OF THE ARCHITECT-ENGINEER

The following procedures will be followed in the selection of an Architect-Engineer subcontractor to complete preliminary planning, detailed design, preparation of working drawings and specifications, and assistance during construction for the ground facilities, structures, buildings, site work and utilities required for the Very Long Baseline Array Radio Telescope Project.

1. Selection Committee - The Director, NRAO will name a selection committee to accomplish the selection of the Architect-Engineer. This committee will include senior engineers and NRAO business employees acquainted with the requirements of the project.

2. Description of Work Requiring A/E Participation - This document will set down in general terms those items of work which will require the services of an Architect-Engineer.

3. Scope of Architect-Engineer Services Required - This document will set down the services which will be required of the Architect-Engineer.

4. List of Preliminary A/E Qualifications - A list of preliminary Architect-Engineer qualifications will be prepared to assist in compiling the names of firms to be solicited. This list will include such items as geographic location of firm, size of firm, type and extent of integrated services required, experience of firm, etc.

5. Selection of Initial List of A/E Firms - An initial list of A/E firms to be considered will be prepared using the following sources:

McGraw-Hill Information Systems Company

Engineering News-Record Listing of Design Firms

National and State Engineering Societies

National and State Architectural Societies

Solicitation Letters to NRAO

Commerce Business Daily

6. Obtain Data on Initial List of A/E Firms - Where adequate data is not available on a firm's general capabilities, a letter requesting Form 251, brochures or other data will be sent.

7. Selection of Firms to be Solicited - This selection of up to ten firms will be made by the Selection Committee using the List of Preliminary A/E Qualifications and rating each firm on its qualifications.

8. Request for Proposals - This document will set forth the scope of the A/E work required and request formal proposals from the firms solicited. It will be much less formal in format than the RFP's used for commercial work. Pricing data will not be requested at this time nor will the type of contract to be used specified.

9. Criteria for Final Selection - A final selection criteria will be prepared setting forth those items upon which the selection would be made and giving each a weighted point value.

10. Review of Proposals - The Selection Committee will analyze the proposals, develop additional information as required, and narrow the selection down to one to three firms. These will be interviewed at their

home offices and discussions held with the key personnel to be assigned to the project. At this time general data on direct and overhead costs will be obtained to ensure that there will not be a major differential in cost between the firms selected for interview and final consideration.

11. Selection of the A/E Subcontractor - After full consideration of all facets, the Selection Committee will make a selection and a recommendation to the Director of NRAO setting forth in writing the basis for the selection.

12. Liaison with the National Science Foundation - The Foundation will be kept fully informed as to the selection process to the extent that the Foundation requests.

13. Negotiating Committee - Upon selection, the Director of NRAO will name a negotiating committee to negotiate the type, cost, and terms of the subcontract with the successful firm.

VLBA

PART 5. OTHER

VERY LONG BASELINE ARRAY

Preliminary Antenna Design and Delivery Schedule

Antenna Design and Engineering	Start	Complete
Initial Design	Aug. 1, 1984	Oct. 30, 1984
AUI Review	Nov. 1, 1984	Nov. 31, 1984
Final Design	Dec. 1, 1984	Jan. 31, 1985

Antenna Authorization* Dates and Delivery Schedules

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

Antenna Contract Term

Design Start	Aug. 1, 1984
Construction Completed	Feb. 28, 1988
Total Term	43 months

*Equals commitment date

VLBA Preliminary Antenna Delivery Schedule