NATIONAL RADIO
ASTRONOMY
OBSERVATORY

PROGRAM PLAN
1986

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NATIONAL RADIO ASTRONOMY OBSERVATORY

CALENDAR YEAR 1986

PROVISIONAL PROGRAM PLAN

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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 Agustin, 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.

Allocated observing time remains at a premium at all NRAO telescopes and no let up is foreseen into 1986. Increasingly sophisticated astrophysical problems demand the integration of large multi-wavelength databases across the electromagnetic spectrum, and radio observers no longer stand isolated from their colleagues at other wavelengths. The demand for radio data is high. A major impetus behind the current utilization of radio data has been the NRAO policy of continually developing state-of-the-art instrumentation to widen the accessibility of broad regimes of the radio spectrum while at the same time increasing instrumental resolution, sensitivity and dynamic range. New technologies are rapidly transformed to practical working receivers and operating systems which expand the observing potential of existing telescopes.

Section II of this Program Plan summarizes the research that visiting investigators are planning to undertake with the NRAO telescopes during

1986. More than 70% of the available observing time will be used for this purpose.

Section III of the Plan describes the continuing research instrumentation developments which will take place at the Observatory during 1986. These include instruments which are used directly as integral elements of the telescope-receiver-computer data acquisition chain or which are part of the off-line signal and image processing and data-analysis scheme. The instrumentation expenditures fall equally heavily on the electronics and computer hardware areas. A dynamic electronics research and development effort is one of the driving forces behind the application of technological advances to astronomical instrumentation and therefore is a vital part of the NRAO. Likewise, imaginative approaches to the optimal use of available computer resources are crucial to the total astronomical data acquisition and analysis process. Highlights of the 1986 effort in these areas will include advanced development of SIS receivers and research into the design of planar arrays in order to exploit multi-beaming techniques at the 12-m telescope, the rapid deployment of 327-MHz receivers on more than half of the VLA antennas, the initial production of 8.4-GHz receivers to outfit the VLA for the NASA Voyager encounter with Neptune, and continued work on an extremely versatile and efficient spectral processor for the 300-ft telescope.

Subsequent sections give the detail of the expenditures required for operations and maintenance of the Observatory and their breakdown according to geographic cost centers. Included are specific sections to describe in detail the arrangements made by the National Science Foundation for the NRAO support of portions of the USNO and NASA programs in astronomy. Provision has been made for the operation of the Green Bank four-element interferometer for the USNO (Section VI) and the production and installation of 8.4-GHz receivers for VLA support of the 1989 encounter of the NASA Voyager spacecraft with Neptune (Section VII).

Appendices to this Plan include a summary of the scientific program of the NRAO permanent staff, a list of the staff and their principal research interests, an organizational chart for the NRAO, and a list of various committees associated with the NRAO, and the 1986 VLBA Program Plan.

II. SCIENTIFIC PROGRAM

The scientific programs that will be carried out with the NRAO telescopes during 1986 come from the community of physicists and astronomers world-wide in response to the availability of recently developed instrumentation and rapidly changing scientific priorities. More than ever before in the history of radio astronomy, the goals of numerous programs depend in a complicated way on multi-wavelength observations in the x-ray, ultraviolet, optical, infrared, and radio spectral regimes. Although many of the 1986 programs have yet to be submitted, the existing proposal backlog is indicative of the many areas of scientific interest that will be pursued at the NRAO in 1986. The following summary, by telescope, illustrates the science that will be accomplished during the year.

The VLA. Spectral versatility, mechanical reliability and stability, and user friendliness continue to improve at the VLA and to impact positively on the broad range of programs that can be carried out. The number of antennas outfitted with 327-MHz receivers will exceed 12 during the year, and an increased demand for low-frequency observations has already been felt. Improved telescope pointing as a result of thermal insulation retrofits will improve the reliability of short-wavelength observations. Absentee and remote observing programs will continue in force. The number of proposal submissions and their success rate remains impressively high.

VLA studies of the Sun continue to concentrate on simultaneous multi-wavelength observations of transient events. Coordinated observations of hard x-ray microbursts will be attempted with the VLA and with balloon-launched instrumentation. Precision observations of features with various scales and characteristics, such as magnetic loops, prominences, new and old active regions, and coronal holes, will be best observed during the next year or two of sunspot minimum when their brightnesses will be minimally confused by the much brighter active regions. The entire Sun will be mapped twice per year during simultaneous 300-ft and Arecibo observations. In the area of planetary studies, a long-term astrometric study of the brightest asteroids will be continued. The VLA will play a critical role in a monitor patrol of the properties of Jupiter's magnetosphere spanning the uv, optical, IR, and radio spectral regimes. As Comet Halley passes in front of radio sources, occultation events will be monitored in order to maximize our knowledge of the physical environments in the coma and tail.

Stellar research has proven to be an extremely fruitful area for the application of VLA sensitivity and spectral flexibility. During the coming year, the fraction of observing time devoted to this area will remain high. Pulsar observations will be used to establish the positions and spectral properties of recently discovered pulsar candidates, including one in the globular cluster M28. For other young pulsars, the weak extended emission of potentially related supernova remnants is targeted for study. Flares from Cyg X-3 and other low-mass binaries will be monitored for the purpose of specifying parameters of the twin jet models for x-ray emission. Yearly astrometric monitoring of the proper motion and lobe structure of Sco X-1 will continue. Survey observations of a group of known and proposed RS CVn binaries will aim to establish period-luminosity and/or luminosity-activity index-correlations for stellar systems of this class. For cataclysmic variables involving magnetic degenerate dwarfs, VLA observations will clarify the nature of the radio-emission mechanism. The detection of radio emission from luminous supergiant winds that are ionized by hot binary companions will provide information about supergiant mass loss. Studies of apparently non-binary stars also show much promise. For known magnetic variables, for example, the correlation of radio emission with rotation will directly test the magnetic origin of the emission and test the oblique rotator model for magnetic stars. Tests of models of coronal heating and radio emission for dwarf stars will be extended from the M dwarfs to the K dwarfs. Spectral surveys of flare stars will be extended to 327 MHz and correlations made with higher frequency flares. High dynamic-range observations of evolved OH/IR stars will map the structure of low-level maser emission and better constrain the geometry of the mass-loss process.

Numerous programs are expected to key on planetary nebulae and the remnants from novae, supernovae, and high-mass stars. A detailed study of the temperature distributions of planetaries will complement the structural picture derived by optical and uv means and ultimately aid in determining the composition of the nebulae and of the pre-ejection stellar envelope. A general survey of the size, flux density, and structure of planetaries will provide a much improved statistical base for study. Radio maps of the nearby, faint, large nebulae will be carefully compared with IRAS maps. Detailed spectral observations of the non-thermal radio remnant of the classical nova GK Per will attempt to explain its anomalous appearance in light of the negative detections from other old novae. The oldest remnants will also be reobserved for faint extended emission that may have been missed in the previous survey. A search for a neutral hydrogen cloud surrounding Kepler's SNR will potentially lead to new information about the interstellar medium well out of the galactic plane. Observations of the central source in the W44 SNR will attempt to reconcile the radio and x-ray morphologies. A flux-limited sample of Crab-like supernova remnants in M31 will significantly aid in establishing neutron-star birth rates.

Considerable attention will be given to morphological, spectral, and kinematic studies of HII regions and molecular cloud star-formation regions in the Galaxy. Especially important are the intercomparison of VLA radio data with the existing IRAS observations of many galactic sources. Absolute position measurements of OH and H_2O masers with respect to compact HII regions, IR sources, and bipolar outflows will help to establish a firm statistical basis for the maser phase in the context of massive star formation. Water-maser polarization measurements will probe the magnetic field configurations of several star-forming regions. Disk-like molecular cloud condensations will be searched for thermal OH emission which could be candidate collapsed structures for Zeeman magnetic field studies. Astrometric-maser observations will continue to provide important distance and motion determinations for kinematic studies in the Galaxy. Formaldehyde observations in Orion will search for protostar candidates as a prerequisite for hydrodynamic modeling of cloud collapse in OB star regions. Several compact HII regions will be directly tested for the radial outward expansion and turbulent motion expected from their young ages. A bench-mark study of the Orion nebula will archive two sets of high-dynamic range, high-resolution continuum maps for multi-level analyses of the physics of star formation. The polarization characteristics of the outer filaments of the Orion nebula will be obtained in order to test the role that magnetic fields have in the formation of filaments. Observations of HII regions in the Outer Galaxy will better characterize star formation there.

The H_2O maser cluster in Sgr B2 will be monitored and the distance to the galactic center derived using the statistical parallax method. Observations at 327 MHz toward the galactic center will help constrain models of the structure of the region. At the same time, follow-up observations of the peculiarities of the streamers, filaments, and large-scale morphology of Sgr A will help strengthen our understanding of the magnetics of the region. Outside the galactic center, magnetic field studies will focus on the Scutum and Norma arms and help distinguish among several competing models for the origin and nature of the galactic magnetic field.

The VLA continues to be heavily used to investigate the spectral, morphological, and temporal properties of every variety of extragalactic source, both in support of and independent of multi-wavelength studies from other non-radio spectral regimes. Classical radio galaxies form only a subgroup of objects under analysis as many weaker sources and normal galaxies come under study. Sbc galaxies having the strongest central radio emission will be compared with IRAS data in an attempt to elucidate the processes of ejection and star formation in spiral nuclei. Radio data on a complete IRAS selected sample of galaxies will be sought in an effort to correlate their IR properties with other peculiar spectral properties. For a selection of galaxy types, high-resolution observations will be used to determine rotation curves, study nuclear features, analyze polarization properties, and survey HII regions. Several interesting pairs of galaxies will be surveyed in order to test the effect of the interactions on increased nuclear radio activity and its correlation with star-formation activity. Further investigation of megamaser galaxies and the search for main-line OH masers in M33 will provide valuable information about extragalactic star-formation centers. A low-frequency 327-MHz survey of Seyfert galaxies and related objects is expected to sharpen the distinction between the character of their radio sources and the absorbing properties of the surrounding gas, while accurate positional measurements of the radio components of other Seyfert galaxies will facilitate comparison with their optical images.

Radio-galaxy studies will begin to take advantage of the developing 327-MHz capability of the VLA in order to uniquely determine the low-frequency structure of radio galaxy halos. High-resolution observations of the interaction between radio jets and the ambient medium should reveal much about the dynamics of jet fluid flow. Other detailed observations of jets will search for motion in the knots of Cen A and attempt to further resolve helical structures and look for motion in the jet of M87. Models for the transport of relativistic material from the nuclei to the distant lobes will be subject to observational test in a survey of the strongest quasars for jet sidedness. The complete study of jet statistics will require the greatest possible sensitivity and dynamic range of the VLA. Computer simulated models of Magnetic field effects in jets and lobes will be tested by means of Faraday rotation and depolarization observations. VLA and MERLIN data will be merged to form the highest quality images for physical analysis of a few specific 3C sources. Snapshots of a large sample of sources from the Bologna B3 survey will be acquired for a statistical test of source alignment effects. Intercomparison of new VLA maps with existing optical observations will provide new insights into the influence of the dynamics of dumbbell galaxy systems on their extended radio source structure.

Several programs to further investigate the radio properties of quasars will be carried out with the VLA. Rotation measures of quasars from the Molonglo survey will be observed in order to refine and extend estimates of intervening magnetic-field strengths out to a redshift of $z = 3$. High-resolution observations of radio sources at high z will be analyzed for evidence of linear size evolution and differences between quasars and radio galaxies. Observations of redshifted HI in the 327-MHz band will be used to sample the HI environment of high redshift quasars as a probe of mass aggregations in the early Universe. The extended radio structures of an x-ray selected sample of BL Lac objects will be observed in order to test the "unified" model of radio sources based on the orientation of relativistic jets. Coordinated VLA, EXOSAT, IUE, and optical observations will be made of a rapidly varying, x-ray-discovered, BL Lac object.

Survey and monitor programs will continue to receive attention at the VLA. High-dynamic range, high-resolution observations of several steep spectrum sources will complement a 408-MHz Bologna program that is monitoring low-frequency variables. Polarization measures at 327 MHz of another sample of low-frequency variables will be used in an attempt to distinguish between intrinsic and extrinsic modulation of the total flux densities. Follow-up deep VLA survey maps will be made of objects in the deepest optical survey field yet available in order to establish the properties of the bluest evolving galaxies and constrain models on galaxy formation. A survey of compact sources in the galactic plane will provide structural and spectral data sufficient to further categorize the sources and to identify those that will be possible VLBI calibrators and probes of the interstellar medium.

The 12-m Telescope. The NRAO millimeter-wave facility remains in high demand as a result of recent improvements to the telescope pointing and in the efficiency of the surface. Superior instrumentation is available to enable sensitive observations of strong spectral lines of important molecules, such as carbon monoxide, in the interstellar and circumstellar environment, in addition to the continuum radiation emitted by galactic and extragalactic objects. Computer hardware and software changes have been designed to optimize the data acquisition and analysis process.

Several observational programs will study the circumstellar environment of evolved stars. The mass lost by many of these stars is a dominant source of material returned to the interstellar medium and is best sampled through the observation and analysis of CO rotation-line emission. Spectral-line studies of CO and other molecular constituents of carbon stars, asymptotic giant branch stars, and other mass-losing stars will have an important bearing on our understanding of the chemical evolution of the interstellar medium. Continuum observations will be used to estimate the gas/dust ratio in the same circumstellar shells. CO detection is expected from the outer neutral shells of planetary nebulae and could potentially be an important tool of understanding their physical evolution.

In other interstellar environments the physical and chemical properties of molecular clouds are subject to intense scrutiny. The detailed spatial and velocity structure of bipolar outflows of gas around star-forming centers will continue to be investigated to improve upon the rudimentary information that exists about these regions. High signal-to-noise ratios and velocity resolutions will be required to probe the clumpiness of molecular clouds. Chemical studies of the interstellar medium which are expected to be carried out include a search for interstellar MgH and MgO, confirmation of the detection of vibrationally excited states of several molecular species, and a search for higher frequency transitions from the recently detected ring molecules SiC_2 and C_3H_2.

Of increasing interest to a greater number of 12-m users is the higher resolution capability of the 1-mm receiver for extragalactic CO investigations. Observations of Seyfert galaxies, for example, are needed to clarify the relationship between molecular gas, neutral gas, and Seyfert activity. Galacto-centric and galaxy-to-galaxy variations of the isotopic species of CO will be investigated over a broad range of galaxy types. The molecular observations will complement HI data in kinematic studies throughout the galactic disks as well as in morphologically significant nuclear, bar, or spiral-arm regions. Galaxies in clusters and the intracluster medium will also be sampled in CO to search for evidence of massive recent star formation in HI deficient central galaxies and to detect molecular clouds that may have formed in the "cooling flows" surrounding massive cluster-center galaxies.

The 140-ft Telescope. Successive improvements to the telescope and K-band maser receivers have consistently upgraded the K-band performance to the point that proposal pressure in the 5-26 GHz frequency range dominates the observing schedule. Spectral baseline instabilities and non-linearities have also been significantly reduced. High-sensitivity continuum measurements in the K-band promise to be increasingly more reliable with the presence of the very stable nutating subreflector and the digital backend.

Programs that will benefit most from the strengthened K-band capability center on molecular-line searches and studies of the physics of the interstellar molecular cloud environment. Follow-up observations of the recently identified C_3H_2 molecule will test its general utility as a valuable, all-pervasive probe throughout the galactic plane. Detection of the acetylene isomer, H_2CC, would be a significant diagnostic of the chemistry of other microwave-invisible hydrocarbon species in the interstellar. New laboratory measurements give hope to the S-band detection of ^{13}CH and the potential discrimination between the two competing chemistries proposed for producing CH. A search for SiH might lead to a better understanding of interstellar silicon chemistry in high-temperature shock regions and as an indicator of dust-grain compositions.

As physical probes of molecular clouds and star-formation regions, microwave spectra-line observations are indispensible. Two-centimeter and six-centimeter formaldehyde-line observations of molecular-cloud envelopes will provide the physical parameters, morphology, gas-density variation with radius, turbulent line broadening, rotational velocity, temperature, and mass that are essential for studying cloud models. The K-band ammonia lines are similarly useful probes of the conditions in molecular clouds. In dense, star-forming cloud cores the NH_3 line widths will be correlated with the presence of IRAS sources, CO outflows, and stellar luminosities. At other cloud/HII region interfaces, NH_3 observations will provide sensitive diagnostics of the kinematics and temperature structure of the region. With the improved L-band receiver, OH Zeeman observations of dark clouds will be made to measure magnetic field strengths and test star-formation theories.

An ongoing HI survey of dwarf galaxies for redshift and hydrogen content will be continued. The goal of the study is a better determination of the local velocity field and the local mean matter density as well as the differentiation of dwarf galaxy properties in and out of cluster environments. HI column-density determinations toward a large sample of active galaxies and quasars will be carried out in order to optimally correct their x-ray fluxes and spectral indices for the effects of galactic absorption. Observations of excited-state OH lines toward the new class of megamaser galaxies will help constrain models for the OH pumping mechanisms.

Investigations of the cosmic microwave background will continue to challenge the limits of the 140-ft system. Once a proper beam splitter is available, careful observations of small, angular-scale polarization in the background can set constraints on the origin, nature, and growth of the density perturbations which eventually evolved into today's galaxies and clusters of galaxies.

Greater than 25% of the 140-ft telescope's research effort will be devoted to VLBI experiments, partly in coordination with other VLBI Network antennas, partly with European VLB stations, and partly in independent VLB experiments. VLB extragalactic programs will focus on the smallest size-scale features in quasars and the nuclei of galaxies in order to understand the mechanisms of energy generation and transport in these sources. A subset of these programs will continue to monitor superluminal sources. Within the Galaxy, VLB experiments will probe regions of maser activity in circumstellar shells and star-formation regions for direct dynamical clues to the evolution of these objects. VLB experiments for terrestrial applications, including precision geodesy, crustal dynamics and polar-motion studies, will also continue.

During the 1985/86 perihelion passage of Comet Halley, the 140-ft will be one of the key elements in NRAO's participation in the International Halley Watch (IHW) program. Regularly scheduled observations are planned which will monitor the comet's OH emission and thereby provide valuable data on the comet's gas production as a function of heliocentric distance, the possible magnetic field effects, and the kinematics of the cometary coma. Other spectral lines will be sampled in order to verify previous tentative detections of water and ammonia from comets and to find other parent molecules that may be clues to the comet's nuclear composition.

The 300-ft Telescope. Mechanical improvements to the NRAO's largest single-dish antenna promise to augment its contribution to the NRAO scientific program. Higher frequency observations, particularly at 5 GHz, will now benefit from a N-S feed translation mechanism which compensates for gravitationally induced motion of the focal point when the telescope is not pointed at the zenith. As a system in high demand for time-consuming survey programs, the telescope detects many sources per day and integrates sufficient signal-to-noise over many days to reach specific program goals.

Long-term commitments of telescope time will be required by source variability studies. Programs to monitor spectral variations on time scales as long as six years have been initiated and will continue. Source variability or the propagation of high-frequency bursts to lower frequencies are features of the dynamic spectra which provide valuable diagnostics of the evolutionary processes at work in these sources or of the properties of the intervening refractive interstellar medium. Programs aimed at differentiating these effects will receive continued emphasis.

Many new pulsars which have been discovered with the 300-ft telescope over the course of the past few years survey work will be targeted for timing measurements. Careful timing observations at several epochs spread throughout the year will monitor the changes in pulsar periods in order to provide important information on the nature and evolutionary history of specific objects and may even identify pulsars in binary systems.

A survey for fast pulsars, making use of a fast pulsar search machine from the University of California, Berkeley, interfaced to the 300-ft telescope, will search a 20° wide band around the galactic plane for pulsars with rotation rates as high as 2000 Hz. The discovery of new millisecond pulsars will provide valuable information about the structure of neutron stars and the final stages of stellar evolution. Follow-up timing and astrometry of additional fast pulsars will also establish very strong standards of time and position.

A survey of global HI characteristics will be undertaken for a large sample of strongly interacting disk galaxies. The resulting spectra will be utilized in comparing such systems with normal field and non-interacting binary spiral galaxies in terms of parameters such as hydrogen mass, line-velocity widths as functions of luminosity, and star-formation rates relative to HI content. The global HI properties will also be usefully compared to indicators of nuclear activity as observed optically and with the VLA.

III. RESEARCH INSTRUMENTS

As a purely observational science, progress in radio astronomy is tightly coupled to technological advances in all those areas that contribute to a successful observation. The experience at the NRAO and elsewhere has been that qualitative technical developments are soon reflected in qualitative, not incremental, scientific advances. Thus, for example, the marked improvements to the sensitivity of radio telescopes at 21 cm that allowed astronomers to obtain accurate measures of the HI velocity of distant galaxies showed us that the large-scale, 3-dimensional, mass structure in the nearby universe is filamentary not homogeneous. These observations tightly constrain the range of possible models for the very early evolution of the universe. Similarly, the exceptional imaging capability of the VLA clearly reveals the ubiquity of nuclear jets as the power source for the extended radio lobes in radio galaxies and quasars. Here the luminosity of the nuclear jets together with their very small angular size point to the need for a black hole at the center of these objects. Fundamental knowledge such as this is unobtainable without a concerted and continuous program of instrumental construction, evolution and improvement.

The National Radio Astronomy Observatory currently operates four major telescope systems for the astronomical community in the United States:

(1) the 140-ft fully steerable radio telescope;

(2) the 300-ft transit radio telescope;

(3) the Very Large Array synthesis radio telescope; and

(4) the 12-m millimeter wave telescope.

Each of these telescopes provides a unique service to astronomers and each benefits by a scientifically considered and prioritized plan for improvements to its capabilities as enumerated below. To this end a NRAO research and development program in electronics and computer hardware is maintained at each observing site as well as in the Central Development Laboratory in Charlottesville. Each of these locations is involved in design, development and construction of auxiliary instrumentation for augmenting the research capabilities of the four telescope systems. However, it is a mistake to think of these instruments solely in terms of steel reflectors and cryogenic radiometers--as research instruments one must consider not only instrumentation, but also data handling and user-interface.

The purpose of the NRAO is to provide unique facilities to the researcher which he/she can use to maximum scientific profit. The typical user, in residence at the NRAO but a few times a year, thus needs to be provided with hardware and software interfaces to the instrumentation that are logical and comprehensive yet provide ready access to the full flexibility available from the instruments. This also has a considerable impact on NRAO plans for the design and utilization of astronomical instrumentation which can be seen reflected in demands on the research equipment plan and budget.

One of the more significant advances in radio astronomy in the last few years was spawned from the recognition that the quality of radio astronomical data could be markedly improved by more sophisticated data manipulation software. Here the most striking example is the use of self-calibration algorithms on VLA and VLBI data to correct the incoming wavefront for atmospheric (and instrumental) effects. This radio analog of the optical "rubber mirror" concept allows the VLA to achieve theoretical angular resolutions unencumbered by atmospheric smearing while at the same time reaching a dynamic range 100 times higher than expected in the design of the VLA. For the specific case of VLA data, the price of this improvement is an enormous computing burden that necessitates not only procurement of faster computers and greater data storage but also leads the NRAO to seek access to a supercomputer, presently as a user of outside facilities but in the future as an operator of a dedicated Class VI facility. However, the single-dish telescopes, as well as the VLA, have also benefited by access to rapid data handling and manipulation hardware and software. The ability to rapidly position-switch the 140-ft telescope and the 12-m telescope--and to deal with the greatly increased data rate--has led to a remarkable improvement in instrumental stability which directly translates into an ability to observe and study fainter and more numerous astronomical objects. But again the direct ramification is a need for faster and more flexible computer power together with more sophisticated software in order to exploit properly these additional scientific opportunities.

The following table shows the planned distribution of funds for the Research Equipment account as currently dictated by the anticipated funds and established scientific priorities in each of the NRAO operating divisions. The NRAO, in consultation with its users, continually updates this table as scientific priorities change. A brief narrative describing the various items in the Research Equipment plan follows the table. It is

RESEARCH EQUIPMENT

(thousands of dollars)

	Expenditure		Estimated	
	1985 (est)	1986 Plan	Add'l Cost	Completion Date
1. Laboratory Test Inst.	$ 75	$ 75	$100/yr	Continuing
2. Miscellaneous Projects	140	160	200/yr	Continuing
3. 300-ft Telescope				
Spectral Processor	90	80	140	1987-8
Lateral Focus	5	-	-	1985
7-feed 5-GHz Receiver	40	-	-	1985
Adaptive Array Receiver	-	25	25	1988
4. 140-ft Telescope				
Receiver Enhancement	10	-	-	1986
Computer/Digital Upgrade	-	25	400	1990
Improvements at High Freq.	4	10	40	1988
Site Development Computer	15	15	45	1987
5. 12-m Telescope				
SIS CO Receiver	2	20	10	1987
130-170 GHz Receiver	7	15	30	1988
340-360 GHz Receiver	2	-	-	1986
Bolometer Receiver	15	-	-	1986
Hybrid Spectrometer	30	50	90	1987
Computer Upgrade	8	20	40	1987
6. VLA Electronics				
300-MHz Receivers	90	75	75	1988
Module Improvements	45	20	25/yr	Continuing
Water Vapor Radiometers	5	15	50	1988
Ant. Pointing Improve.	10	10	40	1988
22-25 GHz Improvements	-	50	190	1989
75-MHz Receivers	10	20	180	1990
RFI Improvements	14	15	25	1987
Second Maser LO	-	25	20	1987
Receiver Upgrade	-	30	140	1989

	Expenditure		Estimated	
	1985 (est)	1986 Plan	Add'l Cost	Completion Date
7. VLA Computing				
Synchronous Comp. Upgrade	$ 121	$ 100	150	1988
DISPLAY CPU Upgrade	21	30	-	1986
AIPS/VAX Enhancements	23	30	50/yr	Continuing
DEC-10 Disks	22	-	-	1985
8. Common Development				
Millimeter Device Develop.	110	113	120/yr	Continuing
Array Receiver Develop.	15	35	150	1989
IBM Replacement Eqpt.	37	-	-	1985
Class VI Evaluation	15	15	15/yr	Continuing
Communications	20	10	10/yr	Continuing
TOTAL	$1001	$1088		

important to note that most of the RE projects extend over several years; those for which monies are allocated in 1986 are not necessarily planned for completion in 1986. However, the expeditious completion of all construction projects, and the subsequent application of the instrumentation or software produced to visitor research endeavors, is a primary goal of the NRAO development program.

Laboratory and Test Equipment

The need to continually improve the telescope instrumentation brings with it a concomitant need to improve the laboratory diagnostic equipment. For example, the design of the 12-m fast beam-switching, optical system must have as its input the 1/f characteristics of the 12-m receivers so that an optimum switch rate can be identified. But knowledge of the 1/f receiver spectra requires acquisition and experimentation with a very low-frequency spectrum analyzer. Such items, for all the NRAO laboratory sites, are included in this budget line. Included also are enhancements to existing test equipment, such as network analyzers and oscilloscopes.

Miscellaneous Projects

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

300-ft Telescope

Since the 300-ft is a transit telescope it is manifestly a survey instrument and, given the mesh construction of its surface panels, it can operate effectively at longer wavelengths, $\lambda > 6$ cm. The enormous collecting area of the 300-ft, together with the very sensitive receivers available at Green Bank, provide an opportunity for exceptional survey sensitivity in the OH and HI lines as well as in the continuum. These characteristics have been, and continue to be, exploited to the benefit of those astronomers interested in discovering new pulsars, extending knowledge of the gas content in galaxies to higher redshift or attempting to determine the nature and distribution of weak radio sources. However, as a survey instrument the 300-ft is limited by the capabilities of its 20-year old computer and backend instrumentation.

The long-range plan for the 300-ft telescope thus calls for those improvements that will optimize the performance of the telescope as a survey instrument. One important goal in this regard is to automate the telescope as much as possible through computer implementations that will minimize its manpower and funding requirements. The following items in the Research Equipment plan address this need:

Spectral Processor: This is a pipelined, fast Fourier transform spectrometer, incorporating real-time interference excision and flexible time and frequency-merging capabilities. It improves on existing instrumentation in two major areas. Spectral-line observations will have greater resistance to interference since spectral estimates are produced once every 10 microseconds instead of once every 10 seconds as is the present case. It will also increase the available number of spectral channels, providing 2048 channels across 40 MHz as compared to 384 channels across 10 MHz in the present autocorrelator. Secondly, the spectral processor will greatly improve pulsar data-acquisition capabilities at the 300-ft. It will provide 256 channels times 4 polarizations across a 20 MHz bandwidth with full dedispersing capabilities. The spectral processor will thus allow highly automated and accurate pulsar timing programs to be performed.

7-Feed, 5-GHz Continuum Receiver: The purpose of the 7-beam, 14-channel receiver is to make 6-cm maps of the entire sky visible from Green Bank. With this nearly completed receiver the 300-ft telescope will cover the declination range 0-75 degrees in 90 days, resolving the sky into 10 million beam areas and detecting about two hundred thousand sources stronger than 10 mJy. Such a map will be a radio analog of the Palomar sky survey. Each map is also a historical record of the sky, so successive maps will reveal all variable sources.

To make effective use of this receiver at zenith distances greater than 20 degrees requires that the telescope gravitational deformation be compensated for by displacing the focal position laterally. Thus the following telescope modification is needed.

Lateral Focus: At the 300-ft there is a significant n-s displacement of the focal point as the telescope moves away from the zenith. Since the demand for the 300-ft at 6 cm is growing, the construction of a mechanical assembly to compensate for this displacement of the feed center with zenith angle was undertaken and is nearly complete. At 5 GHz the aperture efficiency should improve by 50% or more at zenith distances greater than 20 degrees.

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

140-Ft Telescope

The 140-ft, fully steerable radio telescope incorporates great frequency flexibility through dual-polarization maser/upconverter receivers that provide exceptional sensitivity from 5 to 26 GHz. Longer wavelengths are observed with receivers mounted at the prime focus. With very few gaps, system temperatures lower than 50 K are available on the 140-ft from 1 to 26 GHz. It is no surprise, therefore, that so many recent successful searches for molecular spectral lines in this frequency range have been made on the 140-ft telescope and not elsewhere.

Although the frequency flexibility and sensitivity of the 140-ft are exceptional, the operational flexibility is limiting. The present control computer, while not as antiquated as that at the 300-ft telescope, is nevertheless a slow 16-bit machine which has no capacity for expansion and thus cannot make effective use of the new data-taking procedures and data-processing algorithms that have the potential to greatly reduce the operational overhead as well as improve further the sensitivity, particularly the spectral sensitivity, of the telescope. The Research Equipment plan in 1986 calls for the completion of the latest generation receiving equipment and initiation of work on a new control system, spectrometer and digital hardware interface that, when complete, will permit a more automated operation.

Receiver Enhancements: Work concludes in 1986 on the 5-26 GHz maser upconverter system and the 2-5 GHz receiver. The second channel of the 5-26 GHz receiver is now operational and has similar performance to the first channel. Work is concluding on the beam splitting optics which will allow both receivers to be used simultaneously. The 2-5 GHz receiver is a dual-channel FET receiver optimized to cover with maximum efficiency the important 9-cm CH lines as well as the 4.8 GHz transition of formaldehyde.

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

Improvements at High Frequency: The accuracy of the individual surface panels of the 140-ft is sufficient for useful observations to be made at frequencies as high as 45 GHz. However, neither the panel setting accuracy nor the gravitational astigmatism of the telescope will support such high frequencies. Thus, work will commence on holographic measurement of the surface to identify and correct the panel setting; in addition, an effective lateral displacement of the subreflector centroid will be achieved by tilting the subreflector: this will soften the gravitation-induced telescope gain variation with displacement from the meridian.

Site Development Computer: At both the 300-ft and the 140-ft telescopes the need over the next few years is to improve the user-interface to the telescope by simplifing and streamlining the on-line control systems by means of new hardware and new software. Development of the latter can be done only at the expense of telescope observing time unless a development station, identical to the telescope control environment, is provided elsewhere. Thus, the plan is to provide such a replication for program development and debugging; this same computer will serve general-purpose and engineering computing needs.

12-m Telescope

The successful resurfacing project of the former 36-ft telescope has provided users with a 12-m millimeter-wave telescope with a surface accurate enough to support useful observations at frequencies as high as 350 GHz. As with the Green Bank telescopes, however, advances in receiving equipment have greatly outpaced the needed developments in telescope control hardware and backend spectrometer capacity. Thus the plan for the 12-m in 1986 and beyond is to augment or supplant the present control and data-taking facilities in order to provide more efficient use of the telescope with fewer support personnel. In addition, work will begin on SIS receiver arrays, the implementation of which will increase the mapping speed of the telescope in direct proportion to the number of receivers in the array.

SIS CO Receiver: The dual-polarization SIS receiver is designed to cover the 3-mm line of CO and its isotopes with a receiver temperature less than 100 K SSB. Initial telescope tests are encouraging. In 1986 the receiver will be provided with remote tuning capability, and it will be made available to users.

130-170 GHz Receiver: A dual-polarization receiver is being developed to cover the 2-mm band. A SSB noise temperature of 300 K appears realistic with mixers developed at the Central Development Laboratory in Charlottesville.

340-360 GHz Receiver: Despite its limited range, the 870 micron window contains a rich variety of some of the most important molecular lines in astrophysics. At 345 GHz, CO has third overtone, the J=3-2 transition. Since CO is the prime tracer of molecular material in the Galaxy and elsewhere, and since observation of the J=3-2 line is indispensible for an understanding of cloud excitation (temperature and density), it is important that the 12-m telescope have an adequate capability at 345 GHz. A simple receiver has therefore been developed to cover the 340-360 GHz band; with fabrication and testing complete, it now needs to be made flexible enough to be used expeditiously by visiting astronomers.

Bolometer Receiver: A new bolometer element will be installed in 1986 that should increase the 1.4-mm sensitivity of the bolometer by a factor of 2 on the 12-m to 1 Jy/s or better. The bolometer mount will also be redesigned and rebuilt so as to suppress further harmful telescope microphonic vibrations.

Hybrid Spectrometer: In order to provide the greater frequency coverage needed by the higher frequency 12-m receivers as well as to improve the spectral resolution at lower frequencies, a hybrid filter-bank autocorrelator is under construction. The 2.4-GHz total bandwidth and 1536-spectral channels to be incorporated in this device will benefit the present single-beam receivers and, in addition, the spectrometer can be divided into as many as 8 separate spectrometers for use with the array receivers under development at the Central Development Laboratory.

VLA Electronics

The fundamentally reliable VLA electronics can be significantly enhanced at a reasonable cost to provide both very much greater sensitivity at high frequency (22-25 GHz) and unique scientific opportunities at low frequency (75-300 MHz). Improvements at both these ends of the frequency spectrum constitute the thrust of the 1986 plan for development of VLA electronics.

300-MHz Receivers: 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. Some objects radiate more strongly at lower frequency while others are so large that a larger field of view is needed: 300-MHz observations address both these needs. By the end of 1986 as many as 15 antennas will have been equipped with prime focus, 300-MHz receivers; the VLA will then be a very exciting low-frequency synthesis telescope.

75-MHz Receivers: Investigations will proceed into the feasibility of providing a 75-MHz capability on the VLA. Initial experiments are encouraging, the RFI environment is acceptable, and the telescopes can be efficiently fed at 75 MHz. If all continues to proceed well we can expect that the VLA will provide a major new observing capability by giving 20" resolution at a frequency where the current best resolutions are many arcminutes. This capability will enable useful observations of thousands of previously unresolved extragalactic, galactic, and solar system objects.

22-25 GHz Improvements: Many important ammonia-line experiments, such as accretion disks, circumstellar material, distant star-forming complexes, and extragalactic line observations will benefit from the upgrade in K-band performance. An attainable improvement at 24 GHz by a factor of 5-6 means a tremendous boost in speed and sensitivity. The 1986 plan calls for the NRAO Central Development Laboratory to develop an improved front-end amplifier for the 1.3-cm band that will reduce the system temperature to 250 K using GaAs FET amplifiers or HEMT (high electron mobility transistor) amplifiers.

Receiver Upgrade: Straightforward modifications to the waveguide couplers into the dewar will provide an opportunity to reduce the 18-21 cm system temperature for all antennas to significantly under the present 50 K. This will provide needed sensitivity for extragalactic OH and neutral hydrogen mapping observations.

Module Improvements: Modifications are planned to various modules to replace obsolete components and to improve system reliability, maintainability, and performance.

Water Vapor Radiometers: This involves the development of a system to measure the total precipitable water in a path through the atmosphere so as to enable real-time correction to the "instrumental" phase owing to path-length changes. This will improve the stability of the VLA at high frequencies and/or under changing atmospheric conditions.

Antenna Pointing Improvements: Antenna pointing errors degrade the performance of synthesis telescopes at both low and high frequencies. At lower frequencies the increased strength of the background sources which fill the primary beam more than offset the larger primary beamwidth and limit the achievable dynamic range. At high frequencies the pointing errors become a significant fraction of the primary beam so the source image is affected directly. Pointing errors are most frequently caused by differential solar heating of the pedestal and yoke of the antennas. This problem is being cured by coating the critical parts of the antenna structure with insulation to reduce the temperature differentials. This process continues through 1986.

RFI Improvements: The sensitivity of the 300-MHz and 75-MHz systems will be limited by radio-frequency interference locally generated at each antenna. Modifications to various modules will reduce this effect and will increase the instantaneous usable bandwidth.

Second Master LO: Having just one master local oscillator system at the VLA means that the fine adjustments of the LO frequency, such as are needed for VLBI or spectral line observations, can only be made for one object at a time. The VLA is capable of observing up to five objects simultaneously when the antennas are divided into subarrays. Thus, this lack of frequency flexibility is one limitation to the capabilities of the VLA. To circumvent this difficulty, a second master LO system will be built with its own cable distribution network so that any antenna can, under computer control, use either LO system.

VLA Computing

The VLA computing environment includes two identifiably separate functions, viz., telescope control/data acquisition and data reduction/mapping. Enhancements are needed in both these functional areas. The evolution of the VLA to higher frequency, to higher angular resolution, to more rapid temporal sampling, and to higher spectral resolution brings with it increasing demands on the data-taking and data-processing hardware and software. As the scientific benefit from such instrumental evolution is certainly commensurate with the technical effort expended in achieving this evolution--indeed the former is predicated on the latter--these demands need to be addressed expeditiously. Thus the 1986 Research Equipment plan continues to support the necessary augmentation of these facilities.

Synchronous Computer Upgrade: Recognizing that the on-line ModComp computers could no longer keep up with the VLA data rate, and neither did they have the spare capacity to handle the digital control of the new receivers on the array, particularly the 300-MHz system, a phased replacement was begun in 1984. In 1986 the hardware replacement to 32-bit architecture machines should be complete.

DISPLAY CPU Upgrade: The final PDP-11/44 of the pipeline will be replaced by a VAX-11/750 computer and its peripherals. Use of the VAX will permit pipeline data to be written directly into an AIPS catalog for the users' later reduction and, in addition, the pipeline can exploit the display software extant in AIPS.

AIPS/VAX Enhancements: The mapping (AIPS) facility at the VLA comes under increasing pressure as visiting astronomers employ increasingly sophisticated algorithms in order to enable them to extract the maximum scientific information from their data. This translates into a need for added disk space, higher density and more reliable tape drives and enhanced I/O performance from an optimally configured unibus structure on the VAX mapping computers. Even in the best of circumstances, these modest measures cannot hope to adequately satisfy the need for computer capacity at the VLA: supercomputer power is required to form many VLA images properly.

DEC-10 Disks: Purchased in 1985, two RP07 drives have replaced, without loss of storage capacity, four RP04 drives. This upgrade eases the maintenance burden as well as the power requirement and it makes available precious floor space in the VLA computer room.

Common Development

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

Millimeter Device Development: Virtually all astrophysics done at millimeter wavelengths is sensitivity limited, because the emitting gas is both cold and spatially extended in most objects of interest. Thus the spectral lines involved are both of low intensity and of narrow width, containing very little energy. There is accordingly a greater scientific need for continued improvements in receiver sensitivity at millimeter wavelengths than exists at centimeter wavelengths. To this end millimeter-wave device development at the NRAO emphasizes both in-house work and a subcontract with the University of Virginia to supply Schottky diodes specialized to our millimeter-wave, cryogenic, application. The Univesity of Virginia also does subcontract work in an attempt to develop niobium SIS junctions for application at the higher frequencies.

Array Receiver Development: The implementation of an array of receivers in the focal plane of any of the single-dish telescopes has the potential to provide an increase in mapping speed directly proportional to the number of receivers in the array. Although clusters of independent feedhorns and receivers have been built previously--the new 7-feed, 5 GHz receiver for the 300-ft telescope mentioned above is but one example--a superior approach at millimeter wavelengths is to integrate feed and amplifier on a single planar strip. Such planar arrays for the 100-400 GHz range require development in two areas: planar antennas, and planar diodes. In order to achieve receiver sensitivities close to the best conventional receivers, planar antenna elements must be designed to have desirable radiation patterns and impedances suited to the mixer diodes. Planar Schottky diodes are now being developed for this application under subcontract with the University of Virginia. SIS diodes are planar by nature and designs are now being fabricated which will be suitable for incorporation into a planar antenna array.

IBM Replacement Equipment: The replacement of the IBM as the general-purpose computer in Charlottesville presents a need for the IBM-peripherals to be interfaced to the new computer or to the VAX-11/780. Most pressing in this regard is the transfer of the CalComp plotter and the DICOMED film recorder.

Class VI Evaluation: The need for the power of a Class VI supercomputer--60-100 achieved megaflops--to reduce many VLA observing programs has prompted the NRAO to take advantage of the NSF supercomputing initiative in order to evaluate the problems and prospects for running AIPS on a supercomputer. In 1985 the principle emphasis was on getting AIPS to run on the CRAY X-MP/2200 at Digital Productions. In 1986 the thrust will be to optimize AIPS for the supercomputer as well as to support visitor mapping programs on the CRAY for those projects with demonstrable need and proper preparation of the data to be mapped.

Communications: The communications project includes hardware necessary for digital communications between NRAO sites. This includes multiplexer equipment as well as some modems. The multiplexer equipment handles the inter-site DECNET capability, the Socorro-Green Bank fiscal communication and remote terminal access. When completed it will be possible to log on to most NRAO computers from any terminal connected to the digital switch.

IV. EQUIPMENT

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

1.	Maintenance, Shop, and Repair Equipment............	$30.0 k
2.	Office and Library Furnishings and Equipment........	48.0
3.	Living Quarters Furniture...........................	2.0
4.	Building Equipment..................................	5.0
5.	Observatory Services................................	15.0

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. Observatory Services

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

V. OPERATIONS AND MAINTENANCE

The activities at the NRAO group naturally into seven 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 seven units is given in Section IX.

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 $265k. Further major budget items, such as the rent and maintenance of the Charlottesville Edgemont Road building, communications, and utilities, will require $365k. The management fee paid to Associated Universities, Inc., will be $380k.

B. Research Group

The NRAO scientific research group, composed of staff scientists and students (summer, co-operative, and Ph.D.), engages in independent research and competes for observing time on an equal basis with visiting scientists. They are expected to carry out research of the highest caliber while at the same time assisting visiting astronomers in 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 1986, 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.

Over 50% of the overall NRAO travel budget will be expended in the Research Group ($260k) primarily for travel by all staff and visitors from U.S.-based institutions to carry out observing programs at NRAO telescopes or to use Charlottesville's data-analysis facilities. During 1985, $60k 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. Charlottesville Operations

Observatory Services in support of research and development throughout the entire Observatory are provided by the central library, the technical illustrations and drafting service, and the Observatory visual information service. In 1986, the MS&S budget of $550k for these areas is earmarked primarily for publication support (page charges) of papers based on data obtained with the NRAO telescopes as well as for the book and periodical expenses of the four NRAO libraries.

The Computer Division operates the NRAO central computer in Charlottesville and the VLB MKII processor and assists in the development of programs for computers at the telescopes. An astronomical image processing group develops and maintains map processing and analysis software that is currently operating in Charlottesville and at the VLA as well as at numerous institutions world-wide. As has been the case in previous years, a major portion of the MS&S for this Division will be used for computer rental and maintenance. However, in 1986 the computer rental and maintenance funds will be transferred, without augmentation, from the IBM 4341 to a new, fast vector computer. The new computer, to be shared with the University of Virginia on a cost-sharing basis, will be optimized to run the NRAO image processing software system AIPS as well as to facilitate general-purpose computing for visitors and staff.

D. Technical Development

Observatory-wide technical research and development support are concentrated at the Central Development Laboratory. Work on radiometer improvements and the exploration of state-of-the-art techniques for expanding wavelength capabilities insures that the Observatory will have forefront instrumentation in the foreseeable future. A subgroup at the Central Lab is heavily involved in the development of VLBI techniques and correlator improvements. During 1986, $65k is budgeted for MS&S and $145k for rent of the Central Development Laboratory on Ivy Road.

E. 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 1986 budgets for MS&S are: Telescope Services ($149k), Electronics ($154k), Plant Maintenance ($138k), Administrative Services ($101k), and Scientific Services ($74k). An additional $340k will be spent on communications and utilities. It is also estimated that food services and housing will bring in revenues of about $112k. The operation of the Green Bank interferometer for the USNO affects the Green Bank operations budget as a credit of $768k (see Section VI).

F. 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 1986 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 1986 will include continued software development for improved data acquisition. The two Tucson subgroups will require the following MS&S budgets for 1986: Operations and Maintenance ($268k) and Electronics ($195k). An additional $70k is programmed for communications and utilities. Miscellaneous revenue will total about $16k.

G. VLA Operations

Activities surrounding the VLA are coordinated through six divisions which differ in detail from those in Green Bank due to the special requirements of array operations and geographic isolation. The VLA Scientific Services group will require a MS&S budget of $103k. The Computer

Division and Array Operations Division, which are most critical to the mechanical functioning and data collecting capabilities of the telescope, will require MS&S budgets of $395k, and $13k, respectively. Other services related to the efficient functioning of the operation and their MS&S budgets are: Engineering and Services Division ($391k), of which $130k is earmarked for special mainatenance of the VLA railroad and $348k for Administrative Services. Communications, utilities, and building rent (in Socorro) will amount to $904k, while miscellaneous revenue of $134k is expected. Included in the above sums is $283k for computer rent and maintenance, more than $700k for electric power costs, and the cost of visiting observer transport from Albuquerque to the site. A significant part of the communications expenditures will be devoted to remote observing costs.

A summary of the CY 1986 budget for these operations units is provided in the following table:

Operations Unit	Personnel Ceiling	Salaries, Wages & Benefits	Material, Supply, Service	Travel	Total
			($ thousands)		
Operations					
A. General & Admr.	27	$ 1,056	$1,010	$ 98	$ 2,164
B. Research Group	35	1,744	10	340	2,094
C. Cvlle. Oper.	22	818	550	33	1,401
D. Technical Develop.	16	629	210	25	864
E. Green Bank Oper.	96	3,380	844	38	4,262
F. Tucson Oper.	26	1,070	517	52	1,639
G. Socorro Oper.	112	3,737	2,180	104	6,021
Total Operations	334	$12,434	$5,321	$690	$18,445
Design and Construction					
VLBA	60	2,291	9,002	207	11,500
Voyager 2	12	633	1,022	35	1,690
Total Design & Const.	72	2,924	10,024	242	13,190
TOTAL	406	$15,358	$15,345	$932	$31,635

Notes:
1. Does not include commitments carried forward from 1985.
2. Gen. & Admr. includes $380k management fee.
3. Green Bank Oper. includes $768k for USNO interferometer support.

VI. INTERFEROMETER OPERATIONS

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

Over the past several years the NRAO has expanded and upgraded the interferometer in order to improve the data acquisition capabilities of the instrument by adding an east-west baseline link off the original north-south baseline in 1983/84, including the addition of a new 14.2-m telescope located some 30 miles west of the main Green Bank site, and, during 1985 completed the acquisition and installation of a new MassComp computer system. No major additions or improvements are planned for the interferometer in 1986.

Operating and maintenance costs and equipment replacements for the interferometer are planned at $994k in 1986, of which $594k is carried over from prior years accumulations in construction programs and equipment upgrading projects. The remaining $400k is "new" 1986 funds.

Funding for the interferometer program is provided to the NRAO through an interagency transfer between the Naval Research Laboratory and the NSF for inclusion in AUI's contract with the Foundation. The 1986 interferometer allocation is shown in the following tables.

	1985	1986				
	Est. Exp.	New Funds	Uncomm. Carryover	Available for Comm.	Comm. Fwd.	Available for Exp.
			($ thousands)			
1. Operations						
Personnel Compensation	$253.1	$165.0	$136.0	$301.0		$ 301.0
Personnel Benefits	60.7		72.0	72.0		72.0
Material & Supply	123.7		111.0	111.0	$15.0	126.0
Communication & Utilities	49.6		45.0	45.0		45.0
Travel			4.0	4.0		4.0
Common Costs	214.7	235.0		235.0		235.0
Total Operations	$701.8	$400.0	$368.0	$768.0	$15.0	$ 783.0
2. Equipment						
Automotive			$ 15.0	$ 15.0		$ 15.0
Test Equipment	$ 17.0		35.0	35.0		35.0
G.P.S. Rx			32.0	32.0		32.0
Total Equipment	$ 17.0		$ 82.0	$ 82.0		$ 82.0
3. Design & Construction						
Interferometer Addition	$178.9		$144.0	$144.0		$ 144.0
Total Design & Const.	$178.9		$144.0	$144.0		$ 144.0
TOTAL	$897.7	$400.0	$594.0	$994.0	$15.0	$1009.0

VII. VOYAGER 2 NEPTUNE PROJECT

In May 1985, the NSF and NASA entered into a Memorandum of Agreement (MOA) whereby the NRAO would develop, assemble, and install certain electronic equipment on the VLA antennas and then operate the VLA, in conjunction with NASA's Voyager 2 Neptune mission. The utilization of the VLA for Voyager 2 data acquisition will commence on or about April 1, 1989, and end on or before October 1, 1989, with activity concentrated around the day of the closest approach of the spacecraft, August 24, 1989.

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

During 1986 fabrication of the front ends for the Voyager 2 program will proceed at the NRAO in Charlottesville, with 12 front-ends scheduled to be shipped to the VLA during the year for installation and testing on the antennas at the VLA site. The projected Voyager 2 cost for 1986 is expected to run about $1.8M, of which about $0.2M is from 1985 funds carried over for commitment and expenditure in 1986.

Funding for the Voyager 2 program is provided to NRAO through an interagency transfer between NASA and NSF for inclusion in AUI's contract with the Foundation. The 1986 Voyager 2 program allocation is shown in the following table ($ thousands)

	1985	1986				
	Est. Exp.	New Funds	Uncomm. Carry-over	Available for Comm.	Comm. Fwd.	Available for Exp.
Personnel Compensation	$197.0	$506.0		$ 506.0		$ 506.0
Personnel Benefits	47.0	121.0		121.0		121.0
Material & Supply	568.0	680.0	$100.0	780.0	$112.0	892.0
Travel	32.0	35.0		35.0		35.0
Common Costs	150.0	347.0	44.0	391.0		391.0
TOTAL	$994.0	$1689.0	$144.0	$1833.0	$112.0	$1945.0

Total funding for NRAO's participation in the Voyager 2 programs is scheduled to be $5523k, as shown in the following table.

	1985	1986	1987	1988	1988	Total
Central Lab	$ 852.0	$ 925.0	$ 466.0			$2243.0
VLA Site	398.0	764.0	850.0	$ 772.0	$ 505.0	$3289.0
TOTAL	$1250.0	$1689.0	$1316.0	$ 772.0	$ 505.0	$5532.0

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

VIII. 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.

A modest amount of design money was expended during the 1983-85 period, during which time the general array configuration was specified. Official funding for the construction phase of the project was released to the NRAO on May 15, 1985. During 1986, the first antenna will be completed and specific hardware will be produced in the areas of electronics, data recording and playback, and monitor and control. Design specifications for the correlator and the Array Operations Center will be further advanced. The planned activities for 1986 are outlined in more detail in Appendix E.

IX. PERSONNEL

The following table compares the Personnel Services and Benefits (level = full time at December 31) at the Observatory according to employment classification for 1985 and 1986.

Category	1985	1985 ($ thousands)		1986	1986 ($ thousands)	
	Est. Level	Salaries	Benefits	Est. Level	Salaries	Benefits
Operations*						
Scientific and Engineering	104	$ 3,631.7	$ 869.2	104	$ 3,884.6	$ 971.2
Technical	114	2,695.5	645.1	115	2,919.6	730.0
Administrative and Clerical	70	2,168.4	519.0	69	2,265.7	566.5
Operations and Maintenance	48	863.4	206.7	46	877.1	219.3
Total Operations	336	$ 9,359.0	$2,240.0	334	$ 9,947.0	$ 2,487.0
Design & Const.						
VLBA	40	864.3	207.5	60	1,832.9	458.2
Voyager 2	12	197.0	47.0	12	506.0	121.0
Total Personnel	388	$10,420.3	$2,494.5	406	$12,285.9	$3,066.2

* Includes approximately 10 man years charged to Interferometer Operations.

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

Full-Time Employment by Location

	Estimated Distribution				
	GB	CV	TUC	SOC	Ceiling
General & Administration					
Director's Office		6			6
Fiscal Office	8			5	13
Business Management		8			8
Subtotal	8	14		5	27
Research Support					
Basic Research	2	22	2	9	35
Charlottesville Operations					
Computer		16			16
Observatory Services		6			6
Subtotal		22			22
Technical Development					
Central Lab		16			16
Green Bank Operations					
Telescope Services	31				31
Electronics	22				22
Plant Maintenance	16				16
Administrative Services	11				11
Scientific Services	16				16
Subtotal	96				96
Tucson Operations					
Operations/Maintenance			14		14
Electronics			12		12
Subtotal			26		26
Socorro Operations					
Scientific Services				8	8
Engineering and Services				27	27
Computer				17	17
Electronics				28	28
Array Operations				12	12
Administrative Services				20	20
Subtotal				112	112
TOTAL NRAO	106	74	28	126	334

X. 1986 FINANCIAL PLAN

	1984	1985	← 1986				→
	Actual Expend.	Est. Exp.	New Funds 1986	Uncomm. Carry-Over	Total Avail. for Comm.	Comm. from 1985	Total Avail. for Expend.
1. Operations							
Personnel Compensation	$ 9,280.0	$ 9,359.0	$ 9,811.0	$ 136.0	$ 9,947.0		$ 9,947.0
Personnel Benefits	2,059.0	2,240.0	2,415.0	72.0	2,487.0		2,487.0
Travel - Domestic	546.0	515.0	626.0	4.0	630.0		630.0
Travel - Foreign	57.0	45.0	60.0		60.0		60.0
Material & Supply	4,292.0	4,399.0	4,785.0	156.0	4,941.0	$ 250.0	5,191.0
Management Fee	330.0	350.0	380.0		380.0		380.0
Subtotal - Operations	$16,564.0	$16,908.0	$18,077.0	$ 368.0	$18,445.0	$ 250.0	$18,695.0
2. Equipment							
Research Equipment	$ 1,787.0	$ 999.0	$ 824.0	$ 264.0	$ 1,088.0	$ 342.0	$ 1,430.0
Operating Equipment	258.0	220.0	100.0	82.0	182.0		182.0
Subtotal - Equipment	$ 2,045.0	$ 1,219.0	$ 924.0	$ 346.0	$ 1,270.0	$ 342.0	$ 1,612.0
Total - Oper. & Eqpt.	$18,609.0	$18,127.0	$19,001.0	$ 714.0	$19,715.0	$ 592.0	$20,307.0
Less: Common Cost Recovery	-	(172.0)	(391.0)		(391.0)		(391.0)
Net - Oper. & Eqpt.	$18,609.0	$17,955.0	$18,610.0	$ 714.0	$19,324.0	$ 592.0	$19,916.0
3. Design & Construction							
VLBA	$ 1,025.0	$ 5,901.0	$11,500.0	$1,368.0	$12,868.0	$3,457.0	$16,325.0
Voyager 2 Project	-	994.0	1,690.0	144.0	1,834.0	112.0	1,946.0
Interferometer Additions	90.0	179.0	-	144.0	144.0		144.0
VLA Additions	23.0						
Total - Design & Const.	$ 1,138.0	$ 7,074.0	$13,190.0	$1,656.0	$14,846.0	$3,569.0	$18,415.0
TOTAL	$19,747.0	$25,029.0	$31,800.0	$2,370.0	$34,170.0	$4,161.0	$38,331.0

1986 FINANCIAL PLAN FOR OPERATIONS AND EQUIPMENT

	1984	1985	← 1986 →			
	Actual Expense	Est. Expense	Personnel Compen. & Benefits	Material and Supply	Travel	Total Avail. for Comm.
1. Operations						
Gen. & Admr.	$ 2,052.0	$ 2,150.0	$ 1,056.0	$1,010.0	$ 98.0	$ 2,164.0
Research Group	1,804.0	1,791.0	1,744.0	10.0	340.0	2,094.0
Cvlle. Oper.	1,450.0	1,314.0	818.0	550.0	33.0	1,401.0
Technical Dev.	1,128.0	903.0	629.0	210.0	25.0	864.0
Green Bank Oper.	3,660.0	3,900.0	3,380.0	844.0	38.0	4,262.0
Tucson Oper.	1,322.0	1,500.0	1,070.0	517.0	52.0	1,639.0
Socorro Oper.	5,149.0	5,350.0	3,737.0	2,180.0	104.0	6,021.0
Subtotal - Oper.	$16,565.0	$16,908.0	$12,434.0	$5,321.0	$690.0	$18,445.0
2. Equipment						
Research Eqpt.	$ 1,787.0	$ 999.0		$1,088.0		$ 1,088.0
Operating Eqpt.	258.0	220.0		182.0		182.0
Subtotal - Eqpt.	$ 2,045.0	$ 1,219.0		$1,270.0		$ 1,270.0
TOTAL - OPER. & EQPT.	$18,610.0	$18,127.0	$12,434.0	$6,591.0	$690.0	$19,715.0
Less: CC Recovery		(172.0)		(391.0)		(391.0)
NET - OPER. & EQPT.	$18,610.0	$17,955.0	$12,434.0	$6,200.0	$690.0	$19,324.0

Note: See preceding page for design and construction allocations.

Estimated Quarterly Expenditure for Operations and Equipment CY 1986

Quarter Ending →	03/31	06/30	09/30	12/31	Total Available for Expenditure
Pers. Compensation & Benefits	$2,923.0	$5,865.0	$ 9,035.0	$12,434.0	$12,434.0
Material & Supply	1,727.0	2,805.0	4,049.0	4,980.0	5,180.0
Travel	130.0	311.0	522.0	690.0	690.0
Equipment	605.0	810.0	1,135.0	1,512.0	1,612.0
Total	$5,385.0	$9,791.0	$14,471.0	$19,616.0	$19,916.0
Percent Distribution, 1986	27.0%	49.2%	74.0%	98.5%	100%
Actual Expenditures, 1984-85					
1985 (Est. @ 12/31)	28.0%	49.8%	74.6%	97.7%	(2.3)
1984	29.3%	52.1%	75.6%	98.2%	(1.8)

APPENDIX A

RESEARCH PROGRAMS FOR THE NRAO SCIENTIFIC STAFF

During 1986 the permanent staff of the NRAO will be working in a number of research areas as described below. Some of the research will be carried out in collaboration with visiting scientists.

A. STUDIES WITHIN THE GALAXY

1. Stars and the Stellar Environment

The advent of more sensitive receivers, in Green Bank for the 21-cm hydrogen line and at the 12-m for the 115-GHz CO line, make it attractive to try again to detect the ambient material into which the stellar winds of O and WR stars are flowing. Earlier work by other investigators demonstrated the presence of molecular clouds near the wind-blown ring nebulae, but the radiometer sensitivity was a severe limitation. If the physical conditions in the neighboring clouds can be deduced, much better estimates of the lifetime of the mass-loss stage and of the total amount of mass lost can be made.

VLA observations will be repeated for a number of stars classified as VV Cep binaries in order to search for potential multiple year variations in the radio emission due to motion of the hot ionizing companion that orbits in the supergiant wind of the red giant primary star. Any variations that are detected can be very important in determining the physical characteristics of the VV Cep class of binary stars.

The January 1985 outburst of the recurrent nova RS Oph offered a unique opportunity to image the radio shell of a nova-like event. Three epoch observations will be followed up with the VLA in order to follow directly changes in the brightness temperature, angular size, and morphological details. So far the outburst has been better observed at radio, infrared, optical, ultraviolet, and x-ray wavelengths than any other previous nova-like event. The extension of these observations to additional epochs could be very crucial to an improved understanding of the event.

Changes in the source structure of SS 443 will be followed in detail by combining VLA and VLBI observations. Previous observations have already imaged the kinematic and physical evolution of the twin radio jets that emanate from a compact object. The planned observations are intended to confirm the slow drifts from model solutions that have emerged and that are possibly due to a decrease of the precession period of the accretion disk.

Excellent high-resolution maps of some planetary nebulae are available for detailed study. Although no stellar winds from the central stars are discernible in the observations, the nebular structure is found typically to be shell-like, with two opposing bright spots. The maps will be used to explore the possibility that the hot spots are a consequence of collimated flows. New optical data already suggests that such flows do occur in some planetaries.

2. The Interstellar Medium

The small-scale organization of the interstellar medium will be the subject of a 21-cm, 140-ft telescope detailed probe of directions through the galactic halo that have the least interstellar matter. In these directions the neutral hydrogen distribution appears to be fairly simple and not hopelessly confused as in most of the Galaxy. Investigations in the clearest of these directions have already shown the gas distribution to be opaque at energies less than 100 ev. It is still possible, however, that the lowest HI directions are transparent at higher energies. Observations of the low ISM directions will be extended to try to understand the distribution of matter among the various interstellar components.

VLA maps of the ionized carbon radio recombination-line emission across several molecular clouds will be made in order to serve as diagnostics of the density, temperature, and dust absorption of molecular clouds. Regions of ionized carbon occur in the gas interface between HII regions and the dense molecular clouds that are found in association with young, luminous stars. While such regions are commonly seen toward extremely bright nebulae, such as Orion, a few remarkable such CII regions are seen toward molecular clouds with no prominent HII region or luminous star. The excitation of these latter regions is provided by embedded early B-type stars having only very weak HII regions in their vicinity. While the line strength is a measure of the gas temperature, the spatial distribution of the recombination-line emission uniquely reflects the dust absorption coefficient at 1100A and the gas density.

Twelve-meter telescope maps of extended galactic HII regions can be used to investigate the characteristics of free-free and dust emission. The basic observational material can now be obtained as a result of improved telescope pointing properties and the implementation of new control software and dual-beam mapping algorithms. Maps of several regions at 3 mm, when compared to existing centimeter-wave data, show pure free-free emission characteristics. Observational evidence for the existence of dust emission will require mapping the same nebulae in line-free regions near 230 GHz. Further comparison of the single-dish maps with those made by interferometers should lead to a derivation of the degree of internal clumping and of its distribution within the HII regions.

Investigation of the star-forming activity in the nearby Rho Ophiuchus molecular cloud will attempt to determine what factors have contributed to its exceptional rate of star formation. A second center of star formation in the cloud was recently discovered, which contains the fourth most luminous infrared star in the cloud. It is at the center of the only well-defined bipolar flow known in the complex. Ammonia emission from the dense core of the cloud will be examined with the VLA. As seen with the 140-ft telescope, the core has the strongest ammonia lines ever observed.

The study of deuterated molecules has already begun to clarify the chemical ancestry of some species by determining the temperature dependence of deuterium enhancement. Observations of transitions of $H^{13}CN$ and DCN have been made in a number of clouds, and the analysis is expected to indicate the degree to which each of the potential major reaction chains contributes to the HCN and DCN production. If DCN is created primarily by a chemistry involving H_3^+, the deuteration enhancement temperature dependence should follow that observed for DCO^+. If DCN is created, on the other hand, through a reaction chain originating from CH_3^+ and atomic nitrogen, the enhancement temperature dependence should be significantly different. Further observations and analysis remain to fully clarify the situation.

Interstellar medium refractive properties will be studied using pulsars as test probes. Slow intensity variations, which are seen in pulsar observations at 310, 416, and 750 MHz, will be monitored in order to calibrate the contribution attributable to the interstellar medium. These will make useful comparisons to the observations of low-frequency refractive scintillations in extragalactic radio sources.

3. Galactic Studies

The collection of a substantial body of high-sensitivity HI spectra in the direction of high-latitude background sources will form the basis of an extensive study of the maximum extent of the Galaxy. Optical and uv spectral absorption lines seen toward distant stars already indicate the presence of very slight amounts of halo gas, and the 21-cm data should combine to give the location of this material and clarify its connection to matter in the plane. The data should also be valuable in helping to establish the form of the rotation curve for the gas that is located far above the galactic plane. Knowledge of the gas kinematics is essential to an understanding of the force balance that supports the material against the gravitational pull of the Galaxy.

The large-scale survey of continuum emission in the inner few degrees of galactic longitude will continue. The survey concentrates on sources away from the nuclear source, Sgr A, and is revealing the detailed morphologies of long-known objects which were originally detected in low-resolution surveys. Sgr C, in particular, looks remarkably similar to the famous nuclear source. In addition to completing the VLA continuum survey, a recombination-line survey will be carried out. Parallel CO emission kinematic studies with the 12-m telescope will also be pursued.

The kinematics of the gas near the galactic center will also be investigated with the aid of previously obtained high-resolution maps of the J = 3-2 line of HCO^+. The maps delineate the rotating ring of gas situated within 5 parsecs of the galactic center and show a velocity feature which apparently requires radial infall of some of this gas.

B. EXTRAGALACTIC STUDIES

1. Normal Galaxies

The low-resolution VLA survey of all 308 spiral galaxies brighter than B_T = +12 mag north of δ = -45° will be completed. Half of the galaxies have already been mapped at λ = 20 cm, and the detection rate exceeds 90%. So far, the non-detections have been confined to low-surface brightness, dwarf, irregular galaxies. When completed the survey will be the radio analog of the Shapley-Ames Catalog and will provide the basis for future work in a variety of areas. For example, only when maps of most spiral galaxies with normal disks are available will the range of "typical" morphologies be known.

Infrared bright galaxies are expected to be extremely dusty and an ongoing 300-ft survey program is investigating the correlation between the mass of atomic hydrogen in these galaxies and their dust mass. Out of 400 candidates from the IRAS survey, about half have been detected so far in HI. Preliminary correlations suggest that infrared emission from the warm dust component is associated with atomic gas in these galaxies. The correlations will be further studied in an expanded sample.

Possible changes in the radio structures of several clumpy, irregular galaxies will be investigated with the VLA. Earlier observations suggested that changes, on time scales of a few years, may indeed be detectable. If so, the new observations may provide clues to star formation and supernova activity in these galaxies, which from radio and other evidence contain extremely active star-formation regions.

The faint end of the galaxian luminosity function will be investigated by means of a search for faint dwarf galaxies. Complementary surveys in the 21-cm line of neutral hydrogen and in the ultraviolet will be carried out. For the uv survey, data from the Ultraviolet Imaging Telescope will be available for specially chosen fields of particular significance to the study of galaxies. Other problems that the uv observations will address include projects on uv spiral features, a search for young populations in old systems, and stellar population synthesis. For the radio-luminosity function of E/SO galaxies, VLA observations will be used to extend the observations to weak radio luminosities.

CO observations of the Seyfert galaxies NGC 1068, 4051, 4151, and 6814 are required to help delineate their molecular distribution. Detailed VLA HI absorption and emission synthesis observations have already been compiled for each galaxy and indicate that the neutral gas disks of Seyferts are in no way generally disrupted by their nuclear activity and may not even have been affected. The HI rings that are seen appear to be continuations of spiral arms traceable to within a few kiloparsecs of the nucleus. When added to the HI distribution, the CO distribution will help determine the total neutral gas surface density.

The companion to the Seyfert galaxy NGC 4151, UGC 07175, shows an HI distribution exhibiting several long plumes and disturbances analogous to the Magellanic Stream near our Galaxy. The companion appears to be in intimate contact with a distant (z = 0.1) barred spiral which has been considered a prime example of physically associated systems having discordant redshifts. The area will be mapped in much greater detail in order to substantiate the Magellanic Stream physical behavior.

VLA observations of spirals and ellipticals both in and out of clusters of galaxies will allow critical tests to be made of the effects of the environment on the properties of galaxies. Observations are already suggesting that in a dense environment spirals may lose their gas while ellipticals with any detectable gas at all may have recently accreted it. The VLA observations should help elucidate details of the removal and accretion mechanisms. In addition, the observed gas serves as a probe of the galaxy potential to determine, for example, if spirals in clusters have non-luminous halos, like those in the field, and whether any ellipticals have non-luminous halos.

2. Radio Galaxies and Quasars

Multifrequency VLA data will be used for the study of knot structures, spreading rates and magnetic configurations in kiloparsec-scale extragalactic radio jets. These data will be used to study the processes of energy transport, collimation, and relativistic particle reacceleration in large extragalactic sources. Evidence will also be sought for counterjets in radio sources wherein bright jets appear to feed one side only of a double-lobed structure, to constrain competing models for such jet asymmetries.

VLA maps of jet knots and hot spots in radio lobes at 1.5 GHz will be used to select targets for a search for optical synchrotron radiation from extragalactic radio sources using the Faint Object Camera on the Space Telescope. The radio morphologies, magnetic structures, and spectral shapes of such features will ultimately be used to test models of relativistic particle reacceleration by shocks and by turbulence-driven mechanisms.

The VLA will be used to study the structures of four exceptionally large radio sources: (1) The diffuse outer regions of the giant radio galaxy NGC 6251, (2) the exceptionally relaxed radio lobes apparently associated with the radio galaxy 4C 40.08, (3) an unusually large head-tail structure identified with the cluster galaxy IC 260, and (4) an almost featureless diffuse emission region 1450+391 discovered in VLA observations of fields from the B3 radio survey. Such large radio sources provide limiting cases for models of relativistic particle diffusion in active extragalactic systems. These four have been selected for study because they represent different types of very diffuse radio source, all of which are under-emphasized in existing radio structural studies at centimeter wavelengths.

Three-frequency polarimetry of a sample of bright radio galaxies near the celestial equator will be combined with a search for extra-nuclear optical narrow-line emission regions. This project specifically aims (1) to document and classify the polarization characteristics of a sample of bright radio galaxies that were previously understudied because of the limitations of east-west radio interferometers, (b) to determine how often Faraday screens in radio galaxies produce observable polarization asymmetries, and (c) to correlate radio and optical evidence for such screens in order to understand their layout, origin, and excitation.

Classical double radio sources selected from medium depth radio surveys will be candidates for a program of optical photometry and spectroscopy.

The sample is expected to provide a homogeneous group of distant elliptical galaxies for the purpose of studying galaxy evolution and cosmology.

Further observations will be made of the variability of the broad Lα-line in 3C 446. This is the only quasar in which line variability has been detected, and the time scale of variation is much shorter than the expected light-crossing time of the broad-line region. Examination of line variation provides important information on the geometry of the broad-line region and on the density of the emitting gas.

Simultaneous observations from the radio through the x-ray waveband will be made of OJ 287, 1156+295, and 3C 446. Each of these objects has shown rapid variations which are often different at different wavelengths. These observations permit the testing of radiation models such as the synchrotron, self-Compton model and the determination of the time variation of the magnetic field and mass of the emitting plasma.

Several transitions of various molecules will be searched toward quasars having known HI/optical redshifts in the range 0.5-2.5. Detection of molecular gas will considerably strengthen this argument that the HI absorption arises from "normal" disk galaxies. (It is already demonstrated that they do not arise in typical Ly-α forest clouds.) Furthermore, detection of almost any molecule at the searched-for redshift will provide stringent limits on the cosmological variation of baryon mass. These limits are not readily obtained otherwise, and yet they are necessary to complete a series of arguments concerning the constancy of physical constants over the history of the Universe.

If the host galaxies of low-redshift ($z \leq 0.1$) quasars are spirals, their disk continuum emission should be just detectable with the VLA at

λ = 20 cm. Maps of seven such quasars were recently made, and at least two have radio luminosities, morphologies, orientations, and sizes characteristic of disk emission. These radio maps will be compared with sensitive CCD images, and models of the host-galaxy disks will be made.

Quasar synchrotron emission arises from power-law particle distributions which may be accelerated in the vicinity of shocks. Calculations of this type of synchrotron emission will be made and its time-dependent behavior compared with observations. For a large sample of quasars and radio galaxies, radio variability observations on time scale ranging from 30 seconds to 6 years will be analyzed extensively and supplemented with additional observations, including single epoch spectra and structural characteristics.

Several programs will investigate quasar jet morphologies. The role of relativistic beaming in quasars and AGN will be evaluated through the analysis of radio observations of optically selected samples and high-resolution observations of extended, presumably randomly oriented, sources. The precessing-jet quasar PKS 2300-189 is unique in that the space orientation of its radio jets is known, and the jet speeds are known to be nonrelativistic. VLB maps of its core and inner jet structure can be interpreted without the ambiguities caused by relativistic beaming.
The core of PKS 2300-189 was recently found to be unresolved at λ = 3.8 cm with the intercontinental baseline of the NASA Deep Space Network. For a large sample of radio quasars the program to search for distorted structures and the statistical occurrence of one-sided jets will be continued.

Observational and theoretical studies of stimulated radio recombination lines toward quasars and radio galaxies will continue. Whether or not such lines are detectable is dependent on the particular physical conditions surrounding individual sources (temperature, density, fraction of the continuum covered, etc.).

3. Clusters of Galaxies and Cosmology

A variety of programs will address the physics of clusters of galaxies and the individual galaxies which serve as probes of the cluster environment. In dense clusters a multicolor photometric study of the diffuse intracluster light should provide basic data on the properties of the intracluster medium which scatters ambient galactic light. Dynamical arguments point to the existence of the intracluster medium, but very little is known of its makeup. Faraday rotation observations of background radio sources will be used to search for magnetic fields in some clusters and in others theoretical radio source jet models must be reconciled with observed optical and x-ray properties of jetted radio sources in the cluster environment.

The Sunyaev-Zeldovich effect, the scattering of microwave background radiation by intracluster hot electrons, has been shown to be potentially detectable towards five clusters. The 140-ft telescope will now be used to "map" the effect across the face of several clusters as a means of checking the interpretation of the observations. Additional checks will depend on a complete VLA survey of all blank sky reference positions to eliminate the possible contamination by faint sources.

Observations of highly redshifted neutral hydrogen ($z \sim 4$) will be carried out in search of protoclusters of galaxies. Other deep infrared observations will be attempted as a means of detecting individual primeval galaxies in their predicted early bright phase. Currently evolutionary models of galaxies predict increased infrared brightness during the epoch of enhanced heavy element synthesis from the primeval hydrogen and helium.

In an attempt to develop models of galaxy formation in the early universe, VLA observations have been obtained in a deep survey field centered on $(\alpha,\delta) = (08^h52^m15^s, +17°16')$. From a map size of 4096x4096, the angular size distribution of sources as faint as $S = 100$ μJy will be determined and compared with models in which most radio sources are produced by spiral galaxies at cosmological distances. The 6-cm source count below 25 μJy will be derived from a VLA survey down to a 5-μJy noise level. At these levels the source count appears to be dominated by a new population of sources which are not represented at higher flux-density levels. Further optical data will be obtained to establish the nature of these sources. The VLA survey will also be used to establish new limits to the fluctuations in the microwave background at levels between 0.3 and 2 arcminutes, which reflects the homogeneity of the Universe at $z \sim 1000$ when galaxies begin to form.

In the ongoing search for small-scale anisotropy in the microwave background, using the 140-ft telescope, the limits will be pushed below $\Delta T/T \sim 10^{-5}$ at an angular scale of ~ 8 arcmin. At that level theoretical predictions are a factor of two higher than at 4 arcmin. Observational limits to the anisotropy of the background promise to provide serious constraints on the origin, nature, and growth of the primeval density perturbations which eventually evolved into today's galaxies and clusters of galaxies.

C. MISCELLANEOUS

Final maps from the Green Bank 1400-MHz sky survey covering $-5° < \delta < +82°$ have been produced for the right-ascension range $7^h30^m < \alpha < 19^h30^m$. Data from the remaining 12 hours of right ascension will be edited, calibrated, and mapped. AIPS tasks are being developed which compare lists of coordinates (of optically bright galaxies of IRAS sources, for example) with these maps and flag those coinciding with radio sources.

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

Investigation of mosaicing problems for radio telescopes will continue, with emphasis on both algorithms and optimum data gathering. Mosaicing of different fields is necessary for current VLA data, Caltech OVRO millimeter interferometer data, and single-dish data and will be required for the proposed millimeter array. Also, in connection with the proposed millimeter array, it is intended to research possible extensions of the self-calibration techniques for removing atmospheric disturbances from interferometric data of weak objects. Some techniques from optical astronomy, in particular speckle masking, seem to be of great relevance.

Development of image deconvolution algorithms will continue, with special emphasis on methods practicable on the CRAY-X/MP now used by NRAO under the NSF supercomputer access program. The Maximum Entropy approach to image deconvolution has proved to be quite powerful and suggestive, and it is intended that extensions will be made to include polarization imaging and processing of spectral-line data. In addition, other, more ad hoc algorithms show considerable promise and will be studied in detail.

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

APPENDIX B

SCIENTIFIC STAFF

(Does not include Research Associates or Visiting Appointments)

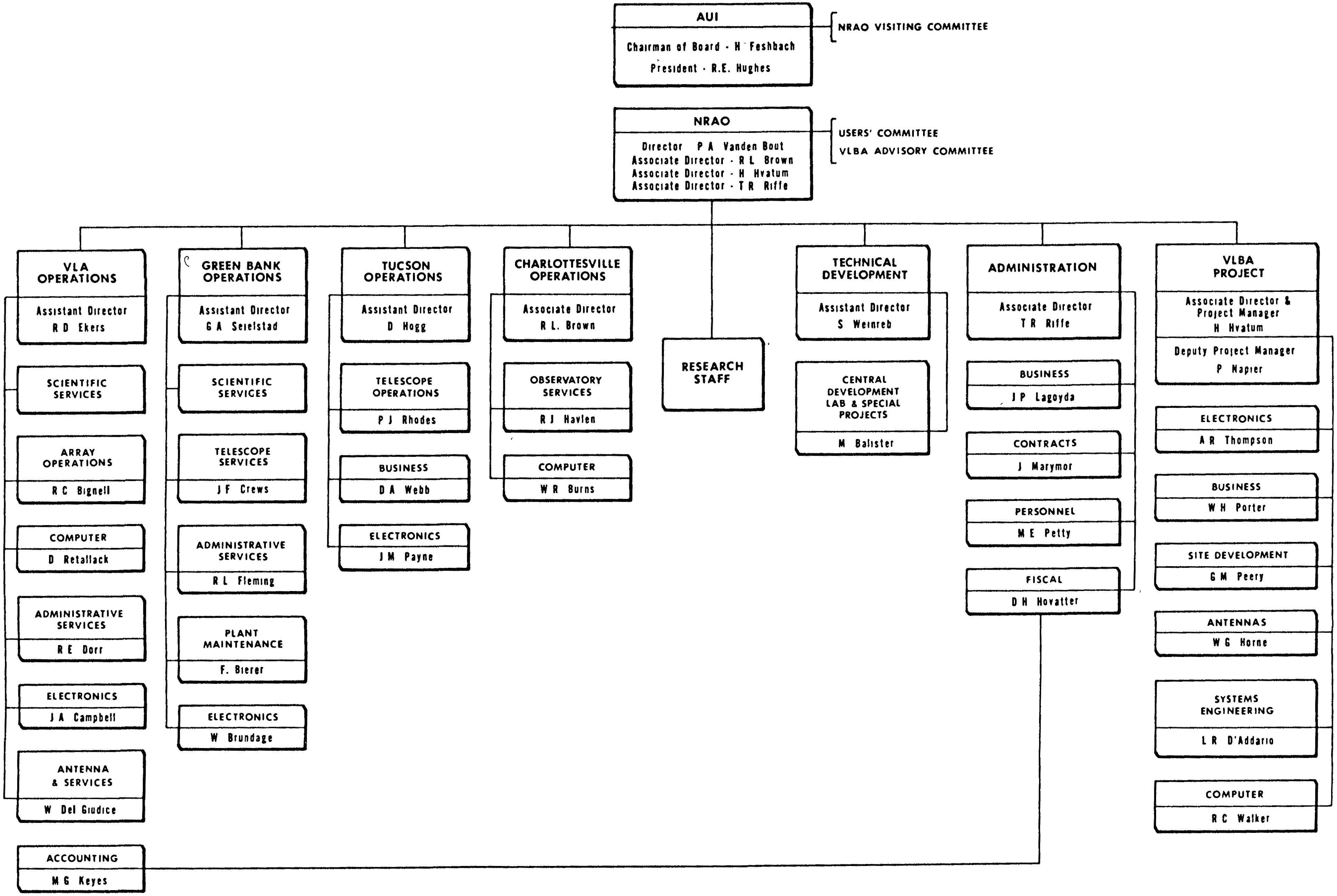
J. M. Benson	Extragalactic Radio Sources; VLBI Image Processing
R. C. Bignell	Polarization and Mapping of Extragalactic Radio Sources; Planetary Nebulae; Supernova Remnants
J. N. Bregman	Theoretical Astrophysics; Quasars
A. H. Bridle	Extragalactic Radio Sources
R. L. Brown	Theoretical Astrophysics; Interstellar Medium
B. G. Clark	VLA Development; VLB; Interferometry
J. J. Condon	QSOs; Normal Galaxies; Extragalactic Radio Sources
T. J. Cornwell	Image Construction Methods; Interferometry; Extragalactic Radio Sources
W. D. Cotton	Extragalactic Radio Sources; VLBI; VLA Development
P. C. Crane	Normal Galaxies; Interferometry
R. D. Ekers	Synthesis Techniques; Galactic Center; Normal and Radio Galaxies; Cosmology
E. B. Fomalont	Interferometry; Extragalactic Radio Sources; Relativity Tests
M. A. Gordon	CO; Galactic Structure
E. W. Greisen	Structure of Interstellar Medium; Computer Analysis of Astronomical Data
R. J. Havlen	Galactic Structure; Clusters of Galaxies
R. M. Hjellming	Radio Stars; Theoretical Astrophysics; VLA Development
D. E. Hogg	Radio Stars and Stellar Winds; Extragalactic Radio Sources

H. Hvatum	Electronics and Instrumentation for Radio Astronomy
P. Jewell	Comets; Circumstellar Envelopes; Interstellar Molecules
K. I. Kellermann	Extragalactic Radio Sources; VLBI Instrumentation
A. R. Kerr	Millimeter Wave Development
H. S. Liszt	Molecular Lines; Galactic Structure
F. J. Lockman	Galactic Structure; Interstellar Medium; HII Regions
R. J. Maddelena	Molecular Clouds; Millimeter-Wave Astronomy
F. N. Owen	Clusters of Galaxies; QSOs; Radio Stars
H. E. Payne	Interstellar Medium; Extragalactic Radio Sources
R. A. Perley	Radio Galaxies; QSOs; Interferometric Techniques
M. S. Roberts	Properties and Kinematics of Galaxies
J. D. Romney	Active Extragalactic Radio Sources; VLBI; Interferometer Imaging
A. H. Rots	Extragalactic Research; Spectral Line Interferometry; Data Display Techniques
G. A. Seielstad	Quasars; Active Galaxies; VLBI
R. A. Sramek	Normal Galaxies; Quasars; Astrometry
B. E. Turner	Galactic and Extragalactic Interstellar Molecules; Interstellar Chemistry; Galactic Structure
J. M. Uson	Clusters of Galaxies; Cosmology
P. A. Vanden Bout	Interstellar Medium; Molecular Clouds; Star Formation
C. M. Wade	Astrometry; Stellar Radio Emission; Minor Planets
R. C. Walker	Extragalactic Radio Sources; VLBA Development
S. Weinreb	Millimeter Wave Development
D. C. Wells	Digital Imaging Processing; Extragalactic Research
A. H. Wootten	Properties of the Interstellar Medium in Galaxies, Star Formation Regions, and Circumstellar Material

APPENDIX C

NATIONAL RADIO ASTRONOMY OBSERVATORY ORGANIZATION CHART

1 July 1985



APPENDIX D

NRAO COMMITTEES

Visiting Committee

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

The current membership of the Committee is:

G. A. Dulk	University of Colorado
J. V. Evans	Comsat Laboratories
A. Hewish	University of Cambridge, England (Cavendish)
K. J. Johnston	Naval Research Laboratory
G. R. Knapp	Princeton University
T. G. Phillips	California Institute of Technology
E. R. Seaquist	University of Toronto
P. Strittmatter	University of Arizona (Steward Observatory)

NRAO Users Committee

The Users Committee is made up of users and potential users of NRAO facilities from throughout the scientific community. It advises the Director and the Observatory staff on all aspects of Observatory activities that affect the users of the telescopes (development of radiometers and auxiliary instrumentation; operation of the telescopes; the computer and other support facilities; and major new instruments). This Committee, which is appointed by the Director, meets twice a year.

The present membership is:

M. F. Aller	University of Michigan
D. C. Backer	University of California, Berkeley
M. Bell	Herzberg Institute
J. H. Bieging	University of California, Berkeley
J. J. Broderick	VPI & SU
F. O. Clark	University of Kentucky
J. M. Cordes	Cornell University
R. M. Crutcher	University of Illinois
J. M. Dickey	University of Minnesota
W. C. Erickson	University of Maryland
E. D. Feigelson	Pennsylvania State University
B. J. Geldzahler	Naval Research Laboratory
S. J. Goldstein	University of Virginia
S. T. Gottesman	University of Florida
P. J. Huggins	New York University
K. J. Johnston	Naval Research Laboratory
K. Y. Lo	California Institute of Technology
J. M. Moran	Center for Astrophysics
D. O. Muhleman	California Institute of Technology
P. Palmer	University of Chicago
D. H. Roberts	Brandeis University
L. F. Rodriguez	Observatorio Astronomico Nacional
R. L. Snell	University of Massachusetts

E. R. Seaquist	University of Toronto
H. Thronson	University of Wyoming
B. L. Ulich	University of Arizona
J. Weisberg	Carleton College

VLBA Advisory Committee

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

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

The current membership of the Committee is:

R. Booth	Onsala Space Observatory
B. F. Burke	Massachusetts Institute of Technology

T. A. Clark	Goddard Space Flight Center
R. Frater	CSIRO, Division of Radiophysics
G. Grueff	Universita de Bologna
J. H. Lancaster	(unaffiliated)
A. T. Moffet	California Institute of Technology
M. J. Reid	Smithsonian Center for Astrophysics
M. Schmidt	California Institute of Technology
I. I. Shapiro	Center for Astrophysics
J. L. Yen	University of Toronto

APPENDIX E

VERY LONG BASELINE ARRAY

VERY LONG BASELINE ARRAY	($11,500,000)

In August, 1985, a careful reassessment of the cost to complete the VLBA was carried out. It reflected the more detailed knowledge of the system resulting from the continuing design effort, as well as improved estimates of subsystem costs. It also included costs of various system improvements proposed in the interim. Not surprisingly, the final figures somewhat exceeded the funding anticipated.

On September 10-11 at Green Bank, a comprehensive design review of the Project was held, which included careful consideration of optional improvements, and of other items that might be reduced, deferred or deleted in the interest of cost reduction without reducing Array capability significantly.

Included herewith is a revised Project budget, Table 1, to replace the plan submitted February 13 of this year, to which the reader is referred for comparison. This new budget is based upon the same funding schedule as the earlier one, but allocates the funds in such manner as to permit construction of other subsystems more nearly in phase with construction of the antennas, so that completed antennas do not stand idle for lack of frequency standards, receivers or other vital items. Table 1 is derived from the cost-to-complete figures mentioned above, but reflecting cost reductions proposed at the September design review.

Higher costs are shown in several areas, partly because better cost data are now available, and partly because system improvements have been incorporated in several areas. However, since costs for such large items as antennas and hydrogen masers are now known, it is now possible to accept a reduced allowance for contingencies, so that the overall Project cost estimate can be kept the same.

Under the current schedule for the construction of Station #1 at Pie Town, NM, which is based upon the above new budget plan, late April, 1987 sees the Pie Town station operable from a central control computer, whereas under the earlier budget plan, no VLBI operations would be possible before spring, 1988 due to lack of hydrogen masers and control facilities.

An overview schedule is included, showing how all subsystems of the VLBA proceed towards completion under this new budget plan. Plans for construction of the Correlator are as yet incomplete, as indicated below.

Stations and Antennas

The overview schedule shows the recently revised order of Station construction. The antenna contractor states there will be no cost increase due to these changes.

St. Croix, Virgin Islands, has been tentatively selected in place of Puerto Rico for Station #6 because of RFI conditions. Selection of exact sites for most locations is proceeding well. Sites 9 and 10 (Hawaii and Massachusetts) are proving most difficult, the latter for reasons of RFI.

A satisfactory review of the antenna design work was held at NRAO June 26-27. Completion and final approval of manufacturing drawings is scheduled for October-November, 1985. A subcontract change order has been signed authorizing manufacture of the first antenna.

The Architect/Engineer contractor has completed drawings for the site work, antenna foundation, and building for the Pie Town Station. The A/E's estimates of cost are considerably higher than expected. However, these estimates are admittedly very conservative, and it is expected that actual bid prices will be more nearly in line with the budget. Construction should start by the end of the year.

During 1986, the first antenna will be completed and erected at the Pie Town site, with acceptance tests scheduled for December. Manufacture of antennas 2, 3, and 4 will be started, as will design and construction work on the Kitt Peak, Los Alamos and Washington (state) sites. Advance procurement of certain long-lead items for all of the last nine antennas will also be authorized in 1986, in the dual interests of economy and a more certain construction schedule.

Electronics

Design and prototyping of receiver front ends, converters, local oscillator components and IF systems are progressing well. In addition, development of HEMT and SIS-junction front end technologies continues, with the goal of achieving successful designs for 23- and 43-GHz low-noise front ends later in the Program.

Extensive tests of cryogenic refrigerators have justified the choice of the small CTI Model 22 unit for all cooled receivers except the large 1.5-GHz front end, on which the larger Model 350 will be installed.

Hydrogen maser proposals from five prospective vendors are now being evaluated. Under the present budget, it is proposed to order several units from the selected bidder before the end of 1985, thus ensuring availability of VLBI-qualified frequency standards for each of the first few stations as their antennas are completed. The first of these will be delivered in late 1986.

Construction of the initial group of receivers (0.33, 0.61, 1.5, 4.8, and 15 GHz) and their associated equipment for the first Station will continue toward a full integrated system test at the VLA in late summer of 1986. Construction of sets of these same receivers for the next three antennas will continue through that year.

Data Recording and Playback Systems (NEROC)

Following NRAO's review of the detailed design report received in May development of prototypes of both the DRS and DPS began at Haystack Observatory. Some final questions regarding ultimate recording capability, system organization and equipment packaging were handled at the September 10-11 VLBA design review. The interface between the DPS and the Correlator is still under study.

It is expected that the DRS prototype will be shipped to the VLA before August, 1986, in time for the aforesaid integrated system test of essentially all non-antenna equipment for the Pie Town Station, prior to its installation at the site. Construction of additional DRS units for the Kitt Peak station (#2) will begin in 1986.

Monitoring and Control

Design and development of both hardware and software for the M/C tasks is well underway. Standard interface boards have been prototyped and tested, and production will start soon. Antenna and focus control systems are in the conceptual and design phases.

Hardware and software production for the Pie Town station are scheduled so as to be available in time for the pre-installation all-system tests at the VLA in August, 1986.

The present budget calls for purchase of the VAX central computer and the first Station computer in 1986, so that the above-mentioned system tests Can be realistically carried out under computer control.

Correlator

Caltech submitted their report on the architectural design of a correlator for the VLBA in June, 1985. A cost estimate followed in July.

Since funding for actual manufacture of the correlator will not be available for several years, it was decided not to undertake a detailed manufacturing design at this time, and the contract with Caltech was terminated. During 1986, NRAO, having the benefit of the Caltech effort, will continue to consider the correlator design, taking advantage of such technological advances as occur prior to the time when the design must be frozen and construction begun. Dr. M. S. Ewing, of the Caltech correlator team, will participate in this effort on a consulting basis.

Under the present budget, the first major funding for Correlator construction becomes available in 1988.

Array Operations Center

Consideration of the proper concept for the AOC is continuing in-house, and the assistance of the Architect/Engineer will be obtained during 1986. An approach is being studied that comprises a combined operations and control center for both the VLBA and the VLA. The aims are to take best advantage for both arrays of the expertise to be available in Socorro, and to minimize the need for costly and tiring daily travel between Socorro and the VLA. It is still anticipated that construction will be completed by early 1989.

Limited funds are provided for rental, beginning in early 1986, of temporary space near the present NRAO Socorro facility to accommodate VLBA activities until the permanent AOC building is available.

Post-Processing

The VLBA Post-Processing computer and associated hardware need not be purchased until fairly late in the Project schedule. Due to similarities between much of the software needed for the VLBA post-processing and software already developed for the VLA, the modest funding called out in 1985-6 seems adequate to support the present phase of the work.

Operations Training

To facilitate an orderly transition into the operations phase of the VLBA program, there should be significant participation in the construction and pre-operations testing phases by people who will ultimately fill key operations roles. Accordingly, modest funding has been set aside in 1985, 1986 and 1987 to support the advance hiring of the first two Station chiefs and two senior people who will form the nucleus of the operating group at the Array Control Center. The Station chiefs are intended to be available to participate in the integrated system test of all non-antenna electronics, control and recording equipment scheduled at the VLA in August, 1986. This fall, the first of these will begin assisting in equipment construction and test. It is expected that all will have been transferred to the operations budget before 1987 July 1.

Funding Schedule and Project Budget

A funding schedule (in current year dollars) of $2.8M; $9.0M; $11.5M; $17.7M; $18.0M; $14.2M for 1984-89 is currently anticipated by NRAO. The $2.8M for 1984 includes $2.5M originally funded for 1984 plus $0.3M added by NSF to carry the VLBA to April 1, 1985 due to a Congressional limitation on the 1985 funding (later extended to May 15). Work extending into 1990 as shown in the overview schedule will be funded *via* carryover from 1989.

As shown in Table 1, expenditures in 1986 will exceed the funding anticipated for that year, but will be met from planned carryover from 1985, as previously agreed with NSF. This permits the advance purchase of the long-lead items for future antennas, as mentioned earlier.

TABLE 1

VLBA BUDGET AND COST ESTIMATE

	1984	1985	1986	1987	1988	1989	1990	1991	TOTAL
ANTENNA STARTS		1	3	3	3				10
SITES	100	590	1,420	1,438	1,572	315			5,435
ARRAY OP CTR		5	112	1,555	738				2,410
ANTENNAS	1,103	2,926	7,328	5,184	5,188	800	72		22,601
ELECTRONICS	550	2,786	1,147	3,000	1,726	1,125	170		10,504
DATA RECORDING	293	428	279	971	972	739			3,682
MONITOR, CONTROL	66	225	691	529	443	35			1,989
CORRELATOR	334	111	300	600	1,700	1,500	860		5,405
POST PROCESSING		20	48	200	300	1,941	1,000		3,509
SYST. ENGINEERING	63	100	126	110	86	82			567
MISC., SPARES					1,000	1,500			2,500
PROJECT MAN.	297	424	623	597	567	611	186		3,305
OPER. TRAINING	0	17	77	56	0	0	0	0	150
TOTAL	2,806	7,632	12,151	14,240	14,292	8,648	2,288	0	62,057
CONTINGENCY	(6)	1,368	(1,199)	1,814	1,257	3,034	(2,288)	0	3,981
PERCENT CONT.	-0.2	17.9	-9.9	12.7	8.8	35.1	-100.0	0.0	6.4
BUDGET (85 $)	2,800	9,000	10,952	16,054	15,549	11,682	0	0	66,038

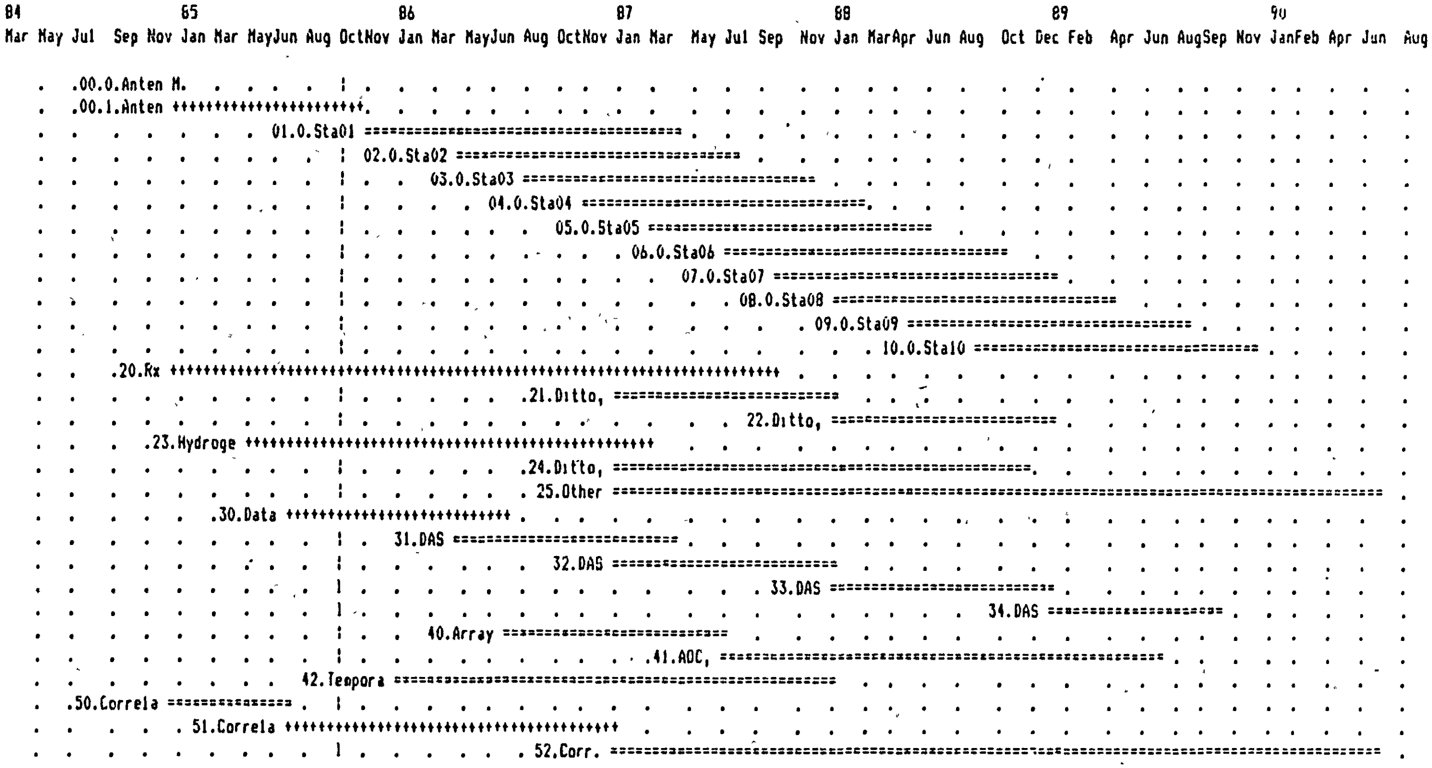
08-Oct-85
VLBA BUDGET AND COST ESTIMATE
(escalated)

	1984	1985	1986	1987	1988	1989	1990	1991	TOTAL
ESCALATION (%)	0	0	5	5	5	5	5	5	
ANTENNA STARTS	0	1	3	3	3	0	0	0	10
SITES	100	590	1,491	1,585	1,820	383	0	0	5,969
ARRAY OP CTR	0	5	118	1,714	854	0	0	0	2,691
ANTENNAS	1,103	2,926	7,694	5,715	6,006	972	92	0	24,509
ELECTRONICS	550	2,786	1,204	3,308	1,998	1,367	217	0	11,430
DATA RECORDING	293	428	293	1,071	1,125	898	0	0	4,108
MONITOR, CONTROL	66	225	726	583	513	43	0	0	2,155
CORRELATOR	334	111	315	662	1,968	1,823	1,098	0	6,310
POST PROCESSING	0	20	50	221	347	2,359	1,276	0	4,274
SYST. ENGINEERING	63	100	132	121	100	100	0	0	616
MISC., SPARES	0	0	0	0	1,158	1,823	0	0	2,981
PROJECT MAN.	297	424	654	658	656	743	237	0	3,670
OPER. TRAINING	0	17	81	62	0	0	0	0	160
TOTAL	2,806	7,632	12,759	15,700	16,545	10,512	2,920	0	68,873
CONTINGENCY	(6)	1,368	(1,259)	2,000	1,455	3,688	(2,920)	0	4,327
PERCENT CONT.	-0.2	17.9	-9.9	12.7	8.8	35.1	-100.0	0.0	6.3
BUDGET, Current $	2,800	9,000	11,500	17,700	18,000	14,200	0	0	73,200
OPERATION				500	2,000	3,800	6,000	7,000	

Schedule Name: VLBA SCHEDULE OVERVIEW
Project Manager: Hein Hvatum
As of date: 25-Sep-85 12:08pm Schedule File: C:\TLDATA\VLBAOV1

An approximate bar chart keyed to Budget BUD32a.

	Who	Status
00.0.Antenna Contract Let	PD, RSi	D
00.1.Antenna Design	WH, RSi	
01.0.Sta01 Build & Outfit (PT)		
02.0.Sta02 Build & Outfit (KP)		
03.0.Sta03 Build & Outfit (LA)		
04.0.Sta04 Build & Outfit (NA)		
05.0.Sta05 Build & Outfit (FD)		
06.0.Sta06 Build & Outfit (SC)		
07.0.Sta07 Build & Outfit (HL)		
08.0.Sta08 Build & Outfit (OV)		
09.0.Sta09 Build & Outfit (HI)		
10.0.Sta10 Build & Outfit (MA)		
20.Rx .3,.6.,1.5,5,15 GHz, 4ea	RT, BC	
21.Ditto, 3ea	RT, BC	
22.Ditto, 3ea	RT, BC	
23.Hydrogen Masers, #'s 1-5	RT	
24.Ditto, #'s 6-10	RT	
25.Other Receivers	RT	C
30.Data Acq System #1 (Proto)	HD	
31.DAS set#2 (1st Production)	HD	
32.DAS sets 3,4,5	HD	
33.DAS sets 6,7,8	HD	
34.DAS sets 9,10	HD	
40.Array Ops Center, design	BP, A/E	
41.AOC, Construct, Outfit	BP, BC, A/E, CB	
42.Temporary AOC, Computer	BP, BC, FN, CB	
50.Correlator Design Studies	CIT	D
51.Correlator Design, cont'd.	PD	
52.Corr. Proto. & Final		C



D Done === Task - Slack time (==---|, or
C Critical +++ Started task Resource delay (---==)
R Resource conflict M Milestone > Conflict
p Partial dependency
Scale: Each character equals 10 days

TIME LINE Gantt Chart Report

Strip 1

VLBA Project Staffing Plan

The following table represents the projected staffing for VLBA design and construction covering the seven years from 1984 to 1990. The change in the anticipated funding schedule from last year, with reduced funding in the earlier years has extended the construction schedule. No operations positions are shown in this schedule. As explained earlier, those occupying Operations Training positions will be assisting with construction and installation tasks prior to their transfer to an operating role.

Project Staffing Plan
(Number Employees @ 12/31)

	1984	1985	1986	1987	1988	1989	1990
Sites	0	2	3	3	2	1	0
Antennas	0	4	9	9	8	1	0
Electronics	8	14	22	24	23	47	0
Data Recording	0	0	0	0	0	0	0
Monitor & Control	1	5	6	6	6	0	0
Correlator	1	2	4	4	4	2	0
Data Processing	0	0	1	4	4	4	0
System Engineering	1	2	2	1	1	1	0
Project Management	6	10	11	10	10	10	0
Operations Training	0	1	2	0	0	0	0
Total	17	40	60	61	58	66	0
Estimated Man Years	15	30	54	63	59	42	8

VLBA Financial Plan - 1986

The distribution of planned commitments and expenditures for VLBA activities for the $11.5M anticipated for January 1 to December 31 is shown in the following table. A brief comment on each category follows.

($ thousands)

	Man Months	Salaries & Wages	Employee Benefits (25% wages)	Material, Supplies & Services	Travel	Contract Charges	Total
Sites	36	137.9	34.4	417.2	30.0	871.5	1,491.0
Antennas	93	280.2	70.0	287.1	45.0	7,012.0	7,694.3
Electronics	224	569.7	142.5	455.4	36.8	0.0	1,204.4
Data Recording	0	0.0	0.0	3.2	5.3	284.6	293.1
Monitor & Control	63	162.6	40.6	506.5	15.8	0.0	725.5
Correlator	44	136.5	34.1	107.6	10.5	26.3	315.0
Data Processing	12	32.1	8.1	4.9	5.3	0.0	50.4
System Engineering	24	81.4	20.4	9.6	21.0	0.0	132.4
Array Oper. Center	0	0.0	0.0	10.5	2.1	105.0	117.6
Project Management	132	378.5	94.6	154.8	26.3	0.0	654.2
Operations Training	17	54.0	13.5	4.9	8.4	0.0	80.8
Subtotal	645	1,832.9	458.2	1,961.7	205.5	8,239.4	12,758.7
<u>Other</u>:							
Spare Parts	—	—	—	—	—	—	0.0
Contingency	—	—	—	(1,258.7)	—	—	(1,256.7)*
Total	645	1,832.9	458.2	703.0	206.5	8,239.4	11,500.0

* Funded through planned carryover.

Salaries and Wages..$1,832,900

In calendar year 1986, the VLBA Project will incur approximately 54 man-years of direct in-house labor costs, covering salaries and wages of employees who have been hired directly into the Project, or transferred from other Observatory operations.

Employee Benefits...$458,200

For 1986, all NRAO cost centers will bear a benefits rate of 25% of salaries and wages.

Materials, Supplies and Services............................$1,961,700

The majority of materials, supplies and services expenditures in 1986 will be in the Sites, Antennas, Electronics and Monitor & Control areas. With the first Station (Pie Town, NM) actually under construction and equipment being completed and installed, many items in all these areas will have to be provided directly by NRAO.

Travel..$206,500

Travel costs incurred in 1986 will include moving and relocation expenses for new and transferred Project employees. Travel will also be necessary in connection with site review and acquisition, construction site inspections and contract progress and review meetings.

Contract Charges..$8,299,400

The major contract work to be performed on the VLBA during calendar year 1986 includes:

(a) Site Development: This total is estimated at $871,500, and covers commitments for survey, A/E design, site preparation and construction work at the Kitt Peak, Los Alamos and Washington (state) sites.

(b) Antennas: The total commitment in this area is estimated at $7,012,000, and covers procurement of antennas #2, #3, and #4 for the above-mentioned stations. Also included is the procurement of long-lead items required for all remaining antennas of the VLBA.

(c) Data Recording: $284,600 is required for the construction by NEROC of the second full data recording system for the VLBA, and for continuing work on the data playback system.

(d) Correlator: $26,300 has been set aside to support a continued consulting effort on the Correlator development by Dr. M. S. Ewing of the California Institute of Technology, as indicated earlier.

(e) Array Operations Center: $105,000 is the projected cost of the initial phase of the A/E design work on the AOC building and facilities for the VLBA.

VLBA ORGANIZATION CHART