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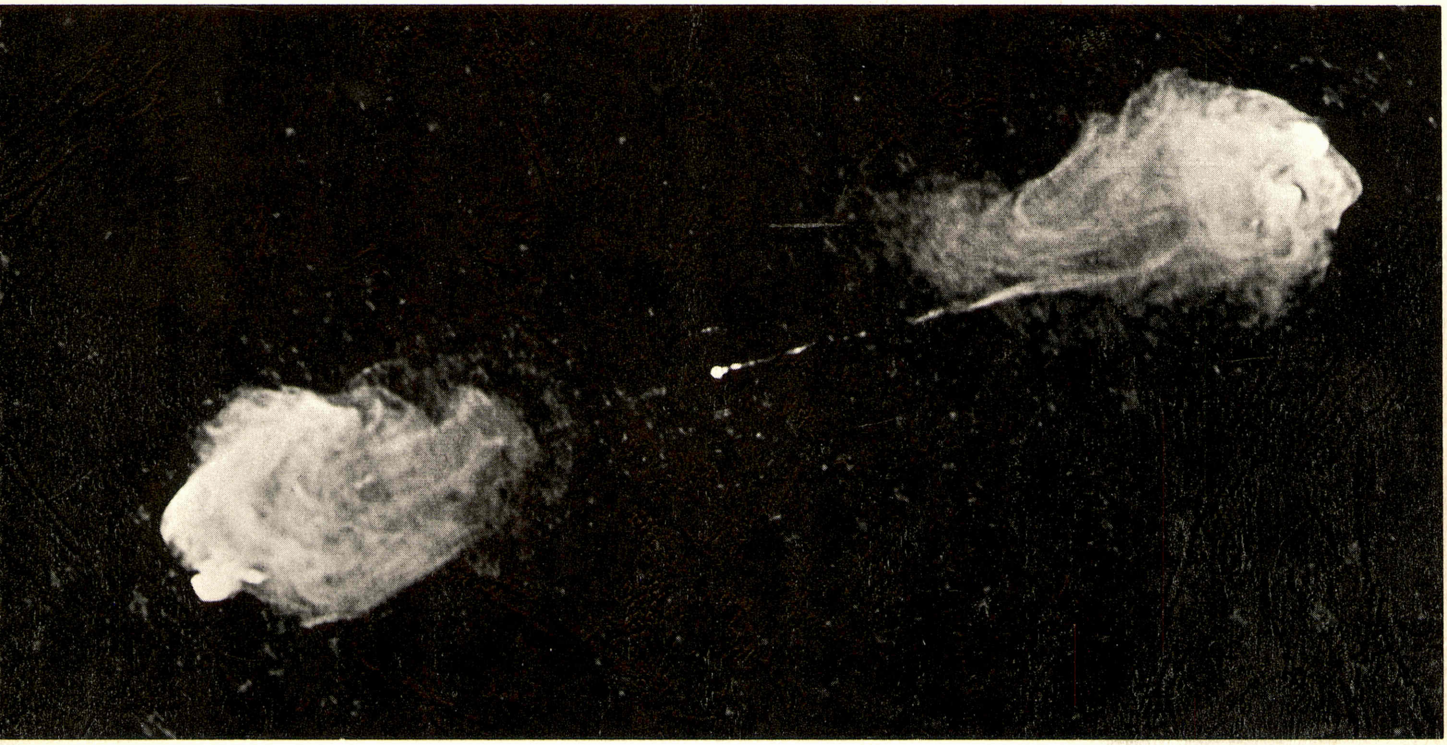
NATIONAL RADIO ASTRONOMY OBSERVATORY



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PROGRAM PLAN 1987

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

CALENDAR YEAR 1987 PROGRAM PLAN

NATIONAL RADIO ASTRONOMY OBSERVATORY

CALENDAR YEAR 1987 PROGRAM PLAN

SECTION		PAGE
I.	INTRODUCTION	1
II.	SCIENTIFIC PROGRAM	4
III.	RESEARCH INSTRUMENTS	20
IV.	OPERATING EQUIPMENT	37
V.	OPERATIONS AND MAINTENANCE	39
VI.	INTERFEROMETER OPERATIONS	45
VII.	VOYAGER 2 NEPTUNE PROJECT	47
VIII.	DESIGN AND CONSTRUCTION	49
IX.	PERSONNEL	50
X.	FINANCIAL PLAN	51

APPENDIX

A.	RESEARCH PROGRAMS FOR THE NRAO SCIENTIFIC STAFF	54
B.	NRAO PERMANENT SCIENTIFIC STAFF WITH MAJOR SCIENTIFIC INTERESTS	72
C.	NRAO ORGANIZATIONAL CHART	75
D.	NRAO COMMITTEES	76
E.	THE VERY LONG BASELINE ARRAY PROGRAM	80

I. INTRODUCTION

> "There is no richer field of science opened to the exploration of man in search of knowledge than astronomical observation; nor is there ... any duty more impressively incumbent upon all human governments than that of furnishing means and facilities and rewards to those who devote their lives to ... success in these pursuits."
>
> John Quincy Adams, 1842

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

Section II of this Program Plan summarizes the research that visiting investigators are planning to undertake with the NRAO telescopes during 1987. 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 1987. 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 1987 effort in these areas will include development of multi-beam receivers, spectrometers, and control hardware for millimeter-wave observations at the 12-m telescope; the rapid installation of 327-MHz receivers and low-noise, K-band receivers on many of the VLA antennas; and continued work on an extremely versatile and efficient spectral processor for spectroscopic and pulsar observations at 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 programs of the NRAO permanent staff, a list of the staff and their principal research interests, an organizational chart for the NRAO, and a list of various committees associated with the NRAO, and the 1987 VLBA Program Plan.

II. SCIENTIFIC PROGRAM

The following summary, by telescope, illustrates the diverse range of scientific topics that have been proposed for observation during 1987 at the NRAO. Most programs reflect the dynamic evolution that has taken place in astronomy during the course of the last decade as a result of bold new strides in instrument sensitivity and the acknowledged interdependence of multi-wavelength disciplines in the search for observational tests of proposed theories and astrophysical models. The world-wide community of physicists and astronomers maintains a continued healthy pressure on the NRAO observing facilities, and the existing proposal backlog is indicative of the many areas of scientific interest that will be pursued at the NRAO in 1987.

The Very Large Array

The four standard VLA configurations, including hybrid configurations for the most southern sources, continue to be heavily oversubscribed in response to the acknowledged power and versatility of the instrument for many programs. Hardware improvement programs, retrofits, and new receivers continually insure that the instrument maintains its leadership role at the vanguard of the science. The majority of the antennas will be outfitted with 327-MHz receivers by the end of 1987, and important low-frequency results are already leading to increased demand. Downtime is very low and user friendliness continues to be highly rated.

Solar and planetary system research programs continue to take advantage of the power of the VLA. The entire disk of the quiet Sun will be mapped at 90 cm as an important comparison to simultaneous 20-cm observations in order to sort out vertical temperature and density variations in the transition region of the solar atmosphere. Bright points that have been seen in coronal holes will be further investigated for their three-dimensional structure. Coordinated X-ray and EUV experiments should provide unique information defining the physical conditions in the region of formation. Continuing planetary programs include a monitor patrol of the properties of Jupiter's magnetosphere extending across the uv, optical, IR, and radio spectral regimes as well as a long-term, multi-wavelength study of the surface properties of the major asteroids. A study of the Neptune/Triton system will investigate phenomena in the atmosphere of Neptune and determine the mass ratio of the system. The newly discovered Comet Wilson will provide a fortuitous opportunity to sample the structure and kinematics of its OH distribution for comparison with the clumpy distribution found in Comet Halley.

Application of the VLA for stellar research continues to draw intense community interest. Several survey programs have been proposed as a means of circumscribing the known stellar radio emission phenomena that are detectable with the VLA. A survey of nearby active Be stars should clarify the nature of their mass-loss mechanism when potential detections are compared with the nonthermal character of other, strongly variable, stellar radio emission. An extensive VLA survey of M dwarf stars has been proposed in order to describe low-mass star radio emission in an attempt to broadly understand the coronal heating process in magnetically active stars. The variability of the three nearest M supergiants will be monitored over the long term in order to constrain proposed models and to better pinpoint the cause of radio variability in either the stellar radiation field or in the stellar wind itself. Follow-up observations of the cataclysmic variable, AE Agr, will determine the variability of its spectral index and clarify the role played by magnetic fields in the degenerate dwarf, binary system. Spectral information on selected symbiotic stars will discriminate between models involving either the hot or cool stars as the source of the wind in the associated binary system. A concerted multi-wavelength attack on the RS CVn stars using the VLA in conjunction with IUE and VLBI observations has been proposed in order to test predictions of gyrosynchrotron and coherent radiation mechanisms and to provide new information on physical conditions in the chromospheres and coronae of these detached binary stars. The very young galactic cluster, NGC 2264, will be surveyed for active A and F stars still evolving onto the main sequence.

The VLA will aid in understanding the intimate relation between stars and the nearby interstellar environment during various stellar evolutionary stages. For Young Stellar Objects, a VLA survey for radio emission will be part of a comprehensive program to increase the known population of such radio emitting objects and to provide some insight regarding the physics of hypersonic mass outflow. Numerous programs will focus on supernovae remnants as a means of understanding the final stages of stellar evolution. A survey of the galactic plane at 327 MHz should yield the discovery of many new SNRs, HII regions, planetary nebulae, and other nonthermal sources. The SNR survey will produce an important flux-limited sample to compare with predicted supernova rates and evolutionary models. The potential detection of the remnants of three possible historic supernovae noted in Cassiopeia by the ancients will provide invaluable data on very young remnants. Peculiar features of other remnants will be investigated, including one where the central neutron star may be detectable. The search for new remnants will also be carried to M33 where several candidates have been detected and a reliable determination of the surface brightness-diameter relation could result from a more definitive VLA study.

A major goal of VLA galactic research is the delineation and characterization of the physical conditions in molecular clouds and star-formation regions. VLA data, when combined with IRAS data on many sources, is indispensible for a thorough, broad-ranging spectral analysis of the relevant physical processes in star-formation regions. General molecular cloud properties will be surveyed in order to search for critical regions of stellar nucleation. In the Orion molecular cloud, observations of ammonia and formaldehyde and maps of the known OH and H_2O masers there are expected to improve kinematic information on dense regions. Similarly, in other molecular cloud regions, such as Rho Oph or the surroundings of W33, molecular-line observations will seek to probe density variations and structural features such as expanding shells, protostellar objects and their relationship to other known signposts of star-formation activity. Observations of the morphology and kinematics of compact HII regions will aid in modelling the physics of the ionization front/molecular cloud interface and its implication for the formation of massive stars. Hydrogen and helium recombination-line observations in several HII regions will be combined with infrared spectral data on argon in order to determine the chemical evolution of helium within the Galaxy. The character of bipolar outflow regions will be thoroughly investigated in order to test emerging models of hydromagnetic accretion disks. Improved maps of well-known Herbig Haro objects are required in order to learn more about energy transport from the optically hidden central sources. Large-scale properties of the star-formation process will be studied with wide-field maps obtained by super-synthesis techniques of four HII region complexes in diverse parts of the Galaxy.

The region of the Galactic Center continues to receive considerable study. A continuum survey extending ± 5 degrees either side of the center will be undertaken in order to provide an extensive database from which to derive the luminous star-formation rate, the distribution of post main-sequence objects, and the morphology of the global magnetic field in the region. Enhanced resolution of the lower radio lobe will be obtained in order to compare its detailed structures and polarization properties to those of its symmetrical counterpart above the Galactic Center. Second epoch maps of the Galactic Center will enable the search for proper motion in the high-velocity, ionized gas and thereby provide a better kinematic test for the presence of a central black hole in the Galaxy.

A large body of data will be accumulated with the VLA for every type of normal and active galaxy known to be radio detectable. HI observations will be used to investigate mass distributions in edge-on spirals, galaxies with collision-induced ring structures, dwarf ellipticals, barred spirals, Seyferts, and Markarian galaxies. A systematic, high sensitivity and resolution map of the disk of M31 will be obtained in order to analyze as completely as possible the energy balance and physical structure of the interstellar medium of a spiral galaxy similar to our own. Observations of a complete sample of isolated pairs of galaxies will provide additional clues on the effects that galaxy interactions have on individual galaxy emissivity and morphology compared with their known optical and infrared properties. The spatial distribution of the absorbing molecular gas in the active galaxy Cen A will be investigated in order to make an effective comparison between the distributions of atomic and molecular gas. Improved observations of the polarized emission arising from critical regions of the face-on spiral IC 342 are required in order to study mechanisms of magnetic field alignment by density waves, supernova explosions, and star formation. Polarization measurements in the extended radio halo of NGC 4631 will help to model the associated magnetic field configuration and impact theories of the propagation and confinement of cosmic rays in galaxies. VLA data for starburst galaxies will be compared with infrared measurements in an attempt to differentiate shapes of the initial mass function and to determine the duration of the nuclear starbursts. Possible time variations will be sought for in the OH megamaser in UGC 8696.

Multiple configuration VLA studies of classical radio galaxies will provide high dynamic range, high resolution, and extended frequency information that is invaluable to the detailed understanding of the radio source structure and theory. With an increasing number of antennas outfitted at 327 MHz, low-frequency VLA observations will play an important role in delineating the spectral structure and physics of significant source features, such as halos, jets, and hot spots. For the prototypical, well-studied source, Cygnus A, extending the observations to the limit of the instrument will provide an opportunity to study filamentary features and a possible counterjet that are as yet unknown in lesser studied sources. In another source the dynamics of a newly found binary radio jet system will be used to constrain physical parameters of the jet. Spatially resolved spectra of a sample of classical double radio sources will test the standard synchrotron aging model for spectral variations within radio sources. Detailed multi-frequency observations of five carefully selected classical double sources are planned in order to discriminate between two possible models for the magnetic and plasma effects that affect polarization measures. An ongoing systematic program to obtain basic spectral and polarization data on ultra-steep spectrum sources in comparison to their optically identified parent galaxies will continue. As a sample of high-luminosity, distant objects, they provide excellent laboratories for studying extreme conditions of radio-source production.

Radio morphologies and spectral properties will be the focus of several VLA studies of high and low-redshift quasars. Sensitive VLA observations of two optically selected samples will be obtained as a first step for determining the possible dependence of radio-to-optical luminosity ratios on optical properties or cosmological epoch. Models for Broad Absorption Line Quasars will be tested with multifrequency observations of a newly discovered sample of sources. VLA cm-wave observations of the cores of lobe-dominated quasars will help to determine their radio, mm, IR, optical spectral shapes and test for the existence of two separate emitting components in their cores. In a search for twin or gravitationally lensed quasars a sample of selected pairs with the smallest co-moving separations will be observed as a test of the origins of these associations. Another sample of most luminous quasars will be surveyed in a search for potential candidates of multiple lensed images to receive further sub-arcsecond resolution study.

VLA studies of galaxies and radio sources in cluster and group environments will receive continuing attention. A comparison of the luminosity function of radio galaxies in high-density groups with isolated galaxies of the same type will be made. Galaxies in the Hydra I cluster will be studied for affects that their dense cluster environment may have produced on their HI morphologies. Diffuse, radio halo sources, thought to be relic radio galaxies, at cluster centers will receive low-frequency, multi-configuration, diagnostic observations for more detailed spectral distribution, polarization, and morphology analysis. In many rich clusters with known accretion flows the radio properties of giant, central galaxies will be investigated. Correlation with the known X-ray and optical properties of these same galaxies may improve our understanding of the nature of interaction between the radio source and the accretion flow. HI redshifts obtained with the VLA will provide a clearer picture of the Pisces-Cetus Supercluster Void and a search will be conducted for HI clouds and protogalaxies within the void.

The 300-ft Telescope

The new 7-feed, 6-cm receiver will greatly enhance the data collecting efficiency of the telescope, thereby enabling time consuming, large-scale programs to be carried out with far less observing time than previously possible. The variability study of galactic plane sources which was initiated using the old receiver during the 1977 to 1984 period will be followed up with the new system. A major objective of the second phase of the patrol will be the real time detection of transient and highly variable sources. An all sky survey in the declination range -2° to +77° will also be carried out with the new 6-cm system. The radio maps will be comparable in source density and resolution with the IRAS infrared maps or ROSAT X-ray maps and should be an invaluable resource for the astronomical community. As an historical record of the sky, repeat observations at later epochs will effectively monitor source variability independent of the luminosity selection effects that have plagued previous studies.

Previously confirmed and suspected extragalactic decimeter wavelength variable sources will receive continued multifrequency monitoring in conjunction with high and low-frequency monitor programs at cooperating observatories. Although low-frequency variability is now a well-established feature of compact, flat-spectrum sources continued observational monitoring is required in order to establish more fully the characteristics of variability and to test proposed alternative mechanisms for producing the variability. Polarization and flux density measurements of another sample of compact sources will be carried out at 2.7 GHz as a continuation of a systematic study begun in 1972 to carefully follow long-term trends in the spectral evolution of these sources.

Selected subsets of galaxies will be studied in the 21-cm line of neutral hydrogen. In an attempt to trace the Pisces-Perseus supercluster across the Zone of Avoidance, probable galaxies identified in the IRAS catalogue will be observed. In another region radial velocities and global parameters of sample galaxies will be obtained as a means of studying the spatial structure in the region between two superclusters. A complete 21-cm database will be established for a subsample of Sa and Sc galaxies, with the goal of investigating the relative star-formation rate at the two ends of the spiral galaxy sequence.

A survey for very rapidly rotating pulsars will cover a 10° wide strip of more than half of the galactic plane in an attempt to identify more millisecond pulsars. The search for millisecond pulsars aims to increase the number of such relics of stellar evolution as probes of the physics of neutron stars and as resources for further timing and astrometry programs, ranging from the investigation of gravitational waves in the early universe to the dynamics of the solar system. An automated SETI search will piggyback on this survey.

The 140-ft Telescope

The 140-ft telescope continues to excel as a general-purpose, frequency flexible, single-dish, research instrument for the general astronomical community.

K-band observations continue to play an important role in the study of molecules in the interstellar medium where physical conditions are particularly appropriate for the low energy transitions found in the 5 to 25-GHz band. The C_3H_2 hydrocarbon ring molecule has been established to be widespread throughout the galaxy and as such is an extremely useful probe of the physical and chemical state of the molecular cloud environment. Observations of C_3H_2 are planned, with the 140-ft telescope, that will survey several, largely unstudied, transitions in order to sample the excitation state of the molecule as a function of varying properties of the interstellar medium. Observations of isotopic species also promise to augment our understanding of the abundance of C_3H_2 and its relation to other carbon-chain molecules.

A new, long-chain carbon molecule, with transitions seen near 3-mm wavelength, will be searched for at K-band with the 140-ft telescope in an attempt to discriminate between possible molecular carriers. Constraints on the chemistry of carbon-chain species in the interstellar medium are hoped for. A search for protonated carbon dioxide in several dark clouds will be undertaken in order to uncover clues to the chemistry of these objects.

Preliminary OH Zeeman observations of dark clouds which were successfully carried out in 1986 will be followed up more extensively on other dark clouds. Such observations provide a direct test of the theory and importance of magnetic fields in the star-formation process. Other star-formation parameters throughout the Galaxy will be sampled by means of newly discovered, extremely distant HII regions. Continuum and hydrogen recombination-line observations near 3.1 GHz will enable the determination of HII-region electron temperatures and their gradient throughout the Galaxy. A new IRAS-selected sample of probable dense, cold, circumstellar shells will be observed for OH and H_2O maser emission in order to confirm their evolved status and to investigate more fully the properties of the cool envelopes produced by numerous mass-losing stars.

The two E/SO galaxies, NGC 1344 and NGC 3923, will be searched for 21-cm emission in order to determine HI rotation curves as probes of M/L. In addition, both galaxies show well-developed, regular shell systems which have also been optically analyzed for radial M/L distribution as a direct comparison to the potential radio result. As part of an extensive study of molecules in the prototypical radio galaxy, Centaurus A, potential emission from the hydrocarbon ring molecule C_3H_2 will be investigated to complement absorption features from this molecule that have already been detected against the strong nuclear continuum feature.

Simultaneous observations of the extragalactic source OJ 287 will be made at Green Bank, the VLA, and Metsahovi Observatory in Finland in an attempt to confirm reported short time-scale variations. If real, the variations would provide powerful constraints on any model for the source. Observations of the Sunyaev-Zeldovich effect will continue in order to improve the results obtained during the past three years. The cosmological implications of the decrement in the microwave background depend on many fine details which the continuing observations will address.

Greater than 25% of the research effort with the 140-ft telescope 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.

The 12-m Telescope

Overall improvements in the instrumentation at the NRAO millimeter-wave facility have brought about an impressive increase in user demand, which promises to continue through the foreseeable future. Demand for frequencies greater than 200 GHz is especially high in view of the enhanced efficiency of the resurfaced telescope whose rms surface accuracy was reduced to about 80 microns. Added stimulus to the 12-m observing program has also arisen by the need to follow up results obtained on the very successful IRAS satellite. The telescope is in heavy demand in the following areas:

Molecular searches in the interstellar environment can potentially yield valuable information on chemical and physical conditions there. Two new vibrationally excited species, HCO^+ and N_2H^+, if detected, would be an important clue toward understanding "shock" or "high temperature" chemistry in star-forming regions. A search for interstellar MgH will also receive attention in order to place good observational limits on the abundances of metal species in molecular clouds and thereby weigh their role in the overall ionization balance.

The detection of giant and supergiant stars at 3 mm and 1 mm may be possible with current 12-m telescope instrumentation. In combination with existing centimeter-wave observations, the short-wave detections would provide added insights into the characteristics of the atmospheres of these stars. For young T Tauri stars, mm-wave observations are proposed in order to better establish our knowledge of the extended energy distribution and thereby constrain current massive disk models of these stars with improved size estimates. The highly successful study of the kinematics and distribution of molecular gas in planetary nebulae will be extended to additional objects. Pending the availability of a suitable nova outburst, observations of shell carbon monoxide are planned in order to more fully elucidate the fate of molecules during the successive nova evolutionary phases.

Investigations of star formation in the molecular cloud environment will be of high priority. With a goal of characterizing the clumping structure in the S140 molecular cloud, CS observations at 245 GHz will be obtained with the 12-m and compared with existing VLA formaldehyde observations. CS observations are also planned of the neutral disk at the galactic center where both the physical conditions of the disk and kinematic evidence for or against a central black hole in the Galaxy will result. Continuum observations of candidate protostars will aid in the development of models of protostellar evolution. For some compact HII regions, sub-mm observations at the limit of NRAO instrumental capability will help to establish the physical conditions of the embedded dust. Investigators will also probe the general characteristics of dust in the vicinity of HII regions by means of a new, successfully tested, mapping technique. When compared to other sub-mm maps obtained at UKIRT, the data can reveal the heating mechanisms of the dust throughout the regions. A newly developed 1-mm polarimeter will be used to study thermal emission from target molecular clouds and to determine magnetic field configurations and grain properties in regions of active star formation.

Added emphasis on extragalactic studies results from the potential of high resolution and greater sensitivity now afforded observers at the 12-m. A sample of barred spiral galaxies will be investigated for morphology and spatial distribution of the molecular gas. The resultant mass and dynamics will help to determine the role of the central bar and relevant stages and locations of star formation. Another program will focus on a detailed investigation of the interstellar medium in the dwarf elliptical galaxy NGC 185. In galaxy samples drawn from IRAS and other infrared surveys, investigators plan to search for thermal emission associated with active star formation, especially from the strongest infrared emitters. A test of the observed CO/far-IR correlation will be made for high infrared luminosity galaxies, where it is suspected that the basic physical constraints of star formation affect the correlation negatively when massive starbursts are involved. Observations of the variability of compact extragalactic sources at millimeter wavelengths will continue to monitor spectral evolution in a sample of active quasars and BL Lacs.

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, within the past year the marked improvements to the sensitivity of the Green Bank telescopes at 1-2 GHz resulting from a new generation of low-noise GaAs FET amplifiers have allowed astronomers to directly measure the magnetic field in a large sample of interstellar clouds by means of the Zeeman effect in atomic hydrogen and OH. These measurements usefully constrain theories of the stability, lifetime, and evolution of star-forming material in the Galaxy. Similarly, the exceptional imaging capability of the VLA realized through the application of the computational resources of a supercomputer have allowed production of multi-epoch images of supernova remnants in which the expansion of the remnants may be seen and studied. Of particular interest are studies of the fate of clumps of ambient interstellar gas that are overrun and illuminated by the supernova blast wave. Such observations provide crucial diagnostics of supernova energetics. The ability to directly observe, not idealize, such phenomena is invaluable. Moreover, 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 an 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 comprehensible yet provide ready access to the full flexibility available from the instruments. This need for a suitable user-interface has a considerable impact on NRAO plans for the design and utilization of astronomical instrumentation which can be seen reflected in demands on the research equipment plan and budget.

One of the more significant advances in radio astronomy in the last few years was spawned from the recognition that the quality of radio astronomical data could be markedly improved by more sophisticated data manipulation software. Here the most striking example is the use of self-calibration algorithms on VLA and VLBI data to correct the incoming wavefront for atmospheric (and instrumental) effects. This radio analog of the optical "adaptive optics" technique allows the VLA to achieve theoretical angular resolutions unencumbered by atmospheric smearing while at the same time reaching a dynamic range 100 times higher than expected in the design of the VLA. For the specific case of VLA data, the price of this improvement is an enormous computing burden that 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 Research Equipment plan represents the realization of these opportunities. The following table shows the planned distribution of funds for the Research Equipment account as currently dictated by the anticipated funds and established scientific priorities in each of the NRAO operating divisions. The NRAO, in consultation with its users, continually updates this table as scientific priorities change. A brief narrative describing the various items in the Research Equipment plan follows the table. It is important to note that most of the RE projects extend over several years; those for which monies are allocated in 1987 are not necessarily planned for completion in 1987. 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.

RESEARCH EQUIPMENT
(thousands of dollars)

	Expenditure 1986 (est)	Expenditure 1987 Plan	Estimated Add'l Cost	Estimated Completion Date
1. Laboratory Test Inst.	60	60	$100/yr	Continuing
2. Miscellaneous Projects	198	102	200/yr	Continuing
3. 300-ft Telescope				
Spectral Processor	110	60	90	1989
Adaptive Array Receiver	10	15	20	1988
4. 140-ft Telescope				
Computer/Digital Upgrade	5	20	150	1989
32 GHz Receiver	-	10	80	1990
Site Development Computer	5	15	250	1991
5. 12-m Telescope				
Hybrid Spectrometer	45	25	100	1989
Telescope Control Upgrade	25	35	40	1988
8-feed, 220-230 GHz Receiver	20	15	50	1988
6. Very Large Array				
22-25 GHz Improvements	75	60	220	1990
327 MHz Receivers	65	50	85	1989
RFI Improvements	10	20	135	1991
Synchronous Computer Upgrade	-	25	160	1990
Image Computer Enhancement	80	25	550	1991
7. Common Development				
Millimeter Device Development	80	70	150/yr	Continuing
Cooled GaAs FET Development	15	25	25/yr	Continuing
Class VI Evaluation	10	10	10/yr	Continuing
Communications	10	10	10/yr	Continuing
Total	823	652		

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 operates effectively at the 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 back-end 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. The first pivotal step in this direction--replacement of the control computer--was completed in 1986. More than just a hardware replacement, the new computer includes modern user-interface software that dramatically increases the versatility of the telescope control. The following items in the Research Equipment plan are needed now to exploit this versatility

Spectral Processor: This is a pipelined, fast Fourier transform spectrometer, incorporating real-time interference excision and flexible time and frequency-merging capabilities. It improves on existing instrumentation in two major areas. Spectral-line observations will have greater resistance to interference since spectral estimates are produced once every 10 microseconds instead of once every 10 seconds as is the present case. It will also increase the available number of spectral channels, providing 2048 channels across 40 MHz as compared to 384 channels across 10 MHz in the present autocorrelator. Secondly, the spectral processor will greatly improve pulsar data-acquisition capabilities at the 300-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.

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.

In 1986, the sensitivity of the telescope at most frequencies was improved by a factor of $\sqrt{2}$ by installation of a polarization beam splitter at the Cassegrain focus which allows both maser/upconverter receivers to be used simultaneously. Now one can choose either to observe at one frequency in two orthogonal polarizations or to observe with two receivers tuned independently anywhere in the range 4.8-25 GHz. The high-frequency performance of the telescope was also improved by application of a tilting, lateral focus, mechanism for the subreflector. This resulted in an increase of a factor of 2 or more in K-band aperture efficiency at large hour angles and provides one motivation for extending the frequency range of the telescope above the present 25 GHz.

Although the frequency flexibility and sensitivity of the 140-ft are exceptional, the operational flexibility is limiting. The present control computer is an out-dated 16-bit machine which has limited capacity for expansion and thus cannot make effective use of the dual receivers and the new data-taking procedures and data-processing algorithms that have the potential to greatly reduce the operational overhead as well as further improve the sensitivity, particularly the spectral sensitivity, of the telescope. The Research Equipment plan in 1987 thus calls for a higher frequency capability and initiation of work on a new control system, spectrometer and digital hardware interface that, when complete, will permit a more versatile operation.

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 pursued which will involve extensive experimentation with reflection spoilers, absorbers and rapid switching techniques. Second, digital hardware interfaces between the telescope RF instrumentation and the control computer will be redesigned and built in anticipation of the next generation control computer. Finally, construction of a 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.

32-GHz Receiver: 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 and there is considerable scientific motivation to observe at higher frequencies driven principally by (a) spectroscopy; (b) cosmic background radiation studies, and (c) VLBI. Although there are many molecular lines between 25 and 43 GHz, the following species have transitions important for astrochemistry in this frequency band: methanol (maser lines), formaldehyde, silicon monoxide, cyanoacetylene, and cyclopropenylidene. A frequency band near 32 GHz is particularly interesting because the atmospheric transparency is greater here than at any frequency above the resonant water line at 22 GHz. Significant continuum research, especially on the microwave background, can take advantage of this window.

In order to observe at 32 GHz the figure of the telescope aperture will have to be measured and the panels reset. Thus, work will commence on holographic measurement of the surface to identify and correct the panel setting. If the reset telescope will indeed support higher frequency observations a GaAs FET receiver will be constructed for this band.

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 simplifying 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 visitor and staff in 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 1987 and beyond is to augment or supplant the present control and data-taking facilities and the analog filter-bank spectrometer in order to provide more efficient use of the telescope.

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 but, 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.

Telescope Control Upgrade: The expanded capabilities of the new instrumentation for the 12-m, for example, the hybrid spectrometer, the fast beam-switcher, and lower noise receivers, all have the effect of increasing the data rates at the telescope. The multi-feed receivers further exacerbate this trend. Since the existing control computer cannot be further expanded, it will be replaced by a DEC 11/44 and a network of dedicated microprocessors. The user-interface software will be a straightforward adaptation of the 300-ft interface; thus the new 12-m control computer will foster adoption of an NRAO-wide "standard" telescope interface.

8-Feed, 220-230 GHz Receiver:

There is heavy pressure on the 12-m telescope for observations of the 2-1 lines of CO and the isotopes. The pressure arises in part simply because of a shortage of good days at 1.3 mm, and in part because the mapping of extended areas with the small beam is intrinsically time-consuming. The mapping process can be significantly speeded up by introducing a multi-feed receiver.

The receiver is envisioned as having eight focal-plane feeds. The orientation and separation of the feeds is now being studied. The initial version of the receiver will use Schottky mixers, some of which are already in hand. However, a novel feature of the design is that the dewars will be able to accept either Schottky mixers or SIS junctions. Accordingly, as SIS junctions become available, the Schottky mixers can be easily replaced. The 8-channel output of the receiver will be fed into the hybrid spectrometer, which can accept 8 independent IFs.

Very Large Array: Electronics

In the last year a staged enhancement of VLA electronics has begun to provide both very much greater sensitivity at high frequency (22-25 GHz) and to permit astronomers to exploit unique scientific opportunities at low frequency (300 MHz). Improvements at both these ends of the frequency spectrum constitute the thrust of the 1987 plan for development of VLA electronics.

300-MHz Receivers: Observations of a large number of astronomical objects 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 1987 as many as 24 antennas will have been equipped with prime focus, 300-MHz receivers; the VLA will then be a very exciting low-frequency synthesis telescope.

Related to this, investigations will proceed into the feasibility of providing a still lower frequency (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 resolution is 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 demand an upgrade to the VLA K-band performance. An attainable improvement at 24 GHz by a factor of 5-6 means a tremendous boost in speed and sensitivity. The 1987 plan calls for initial installation of an improved front-end amplifier for the 1.3-cm band that will reduce the system temperature to 150 K using HEMT (high electron mobility transistor) amplifiers developed at the NRAO Central Development Laboratory.

Very Large Array: 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 1987 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 1987 the hardware will be augmented with needed disk and memory capacity.

Image Computer Enhancement: 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 CPU speed greatly in excess of that available on VAX-class minicomputers, added disk space, higher density and more reliable tape drives and enhanced I/O performance. 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.

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 University of Virginia also does subcontract work in an attempt to develop niobium SIS junctions for application at the higher frequencies.

Cooled GaAs FET Development: This type of amplifier has become widely used for centimeter-wave radio astronomy receivers largely through the development work done at NRAO. The amplifiers are more reliable, stable, and have lower noise than parametric amplifiers. They are also used as IF amplifiers for millimeter-wave receivers and hence the sensitivity of almost all observations performed at the NRAO is improved with the development of these amplifiers.

GaAs FET amplifiers have been designed at 0.3, 1.5, 5.0, 8.3, 10.7, 15, and 23 GHz: Over 200 units have been constructed. Work in 1987 focuses on incorporation of lower noise, wider bandwidth HEMT (high electron mobility transistor) devices. Design of very wideband amplifiers for IF use is under investigation.

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 1985-86 the principal emphasis was on getting AIPS to run on the CRAY X-MP/2200 at

Digital Productions. In 1987 the thrust will be to optimize AIPS for the supercomputer as well as to support visitor mapping programs on the CRAY at the NSF Carnegie/Pittsburgh Center 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 among NRAO sites and with the NSF supercomputer center. 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. OPERATING EQUIPMENT

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

1.	Maintenance, Shop, and Repair Equipment	$25.0
2.	Office and Library Furnishings and Equipment	30.0
3.	Living Quarters Furniture	4.0
4.	Building Equipment	6.0
5.	Observatory Services	20.0

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 graphics arts and information services. Items such as cameras, film processing units, projectors, measuring equipment, etc., are included in this amount.

V. OPERATIONS AND MAINTENANCE

In 1987 a new operations division, VLBA Operations, is added to the previous seven NRAO operations units. These units include both the individual operations at the three observing sites and the integrated operations which encompass all four geographic locations. The geographic distribution of personnel in these eight units is given in Section IX.

A. General and Administrative

Serving the needs of the entire Observatory, this unit is comprised of the Director's Office, Fiscal Office, and Business Office. Total Materials, Supplies, and Services (MS&S) funding will be $282k. Further major budget items, such as the rent and maintenance of the Charlottesville Edgemont Road building, communications, and utilities, will require $380k. The management fee paid to Associated Universities, Inc., will be $400k.

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. They are distributed between the Charlottesville and Socorro sites as 59% and 31%, respectively, with the remainder in Tucson or Green Bank.

In 1986, the NRAO summer student program was curtailed in response to budgetary pressures; in 1987 the expectation is that the program will be restored as a vital element in NRAO's commitment to the training of future radio astronomers.

Over 40% of the overall NRAO travel budget will be expended in the Research Group ($205k) primarily for travel by all staff and visitors from U.S.-based institutions to carry out observing programs at NRAO telescopes or needed by visitors to travel to use Charlottesville data-analysis facilities. During 1985, $30k is planned for foreign travel by the staff, and $20k is available for qualifying U.S. scientists who need travel support to observe at unique foreign telescopes.

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 1987, the MS&S budget of $493k 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 more than 100 institutions world wide. As has been the case in previous years, a major portion of the MS&S for this Division will be used for computer-related expenses and maintenance. In 1986 a new CONVEX C1 mini-supercomputer was purchased with the University of Virginia on a cost-sharing basis, and has been optimized to run the NRAO image processing software system AIPS for the benefit of visitors and staff. The second of four scheduled payments on the C1 will be made in 1987.

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 new millimeter-wave amplification devices. During 1987, $55k 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 1987 budgets for MS&S are: Telescope Services ($156k), Electronics ($162k), Plant Maintenance ($145k), Administrative Services ($106k), and Scientific Services ($77k). An additional $320k will be spent on communications and utilities. It is also estimated that food services and housing will bring in revenues of about $120k. The operation of the Green Bank interferometer for the USNO affects the Green Bank Operations budget as a credit of $805k (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 1987 effort to the installation of a new control computer and its digital hardware, a new spectrometer, and a multi-beam receiver. The Operation and Maintenance group handles all visiting astronomer logistics and observing support, which for 1987 will include continued software development for improved telescope control and data acquisition. The two Tucson subgroups will require the following MS&S budgets for 1987: Operations and Maintenance ($191k) and Electronics ($169k). An additional $160k is programmed for building rent, communications, and utilities. Miscellaneous revenue will total about $20k.

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 $98k. 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 $591k and $12k, respectively. Other services related to the efficient functioning of the operation and their MS&S budgets are: Engineering and Services Division ($447k) of which $150k is earmarked for special maintenance of the VLA railroad, $50k is set aside for special maintenance of the array electric power distribution system, and $329k for Administrative Services. Communications, utilities, and building rent (in Socorro) will amount to $1145k, while miscellaneous revenue of $135k is expected. Included in the above sums is $445k for computer rent and maintenance and more than $750k for electric power costs. A significant part of the communications expenditures will be devoted to remote observing costs.

H. VLBA Operations

The first VLBA operating funds are to be received in 1987. In looking forward to a combined VLBA-VLA operations program, the decision was made to categorize initially the VLBA operations into divisions similar to the existing VLA operations groups. The total MS&S budget for VLBA operations of $176k is comprised of $2k for Scientific Services, $21.5k for Administrative Services, $9k for Engineering Services, and $39k for Electronics ($25k of which is estimated for shop and lab equipment), $47k for the Computer Division ($40k of which is for magnetic tape expenses), $1k for the Array Operations Division, and

$56.5k for other expenses, including an estimated $30k for electric power and $26k for communications and data links.

A summary of the CY 1987 budget for these operations units is provided in the following table:

	Personnel	Salaries, Wages & Benefits	Material, Supply, Service	Travel	Total
		($ thousands)			
Operations					
A. General & Admr.	27	$1,100	$1,062	70	$ 2,232
B. Research Group	29	1,718	10	205	1,933
C. Cvlle. Oper.	23	897	493	25	1,415
D. Technical Develop.	12	528	200	15	743
E. Green Bank Oper.	89	3,145	845	30	4,020
F. Tucson Oper.	25	1,020	500	40	1,560
G. Socorro Oper.	106	3,488	2,487	70	6,045
H. VLBA Oper.	5	201	191	8	400
Common Cost Recovery			(393)		(393)
Total Operations	316	$12,097	$5,395	463	$17,955
Design and Construction					
VLBA	63	$ 2,483	$6,584	333	$ 9,400
Voyager 2	15	650	625	41	1,316
Total Design & Const.	78	$ 3,133	$7,209	374	$10,716
TOTAL	394	$15,230	$12,604	$837	$28,671

1. Does not include commitments carried forward from 1986.
2. Gen. & Admr. includes $400k AUI management fee.
3. Green Bank Oper. includes $805k new funds 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 reimbursement 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. In 1986 scientific support for the interferometer was improved by the appointment of an astronomer resident in Green Bank with responsibility for the USNO program. No major additions or improvements are planned for the interferometer in 1987.

Operating and maintenance costs and equipment replacements for the interferometer are planned at $860k in 1987, of which $54.6k is carried over from prior years' accumulations in construction programs and equipment upgrading projects.

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 1987 interferometer allocation is shown in the following tables.

	1985 Expended Actual	1986 Expended Est	1987 New Funds
1. Operations			
Personnel Compensation	$264.2	$278.0	$313.5
Personnel Benefits	75.7	82.0	89.5
Material & Supply	68.4	222.0	73.6
Communications & Utilities	36.9	39.0	46.1
Travel	0.0	2.0	4.0
Common Costs	224.8	249.0	263.4
Total Operations	$670.0	$872.0	$790.2
2. Equipment			
Automotive		$ 12.1	
Test Equipment	$ 18.3	10.3	$ 15.0
G.P.S. Receiver		23.6	
Total Equipment	$ 18.3	$ 46.0	$ 15.0
3. Design & Construction			
Interferometer Addition	$209.8	$ 0.0	$ 32.9*
Total Design & Construction	$209.8	$ 0.0	$ 32.9
TOTAL	$898.1	$918.0	$837.9

* uncommitted carryover

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 1987 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 1987 is expected to run about $1.5M, of which about $50k is from 1986 funds carried over for commitment and expenditure in 1987.

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 1987 Voyager 2 program allocation is shown in the following table ($ thousands).

	1986	1987				
	Est. Exp.	New Funds	Uncomm. Carry-over	Available for Comm.	Comm. Fwd.	Available for Exp.
Personnel Compensation	$ 420.0	$ 494.0		$ 494.0		$ 494.0
Personnel Benefits	101.0	156.0		156.0		156.0
Material & Supply	895.0	252.0	$300.0	552.0	$275.0	827.0
Travel	15.0	41.0		41.0		41.0
Common Costs	340.0	373.0	20.0	393.0		393.0
TOTAL	$1771.0	$1316.0	$320.0	$1636.0	$275.0	$1911.0

Total funding for NRAO's participation in the Voyager 2 programs is scheduled to be $5783k, as shown in the following table.

	1985	1986	1987	1988	1989	Total
Central Lab	$ 720.0	$ 925.0	$ 466.0			$2111.0
VLA Site	531.0	1114.0	850.0	$771.0	$406.0	3672.0
TOTAL	$1251.0	$2039.0	$1316.0	$771.0	$406.0	$5783.0

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 1987, the first four antennas will be completed and put into operation, and specific hardware will be produced in the areas of electronics, data recording and playback, and monitor and control. Design specifications for the correlator will be further advanced. Construction will also begin on Phase I of the combined VLBA-VLA Operations Center which has been funded by the State of New Mexico. The planned activities for 1987 are outlined in more detail in Appendix E.

IX. PERSONNEL

1987 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	1	17	2	9	29
Charlottesville Operations					
Computer		17			17
Observatory Services		6			6
Subtotal		23			23
Technical Development					
Central Lab		12			12
Green Bank Operations					
Telescope Services	31				31
Electronics	22				22
Plant Maintenance	15				15
Administrative Services	8				8
Scientific Services	13				13
Subtotal	89				89
Tucson Operations					
Operations/Maintenance			13		13
Electronics			12		12
Subtotal			25		25
Socorro Operations					
Scientific Services				8	8
Engineering and Services				25	25
Computer				17	17
Electronics				26	26
Array Operations				11	11
Administrative Services				19	19
Subtotal				106	106
VLBA Operations					
Array Operations				2	2
Electronics				2	2
Computer				1	1
Subtotal				5	5
TOTAL NRAO	98	66	27	125	316

X. NATIONAL RADIO ASTRONOMY OBSERVATORY
CY 1987 PROVISIONAL FINANCIAL PLAN

	1985 Actual Expend.	1986 Est. Expend.	1987 New Funds*	1987 Uncomm. Funds Carried Over from 1986	1987 Total Avail. for Commit.	1987 Commitments Carried Over from 1986	1987 Total Available for Expend.
I. OPERATIONS							
Personnel Comp.	$ 9,316.0	$ 9,325.0	$ 9,663.0		$ 9,663.0		$ 9,663.0
Personnel Benefits	2,367.0	2,332.0	2,434.0		2,434.0		2,434.0
Travel	613.0	416.0	463.0		463.0		463.0
Material & Supply	4,426.0	4,700.0	5,388.0		5,388.0	$ 271.0	5,659.0
Management Fee	350.0	380.0	400.0		400.0		400.0
Common Cost Recovery	(148.0)	(340.0)	(393.0)		(393.0)		(393.0)
Total Operations	$16,924.0	$16,813.0	$17,955.0		$17,955.0	$ 271.0	$18,226.0
II. EQUIPMENT							
Research Equipment	$ 959.0	$ 823.0	$ 500.0	$ 152.0	$ 652.0	$ 240.0	$ 892.0
Operating Equipment	169.0	134.0	50.0	35.0	85.0	-	85.0
Total Equipment	$ 1,128.0	$ 957.0	$ 550.0	$ 187.0	$ 737.0	$ 240.0	$ 977.0
Total: Oper. & Equip.	$18,052.0	$17,770.0	$18,505.0	$ 187.0	$18,692.0	$ 511.0	$19,203.0
III. DESIGN & CONST.							
VLBA Project	$ 3,209.0	$ 7,945.0	$ 9,400.0	$ 475.0	$ 9,875.0	$ 7,648.0	$17,523.0
Voyager 2 Project	909.0	1,771.0	1,316.0	320.0	1,636.0	275.0	1,911.0
Interferometer Addn.	228.0			33.0	33.0	-	33.0
Total: Design & Const.	$ 4,346.0	$ 9,716.0	$10,716.0	$ 828.0	$11,544.0	$ 7,923.0	$19,467.0
TOTAL PLAN	$22,398.0	$27,486.0	$29,221.0	$1,015.0	$30,236.0	$ 8,434.0	$38,670.0

* Includes USNO Funds $805k; NASA funds $1316k; NSF funds $27,100k.

1987 FINANCIAL PLAN FOR OPERATIONS AND EQUIPMENT

	1985	1986	1987 Available for Commitment			
	Total Expenditure	Est. Expenditure	Wages & Benefits	M&S Services	Travel	Total Available
I. OPERATIONS						
Gen. & Admr.	$ 1,902.0	$ 1,832.0	$1,100.0	$ 662.0	$ 70.0	$ 1,832.0
Research Sup.	1,796.0	1,868.0	1,718.0	10.0	205.0	1,933.0
CV Oper.	1,360.0	1,326.0	897.0	493.0	25.0	1,415.0
Technical Dev.	808.0	758.0	528.0	200.0	15.0	743.0
GB Oper.	3,963.0	3,994.0	3,145.0	845.0	30.0	4,020.0
TUC Oper.	1,471.0	1,539.0	1,020.0	500.0	40.0	1,560.0
SOC Oper.	5,422.0	5,456.0	3,488.0	2,487.0	70.0	6,045.0
VLBA Oper.	-	-	201.0	191.0	8.0	400.0
Management Fee	350.0	380.0		400.0		400.0
CC Recovery	(148.0)	(340.0)		(393.0)		(393.0)
Total Operations	$16,924.0	$16,813.0	$12,097.0	$5,395.0	$463.0	$17,955.0
II. EQUIPMENT						
Research Equip.	$ 959.0	$ 823.0		$ 652.0		$ 652.0
Operating Equip.	169.0	134.0		85.0		85.0
Total Equipment	$ 1,128.0	$ 957.0		$ 737.0		$ 737.0
TOTAL OPERATIONS & EQUIPMENT	$18,052.0	$17,770.0	$12,097.0	$6,132.0	$463.0	$18,692.0

Note: See preceding page for design and construction allocations.

ESTIMATED QUARTERLY EXPENDITURE
FOR OPERATIONS AND EQUIPMENT
CY 1987

Quarter Ending	03/31	06/30	09/30	12/31	Total Available for Expenditure
Personnel Compensation & Benfits	$2,898.0	$5,743.0	$ 8,809.0	$12,097.0	$12,097.0
Material & Supply*	1,940.0	3,163.0	4,515.0	5,509.0	5,666.0
Travel	87.0	209.0	350.0	463.0	463.0
Equipment	364.0	486.0	681.0	878.0	977.0
Total	$5,289.0	$9601.0	$14,355.0	$18,947.0	$19,203.0
Percent Distribution, 1986	27.6%	50.0%	74.8%	98.7%	100%
Actual Expenditures, 1985-86					
1986 (Est. @ 09/30 and 12/31)	22.2%	46.3%	71.0%	98.2%	(1.8%)
1985	28.0%	49.8%	74.6%	98.5%	(1.5%)

* includes Management Fee and Common Cost Recovery

APPENDIX A

During 1987 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

A uniform set of observations of the 150 nearest stars to the sun are being observed with the VLA in order to determine the accurate radio-luminosity function of normal stars. Such a stellar radio-luminosity function would be a valuable aid in understanding post main-sequence stellar evolution, particularly for pathological atmospheres or cases involving interacting systems. A pilot program is planned to search for radio emission from bright stars at millimeter wavelengths. Giant and supergiant stars which have large, extended atmospheres should now be detectable at 1 mm and 3 mm with the sensitivity of the 12-m instrumentation. Potential detections will provide a check on the canonical values of stellar radii for pure black-body radiation. Additionally, the effects of stellar winds, dust shells, chromospheric or coronal radiation, and nonthermal electrons might be observable.

There are increasing indications, from both observations and theory, that the material ejected during the eruptive phase of a nova or planetary nebula expands into a region dominated by material lost from the star in an earlier wind stage. Such massive winds have been observed in many stars, notably the Wolf-Rayets, and the remnant of the cooled wind has been detected around late stars, such as M supergiants as well as a few planetaries.

The sensitivity of the CO receivers on the 12-m has now improved to the point where it is worthwhile to attempt again to find evidence of the mass-loss envelope around evolved, massive stars. The cooled envelope gives a direct measure of the total mass lost in the wind phase, a number now only estimated on theoretical grounds. A number of the more promising novae should also be searched. A good candidate is GK Per, where there is evidence of interaction between the nova envelope and some surrounding material. Other radio/infrared observations of novae will be aimed at understanding the dynamical and dust/chemical evolution of their winds and shells.

Red-giant, circumstellar shells that have been mapped with the OVRO interferometer are undergoing detailed analysis. So far, growing evidence indicates that mass loss from red giants may not be a smooth, spherically symmetric process. If mass loss is initiated, for instance, when radiation pressure liberates clumps of dust condensing at the tops of giant convective cells in the envelopes, much of current thought on the chemistry and structure of circumstellar shells must be changed.

Further VLA observations will be undertaken to monitor the relative motion of the radio lobes of Sco X-1 and the variation of the intensity of the lobes. This nearby galactic source has the same morphology as the luminous extragalactic sources but is sufficiently close so that its motion can be determined over periods of a few years. With respect to another enigmatic stellar source, SS 433, analysis of 1978-1986 radio and optical data will aim to understand both the astrophysical processes in the jets and the second order effects in the kinematics of the jets.

The first two epochs (1984.9, 1986.5) of the ongoing pulsar astrometry and proper motion program have been fully reduced. Analysis of the absolute positions of each pulsar is being compared with positions derived from pulse timing analysis. Discrepancies have been noted with previous observations. The relative motion of each pulsar will be measured with respect to those background quasars that are found within about 10' of each pulsar.

2. Galactic Studies

Observational constraints on the large-scale distribution of galactic HI beyond the local region of the Galaxy will be investigated A large set of HI spectra taken towards distant stars for which uv absorption spectra exist will be analyzed to best distinguish foreground and background HI components relative to the known stellar distances. The data should allow the HI distribution to be mapped on lines of sight deep into the inner Galaxy. Other data accumulated in random, high-latitude directions will be analyzed to determine statistical properties of the galactic HI, such as the filling factor and the fluctuation spectra.

A series of 21-cm HI observations covering a 12°x20° region of the galactic disk provide a particularly rich data set for modelling the structure of HI in the disk. Synthetic models are under computer analysis where the HI may be in the form of clouds, sheets, expanding shells, or a uniform component with or without holes. By matching the models to the data it should be possible to estimate the filling factor of HI, the most common structures in HI, and to define the limitations of the information that can be culled from such a data set.

Visibility measurements for a wide range of Fourier components will be used to analyze turbulence parameters in the interstellar medium. The interferometric observations will separate the effects caused by the macroscopic structure of the medium from effects due to direct measurements of the wave-number spectrum of turbulence. For cool stellar wind environments influenced by the presence of a hot ionizing stellar companion, VLA observations of the time-dependent properties of the ionized, radio-emitting gas will be modelled.

The discovery of an infrared source, which may be the first true "protostar" in Rho Ophiuchus, as a result of an earlier investigation of star-forming regions in that cloud will spur continuing efforts in this area. Follow-up observations are planned on the VLA and on the OVRO millimeter-wave interferometer. A further, new region of interest containing the strongest known ^{13}CO line in the complex, and a small IRAS source, will also be studied.

Maps of the HII regions in the S88B molecular cloud have been obtained with the VLA, Westerbork, and Penticton arrays and the HI content of the L1551, L134, and L clouds is being studied. For other HII regions a new technique will be used to simultaneously observe recombination lines and continuum emission. The combination of high angular resolution and the absence of stimulated emission should give new information about ionized gas in HII regions.

The 1.2-mm emission of dust complexes associated with HII regions will be observed in order to establish the dust spectrum on the long wave side of the dust-emission function and to determine absorption cross sections and column densities. Similarly, with compact HII regions, fluxes at 345 GHz in combination with submillimeter and far infrared observations should establish the long-wave spectrum of dust emission from these young objects in 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.

3. <u>Interstellar Molecules</u>

The discovery of vibrationally-excited CS (in IRC 10216) will be followed up. A second transition will be sought to establish whether the transitions within the v = 1 state contain population inversion as a result of the Kwan-Scoville effect. Such a determination is needed to see whether the detection of excited CS, together with the failure to detect vibrationally excited CO in IRC 10216, is in violation of the chemical "freeze-out" model for circumstellar shells. Work will continue on vibrationally excited HCO^+, N_2H^+, and HNC. Refined laboratory work on HCO^+ is underway to determine whether several interstellar lines already detected in this project are indeed vibrationally excited HCO^+

An analysis of how small (3-member) rings form in the interstellar medium indicates that C_3H_2, already identified, may be unique. Observations to search for several other 3-member rings, some representing new laboratory results, are planned to check the analysis. Large ring molecules, known as polycyclic aromatic hydrocarbons, may be present in IRAS cirrus clouds, and observations for C_3H_2 are planned as a test for the possibility that aromatic compounds of any type may exist there. Although the chemistry of C_3H_2 is poorly understood, newly obtained determinations of the frequency of its isotopes should allow a thorough study of its abundance and of how isotopic fractionation occurs in it.

Investigation of the CI line at 492 GHz with the UKIRT has begun. This line is the ground-state transition of the third most abundance reactive element in the Universe; yet because of the difficult atmospheric region in which it lies, little is known of its distribution. Attempts will be made to measure the optical depth of the line through the first detection of ^{13}CI. Using a broad filterbank it should also be possible to make the first detection of extragalactic CI.

B. EXTRAGALACTIC STUDIES

1. Normal Galaxies

Radio "identifications" of galaxies in the Uppsala General Catalogue are being made from the NRAO 1400-MHz, 300-ft survey. The diameter-limited ($\gtrsim$ 1 arcmin) UGC sample contains about 12,000 galaxies in the 6.5 sr band between $\delta = -2°30'$ (the UGC catalog limit) and $\delta = +82°$ (the radio map limit). About 400 of these galaxies lie within 3σ

of radio sources stronger than 150 mJy. These identification candidates fall into three groups: (1) normal spirals brighter than $B_T \approx 12.0$, (2) elliptical and SO galaxies with active nuclei, and (3) morphologically "peculiar" galaxies and multiple systems. Most of the identification candidates will be mapped with the VLA.

The VLA has been used to make low-resolution ($\theta \approx 48$ arcsec) λ = 20-cm maps of all 308 spiral galaxies with $B_T \lesssim 12$ mag and $\delta \gtrsim -45°$. Nearly all of the galaxies were clearly detected. A radio atlas of bright spiral galaxies will be prepared. These maps will be compared with IRAS $\lambda = 60\mu$ infrared data to determine the relation between basic radio-continuum properties (e.g., luminosity and morphology) and the rate of massive star formation.

An analysis of the size, rotational-velocity (R-V) dependence of galaxies reveals certain regions of the R-V plane which are essentially empty of disk-type galaxies. It is hoped that further analysis and search for possible new candidates in the sparse region of the RV diagram will indicate the range of parameter space in which stable galaxies can form.

An analysis of Population II-type systems (globular clusters and elliptical nebulae), in the light of current knowledge, re-emphasize the dilemma of their lack of interstellar material. Explanations are available for this (e.g., sweeping for globular clusters and heating to X-ray energies for ellipticals), and observational tests are being devised to check these explanations.

A quantitative study of the existence and distribution of dark matter in spirals and ellipticals will be undertaken using several different approaches. The elliptical NGC 4278 will be studied in great detail. The intensity and velocity distribution of both the stellar component and the neutral hydrogen will be mapped and model fitting will be done to the results. Several ellipticals with hints of the presence of HI will be mapped in search of galaxies for which M/L can be determined at large distances from the center from the HI rotational velocities.

For a few edge-on spirals, high angular-resolution, HI maps will be obtained in order to determine the thickness of the HI layer as function of distance from the center. Assuming a vertical velocity dispersion will then make it possible to estimate the disk mass directly. For other nearby spirals, a sample will be mapped in HI snapshot mode in search for galaxies with perfectly symmetric, extended HI disks, which would be suitable for an HI rotation curve analysis. NGC 3198, currently the prototype and best example of a galaxy with a flat rotation curve far beyond the optical radius, will be reobserved in HI with the VLA. The purpose is to improve the sensitivity of existing observations by one order of magnitude and determine unambiguously whether the HI rotation curve stays flat or declines beyond 2 Holmberg radii. The hope is to detect a boundary to the dark halo of NGC 3198.

VLA observations of a large, complete sample of E/SO galaxies obtained in 1986 will be analyzed to derive a radio-luminosity function and study other radio characteristics of this class of galaxy. The primary emphasis is to extend our understanding of these objects to weaker radio luminosities. Also, observations of clumpy galaxies will be continued to study variability and structural changes in these objects. There is evidence that star formation may be proceeding in these objects at a rate faster than in any other class of galaxy. If so, there may be detectable structural changes and/or variability resulting from extensive SN explosions. To study this, maps must be obtained at several epochs and at several wavelengths.

VLA maps of two emission-line galaxies will be analyzed. These galaxies are apparently in a period of extremely rapid star formation characterized by a ratio of Wolf-Rayet stars to O stars of near unity. A better estimate of this ratio than is now available is badly needed. The maps will be used to separate the thermal and nonthermal components. The total ultraviolet flux, derived from the thermal radio flux, will give an estimate of the population of young massive stars which in turn can be compared to the number of Wolf-Rayet stars as estimated from the uv spectrum.

Observations of infrared-bright galaxies from the IRAS survey in the HI line will continue, and a new program to seek CO emission from the most interesting objects in the sample will begin. This survey will then contain complete information on the solid, atomic, and molecular material in the interstellar media of these galaxies. Other CO studies of galaxies will investigate the spiral arm-interarm contrast and the distribution of CO in regions of stars and starbursts. The extensive CO mapping project in M31 will continue in a massive undertaking to specify the CO properties of spiral-arm and shock-front regions.

Many characteristics of megamaser galaxies are still not understood. Indications of variability seen in the MK 273 OH megamaser during the past year will be investigated more thoroughly. The possibility that the megamaser may involve amplification of both spontaneous emission and the continuum background is also under study. A search for CH in OH megamaser galaxies is also planned as a means of obtaining more information about the pumping agents responsible for both species.

2. Radio Galaxies and Quasars

Extragalactic radio sources exhibit many detailed morphological properties, spectral features, and polarization characteristics that, when observationally analyzed, continue to challenge theoretical models. Several programs will investigate the wide variety of physical conditions that are found in these sources. Three-frequency polarimetry of a complete sample of bright radio galaxies near the celestial equator will be combined with an associated search for extra-nuclear, optical, narrow-line emission regions. The aims of this work are (a) 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.

The VLA will continue a search for counterjets in strong, extragalactic radio sources, especially quasars, in which bright jets appear to feed one side only of a double-lobed structure. Successful detection of counterjets can be used to constrain models of jet asymmetries by determining brightness ratios and jet/counterjet asymmetry relationships. In the low-power radio galaxies NGC 315, 3C 31, 3C 272.1 (M84), and 3C 296, the initial one-sidedness at the bases of such sources will be examined for correlation with their magnetic field structures, collimation properties, and clumpiness.

The jets of several giant radio galaxies will be searched for linear polarization using the VLA at 327 MHz both to explore the techniques of polarization mapping at this low frequency and to obtain constraints on radio jet depolarization far from the parent galaxies in such sources. Bridle and Perley will also continue a multi-frequency study of the large-scale structure of the jets and lobes in the giant radio galaxy NGC 6251.

For the nearby, strong radio galaxy, Fornax A, many detailed final observations remain. Its lobe emission contains remarkable radio loops and filaments and significant depolarization occurs in cloud-like clumps well outside of the stellar distribution of the galaxy. HI emission from Fornax A has led to the discovery of a foreground galaxy which is de-polarizing the non-thermal emission from the lobes of the radio galaxy. This will enable the first determination of the magnetic fields in the disk of an external, normal galaxy to be made.

Numerical modeling on synchrotron emission from radio jets with prescribed magnetic fields will continue. Turbulence and magnetic field randomization on various scales are expected to effect the observational parameters of total intensity, polarization, depolarization, and Faraday rotation over radio jets. Theoretical jet models consistent with the radio data on 3C 75 and the optical and X-ray results for Abell 400 are also being carried out. VLA observations of the M87 jet will be analyzed in order to improve on earlier maps and to establish better observational constraints on existing models.

A comprehensive study of variability of extragalactic objects, begun in 1979, will be continued. Further studies will be made of the nature of variability on time scales of about one day. Observations in 1985/86 with the 100-m telescope showed unusual and intriguing features on this time scale. An attempt will be made, with simultaneous observations with different telescopes at several wavelengths, to confirm reported periodic variability in some BL Lac sources, and better establish the characteristics of such variability. Possible variability and/or structural changes in hot spots in lobes of double sources will also be investigated.

Six years of radio to X-ray mutifrequency data for 3C 446 and BL Lac will be analyzed to determine interrelationships between emission properties in the different spectral domains. Large continuum variations have occurred during the period, and of particular concern is the relationship of the X-ray variations to variations observed in the radio and infrared-ultraviolet regions. The continuum properties will be compared to the predictions of models such as the synchrotron-self-Compton models. Dramatic variability in the form of flares have been observed in both sources, which will provide the basis for a comparison with models for particle acceleration and radiative cooling.

Variations in the BL Lac object, OJ 287, will also be tested observationally for periodicity.

Studies of some individual sources will make use of VLBI techniques to study the dynamics of a few selected sources with known atypical behavior. If possible the first VLBA antennas might also be utilized for these studies in order to greatly enhance the dynamic range of the images. Superluminal motion in the quasar 3C 454.3 and in the radio galaxies 3C 111 and 3C 390.3 will be monitored. Particular emphasis will be given to the continued investigation of subluminal motions in NGC 1275 (3C 84) and in the complex quasar 3C 147 with global observations of 2.8 cm.

Several transitions of various molecules will be sought toward quasars having known HI/optical redshifts in the range 0.5-2.5. Detection of molecular gas will considerably strengthen the 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.) Also, any molecule detected at the searched-for redshift will provide stringent limits on the cosmological variation of baryon mass; these limits are not readily obtained otherwise, yet are necessary to complete a series of arguments concerning the constancy of physical constants over the history of the Universe.

Observational and theoretical studies of stimulated radio recombination lines toward quasars and radio galaxies will continue. Observations of a small sample of absorption-line quasars have been made both with single-dish radio telescopes and with the VLA. These data will be analyzed and limits placed on the size, ionization fraction, and mass of the foreground absorbing clouds.

3. Clusters of Galaxies and Cosmology

A search for diffuse optical emission from the cores of relatively nearby dense clusters of galaxies will be carried out using an observing technique which minimizes the corrections due to field flattening and sky subtraction. The data will constrain the faint end of the galaxy luminosity function as well as the amount of matter stripped from galaxies through the dynamical processes which determine the structure of such clusters of galaxies. This should pose useful constraints on the various theories of the formation and evolution of clusters of galaxies.

A statistical study of 240 radio quasars is underway as a means of finding distorted structure that might be the result of the quasars' cluster environment. Evidence of cluster magnetic fields should be detectable in an ongoing program which samples the Faraday rotation of radio sources behind clusters of galaxies.

A sample of wide-angle tail sources (WATS), galaxies seen in rich clusters of galaxies, will be the object of a thorough multifrequency, multi-configuration VLA study. The bent tails are no longer thought to be caused by motion of the parent galaxies through the intracluster medium. Differentiation of several alternative bending schemes requires a complete analysis of a range of source information on morphology, polarization, and spectral index distribution.

Efforts to improve measurements of the Sunyaev-Zeldovich Effect, the scattering of microwave background radiation by intracluster hot electron gas, will be made with the NRAO 12-m telescope. Currently, systematic errors limit the 3-mm continuum observations to a detectable decrement of $\Delta T \sim 1$ mK, but a factor of ten improvement is expected. VLA, 2-cm observations searching for the decrement will also be processed. Observations of the Sunyaev-Zeldovich Effect near extended quasar jet sources are planned in order to test models for jet confinement by thermal pressure.

The new VLA Deep Source Survey will be analyzed to give a radio source count down to 25 μJy and statistical information on the distribution of radio sources down to the 5 μJy noise level. The data will be used to examine anisotropies in the microwave background on a scale of 16 arcseconds. Other existing data will be used to improve the 6-cm number count in the poorly covered region between 0.5 and 10 mJy.

The VLA will be used at 6 cm to map high-resolution observations of a statistical sample of radio sources with flux densities in the range 5 mJy to 60 mJy. These data will be used to investigate the morphology of the low end of the evolving radio source population, to study the size-flux density relation, and to determine accurate positions to be used to search for optical counterparts.

The analysis of VLA observations of quasars in the Palomar Bright Quasar Survey will be extended to derive the bivariate radio-optical luminosity function and its dependence on cosmic epoch. New VLA observations will be made of the remaining apparently bright and absolutely bright quasars to improve the statistics at the high end of the luminosity function. Possibly this will be extended to include radio observations of a sample of optically faint quasars.

The Green Bank 1400-MHz survey maps are already so strongly confusion limited that all of the $\approx 10^5$ beam areas per steradian contain information about the sky distribution of faint (10 mJy < S 100 mJy) radio sources. The map flux-density distributions in 2-sr region near the north galactic pole will be used to check the large-scale homogeneity of radio sources in space. Clustering on scales larger than about 100 Mpc in the redshift range $0.3 < z < 2$ should produce statistically significant fluctuations between the flux-density distributions in different areas of sky on scales of several square degrees. The sensitivity of this test will probably be limited only by $\sqrt{N}$ statistical uncertainties, since the radio maps are quite uniform and there are no problems with extinction or confusion by galactic stars.

C. MISCELLANEOUS

The new 7-feed x 2 polarization = 14 channel receiver will be used on the 300-ft telescope to make a λ = 6-cm map of the northern sky. The telescope will be scanned in elevation at the slew rate (10°/minute) to cover the sky twice in about one month. Receiver tests made on the 140-ft telescope indicate that the beam FWHM will be ≤ 3 arcmin and the rms map noise should be about 4 mJy, so that $\approx 10^5$ sources with $S \geq 20$ mJy will be detected. An atlas of contour plots on the scale of the Palomar Sky Survey (67 arcsec/mm) will be produced; on this scale the beam FWHM circle is 2.5 mm in diameter and there will be about 200 sources per 6°x6° "plate." The rms confusion should only be

1 mJy, so that the detection limit can be pushed down as low as 5 mJy by repeated mapping.

Regions of an all-sky survey will be repeated at various time intervals in order to determine the fraction of sources which vary. These data are needed because all previous variability studies have dealt with sources found once in a catalog. This mode of survey finds preferentially those sources outbursting at the time of the survey. It does not find sources below the survey's flux density limit but which occasionally flare up and exceed the limit.

A new way of illuminating the 300-ft telescope will be investigated that greatly reduces its far sidelobes. Currently, contamination of HI profiles by stray radiation entering the telescope's far sidelobes seriously limit the accuracy of 21-cm galactic spectra. Preliminary calculations indicate that an immediate order of magnitude reduction in stray radiation is possible, with prospects for further improvement in the near future.

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 mm-interferometric data, single-dish data, and will be required for the proposed millimeter array. Effort will be devoted to investigating the practical limitations of the mosaicing technique for processing real, as opposed to simulated, data.

Development of image deconvolution algorithms will continue, with special emphasis on overcoming the failings of the Maximum Entropy method. Work will also continue on the application of self-calibration to the correction of aberrations in single-dish radio telescopes.

APPENDIX B

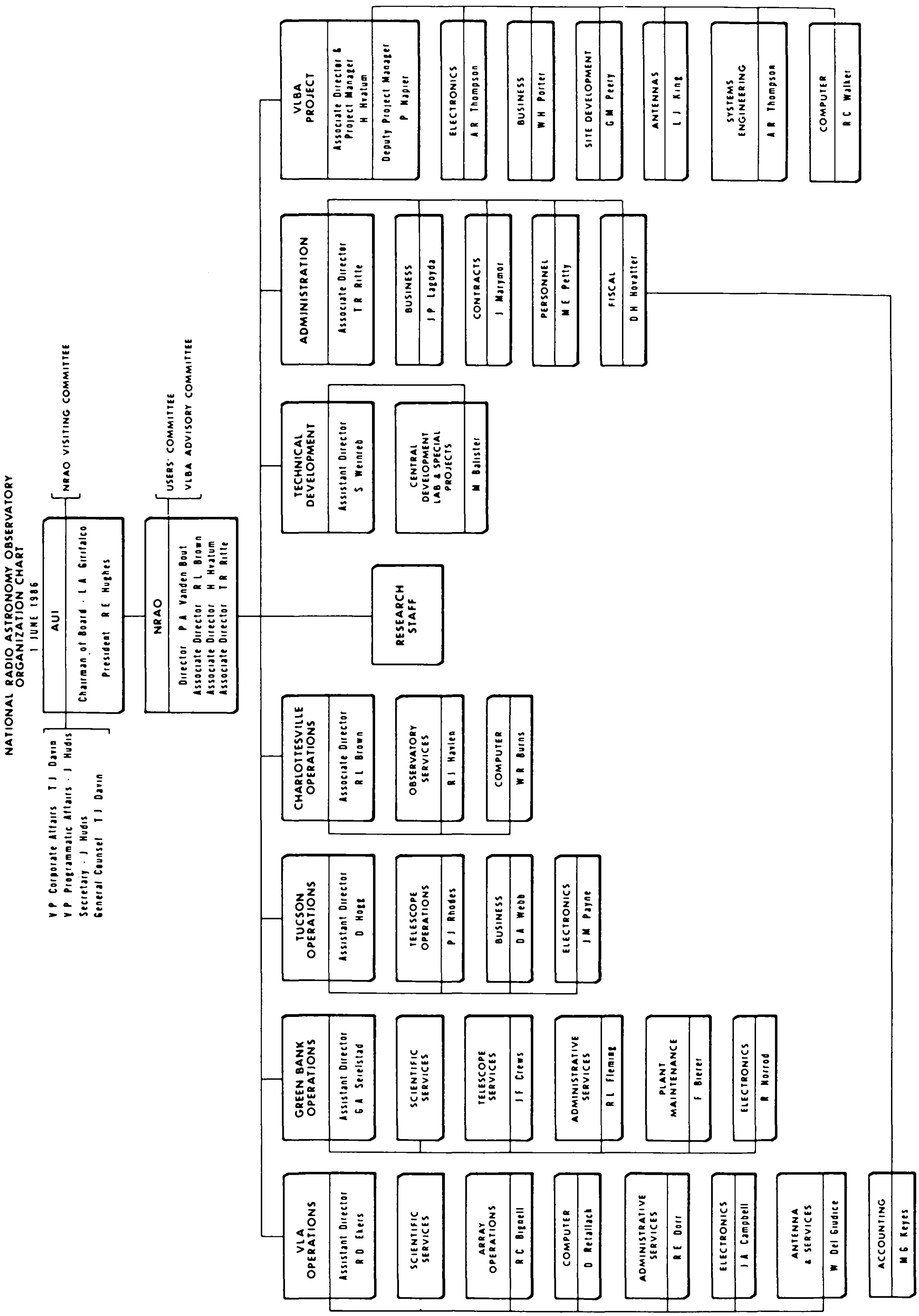
SCIENTIFIC STAFF

(Does not include Research Associates or Visiting Appointments)

J. M. Benson	CV	Extragalactic Radio Sources; VLBI Image Processing
R. C. Bignell	SO	Polarization and Mapping of Extragalactic Radio Sources; Planetary Nebulae; Supernova Remnants
J. N. Bregman	CV	Theoretical Astrophysics; Quasars
A. H. Bridle	CV	Extragalactic Radio Sources
R. L. Brown	CV	Theoretical Astrophysics; Interstellar Medium
B. G. Clark	SO	VLA Development; VLB; Interferometry
J. J. Condon	CV	QSOs; Normal Galaxies; Extragalactic Radio Sources
T. J. Cornwell	SO	Image Construction Methods; Interferometry; Extragalactic Radio Sources; Spectral Analysis; Maximum Entropy Principle
W. D. Cotton	CV	Extragalactic Radio Sources; Interferometry; Computational Techniques for Data Analysis
P. C. Crane	SO	Normal Galaxies; Interferometry
R. D. Ekers	SO	Synthesis Techniques; Galactic Center; Normal and Radio Galaxies; Cosmology
E. B. Fomalont	CV	Interferometry; Extragalactic Radio Sources; Relativity Tests
M. A. Gordon	TU	Interstellar Medium; Star Formation; Dust Emission; Observation Techniques
E. W. Greisen	CV	Structure of Interstellar Medium; Computer Analysis of Astronomical Data
R. J. Havlen	CV	Galactic Structure; Clusters of Galaxies
R. M. Hjellming	SO	Radio Stars; Interstellar Medium; VLA Development; Millimeter Array Design; Aperture Synthesis Algorithm Development

D. E. Hogg	TU	Radio Stars and Stellar Winds; Extragalactic Radio Sources
H. Hvatum	CV	Electronics and Instrumentation for Radio Astronomy
P. Jewell	TU	Comets; Circumstellar Envelopes; Interstellar Molecules
K. I. Kellermann	CV	Radio Galaxies; Quasars; VLBA
A. R. Kerr	CV	Millimeter Wave Development
H. S. Liszt	CV	Molecular Lines; Galactic Structure
F. J. Lockman	CV	Galactic Structure; Interstellar Medium; HII Regions
R. J. Maddalena	GB	Molecular Clouds; Galactic Structure; Star Formation
F. N. Owen	SO	Clusters of Galaxies; QSOs; Radio Stars
P. J. Napier	SO	VLBA
H. E. Payne	GB	Interstellar Medium; Extragalactic Radio Sources
R. A. Perley	SO	Radio Galaxies; QSOs; Interferometric Techniques
M. S. Roberts	CV	Properties and Kinematics of Galaxies
J. D. Romney	CV	Active Extragalactic Radio Sources; VLBI; Interferometer Imaging
A. H. Rots	SO	Extragalactic Research; Spectral Line Interferometry; Data Display Techniques
G. A. Seielstad	GB	Quasars; Active Galaxies; VLBI
M. S. Schenewerk	GB	Interstellar Medium; Comets; Circumstellar Envelopes
R. A. Sramek	SO	Normal Galaxies; Quasars; Astrometry
B. E. Turner	CV	Galactic and Extragalactic Interstellar Molecules; Interstellar Chemistry; Galactic Structure
J. M. Uson	SO	Clusters of Galaxies; Cosmology

P. A. Vanden Bout	CV	Interstellar Medium; Molecular Clouds; Star Formation
J. H. Van Gorkom	SO	Galactic Center; Nearby Galaxies; Clusters of Galaxies; Spectral Line Interferometry
C. M. Wade	SO	Astrometry; Stellar Radio Emission; Minor Planets
R. C. Walker	SO	Extragalactic Radio Sources; VLBI; VLBA Development
S. Weinreb	CV	Millimeter Wave Development
D. C. Wells	CV	Digital Imaging Processing; Extragalactic Research
A. H. Wootten	CV	Properties of the Interstellar Medium in Galaxies, Star Formation Regions, and Circumstellar Material


NATIONAL RADIO ASTRONOMY OBSERVATORY
ORGANIZATION CHART
1 JUNE 1986
V P Corporate Affairs T J Davin
V P Programmatic Affairs - J Hudis
Secretary - J Hudis
General Counsel T J Davin
AUI
Chairman of Board - L A Girifalco
President R E Hughes
NRAO VISITING COMMITTEE
NRAO
Director P A Vanden Bout
Associate Director R L Brown
Associate Director H Hvatum
Associate Director T R Riffe
USERS' COMMITTEE
VLBA ADVISORY COMMITTEE
RESEARCH STAFF
VLA OPERATIONS
Assistant Director R D Ekers
SCIENTIFIC SERVICES
ARRAY OPERATIONS
R C Bignell
COMPUTER
D Retallack
ADMINISTRATIVE SERVICES
R E Dorr
ELECTRONICS
J A Campbell
ANTENNA & SERVICES
W Del Giudice
ACCOUNTING
M G Keyes
GREEN BANK OPERATIONS
Assistant Director G A Seielstad
SCIENTIFIC SERVICES
TELESCOPE SERVICES
J F Crews
ADMINISTRATIVE SERVICES
R L Fleming
PLANT MAINTENANCE
F Bierer
ELECTRONICS
R Norrod
TUCSON OPERATIONS
Assistant Director D Hogg
TELESCOPE OPERATIONS
P J Rhodes
BUSINESS
D A Webb
ELECTRONICS
J M Payne
CHARLOTTESVILLE OPERATIONS
Associate Director R L Brown
OBSERVATORY SERVICES
R J Havlen
COMPUTER
W R Burns
TECHNICAL DEVELOPMENT
Assistant Director S Weinreb
CENTRAL DEVELOPMENT LAB & SPECIAL PROJECTS
M Balister
ADMINISTRATION
Associate Director T R Riffe
BUSINESS
J P Lagoyda
CONTRACTS
J Marymor
PERSONNEL
M E Petty
FISCAL
D H Hovatter
VLBA PROJECT
Associate Director & Project Manager H Hvatum
Deputy Project Manager P Napier
ELECTRONICS
A R Thompson
BUSINESS
W H Porter
SITE DEVELOPMENT
G M Peery
ANTENNAS
L J King
SYSTEMS ENGINEERING
A R Thompson
COMPUTER
R C Walker

APPENDIX D

NRAO COMMITTEES

Visiting Committee

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

The current membership of the Committee is:

R. J. Allen	University of Illinois
G. A. Dulk	University of Colorado
J. V. Evans	Comsat Laboratory
K. J. Johnston	Naval Research Laboratory
G. R. Knapp	Princeton University
T. G. Phillips	California Inst. of Technology
E. Seaquist (Chairman)	University of Toronto
P. Strittmatter	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
W. Baan	Arecibo Observatory
D. C. Backer	University of California, Berkeley
T. M. Bania	Boston University
J. O. Burns	University of New Mexico
J. J. Broderick	VPI & SU
F. O. Clark	University of Kentucky
J. M. Cordes	Cornell University
R. M. Crutcher	University of Illinois
I. de Pater	University of California
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
L. A. Higgs	Dominion Radio Astrophys. Obs.
P. J. Huggins	New York University
G. Hurford	California Inst. of Technology
K. J. Johnston	Naval Research Laboratory
R. N. Martin	University of Arizona (Steward Obs.)
J. M. Moran	Center for Astrophysics
D. O. Muhleman	California Institute of Technology
P. Palmer	University of Chicago
D. H. Roberts	Brandeis University
R. L. Snell	University of Massachusetts

D. R. Stinebring	Princeton University
H. A. Thronson	University of Wyoming
B. L. Ulich	University of Arizona

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 foreign 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

Revised Construction Plan and Budget for VLBA

Included in this Appendix is a further revision of the NRAO budget plan (BD61) and overview schedule for the construction of the Very Long Baseline Array (VLBA), reflecting the reduction in 1986 funding from \$11.5M to \$8.552M, and the cut in anticipated 1987 funding from about \$17.7M to \$9.4M. Funding requested for succeeding years is that required to complete the Project in a manner as expeditious as is reasonably possible, considering the effects to date of uncertain funding. Also included is a table (FIN05) outlining the planned utilization of Project funds during 1987.

The revised overview schedule reflects the slowed antenna procurement scenario described below, and the presently-planned order of Station construction. Under this Plan, the earlier stations will initially have only a part of their complement of receivers and recording equipment, with the remainder to be provided later as funding permits.

Antennas and Stations

Regrettably, the favorable antenna contract with Radiation Systems, Inc. (RSi) had to be renegotiated, since available 1986 funding would no longer support the contract provision for the advance mass purchase of a substantial list of long-lead items for the remaining nine antennas of the VLBA. This factor resulted in an overall price increase of \$400,000, which has been reflected in the final cost estimate for the Project. Additional costs approximating \$600,000 were added for extra weight of steel and a new vertex room not anticipated in the original bid. These have been absorbed from contingency. Note also that the contract was renegotiated on the basis of the original authorization schedule of three antennas each year in 1986, 1987 and 1988.

As a result of unanticipated savings of nearly \$1M on the maser procurement, plus careful planning and deferral of other expenditures, it proved possible to authorize the construction of three antennas (though not the long-lead items) in 1986 at essentially the original quoted price. (This was done prior to the final reduction in 1986 funding from \$9M to \$8.552M.) It is now clear that, against a 1987 allocation of only \$9.4M, only one additional antenna can be ordered in 1987, as shown in the budget plan. The proposed higher funding levels beginning in 1988 will permit resumption of 1986-deferred expenditures, plus the ordering of two antennas each in 1988 and 1989, with the final antenna coming in 1990. However, should reductions on the order of those of 1986 and 1987 continue, antenna procurements would have to drop to no more than one (1) per year, in order to allow needed production of other subsystems. (Note that the antenna cost figures in the budget plan, though thought fairly accurate, are estimates, since there have as yet been no actual contract negotiations on the basis of a stretched production schedule).

At Station #1, Pie Town, NM, site preparation and foundation construction are complete, and antenna parts began arriving in early

September. Azimuth track has been installed and aligned. Progress indicates that this antenna will be ready for acceptance tests by mid-December. Manufacture of the next three antennas has begun on schedule.

Contracts have been let for feed cones, focus rotation mounts and subreflectors for the first several antennas, and design and manufacturing activities are progressing well.

Site #2 at Kitt Peak has been prepared, and foundation construction is under way. Site #3, Los Alamos, NM, has been acquired, and construction contracts have been approved. The agreement for the use of Site #4, North Liberty, IA, is nearly in place, and bids for the construction will be solicited shortly.

Only Site #5 construction will be undertaken with 1987 funds.

Array Operations Center (AOC)

The A/E contractor, Stevens, Mallory, Pearl and Campbell, has developed a concept for an AOC building which includes space for both VLBA and VLA operations, so arranged that construction can be phased to the availability of funds. Arrangements have been made with New Mexico Institute of Mining and Technology (NMIMT), Socorro, NM, for an on-campus site for the AOC. The New Mexico legislature has appropriated $3M for the first phase of the construction of this joint VLA/VLBA center, and detailed design is in progress.

Electronics

A contract for ten hydrogen maser frequency standards has been signed with Sigma Tau Standards Corp., Tuscaloosa, AL. The first three units were authorized from 1985 funds, and their delivery is scheduled for July, 1987. Three more will be authorized in early 1987 ($448k), and the final four in 1988 ($597k).

The three electronics racks destined for the Pie Town station were completed and shipped in late September to the VLA for overall system tests in conjunction with the Station computer and other elements of the Monitoring and Control (M/C) system. These include Rack "C", the Master LO Rack, to be located in the control building, and Racks "A" and "B", located in the antenna vertex room and containing the front ends, converters, LO synthesizers, etc. Front ends shipped include 15-, 10.7-, 4.8- and 1.5-GHz cooled units, and the 330/610 MHz room temperature unit.

Construction of electronics for the later stations will be paced in 1987 by funding limitations. While receivers have been provided for Pie Town at most of the planned frequencies in order to prove out the antenna and other equipment designs, later antennas will initially have receivers only at 1.5, 4.8 and 23 GHz.

Development of SIS junction and/or HEMT technologies aimed at providing low-noise front ends for 43 GHz much later in the Project will continue at a modest level in 1987.

Data Recording

Prototyping of the Data Acquisition System (DAS) at Haystack Observatory is behind schedule as a result of some problems in meeting VLBA specifications, particularly with regard to the 12-hour continuous recording time between tape changes. A solution has been agreed upon, and a prototype electronics rack and recorder are now scheduled to be available to NRAO in January, 1987 for test and installation at Pie Town.

Some additional 1986 funds will be allocated to needed further development activities, while the first phase of the DAS production program will be authorized out of the 1987 allocation. This will include three electronics racks (DAR) and three recorder racks (REC), sufficient to support the checkout and initial operation of the stations that will be nearing completion in 1987.

Monitoring and Control

Production runs of standard interface boards for connecting the various subsystems of a station to the M/C bus have been completed for the first two stations. The Pie Town Station computer was delivered, and the previously-developed software appropriate for the first VLBA system tests was brought up on this machine. Software for providing many of the displays (screens) that will be required for operations has been written.

The VAX computer for central control of the VLBA is being procured with 1986 funds. Funds for 1987 and the "out-years" will provide the station computers, terminals, interfaces, clocks, weather stations and continuing software development and support required for the new stations coming on-line, and the operation of the Array as a whole.

Correlator

Under the proposed budget, major construction funding for the correlator becomes available in 1988. Meanwhile, the NRAO Correlator

Group is conducting an extensive investigation of the spectral-domain ("FX") correlator concept, including analytic studies, computer simulations and architectural development. This approach, in which the required frequency analyses are performed on the individual station data streams prior to, rather than on a baseline basis after, correlation, promises to lead to a much less expensive and technically superior correlator.

The proposed budget plan reflects growing pressure from the community to bring the correlator along relatively early, even if it should mean delaying some other elements of the VLBA.

The above studies will continue in 1987, including some simulation runs on the Cray-XMP, made necessary by the limitations of local machines. Certain critical hardware developments are also planned for that year.

Systems Engineering

The small budget allocation for Systems Engineering reflects the fact that this Project-wide technical oversight function has largely been assumed, during the construction phase, by a Committee comprised of senior members of different Project Groups, working closely with the Project Manager. This item will probably not appear as a line item in the VLBA budget after 1987.

Post-Processing

The VLBA Post-Processing computer and associated equipment need not be purchased until fairly late in the Project schedule. Since the software needed for this bears considerable resemblance to much that is already in use, only modest salary funds for this work have been provided in the plan until 1989. Some effort is nonetheless in progress concerning how existing processing software may be modified and augmented for the VLBA task.

Project Management

During 1987 nearly all VLBA project management functions will be transferred from Charlottesville to the NRAO office in Socorro, NM. The Electronics, Correlator and Data Processing activities will continue primarily in Charlottesville.

Operations Training

For an orderly transition into the operations phase of the VLBA program, some of the key future operations personnel will participate in the construction and pre-operations testing phases. Modest funding has therefore been provided in 1985-7 for the salaries of the first two station chiefs and the two senior people who will form the nucleus of the operating group at the Array Control Center.

BD61 860929/S1
29-Sep-86
VLBA BUDGET AND COST ESTIMATE
Constant '87 $K

	*1983,4	*1985	+1986	1987	+1988	1989	1990	1991	1992	TOTAL
ANT STARTS/INSTLS		1/1	3/1	1/3	2/1	2/2	1/2			
STATIONS FUNDED			PTKPLANL	FD	BRSC	OVHI	NE			
SITES	32	195	2,322	1,099	2,370	1,990	990	125		9,123
ARRAY OP CTR			42	200	2,500	220				2,962
ANTENNAS	1,068	2,460	6,604	3,694	5,138	5,245	3,360	115		27,704
ELECTRONICS	450	1,657	1,305	1,941	1,843	2,015	1,947	2,465		13,623
DATA RECORDING	290	424	201	530	800	800	800	800		4,645
MONITOR, CONTROL	55	102	700	455	470	442	183	173		2,580
CORRELATOR	315	139	250	427	1,218	1,250	400			3,999
POST PROCESSING				25	152	1,000	1,400	1,300		3,877
SYST. ENGINEERING	55	86	85	30						256
MISC., SPARES						800	600	1,200		2,600
PROJECT MAN.	224	421	638	705	545	550	555	400		4,038
OPER. TRAINING		12	80	25						117
PLANNED* COMITMTS	2,509	5,496	12,227	9,131	15,036	14,312	10,235	6,578	0	75,524
CONTINGENCY	N/A	N/A	120	269	349	481	433	1,584	0	3,235
PERCENT CONT.	0.0	0.0	1.0	2.9	2.3	3.4	4.2	24.1	0.0	4.3
BUDGET (86 $)	2,800	9,000	8,552	9,400	15,385	14,793	10,668	8,162	0	78,759

* - Actual for 1983,4,5.
+ - BR bldg deferred to 1988.

BD61 860929/S1
29-Sep-86
VLBA BUDGET AND COST ESTIMATE
(Current $K)

	*1983,4	*1985	+1986	1987	+1988	1989	1990	1991	1992	TOTAL
ESCALATION (%)	0	0	0	0	4	4	4	4	4	
ANT STARTS/INSTLS		1/1	3/1	1/3	2/1	2/2	1/2			
STATIONS FUNDED			PTKPLANL	FD	BRSC	OVHI	NE			
SITES	32	195	2,322	1,099	2,465	2,152	1,114	146	0	9,525
ARRAY OP CTR	0	0	42	200	2,600	238	0	0	0	3,080
ANTENNAS	1,068	2,460	6,604	3,694	5,344	5,673	3,780	135	0	28,777
ELECTRONICS	450	1,657	1,305	1,941	1,917	2,179	2,190	2,884	0	14,523
DATA RECORDING	290	424	201	530	832	865	900	936	0	4,978
MONITOR, CONTROL	55	102	700	455	489	478	206	202	0	2,687
CORRELATOR	315	139	250	427	1,267	1,352	450	0	0	4,200
POST PROCESSING	0	0	0	25	158	1,082	1,575	1,521	0	4,360
SYST. ENGINEERING	55	86	85	30	0	0	0	0	0	256
MISC., SPARES	0	0	0	0	0	865	675	1,404	0	2,944
PROJECT MAN.	224	421	638	705	567	595	624	468	0	4,242
OPER. TRAINING	0	12	80	25	0	0	0	0	0	117
PLANNED* COMITMTS	2,509	5,496	12,227	9,131	15,637	15,480	11,513	7,695	0	79,689
CONTINGENCY	N/A	N/A	120	269	363	520	487	1,853	0	3,611
PERCENT CONT.	0.0	0.0	1.0	2.9	2.3	3.4	4.2	24.1	0.0	4.5
BUDGET, Current $	2,800	9,000	8,552	9,400	16,000	16,000	12,000	9,548		83,300

* - Actual for 1983,4,5.
+ - BR bldg deferred to 1988.

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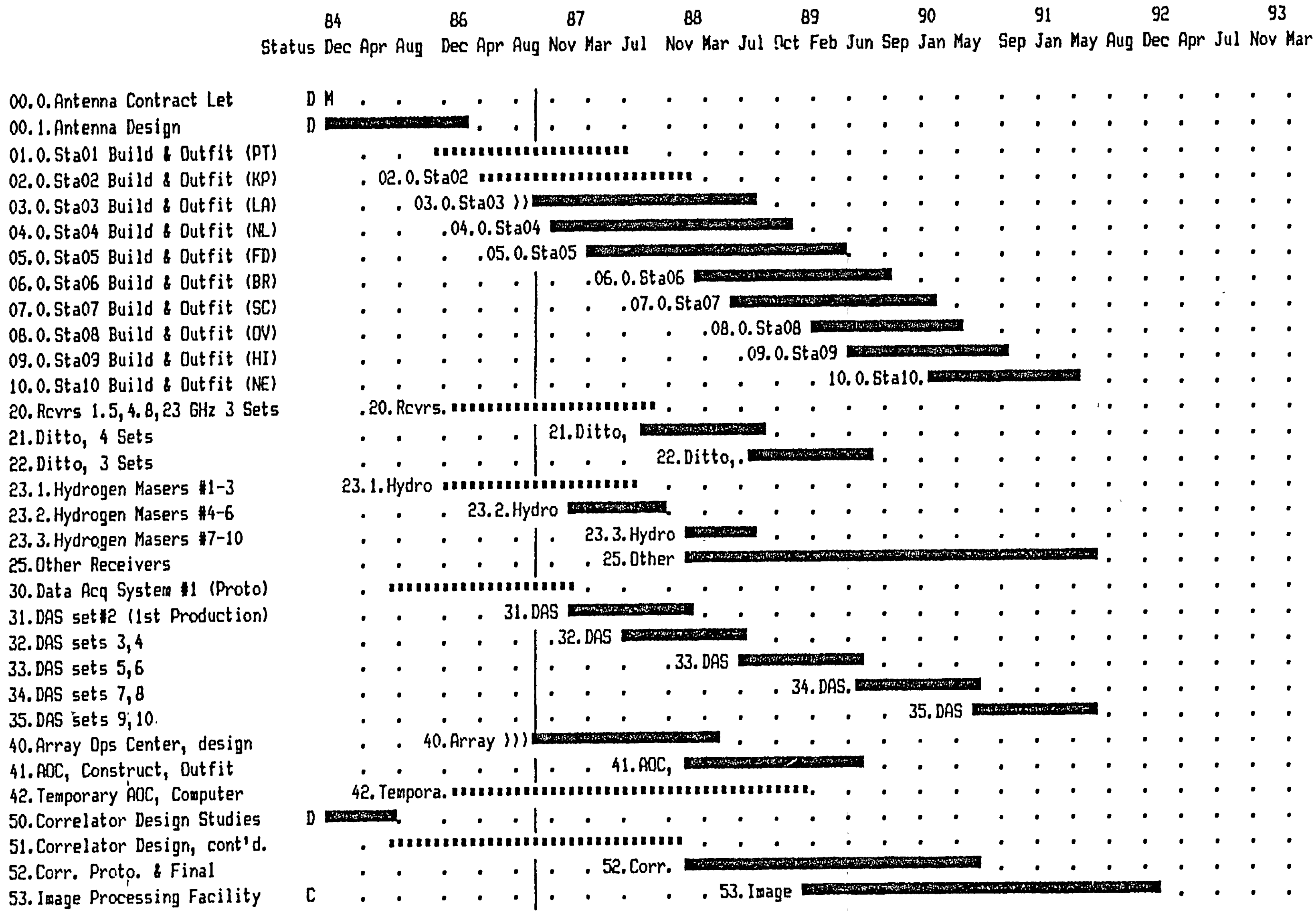
Project Manager: Hein Hvatum, Peter Napier
As of date: 29-Sep-86 7:26am Schedule File: C:\TLDATA\VLBAOV7

An approximate bar chart keyed to Budget BD61



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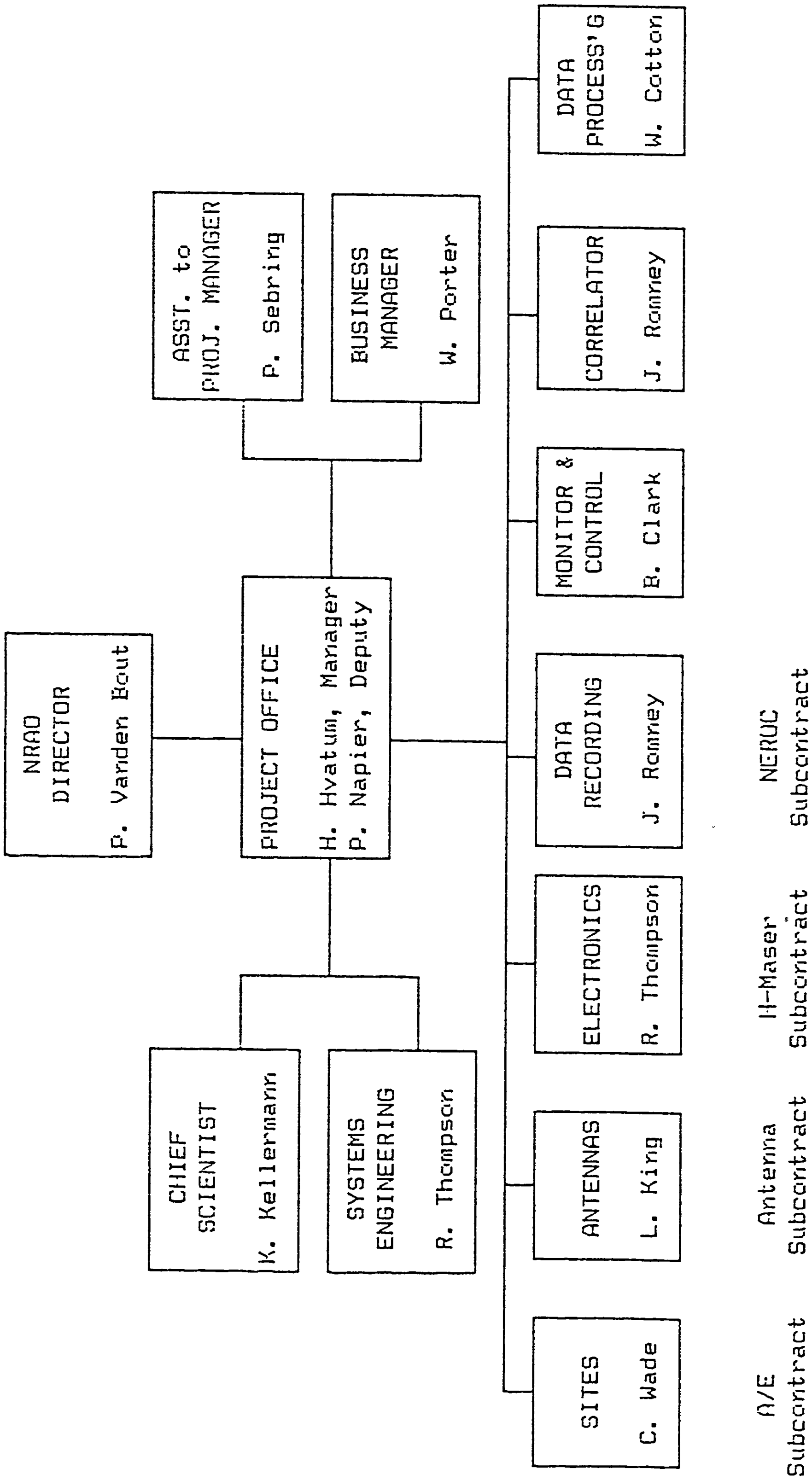
02-Oct-86

1987 Financial Plan VLBA Current '87 $	Effort	Salaries & Wages	Benefits (@ 25%)	Materials & Services	Travel	Contract Charges	Total
Sub-project	Man-months	$k	$k	$k	$k	$k	$k
Sites	36	147	37	314	60	541	1099
Antennas	114	319	80	102	35	3158	3694
Electronics	246	639	160	579	115	448	1941
Data Recording	-			15	15	500	530
Monitor & Control	72	200	50	135	10	-	455
Correlator	97	283	71	65	8	-	427
Data Processing	6	20	5				25
System Engineering	6	20	5		5		30
Array Oper. Center	-	-	-	20	5	175	200
Project Management	117	342	85	203	75		705
Operations Training	4	16	4		5		25
Planned Commitments	698	1986	497	1493	333	4822	9131
New Funds, 1987							9400
Carryover from prior years							475
Net Contingency, $K							744

Project Staffing Plan
(Number Employees @ 12/31)

	1984	1985	1986	1987	1988	1989	1990	1991
Sites	0	2	3	3	3	3	2	1
Antennas	0	3	9	10	9	8	7	0
Electronics	8	18	18	21	22	26	26	24
Data Recording	0	0	0	0	0	0	0	0
Monitor and Control	1	5	5	6	6	5	4	4
Correlator	1	3	6	9	11	9	7	0
Data Processing	0	0	0	1	3	4	3	2
System Engineering	1	2	2	1	0	0	0	0
Project Management	6	10	11	11	10	10	10	7
Operations Training	0	1	2	1	0	0	0	0
Total	17	44	56	63	64	65	59	38

staff02



VLBA PROJECT ORGANIZATION
NRAO 1986 September 23