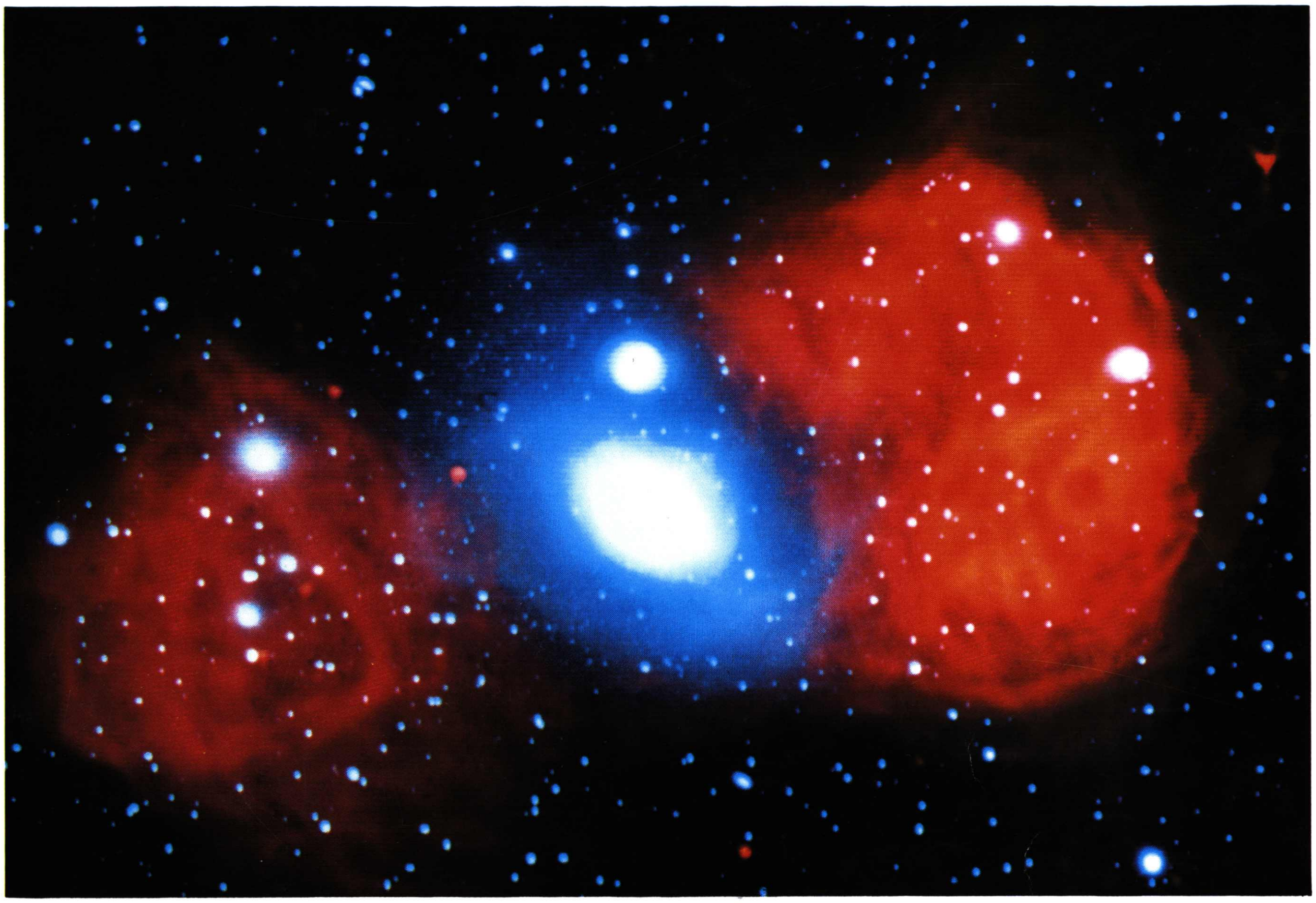
NATIONAL RADIO



ASTRONOMY OBSERVATORY

PROGRAM PLAN 1990

Cover: The Radio Galaxy Fornax A

The cover photograph is a superposition of the VLA radio emission (shown as red) from the radio galaxy Fornax A and the visible light in the vicinity of NGC 1316 (shown as blue-white). The two main radio emitting lobes are produced by relativistic electrons in magnetic fields which have been transported hundreds of thousands of light years outward from the elliptical galaxy NGC 1316 which lies between the two regions. The energy for the relativistic flow apparently was provided by the gravitational capture of small galaxies by NGC 1316. The shock waves and trails of the infallen galaxies produce the features in the radio lobes seen as filaments and rings. The small galaxy near NGC 1316 may soon be captured.

Observation details:

Observers: E. Fomalont (NRAO), R. Ekers (Australia Telescope), K. Ebneter and W. Van Breugel (U. California)

Frequency of 1.384 GHz; five hours of D-configuration and five hours of C-configuration

Resolution of 15"; field of view is 60' x 40'

NATIONAL RADIO ASTRONOMY OBSERVATORY

CALENDAR YEAR 1990

PROVISIONAL PROGRAM PLAN

October 1, 1989

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I. INTRODUCTION

The National Radio Astronomy Observatory is funded by the National Science Foundation under Cooperative Agreement AST-8814515 with Associated Universities, Inc. The Observatory operates major telescope systems for research in radio astronomy and carries out research and development in related fields of advanced technology and image processing.

The three major telescope systems operated by the NRAO for scheduled astronomical observations are: the 27-element Very Large Array telescope (VLA) located on the Plains of San Agustin, near Socorro, New Mexico; the 12-meter millimeter wavelength telescope on Kitt Peak, Arizona; and the 140-foot telescope in Green Bank, West Virginia. Additionally, interim observations are conducted with the individual antennas of the Very Long Baseline Array (VLBA) as the antennas are completed.

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

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

Section II of this Program Plan summarizes the research that visiting investigators are planning to undertake with the NRAO telescopes during 1990. More than 70 percent of the available observing time will be used for the research programs of visiting astronomers. The remaining 30 percent or less is shared by the observing programs of staff scientists, scheduled maintenance, and tests and calibration of the telescopes.

Section III of the Plan describes the continuing research instrumentation developments which will take place at the Observatory during 1990. These include instruments which are used directly as integral elements of the telescope-receiver-computer data acquisition chain and those which are part of the off-line signal and image processing and data analysis procedure. 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 1990 effort in these areas will include implementation of multi-beam receivers, spectrometers, and control hardware for millimeter-wave observations at the 12-meter telescope; the rapid installation of low-noise, L-band HEMT amplifiers on the VLA antennas; and replacement of the 5-18 GHz upconverter receivers on the 140-foot telescope with 5-18 GHz/25-32 GHz broadband HEMT receivers.

Subsequent sections give the program of expenditures required for operations and maintenance of the Observatory and their breakdown according to geographic cost centers. Included is a specific section describing the arrangements made through the National Science Foundation for the NRAO support of that portion of the USNO program in astronomy related to operation of the Green Bank three-element interferometer.

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

II. SCIENTIFIC PROGRAM

The following summary, arranged by telescope, illustrates the diverse range of scientific topics that have been proposed by visiting astronomers for investigation during 1990 at the NRAO. Each of the programs has been designed by its authors to take advantage of the unique qualities of the NRAO instrument on which it is undertaken. The demand for telescope time is now higher than at any time in the history of the NRAO. This we regard as a clear demonstration of the scientific impact of sensitive and versatile instrumentation as well as a mandate to enhance and improve Observatory facilities.

The Very Large Array

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

The VLA has become a mature scientific instrument whose power and versatility is sought after by all segments of the astrophysical research community. During 1990 its power will be brought to bear on a diverse range of topics, from the composition and astrometry of asteroids in our own solar system to the magnetic field environments in distant clusters of galaxies.

As the most productive of ground-based astronomical instruments, its demand continues unabated fully a decade beyond its implementation in 1980.

Numerous solar and planetary observations will be carried out with the VLA during 1990. Key to the solar experiments is the very high dynamic range that is achievable with the VLA. Multiwavelength observations targeted on an active solar limb feature simultaneously with rocket-borne uv and X-ray detectors will investigate the solar corona, chromosphere, and transition region at the highest possible resolution. Time-varying phenomena in the solar corona, such as spicules and plumes in coronal holes, will similarly be explored simultaneously with ground-based optical measurements.

Upcoming planetary observations will build upon the success of past VLA synthetic aperture radar experiments towards Mars and the rings of Saturn. A major effort will extend this technique to Titan and possible other solar system objects. High resolution spectral observations of the brightest asteroids are expected to help determine their surface properties. As solar system objects, the asteroids can add to a more precise determination of the coordinate frame of the solar system.

The VLA is a powerful tool for the investigation of weak stellar sources. Thermal emission from the stellar photosphere of Mira variables will be surveyed and direct measurements made of their size and brightness temperature over a portion of each star's pulsation cycle. Ground-based VLA support observations of flare stars will be carried out simultaneously with a program on the Hubble Space Telescope to observe their coronal ultraviolet lines. A new survey of cool giant and supergiant stars will be conducted to much fainter limits in order to expand the known sample of radio continuum, stellar emission sources from winds and chromospheric emission mechanisms. Dynamics of the OH/IR star population will be studied with a survey of OH emission from the circumstellar shells of evolved stars in the inner disk of our Galaxy. The circumstellar envelopes of four nearby high latitude evolved stars will be searched for HI emission as a valuable diagnostic of mass, mass loss rate, and stellar photospheric chemistry. Several programs will actively continue recent work on radio emission from X-ray binaries that involve Ginga X-ray observations, IUE ultraviolet, and many ground-based optical observations to identify X-ray emitting states of the X-ray emitting accretion disk in an X-ray color-color diagram.

Pulsar observations with the VLA will consist of both detection and astrometry experiments. A search for new radio pulsars will be directed toward known steep-spectrum radio sources, new suspected supernovae remnants, and gamma ray burst sources. A search for the integrated radio emission of the millisecond pulsar population of globular clusters will be carried out. An astrometric study of PSR 1859+01 associated with the W44 supernova remnant is designed to directly test the connection between the formation of the remnant and the birth of a neutron star.

VLA studies of planetary nebulae and supernova remnants will continue to improve our radio view of the advanced stages of stellar evolution. HI maps of the planetary nebulae NGC 7027 and IC 418 will be directly compared with CO maps in order to clarify evolutionary models and the formation of circumnebular HI. Similar studies of the protoplanetary CRL 618 will be useful in the analysis of its chemistry and the interaction between its fast and slow wind. A collection of southern supernova remnants will be imaged with the VLA in an attempt to investigate the interaction between the supernova ejecta and the surrounding HI medium. Other supernova remnant studies will focus specifically on filled center remnants or sources with unusual morphologies.

Galactic studies with the VLA continue to advance our understanding of the star-formation process. Ammonia spectral-line observations in the molecular outflows of star-formation regions will attempt to clarify the structure, kinematics, and energy source of such regions. Observations of lower luminosity outflows in ammonia are now possible with the newly upgraded VLA K-band receivers, and a direct comparison with the well-studied high-luminosity outflow sources will be possible. Direct mapping of the molecular disk associated with the bipolar outflows in some sources is also possible. In other regions ammonia-line studies will be used to probe the nature of molecular cloud core kinematics. Individual cloud core clumps in the Orion KL nebula, W51, NGC 7538, etc., will be examined for evidence of collapse and spin-up. Improvements of up to a factor of eight are expected in spectral resolution and in the resulting kinematic analysis. Evidence of recently collapsed protostars and their thermal characteristics and morphology will be investigated in specific regions of known infrared or CO molecular-line properties. A survey of young stellar objects will be completed in order to provide a broader statistical base for the study of their evolution. In other selected star-forming regions, molecular lines of species such as methanol, methylamine, SiC_2 and HC_7N, in addition to ammonia (NH_3), will be observed in order to investigate the kinematics and photo-chemistry of stellar envelopes and star-forming regions.

Studies of the general interstellar medium and its relation to galactic structure will continue. HI observations will investigate the thermal equilibrium and structure of high latitude, infrared cirrus clouds and improve in general our knowledge of their physical properties and the nature of high latitude dust. A survey of the HI Zeeman effect towards dense interstellar clouds will be conducted. The Orion super-bubble will be imaged at 327 MHz in order to improve the overall picture of the region of complex interactions between HII regions, giant molecular clouds, stellar winds, and star formation. The VLA 327 MHz capability will also be used to study the prominent large-scale, jet-like feature emanating from the galactic center. Normal galaxies will continue to be the focus of many VLA programs which rely upon multi-wavelength, multi-configuration observations in order to distinguish between emission mechanisms, clarify kinematic models, and segregate evolutionary scenarios. The D configuration of the VLA is an efficient detector of extended low surface brightness material. Several programs will map this material far outside the optical cores of galaxies in order to better determine rotation curves and galaxy masses. Low surface brightness galaxies at the faint end of the galaxy luminosity function will be surveyed in the direction of the Boötes Void. Another study of three fields out to a distance of 50 Mpc will test the luminosity function and sample the faint galaxy distribution in distinct regions of the local environment. Follow-up observations of an isolated intergalactic HI cloud seen from Arecibo will be made in an attempt to verify its possible rotation. Detailed HI maps will be made for a few spiral, SO, and irregular galaxies known to have active star-formation properties on the basis of previous CO and/or IR measurements. The radio properties of some galaxies and galaxy pairs will be surveyed as an important tracer of the dynamical interactions that take place between some galaxies during their lifetimes. In most cases gas flow models will be directly compared to the observations.

The structure of the magnetic fields in several galaxies will be the focus of numerous programs on the VLA. In the central area of M31, the magnetic field structure will be directly compared to the observed structure of the ionized gas. For several spiral galaxies the polarization measures will help investigators classify the magnetic field configuration as either axisymmetric or bisymmetric.

VLA observations of classical radio galaxies and quasars continue to provide researchers with vital clues to their morphological spectral properties. Although Cygnus A is one of the most completely studied radio galaxies, additional observations at two additional frequencies are essential to a complete multifrequency spectral analysis of the source and for a study of spectral evolution in the lobes and hot spots of the source. Jet/counterjet ratios will be examined in a sample of ten radio galaxies for direct comparison with a previous sample of quasars and as a test of relativistic beaming models. Spectral mapping of a number of well-studied sources will bring to ten the total number of frequencies mapped in order to test standard models of particle acceleration and synchrotron loss in spatially distinct portions of each source. Additional spectral and polarization observations of jets in low luminosity sources will test proposed models for the prominent structural knots that appear in each jet. A search for CO at high redshift ($z = 3.8$) will be made in the radio galaxy 4C41.17 as a potential diagnostic of the star formation and kinematics of a galaxy in the early universe.

In groups and clusters of galaxies, VLA observations help to determine how the local environment influences galaxy evolution. The HI distribution and kinematics in four compact groups will be observed to help determine the evolutionary state of compact groups. The radio inventory of Abell cluster sources and their properties will be extended by means of an additional 90-cm survey. Additional cluster sources may be detected, especially if there is a population of steep spectrum sources. The rotation measures of two bright tailed radio sources in the centers of non-cooling-flow Abell clusters will be determined in order to compare the derived magnetic field properties with those determined for cooling flow clusters. Search for a cluster-wide halo in the Perseus Cluster will be carried out using VLA 90-cm observations.

The Interim VLBA

During the coming year several program will be carried out with individual, newly outfitted VLBA antennas, both singly and in combination with other VLB Network antennas in order to take advantage of a growing national instrumental resource and to fully debug and exercise the new facilities. The two VLBA antennas closest to the VLA will be used with the VLA to support SMM observations of solar spike bursts. The baseline lengths are appropriate to place important constraints on source size and brightness. Two of the VLBA antennas will be used in a five-telescope array to search for speckles in the diffractive scattering disk of the Vela pulsar with the goal of better characterizing interstellar plasma and scattering processes. A single VLBA antenna will be used to monitor OH and H_2O in a search for refractive focussing effects in the interstellar medium. Three VLBA antennas and the VLA will be used in a pilot study for the determination of the distance to the Galactic Center using OH/IR stars and the limitations imposed on it by interstellar scattering. VLBA baselines that include one VLA antenna combined with MERLIN baselines will be used to produce a high-quality radio image of parsec-scale structure at the core of the galaxy Mrk 501 in order to study the dramatic structural twist seen in its asymmetric core-jet feature. As other baselines become available in the few hundred kilometer range, additional experiments will make use of the increasing VLBA resolution and image quality capabilities.

The 12-Meter Telescope

During the next year the system sensitivity for both the 70-90 GHz and 200-240 GHz bands will be significantly improved by the introduction of SIS receivers. An improved version of the 90-115 GHz SIS receiver will enhance the capabilities in this important spectral range. It is expected that the considerable efforts devoted to improvements in the precision of the antenna pointing will enable observations to be made with better calibration and higher accuracy, so that meaningful comparisons of the line strengths of several transitions of the same molecule can be made, even if the data span a wide range in frequency.

The inferior conjunction of Venus in early 1990 provides an excellent opportunity to explore the temperature, density, and bulk motion of the middle atmosphere (80-110 km) of this planet, using observations of CO at 230 and 220 GHz. It may be possible to study the dynamics of the upper atmosphere as well if the spectral resolution of the data is high enough. An attempt will be made to detect CO on Jupiter, and additional observations of CO on Mars will pursue the suggestion that there are global changes in the atmosphere of this planet which arise because of periodic dust storm activity.

It is becoming much more common to use millimeter-wave line data in conjunction with high-resolution optical spectroscopy to obtain a better picture of the physical and chemical nature of galactic molecular clouds. For example, optical absorption data are now available for a large number of stars thought to lie beyond those molecular clouds that are nearest to the sun. A search in the direction of the stars will be made for CO emission features that correspond to the Na and Ca optical absorption lines that have already been measured. Careful analysis of such CO lines, if present, will lead to unambiguous distances for the clouds.

At the other extreme of distance, a similar technique can be used to improve the accuracy with which the temperature of the "3 K" cosmic background radiation is known. There continues to be some controversy about the best value for this quantity and about whether the "temperature" depends on the wavelength of the measurement. Optical observations of the CN lines in principle give a measurement with high precision, if the local excitation conditions can be estimated. One way of doing this is to search for the radio emission from the CN in the line of sight towards the same stars being used for the cosmic background work. The strength of the radio emission, or even a strict upper limit, can then be used to restrict the range of local excitation, thus improving the precision of the estimate of the CBR temperature. Such a program will be undertaken with the 12-meter telescope this winter.

A burning question that carries implications for a wide range of current research is whether there is a universal initial mass function for the formation of stars, or if the number of stars formed in each mass range is a function of the physical conditions in the region of star formation. The answer to this difficult question will undoubtedly have to wait for many more years of research. However, one promising avenue that will be explored this winter is the study of the mass spectrum of the compact, dense molecular clouds in which star formation is almost certainly imminent. A preliminary investigation has identified a relatively isolated region which has clump structure, and the observations during the next year will examine the density distribution of the clumps as well as search for detailed structure within the clumps themselves.

Since more sensitive receivers are now available, it is possible to undertake large observational programs that earlier could just not be done. For example, an attempt will be made to map one of the "grand design" spirals in the 1.3 mm emission of CO. The data will be used to address such questions as the correlation between the molecular material and other constituents of the spiral arms (neutral hydrogen, magnetic field strength, and relativistic electrons), the distribution of the molecular material with respect to the spiral pattern, and the role of spiral density waves in triggering star formation.

Another approach to the understanding of star formation in spirals is to focus on the molecular gas apparently associated with the great neutral hydrogen shells that are now being found with increasing regularity in neighboring spirals. These huge structures have apparently resulted from supernovae, or from the winds of massive young stars. It is of interest to see if these expanding shells have piled up enough cool molecular material that they can become the site for a new generation of stars.

These programs are merely representative of the extensive research that will be undertaken in the field of extragalactic molecules. The (1-0) CO line is now used mainly for searches. Examples of such programs are those searching for molecular material in elliptical and lenticular objects, and the studies of distant infrared-bright active galaxies. The CO content of many spirals has now been measured, and interest is shifting to observations of other molecules, such as CS, in order to gain information about the denser molecular regions. However, there are a number of the nearby, large galaxies such as Maffei 2 for which maps either in (1-0) or in (2-1) CO must be completed.

Finally, there continues to be heavy demand on the 12-meter for observations that explore the chemical and physical condition of the interstellar medium in the Milky Way. Thus the recent discovery elsewhere of masering recombination lines has stimulated interest in the excitation of these lines, which can be determined from observations of a suitably chosen sets of lines at short millimeter wavelengths. A central problem in interstellar chemistry continues to revolve around the molecules containing refractory elements. Hope for progress in this field has been spurred on by the publication of laboratory rest frequencies for two of the most promising molecules, NaO and AlO. With the more precise frequencies now in hand, the search for the lines of these molecules can be pursued vigorously. Other programs will attempt to detect the lines from several protonated species, often considered to be crucial in assessing the relative importance of ion-molecule and grain-surface chemistry in the production of the rich sample of molecules which have now been discovered.

The 140-Foot Telescope

The spectral processor has been installed at the 140-foot telescope. This major instrumental addition has offered the general scientific community the opportunity to conduct pulsar research. Previously, the necessary backend signal-processing equipment had been supplied by the individual research teams wishing to use it. The newly available option promises to increase the quantity and quality of pulsar research in and beyond 1990.

A specific project involves accurate timing of a distributed grid of pulsars. One goal is to discover, or place severe limits on, any gravitational radiation left over from the early moments of the universe. A background of gravity waves traversing the solar system could add a stochastic component limiting the accuracy of timing measurements. A second goal is achieved for those pulsars residing within globular clusters. These permit determination of the gravitational fields (hence mass distributions) within the clusters. For those pulsars that are members of binary systems, a third goal, testing general relativity, can be accomplished.

A second pulsar project lends support to the mission of the Gamma Ray Observatory (GRO). The GRO will search known radio pulsars for pulsed gamma rays. To bring the search within the realm of feasibility, only a portion of parameter space can be searched. The strategy is to fold all the gamma-ray data on the period of the radio pulsar. These periods are in the process of being accurately determined.

Very deep searches for rapid (periods ≤ few milliseconds) pulsars and for pulsars in binary systems will be conducted. The 140-foot telescope, despite its modest size, competes with any in the world for these searches due both to the sensitivity of its receivers and to the sophistication of the spectral processor.

The 140-foot telescope has assumed several of the studies previously conducted using the 300-foot telescope. The role of "redshift machine" for determining the large-scale distribution of matter in the universe is one instance. For 1990, this effort will concentrate on extending the survey to greater distances, as well as following possible filamentary distributions of galaxies to southern declinations. Physically connected distributions of galaxies are particularly difficult to establish when they cross the Zone of Avoidance centered on the Galactic Plane. A blind survey for galaxies revealed by their neutral hydrogen emission will continue in the Zone.

A new area of research has emerged with the discovery of an exceptionally large and gas-rich galaxy from which no optical light is received. The galaxy may be in its youth, before sufficient time for star formation has elapsed. Because the first such galaxy was discovered accidentally, the incidence of like objects is unknown. A proposal to search systematically with the 140-foot telescope will begin in 1990.

A major fraction of the available time on the 140-foot telescope is devoted to molecular spectroscopy. The centimeter-wavelength range the telescope covers is particularly well-suited for transitions of heavy molecules (atomic weights ≈20-50), most of which are organic. Therefore, the extension in 1990 of the telescope's capability to cover the frequency range 25-32 GHz opens up a previously unexplored range of potentially great interest. To follow up on the interest in long carbon-chain molecules, one investigation will attempt to correlate the strengths of cyanopolyyne lines around carbon stars with the infrared light curves of the stars.

Some atomic spectroscopic observations will have cosmological significance. Continuing searches for $^3He+$ in galactic HII regions and in planetary nebulae will test models of element formation during the first few minutes of the universe.

A 6-cm survey of the northern sky using the 300-foot telescope has revealed ≈100,000 sources stronger than the survey's completeness limit of 25 mJy. Probably every continuum source ever studied by the VLBA will be in this survey, as are many peculiar and rare objects such as gravitational lenses. A major effort in 1990 will use the 140-foot telescope to extend this survey from the equator to declinations as far south as -45°. Improvements in the sensitivity of the amplifiers themselves, utilization of a wider bandwidth, and the higher efficiency of the 140-foot telescope at 6 cm combine to make this southern extension of the survey approximately as deep as the completed northern portion. (If arrangements can be worked out, the Green Bank receiver will be taken to the CSIRO 210-foot telescope in Parkes, Australia to complete the survey to the South Pole.)

The 140-foot will continue as a major station in the international Very Long Baseline Interferometry network. Its collecting area and low-noise receivers make it particularly valuable for the special experiments requiring the greatest sensitivity. Two examples of experiments the 140-foot and only a few other telescopes can participate in are a study of methanol masers and a study of active extragalactic objects using the new frequency synthesis technique. The former study requires 12 GHz capability, which few telescopes had until 140-foot observations discovered the surprising maser emission. The latter study requires frequency flexibility. It partially fills gaps in the u,v plane by observing at more than one frequency (on different days). The more complete transform plane coverage extends the dynamic range of resulting maps. The technique will be applied to 3C 84.

One investigation in 1990 will measure magnetic field strengths in interstellar clouds using the Zeeman effect in SO molecules. The choice of this molecule permits for the first time field strength determinations in high-density environments (10^5-10^6 cm^{-3}). At the other extreme of low-density interstellar gas ($10^{1.7}$-10^3 cm^{-3}) is a continuing survey of the inner Galaxy for low-frequency hydrogen recombination lines (H310α). The ionized gas probed by this survey does not appear to be distributed broadly, but rather seems associated with individual sources. Knowledge of this distribution is important to understanding the evolution and dynamics of HII regions. The frequency range of the survey is also appropriate for detecting carbon recombination lines. These serve as useful probes of the physical conditions in the warm ISM.

The chemical reactions that lead to ozone depletion in the earth's atmosphere and greenhouse warming are complex and interactive. One major reactive reservoir that has not been studied is the atmospheric hydroxyl (OH) reservoir. Since this molecule has one transition at 6 cm, it is amenable to study with radio telescopes. The 140-foot telescope will be used for a feasibility test only to see whether atmospheric OH can be detected.

OH observations in comets will continue, following the successful studies of Comet Halley in 1986 and Comet Brorsen-Metcalf in 1989. The observations reveal unique information about gas production, molecular excitation, and kinematics. Especially valuable are studies over a range of heliocentric distances.

III. RESEARCH INSTRUMENTS

As a purely observational science, progress in radio astronomy is dependent on technological advances in all those areas that contribute to a successful observation. The experience at the NRAO and elsewhere has been that qualitative technical developments are soon reflected in qualitative, not incremental, scientific advances. The VLA image of the radio galaxy Fornax A shown on the cover of this Program Plan is an appropriate illustration of this point. Here the two radio lobes can be seen to surround the stellar distribution which defines the visible galaxy. The manner in which the radio and optical emission share complementary regions of space demonstrates that the physics that gives rise to the emission in these two wavebands is itself different and exclusionary--the process which gives rise to radio emission operates either not at all or with much less efficiency in regions populated by stars. Moreover, the filamentary character of the radio emission shows us that the magnetic field is itself filamentary and twisted, presumably as a result of violent shocks within or passing through the radio lobes. Fundamental knowledge such as this is unobtainable without a concerted and continuous program of instrumental construction, evolution, and improvement.

Each of the three major telescopes operated by the NRAO as well as the partially completed VLBA provides a unique service to astronomers and each benefits by a scientifically considered and prioritized plan for improvements to its capabilities as enumerated below. To this end an NRAO research and development program in electronics, instrumentation, and computing techniques is maintained at each observing site as well as at the

Central Development Laboratory in Charlottesville. Each of these locations is involved in design, development, and construction of auxiliary instrumentation for augmenting the research capabilities of the NRAO 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 the user-interface. The purpose of the NRAO is to provide unique facilities to the researcher which he/she can use to maximum scientific profit. The typical user, in residence at the NRAO but a few times a year, thus needs to be provided with hardware and software interfaces to the instrumentation that are logical and comprehensible, yet which provide ready access to the full flexibility available from the instrument. The need for a suitable user-interface has a considerable impact on NRAO plans for the design and utilization of astronomical instrumentation which can be seen reflected in demands on the research equipment and budget.

One of the most significant advances in radio astronomy in the last few years was spawned from the recognition that the quality of radio astronomical data could be markedly improved by more sophisticated data manipulation software. Here the most striking example is the use of self-calibration algorithms on VLA and VLBI data to correct the incoming wave-front for atmospheric (and instrumental) effects. This radio analog of the optical "adaptive optics" technique allows the VLA to achieve theoretical angular resolution unencumbered by atmospheric smearing while at the same time reaching a dynamic range 100 times higher than expected in the design of the VLA. For the specific case of VLA data, the price of this improvement is an enormous computing burden that requires the astronomer to seek the resources of faster computers and greater data storage capacity. The NRAO, cognizant of these escalating demands, has sought additional computing facilities and personnel for algorithm development and user support through the proposed "Array Telescope Computing Plan." The plan will be resubmitted to the NSF in 1990. However, the single-dish telescopes, as well as the VLA, have also benefited by access to rapid data-handling and data-manipulation hardware and software. The multi-feed receivers on the 140-foot telescope and on the 12-meter telescope have led to a remarkable improvement in the capacity to map large regions of the sky and to study more numerous astronomical objects. But again the direct ramification is a need for faster, more flexible, and distributed computer power together with more sophisticated software in order to exploit properly these additional scientific opportunities.

The Research Equipment plan is designed to realize these opportunities. This plan has been under-funded in the past few years and while our 1990 planned expenditures are $750k, we anticipate budgeting only $350k in uncommitted carryover funds from 1989. <u>There are no new funds for the research equipment plan.</u>

The following table shows the planned distribution of funds for the Research Equipment account and reflects 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 1990 are not necessarily planned for completion in 1990.

RESEARCH EQUIPMENT

($ in thousands)

	Expenditure 1989 (est)	1990 (plan)	Add'l Cost	Completion Date
1. Laboratory and Test Equipment	$ 50	$100	$100/yr	continuing
2. Miscellaneous Projects	70	70	200/yr	continuing
3. Very Large Array				
1.3-1.7 GHz Improvements	48	150	150/yr	1993
75 MHz Receivers		20	20/yr	1991
Correlator System Controller	10	10	20/yr	1992
Phased Array Processor	20			
Imaging Computer Additions	170	20		continuing
MM Array Development	10	20		continuing
4. 12-m Telescope				
Multi-Beam 230 GHz Receiver		10	250	1992
Multi-Band SIS Receiver	30	50	70	1990
Hybrid Spectrometer	13	45		1990
AOS Development	10	10	200	1992
Pointing Improvements	5	10	50	1990
Telescope Control Upgrade	35	50	35	1990
5. 140-ft Telescope				
Spectrometer/Computer Development	5	25	175	1992
5-45 GHz HEMT Receiver	30	25	60	1991
Analysis Computer	20		50	1991
6. Common Development				
Millimeter Device Development	100	90	150/yr	continuing
HEMT Amplifier Development	10	10	20/yr	continuing
Computational Imaging		20		
Single Dish Support	15	15		
TOTAL	$651	$750		

1. Laboratory Test Equipment

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

2. Miscellaneous Projects

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

3. Very Large Array: Electronics

The 327 MHz and 22 GHz receiver systems which have dominated the Electronics RE over the past years are now complete, and we have begun improvements of the L-band receiver system.

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

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

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

Two more L-band receivers were built in 1989 and a construction rate of six per year is planned starting in 1990, with completion in 1993.

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

<u>75 MHz Receivers</u> - As described in the "Low Frequency Radio Astronomy" Workshop (Green Bank, Nov. 84, ed. Erickson and Cove), we are increasing the low-frequency capability of the VLA by equipping VLA antennas with 75 MHz receivers. The installation of these receivers will be coordinated with the installation of B rack shields for RFI suppression. Five antennas were equipped with receivers and shields by mid-1989. We plan to add further receivers as funds become available.

<u>Correlator System Controller</u> - The future reliability of the system controller and its associated array processor is unknown as there has been an increase in the number of failures in the past years. A more up-to-date system would support a high-level language which would facilitate the

implementation of more correlator modes, improve the data quality, and increase the dynamic range.

Phased Array Processor - Study of impulsive phenomena with the VLA is made possible not by the imaging capability of this instrument but simply by the large collecting area and instantaneous sensitivity afforded by the superb receiving systems. Here the desire is to measure rapidly all the Stokes parameters of the emission from flare stars and pulsars as a function of time. The positions are known and the objects are true point sources. For such an observation the signal from all the antennas needs to be added, in phase, in a special microprocessor and sampled rapidly. The phased array processor is designed to provide precisely this capability. This project will be completed in 1990.

Imaging Computer Additions - Access to the full data rate of the VLA provided by the new on-line computers is a mixed blessing. Scientifically, it permits true spectro-polarimetry for the first time since the VLA was constructed; polarization images of OH masers (and similar science) are at last possible. But the price one pays for this information is a sustained data rate greater than can be accommodated by the downstream imaging computers. A very substantial enhancement in computing resources is needed and, indeed, such has been requested in the proposal "Array Telescope Computing Plan" submitted to the NSF. In the interim, and prior to the expected start of funding for this proposal in 1991, we acquired a second CONVEX C-1 computer for calibration and imaging at the AOC, and in 1990 we plan some modest enhancement of the disk storage capacity, tape handling, and interactive display for both CONVEX imaging computers. We also intend to enlarge our meager workstation environment with the purchase of a small number of SUN workstations or an equivalent.

Millimeter Array Development - The design and planning for a national Millimeter Array continues in 1990, again with efforts focused on site evaluation. We have constructed automatic tipping radiometers operating at 225 GHz to assess the transparency of the sky at millimeter wavelengths and the fluctuation spectrum of the sky brightness. With the former measurement we intend to produce a quantitative measure for each site of the number of days per year at which millimeter observations will allow us to assess the phase stability of the sites.

In 1990 one site-testing radiometer will operate full-time in the Magdalena mountains near Socorro, NM and a second will measure Mauna Kea, HI at the location of the CSO telescope. A third radiometer will be installed late in the year at a potential millimeter array site near Springerville, in the White Mountains of Arizona. Truly unattended in a remote location, this last radiometer will be equipped with solar cells and batteries for its power source, and it will transmit its data via radio link to Springerville. If successful, this apparatus will allow other undeveloped sites to be tested.

4. The 12-Meter Telescope

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

it will be redesigned and replaced. Replacement of the steel feedlegs with carbon fiber feedlegs is being investigated.

Multi-Beam 230 GHz Receiver - The 8-beam Schottky receiver for 230 GHz is already operational. In 1989 we started development of a multi-beam SIS receiver using some of the techniques developed for the 8-beam Schottky mixer receiver. Our aim is to produce a 32-beam spectral line system by 1993.

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

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

Construction has begun on a 4.2 K system that can handle eight inserts which include SIS mixer/feed/amplifier assemblies. The telescope version of the system, with coverage of the 1 mm and 3 mm windows, will be ready for incorporation into a receiver on the 12-meter in 1990. The objective is to have complete coverage of all the windows between 70 and 360 GHz with this receiver in the near future.

Hybrid Spectrometer - In order to provide the greater instantaneous bandwidth needed by the higher frequency 12-meter telescope receivers, as well as to improve the spectral resolution at lower frequencies, a hybrid filter-bank autocorrelator has been constructed. The 2.4 GHz total bandwidth and 1536 spectral channels incorporated in this device will benefit the present single-beam receivers but, in addition, the spectrometer can be divided into as many as eight separate spectrometers for use with the existing 8-beam receiver. An interim system without the full frequency versatility is now operational. The full system will be completed in 1990.

AOS Development - The development of multi-beam receivers will require the development of a new generation of spectral line backends. We have studied competing technologies (AOS, hybrid, digital, SAW devices, etc.) and have concluded that the acousto-optic spectrometer is the most promising, cost-effective, technique for a multiple beam system. A prototype AOS with bandwidth of 500 MHz and resolution of 3 MHz is currently being developed. A multiple AOS spectrometer for multi-beam receivers at the 12-meter is planned for the future.

Telescope Control Upgrade - The existing control system for the 12-meter telescope has been stretched to the limit in supporting the current generation of instrumentation, and already imposes a severe limitation on the potential of the telescope and new data-acquisition equipment. It is long overdue for replacement. The implementation of a new system must not necessitate any prolonged shutdown of the whole telescope, so the approach adopted involves a gradual off-loading of control tasks into a loosely coupled network of microprocessors, based upon a standard bus system. This greatly simplifies the eventual replacement of the control computer itself. During 1990, most of the CPU-intensive control tasks will be implemented in satellite microprocessors. We will replace the main control computer itself with modern hardware and install a user-friendly software interface to the telescope, thereby benefiting both operators and astronomers during the normal summer shutdown of 1990. The new control system is being designed with a remote observing capability in mind.

5. The 140-Foot Telescope

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

During the last two years significant improvements have been made in the high-frequency sensitivity of the 140-foot. The sensitivity at most frequencies was improved by $\sqrt{2}$ by installation of a polarization beam splitter at the Cassegrain focus which allows both maser/upconverter receivers to be used simultaneously. One can choose either to observe at one frequency in two orthogonal polarizations or to observe with two receivers tuned independently anywhere in the range 4.8-25 GHz. A tilting, lateral focus mechanism for the subreflector was installed, resulting in an increase of a factor of two or more in K-band aperture efficiency at large hour angles. Finally, the surface panels were adjusted based on holographic surface maps, reducing the rms error from 1.0 mm to approximately 0.6 mm. The aperture efficiency at 33 GHz is now in the range of 10 percent to 15 percent, depending on declination. These successful improvements have encouraged us to continue our program to instrument the 140-foot at higher frequencies.

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

5-35 GHz Receiver: The accuracy of the individual surface panels of the 140-foot telescope is sufficient for useful observations to be made at frequencies as high as 35 GHz. There is considerable scientific motivation to observe at higher frequencies, driven principally by (a) spectroscopy, (b) cosmic background radiation studies, and (c) VLBI. Although there are many molecular lines between 25 and 35 GHz, the following species have transitions important for astrochemistry in this frequency band: methanol (maser lines), formaldehyde, silicon monoxide, cyanoacetylene, and cyclopropenylidene. A frequency band near 32 GHz is particularly interesting because the atmospheric transparency is greater than that at any frequency above the resonant water line at 22 GHz. Significant continuum research, especially on the microwave background, can take advantage of this window.

The present Cassegrain receiver systems use parametric upconverters to convert signals from 5 to 16 GHz into the 18-25 GHz frequency range of the ruby maser amplifiers. State-of-the-art HEMT amplifiers are now competitive or superior to the noise performance of the upconverter/maser system below 16 GHz. Conceptual work has been completed on a project to re-work the Cassegrain receivers to incorporate HEMT amplifiers for the 5-18 GHz range, and also above 25 GHz, but retaining the masers for the 18-25 GHz range. In 1990 we expect to have this HEMT receiver ready for use over the 5-35 GHz frequency range.

6. Common Development

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

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

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

GaAs FET and HEMT amplifiers have been designed at 0.3, 1.5, 5.0, 8.3, 10.7, 15, 23, and 43 GHz. Several hundred units have been constructed. Work in 1990 will focus on development of broader band amplifiers for various applications at all sites. We will also start work on a prototype amplifier at 86 GHz for the VLBA project.

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

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

IV. OPERATING EQUIPMENT

The following list represents operating equipment items which are vital replacements for obsolete equipment. At this time we cannot project the availability of any funds to support these needs, with the exception of the USNO funds. The distribution of funds (in thousands of dollars) in the various equipment accounts is as follows:

1.	Maintenance, Shop, and Repair Equipment	$ 5
2.	Office and Library Equipment	10
3.	Living Quarters Furnishings	5
4.	Building Equipment	5
5.	Observatory Services	25
6.	USNO Related Services	40

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

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

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

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

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

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

4. Building Equipment

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

5. Observatory Services

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

6. USNO Related Services

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

V. OPERATIONS AND MAINTENANCE

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

General and Administrative

Serving the needs of the entire Observatory, this unit is comprised of the Director's Office, Fiscal Office, and Business Office. Total Materials, Supplies, and Services (MS&S) funding will be $315k. Further major budget items, such as the rent and maintenance of the Charlottesville Edgemont Road building, communications, and utilities, will require $350k. The management fee paid to Associated Universities, Inc., is estimated to be $480k.

Research Support

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

In 1989 the NRAO summer student program was augmented by an award of $95,000 from the NSF Research Experiences for Undergraduates (REU) program to Associated Universities, Inc. Twenty students were supported through this award. In 1990 a modest NRAO summer student program is planned and once again support for additional students will be sought through the REU program. The expectation is that the program will continue as a vital element in NRAO's commitment to the training of future astronomers, engineers, and computer scientists.

Over 33 percent of the overall NRAO travel budget will be expended in the Scientific Staff group, primarily for travel by staff and visitors from U.S.-based institutions to carry out observing programs at NRAO telescopes or by visitors to travel to the Socorro or Charlottesville data-analysis facilities ($150k). During 1990, $30k is planned for foreign travel by the staff, and $20k is available for qualifying U.S. scientists who need travel support to observe at unique foreign telescopes.

The Scientific Services group, in support of research and development throughout the entire Observatory, provides central library, technical illustrations and drafting services, and Observatory visual information services. In 1990, the MS&S budget of $210k for these areas is earmarked primarily for publication support (page charges) of papers based on data obtained with the NRAO telescopes as well as for the book and periodical expenses of the five NRAO libraries.

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

Technical Development

Observatory-wide technical research and development support are concentrated at the Central Development Laboratory. Work on radiometer improvements and the exploration of state-of-the-art techniques for expanding wavelength capabilities insures that the Observatory will have forefront instrumentation in the foreseeable future. A subgroup at the Central Lab is heavily involved in the development of new millimeter-wave devices for low-noise receivers. During 1990, $47k is budgeted for MS&S and $120k for rental of space for the Central Development Laboratory on Ivy Road.

Green Bank Operations

Green Bank is organized into five divisions: Telescope Services, Electronics, Plant Maintenance, Administrative Services, and Scientific Services. Together these five divisions maintain and operate the 140-foot telescope, an 85-foot telescope for VLBI and pulsar timing, and a twin-element interferometer for monitoring flux densities of compact radio sources. The latter two telescope systems are operated for the U.S. Naval Observatory. New electronics instrumentation specifically for the 140-foot telescope is developed on site. Software to analyze the single-dish data is also created in Green Bank. In addition, Green Bank provides support for other NRAO sites. This support includes electronics instrumentation, machine shop work, graphics services, cryogenics maintenance and development, and feed testing. A total of $259k for M&S is budgeted for the five Green Bank divisions, plus an additional $250k for communications and utilities. The estimated revenues from food services and housing will be $150k. Operation of the USNO supported facilities is shown separately for 1990, with a total cost of $810k (see Section VI).

Tucson Operations

The two divisions in Tucson are responsible primarily for the maintenance, operation, and observer support of the 12-meter millimeter wavelength telescope at Kitt Peak. There is now additional responsibility, shared with VLBA operations, for the VLBA 25-meter telescope also at Kitt Peak.

A major effort at the 12-meter telescope is currently being devoted to integrating a new micro-processor-based telescope control system into the telescope environment. This involves a complete redesign of most of the digital electronics hardware and a complete rewrite of all of the real-time software. During 1990 the new 8-feed, 1 mm receiver and the 1536-channel hybrid spectrometer will be coming into regular operation, but both systems will be upgraded during the year, budget permitting, to give greater versatility and higher performance. A completely new range of lower noise SIS receivers, covering the entire operating range of the telescope, is under construction and will gradually come on line at the telescope during 1990. These new telescope subsystems yield a much greater data rate, which will necessitate considerable expansion of the existing data analysis capabilities, at the telescope and downtown, both in hardware and software.

For budget purposes the electronics, operations, computing, administration, and scientific support groups are split into Operations and Maintenance ($115k) and Electronics ($120k). An additional $138k is programmed for building rent, communications, and utilities. Miscellaneous revenue will total about $20k.

Socorro Operations

Activities surrounding the VLA are coordinated through seven divisions which differ in detail from those in Green Bank due to the special requirements of array operations and geographic isolation. The seven divisions are: Scientific Services, Array Operations, Computing, Administrative Services, Electronics, Antenna Services, and Observatory Services. The divisions are budgeted a total of $1104k for MS&S in 1990. In addition to this amount, $975k is budgeted for communications and utilities and $305k is required for computer rental and maintenance. An amount of $95k is budgeted as the VLA's portion of the AOC building rent and maintenance costs. Food services and housing will bring in an estimated $50k in revenue.

VLBA Operations

By the end of 1990 a total of six antennas should be ready for operation. To support this, the VLBA operations budget will need to increase by 66 percent over 1989. In the long-term, we anticipate a combined VLBA-VLA operations program. Thus we categorize, initially, the

VLBA operations into divisions similar to the existing VLBA operations groups. The total MS&S budget for VLBA operations is $132k. Other costs include $120k for communications and utilities, $10k for computer maintenance, and $30k for AOC building rent and maintenance.

A summary of the CY 1990 NRAO budget for the various sites is provided in the following table.

CY 1990 PRELIMINARY FINANCIAL PLAN
($ thousands)

	Personnel	Salaries, Wages, & Benefits	Material Supply & Service	Travel	Total
<u>Operations</u>					
General & Administration	23	$ 1,068	$ 684	$ 103	$ 1,855
Research Support	40	2,489	309	177	2,975
Technical Development	15	766	157	12	935
Green Bank Operations	68	2,756	939	27	3,722
Tucson Operations	29	1,380	393	35	1,808
Socorro Operations	116	4,656	2,334	55	7,045
VLBA Operations	41	1,163	292	45	1,500
Management Fee			480		480
Common Cost Recovery			(200)		(200)
Total Operations	332	$ 14,278	$ 5,388	$ 454	$ 20,120
<u>Equipment</u>					
Research			0		0
Operating			0		0
Total Equipment			0		0
<u>Design and Construction</u>					
VLBA Construction	60	$ 2,690	$ 9,010	$ 200	$ 11,900
GBT Design	16	835	4,675	70	5,580
Total Design & Construction	76	$ 3,525	$ 13,685	$ 270	$ 17,480
TOTAL - ALL	408	$ 17,803	$ 19,073	$ 724	$ 37,600

Notes:

1. Green Bank Operations includes new funds of $810k for operations and equipment in support of USNO telescope operations.

2. Green Bank Operations does not include anticipated funding from NSF for SSTI grant (approx. $615k).

VI. USNO OPERATIONS

In 1990 NRAO will continue to operate two telescope systems for the USNO. The primary system uses one 85-foot antenna as a VLBI station permanently involved in the NAVNET of stations. NAVNET determines the earth's (variable) rotation rate and, with less accuracy, the position of the poles. It uses 1-3 antennas in addition to the 85-foot-one in Green Bank, all equipped to operate simultaneously at 2.3 and 8.4 GHz. These observations so far do not use all hours of every day. The time not used for VLBI is devoted to pulsar timing observations. Some 50 pulsars are observed as often as possible at 610 MHz. The goal is to monitor for changes in their periods, especially for "glitches" or discontinuous jumps in period.

Two other 85-foot antennas are linked by fiber optics as an interferometer. In 1990 this interferometer will also operate at 2.3 and 8.4 GHz. It observes ≈100 compact radio sources daily, monitoring changes in their flux densities. Changes may be either intrinsic to the source or they may be attributed to changes in the path the radiation travels through the interstellar plasma of our own galaxy.

USNO Expenditures and Funding Plan
($ in thousands)

	1988 Expended Actual	1989 Expended Estimated	1990 New Funds
Operations			
Personnel Compensation	$ 255.5	$ 264.0	$ 266.0
Personnel Benefits	71.3	72.0	73.0
Material & Supply	50.2	87.0	111.0
Communications & Utilities	38.5	21.8	30.0
Travel	0	0	0
Common Costs	156.6	217.8	330.0
Total Operations	$ 572.1	$ 662.6	$ 810.0
Equipment			
Shop	0	$ 0	$ 0
Test Equipment	$ 25.7	0	0
Computer Equipment	0	0	0
Total Equipment	$ 25.7	0	$ 0
Design & Construction			
VLBI Upgrade	$ 514.0	$ 273.2	$ 0
Total Design & Construction	$ 514.0	$ 273.2	0
TOTAL - ALL	$ 1111.8	$ 935.8	$ 810.0

VII. VERY LONG BASELINE ARRAY

The revised construction plan which follows was submitted in August 1989. However, in order for us to maintain our operations at the level of $31.2M in new NSF funds, it is necessary to reduce the 1990 VLBA construction budget to $11.9M.

Revised Construction Plan and Budget for the VLBA

Included is NRAO's 1990 budget plan for VLBA construction, BD72N01, and associated overview schedule. This budget reflects a proposed $12.2M funding for 1990, with an increase only for inflation in 1991. An increase in new funds in 1992, from $3.9M to $4.5M, results from the additional manpower requirements needed to support the stretched out antenna contract and subsequent outfitting.

As detailed in the prior 1989 VLBA budget request, the 1990 budget included $2M of items delayed from 1989 and pointed out that prior authorization of that amount would be necessary at the beginning of the Foundation's 1990 fiscal year, October 1989, to continue orderly progress in the VLBA construction program. This VLBA section of the NRAO 1990 Program Plan was submitted early to allow an advanced authorization of $2M. This authorization allows:

1. Initiation of construction of the Mauna Kea, HI site and building this year. Aside from avoiding general delay costs, it should allow Hawaii site readiness in time for RSI's antenna erection crew. The estimated 1989 commitment for the site totals $1,050k.

2. Authorization of the second production run of eight recorders to Haystack Observatory this year. Up to six months lead time is required for

parts procurement to keep production from being interrupted and incurring extra costs. Estimated cost for the next Change Order to Haystack is $950k.

For the 1990 budget there are also delayed authorizations to 1991. A $4M advanced authorization process will likely be requested from the NSF next year for the following:

1. Authorization of the third recorder production run at Haystack Observatory. $950k of 1991 funds are likely required in October 1990.

2. Authorization of the purchase of the data processing mini-supercomputers. $1.1M of 1990's funds for this have been delayed to 1991 and combined with an existing 1991 allocation of $1.9M. However possible advantages of the delay are a combined $3M which may provide more purchasing leverage and more advanced performance. The delayed purchase commitment is scheduled for October 1990.

Antennas and Sites

The schedule for manufacture and erection of antennas indicates the tenth and last antenna scheduled for erection by mid 1991. Site acquisition for all locations is essentially completed. The construction status of the individual sites follow.

Pie Town, NM - This site has been operational since April 1988, and has participated in VLBI Network observations since then, as well as in a number of NASA Crustal Dynamics observations.

Kitt Peak, AZ - This site was made operational in June 1989 when it participated in a 18-cm Network run. The antenna was remotely controlled from the Socorro Array Operations Center, simultaneously with the Pie Town antenna.

Los Alamos, NM - Electronic outfitting of this antenna is essentially complete. However full-time staffing to support Network operations is delayed until February 1990 because of operation budget constraints.

Fort Davis, TX - This antenna is complete except for punch list items. It is scheduled to be outfitted beginning in August, 1989. Staffing for operation is scheduled for July 1990.

North Liberty, IA - This almost complete antenna is scheduled for outfitting to begin in January 1990 and staffed by December 1990. Final completion and test of the North Liberty and Owens Valley antennas is scheduled to resume in August, after installation of their azimuth drive gearbox retrofit kits by the contractor.

Owens Valley, CA - This antenna is virtually completely assembled. Staffing is scheduled for July 1991.

Brewster, WA - Antenna erection is scheduled to start this August. Operational staffing is scheduled for April 1991.

St. Croix, VI - Site preparation for the antenna foundation and control building began in mid-June. Antenna erection is scheduled to start in November 1989. Staffing of this site is scheduled for December 1991.

Hancock, NH - Final building permits are being sought to allow site preparation to start in August, 1989. Antenna erection is scheduled to start in April 1990. Staffing for this site is planned for April 1992.

Mauna Kea, HI - Construction drawings are being prepared for general contractor bidding in the fall. Antenna erection is scheduled to start in September 1990. The Mauna Kea antenna is scheduled for operation in May, 1992.

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

<u>Array Operations Center</u>

In November 1988 the Array Operations Center was completed and occupied by approximately 100 NRAO staff. This building is located on the campus of the New Mexico Institute of Mining and Technology in Socorro NM.

<u>Electronics</u>

The VLBA electronics construction plan generally continues to keep pace with antenna outfitting requirements. This year will expect to see completion of the receiving system racks (Racks A, B, and C) through serial #9. In 1990 Racks #10 and #11 are scheduled for completion. Front ends for initial outfitting will approximately keep pace with the racks, except that for greater efficiency we will build all of the remaining front ends for 1.5 GHz (i.e., through #11 to provide one spare) this year, and leave the 4.8 GHz front ends #8 to #11 to be completed next year.

Of the front ends for later outfitting, the plan calls for completion of the 330/610 MHz front ends #2-#5, 2.3 GHz #2-#3, and 8.4 GHz #4-#8 by the end of this year. In 1990 the front end fabrication schedule is 330/610 MHz #6-#11, 2.3 GHz #4-#5, 8.4 GHz #9-#11, 15 GHz #2-#5, and 43 GHz #2-#6. The prototype 43 GHz front end will be developed this year, using a HEMT amplifier designed in the NRAO Central Development Laboratory in 1988. Three Data Acquisition racks, #6-#8 are scheduled are being completed in Charlottesville this year. In 1990 DAR Racks #9-#12 are scheduled for completion.

Masers #7-#9 have been delivered by Sigma-Tau Frequency Standards. Serial #10 and #11 are scheduled for assembly in 1990.

Data Recording

Seven production recorders are under fabrication at Haystack Observatory. Assembly of electronic boards for the production run is approximately 50 percent complete as of July 1989. Procurement of parts for the seven recorder production run, plus parts for an eighth to be assembled in Socorro, is almost complete. An order for eight more recorders to be assembled in 1989 is expected to be placed in late 1989.

With the completion of Recorder #3, Playback Drives #1 and #2, and DAR #4, the preproduction phase of Haystack Observatory's Recorder contract is mostly complete. Still to be developed are the special boards required to allow properly buffered multi-track playback for completed Playback Drives #1, delivered to Charlottesville, and #2 which remains at Haystack for development test of the subject boards.

Jointly funded by NASA/JPL, a series of tests and computer-physics dynamics modeling were performed at Haystack Observatory to study the tracking performance of the transport to gain a better understanding of the limiting performance factors. Recommendations for specific minor but important changes were made to improve consistency and reduce interchangability problems between transports.

At NRAO Charlottesville the Playback Interfaces have been designed. Prototype circuit boards and electronic parts have been ordered. Completion of Data Acquisition Racks #7 and #8 (#6 is completed) at Charlottesville is scheduled for 1989. In 1990 Data Acquisition Racks #9-#12 are scheduled for fabrication at Charlottesville, as are production quantities of Playback Interfaces.

Monitoring and Control

The monitor and control hardware and firmware are operating at Pie Town, Kitt Peak and Los Alamos. These include the standard interface boards for the receiving system, data acquisition system, and antenna control system; the utility monitoring system of the control building; the focus/rotation control for the subreflector mount; the weather station; and the station monitor and control computer hardware and software. These systems allowed the unattended remote control of Pie Town and Kitt Peak antennas during Network runs.

Serial versions of many of these systems are in an advanced stage of test and fabrication, with additions and modifications in firmware being added to correct bugs as they are uncovered by the observations and tests performed at Pie Town. The debug and improvement of these systems, along with production of assembled boards by vendors will continue in 1989. Assembly and test of modules will continue through 1990.

During 1989, a conversion of the array control software to run on Sun Workstations under the VxWorks operating system is being made. Most of the conversion is expected to be accomplished this summer. It will be followed by code development for the Sun to support integrated multi-station monitor and control. This effort will continue in 1990 with emphasis on testing, optimization, and debugging.

The porting of the operating system to the station computer MVME 121 CPU boards has been completed. The SUN Computer host for the station software development system is up, running and accessible to the AOC's network, and is in production for VxWorks code development. A preliminary version of the station MVME 121 Monitor-Control Bus interface is now operating. The tape drive control operator interface program is being tested under VxWorks. Work also continues on the currently existing, VersaDos, station computer software, primarily in the elimination of bugs found during observing. Installation of the new operating system at the operating antennas is scheduled for early 1990. Improvement of station software will continue in 1990.

Correlator

Work continues on the VLBA correlator. In May 1989 NRAO authorized fabrication of the custom "FX" prototype chip after extensive simulation tests of the chip design. Most of the circuit board design, layout and specifications have been completed, and fabrication by vendors is underway. The two channel, seven station subset of the VLBA correlator will be fabricated and tested at NRAO's Charlottesville laboratory in 1989 and 1990. It is scheduled for delivery in early 1991 to the Array Operations Center. Expansion of the correlator to the full VLBA eight channel, 20 station configuration will take place in Socorro.

Architectural design of the correlator software has been completed, as were the model-computation and the control-script interface tasks. Detailed programming is underway and will continue through 1989 and 1990. Specification of requirements for the database management system which will become an integral part of the correlator software were finalized. The DBMS is under procurement from a vendor selected on the basis of life cycle cost.

Post Processing

Programming work continues to add to the AIPS package the programs necessary to process VLBA data. Two additional programmers are expected in this division by year end. Purchase commitment for mini-supercomupters is scheduled for October 1990.

Project Management

The project office, and its engineering and scientific support is now located in the Array Operations Center in Socorro. The electronics, correlator and post processing activities will continue primarily in Charlottesville in 1990.

File: FIN72N01 JChavez
27-Jul-89

1990 Financial Plan VLBA Constant'89	Effort	Salaries & Wages	Benefits (@ 27.5%)	Materials & Services	Travel	Contract Charges	Total
Sub-project	Man-months	$k	$k	$k	$k	$k	$k
Sites	12	56	15	532	40	750	1393
Antennas	99	292	79	64	60	618	1113
Electronics	252	652	179	1348	45	144	2368
Data Recording	30	82	17	674	5	974	1752
Monitor & Control	48	159	43	114	10	0	326
Correlator	108	377	103	97	20	0	597
Data Processing	36	100	28	253	16	0	397
System Engineering	0	0	0	0	0	0	0
Array Oper. Center	0	0	0	2317	0	0	2317
Spares	0	0	0	656	0	0	656
Project Management	96	292	80	127	30	0	529
Operations Training	0	0	0	0	0	0	0
Planned Commitments	681	2010	544	6182	226	2486	11448
New Funds, 1990							11731
Carryover from prior years							0
Net Contingency, $K							283

File: FIN72N01
27-Jul-89

1990 Financial Plan VLBA Current '90	Effort	Salaries & Wages	Benefits (@ 27.5%)	Materials Services	Travel	Contract Charges	Totals
Sub-project	Man-months	$k	$k	$k	$k	$K	$K
Sites	12	58	16	553	42	780	1449
Antennas	99	304	82	67	62	643	1158
Electronics	252	678	186	1402	47	150	2463
Data Recording	30	85	18	701	5	1013	1822
Monitor & Control	48	165	45	119	10	0	339
Correlator	108	392	107	101	21	0	621
Data Processing	36	104	29	263	17	0	413
System Engineering	0	0	0	0	0	0	0
Array Oper. Center	0	0	0	2410	0	0	2410
Spares	0	0	0	682	0	0	682
Project Management	96	304	83	132	31	0	550
Operations Training	0	0	0	0	0	0	0
Planned Expenditures	681	2090	566	6430	235	2586	11907
New Funds, 1990							12200
Carryover from prior years							0
Net Contingency, $K							293

VLBA BUDGET AND COST ESTIMATE (Constant $)

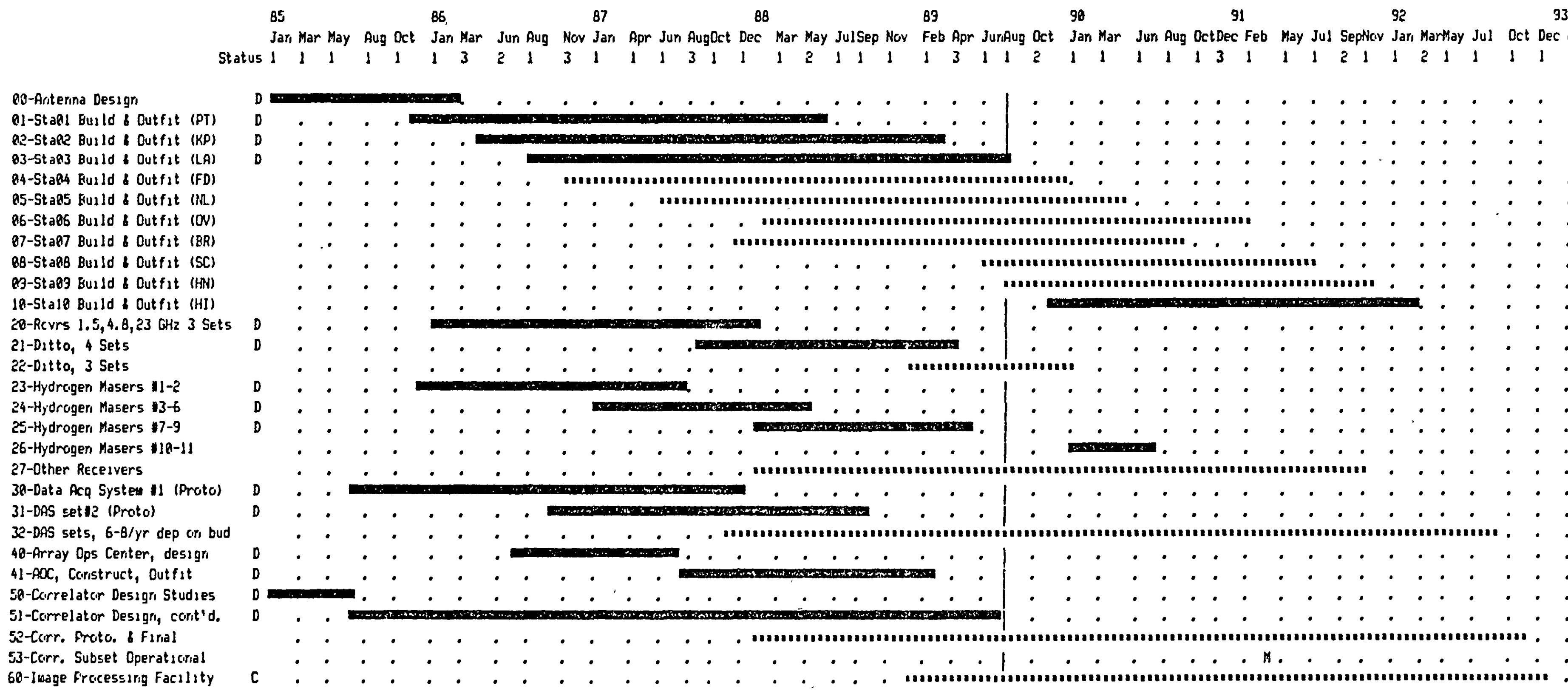
	1983,4	1985	1986	1987	1988	1989	1990	1991	1992	TOTALS	
ANT STARTS/INSTLS		1/1	3/1	2/2	2/2	2/2	0/2				
SITES	32	194	2,204	1,605	1,171	2,535	1,393	239	10	9,383	
ARRAY OPNS CTR			33	19	41	228	2,317	853	345	3,836	
ANTENNAS	1,088	2,460	6,540	5,180	5,090	5,957	1,113	330	150	27,308	
ELECTRONICS	533	1,573	1,652	2,045	1,277	1,611	2,368	1,821	394	13,274	
DATA RECORDING	290	424	4	906	1,242	(27)	1,752	2,388	1,544	8,523	
MONITOR, CONTROL	63	94	316	549	376	621	326	31	9	2,385	
CORRELATOR	322	133	196	370	895	874	597	435	0	3,822	
POST PROCESSING	0	0	0	75	61	157	397	3,114	0	3,804	
SYST ENGINEERING	54	86	76	24	0	0	0	0	0	240	
MISC & SPARES	0	0	0	16	122	504	656	1,822	0	3,120	
PROJ MGT& SUPPORT	272	374	606	657	590	527	529	500	224	4,279	
OPNS TRAINING	0	12	49	26	0	0	0	0	0	87	
EXPENDITURES	2,655	5,350	11,676	11,472	10,865	12,987	11,448	11,533	2,676	80,661	
CONTINGENCY	N/A	N/A	N/A	N/A	N/A	153	283	116	1.332	1,886	
PERCENT CONT.	0.0	0.0	0.0	0.0	0.0	1.2	2.5	1.0	49.8	2.3	
NEW FUNDS (1989 $)	2,806	9,000	8,552	11,400	11,600	11,800	11,731	11,649	4,008	82,547	
CARRYOVER from prior years						1,340					
PROJECTED carryover from prior years											
OPERATIONS (1989 $)				143	500	900	1,442	3,421	5,214	6,765	('93)

BD72N01
22-Aug-89
VLBA BUDGET AND COST ESTIMATE (Current $)

	1983,4	1985	1986	1987	1988	1989	1990	1991	1992	TOTALS	
INFLATION (%)	0	0	0	0	0	0	4	4	4	4	
ANT STARTS/INSTLS		1/1	3/1	2/2	2/2	2/2	0/2				
SITES	32	194	2,204	1,605	1,171	2,535	1,449	259	11'	9,459	
ARRAY OPNS CTR	0	0	33	19	41	228	2,410	923	388	4,041	
ANTENNAS	1,088	2,460	6,540	5,180	5,090	5,957	1,158	357	169	27,999	
ELECTRONICS	533	1,573	1,652	2,045	1,277	1,611	2,463	1,970	443	13,567	
DATA RECORDING	290	424	4	906	1,242	(27)	1,822	2,583	1,737	8,981	
MONITOR, CONTROL	63	94	316	549	376	621	339	34	10	2,402	
CORRELATOR	322	133	196	370	895	874	621	470	0	3,881	
POST PROCESSING	0	0	0	75	61	157	413	3,368	0	4,074	
SYST ENGINEERING	54	86	76	24	0	0	0	0	0	240	
MISC & SPARES	0	0	0	16	122	504	682	1,971	0	3,295	
PROJ MGT& SUPPORT	272	374	606	657	590	527	550	541	252	4,369	
OPNS TRAINING	0	12	49	26	0	0	0	0	0	87	
EXPENDITURES	2,655	5,350	11,676	11,472	10,865	12,987	11,906	12,474	3,010	82,394	
CONTINGENCY	N/A	N/A	N/A	N/A	N/A	153	294	126	1,499	2,073	
PERCENT CONT.	0.0	0.0	0.0	0.0	0.0	1.2	2.5	1.0	49.8	2.5	
NEW FUNDS, Current $	2,806	9,000	8,552	11,400	11,600	11,800	12,200	12,600	4,509	84,467	
CARRYOVER from prior years						1,340					
PROJECTED carryover from prior years											
OPERATIONS, Current $				143	500	900	1,500	3,700	5,865	7,610	('93)

Schedule Name: VLBA SCHEDULE OVERVIEW
Project Manager: Peter Napier
As of date: 4-Aug-89 3:35pm Schedule File: C:\TLDATA\VLBAOV10

An approximate bar chart keyed to Budget BD72N01



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

Task
Started task
M Milestone

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

TIME LINE Gantt Chart Report

Strip 1

VIII. GREEN BANK TELESCOPE DESIGN AND CONSTRUCTION

Design

The Green Bank Telescope preliminary design work that began in 1989 will continue into the early months of 1990. The preliminary design and major design details will be determined following the late 1989 completion of mechanical and electromagnetic studies of the antenna structure. The final in-house design and development of the antenna systems specifications will be completed in early to mid-1990. These task will be performed in parallel with the preparation of the antenna bid documents.

Currently, it appears that the final engineering design, fabrication, shipping, and erection will be bid as a single procurement and will be purchased under one contract. There are multiple advantages to this approach, among them the provision of a single point source of responsibility for antenna design and performance, a reduced dilution of liability, an increased efficiency in contract administration, and a potential for savings in both the contract costs and the final delivery schedule of the complete antenna. The proposal and bidding process will require close and timely communication between NRAO and NSF. A successful completion of the process will lead to an antenna contract in late 1990.

Development of the Green Bank Telescope instrumentation, control and monitor systems, and data processing systems will also proceed throughout 1990. Due to the nature of this work and its place in the overall project schedule, a gradual but deliberate buildup of activity in these areas is appropriate. These tasks will be well underway by the end of the year.

<u>Budget</u>

The 1990 Green Bank Telescope budget requires commitment of approximately $5,580,000, as shown in Table IX.

The major commitment in 1990 will be for contract charges (estimated at approximately $3,500,000) for the antenna design phase. These design services will include the analysis, design, and documentation of the structure, as well as other critical components of the antenna system (servo, encoder, gearboxes, etc.).

Other 1990 budget items include approximately $835,000 for salaries, wages, and benefits, $670,000 for materials and other services, and $70,000 for travel. The early stages of the project will be fairly travel intensive due to the need to visit antenna manufacturers and other component suppliers to investigate the state-of-the art.

<u>Personnel</u>

The NRAO will move quickly to bring the necessary personnel onto the Green Bank Telescope project to get it moving on schedule. The current plan shows a total of 16 people dedicated to the project by the end of 1990. A total of 171 man-months of effort will be applied to the project by this staff. Further, other Observatory staff members will participate in the Green Bank Telescope on an as-needed basis.

IX. NATIONAL RADIO ASTRONOMY OBSERVATORY
CY 1990 PRELIMINARY FINANCIAL PLAN
($ in thousands)

	New Funds*	Uncomm. Funds Carried Over from 1989	Total Available for Commitments	Commitments Carried Over from 1989	Total Available for Expenditures
Operations					
Personnel Compensation	$ 11,198		$ 11,198		$ 11,198
Personnel Benefits	3,080		3,080		3,080
Travel	454		454		454
Material & Supply	5,108		5,108	$ 200	5,308
Management Fee	480		480		480
Common Cost Recovery	(200)		(200)		(200)
Total: Operations	$ 20,120		$ 20,120	$ 200	$ 20,320
Equipment					
Research Equipment	0	$ 350	$ 350	$ 50	$ 400
Operating Equipment	0	0	0	0	0
Total Equipment	0	$ 350	$ 350	$ 50	$ 400
Total: Operating & Equipment	$ 20,120	$ 350	$ 20,470	$ 250	$ 20,720
Design & Construction					
VLBA Construction	$ 11,900	$ 200	$ 12,100	$ 3,200	$ 15,300
GBT Design	5,580	100	5,680		5,680
USNO Interferometer		800	800	100	900
Total: Design & Construction	$ 17,480	$ 1,100	$ 18,580	$ 3,300	$ 21,880
TOTAL PLAN	$ 37,600	$ 1,450	$ 39,050	$ 3,550	$ 42,600

*Includes USNO funds $810k and NSF funds $31,210k (excluding GBT).

APPENDIX A

NRAO SCIENTIFIC ACTIVITIES FOR THE YEAR 1990

The NRAO permanent staff will investigate a number of topics in a variety of research areas during 1990, as described below. Visiting scientists will collaborate in some of this research.

A. GALACTIC STUDIES

The Sun and the Solar System

Imaging of the sun by synthesis techniques continues to be important. Preliminary VLBI observations with VLBA and VLA antennas have been started to detect compact emission from solar flares. To date, no clear detections of such flares have been reported, and the VLBA antennas provide excellent tools for such a study. Some initial data have been obtained during 1989 August during a flare, but is not yet correlated. More data will be obtained during the coming year.

The VLA will be used to determine the magnetic field configuration and density of the solar wind at low elongations of a few solar radii. The Crab pulsar will be monitored in both rotation measure and dispersion measure as it passes close behind the Sun. Comparison of these two quantities will yield information on both the small and large-scale fluctuations in the magnetic field and density of the solar wind.

The confirmation of the existence of coherent radiation in the scattering disks in Interplanetary Scintillation when observed with short time integrations (10 ms) has been confirmed, using the VLA. An investigation will be undertaken of the possibility of using the properties of the scattered radiation to determine the structure of background objects. For example, since a point source leads to scattered radiation which is completely coherent, one may be able to use the observed lack of coherence of the scattered radiation to deduce the structure of the background object.

Stars and Their Environment

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

FU Orionis stars are eruptive variables that appear to be closely related to the young T Tauri stars. Current evidence suggests that they are surrounded by an accretion disk which may be the source of the material that fuels the eruption. All of the FU Ori variables identified to date are surrounded by ring nebulae which may have resulted from the stellar wind from a central object. One of these rings has been detected in CO, a result interpreted in terms of a wind-driven shell. Observations of various molecular transitions will be made of the other stars in an effort to infer the amount of energy the stellar winds are transferring to the ring nebulae.

Wolf-Rayet stars are targets of both continuum and line studies. Preliminary analysis of VLA observations of the Wolf-Rayet star Gamma Vel reveals that the star has been resolved at all wavelengths between 20 and 1.3 cm, and that the effective temperature of the disk is about 7500 K. However, careful calibration of the fluxes shows that the spectrum rises towards shorter wavelengths more rapidly than expected for an isothermal wind expanding with constant velocity. An attempt to model the spectrum in terms of changes in temperature and ionization level will be made.

Maps of the CO (1-0) emission near three ring nebulae surrounding WR stars have been completed. Analysis is in progress which attempts to identify the CO associated with the nebulae themselves, so as to measure certain of the properties of the stellar mass loss. The process is severely hampered by the contamination of the ambient CO that occurs at these low galactic latitudes.

X-ray binaries are another important object. Systematic investigations are underway of the coupling between radio emission in the form of variable components and jets and accretion disk environments in X-ray binaries. This includes VLA radio spectrum studies of radio jets that vary as a function of binary phase, multi-wavelength studies of changes in X-ray states where the radio and X-ray emission are coupled on time scales as short as minutes, and radio observations of X-ray transients (like GS 2000+25 and V404 Cyg) detected by X-ray, all-sky monitors. Computations are planned of the distortion effects in non-symmetrical, relativistic jets in X-ray binaries (this may also be applied to quasars and AGN's). Known effects of rotation and shape distortions, due to differential special relativity effects over non-symmetric objects, will be applied to study the differences between the appearance of radio jets and their true emissivities in their own reference frame.

The X-ray source in Sco X-1 has been studied by monitoring the evolution of the triple radio source over the last five years with the VLA. The core of the triple source is coincident with a strong X-ray binary star system. The two lobes are moving radially away from the core at a velocity of 36 km/s. VLBI data has been obtained at 18 cm of the three components and reductions are now in progress. Improvements of the images of these very faint components are planned using the new software in AIPS for MkIII reductions.

Moving along the stellar evolutionary sequence, several spectral-line studies of evolved stars, in particular of those possessing circumstellar envelopes, are planned. Single-dish studies of SiO masers at millimeter wavelengths are planned in late-type red giant stars. The nature of these masers is largely unknown. Although the velocity structure of total-power line profiles appears chaotic, polarization studies in recent years have shown a fair degree of orderliness. The advent of the new Hybrid Spectrometer at the 12-meter telescope opens the possibility of a new polarimetry capability, since this instrument is able to operate as a correlation polarimeter. Several VLBI studies of maser emission in the shells surrounding evolved stars are also planned. MkIII VLBI spectral line polarization observations of OH masers in supergiant stars are already in hand, and analysis will proceed. Multiple-epoch VLBI observations of water masers in a few giant stars have also been taken, and these will be imaged and a study of the properties of variability will be done. A monitoring experiment on OH masers using one of the VLBA antennas is planned, the goal being a search for evidence of extreme scattering events in these objects. Finally, a collaborative effort with Australian and Japanese groups will obtain VLBI observations of methanol and SiO masers.

In pre-planetary nebulae, such as IRC 10216, many molecules are created by chemical reactions in the outer envelope, where dissociation by

UV radiation creates a reservoir of ions and radicals. SiC_2 is thought to be such a molecule. A synthesis map of its distribution in IRC 10216, for comparison with a predecessor molecule--SiS mapped at OVRO--will be obtained.

Several studies of planetary nebulae, the next step in evolution, are planned. An important object is NGC 7009, which has been subject to detailed calculations of its density distribution of ionized gas based upon optical observations. To determine the density in this way, assumptions about the velocity of gas in the nebula must be made, along with the use of radial velocity images. To check these important techniques, the density distribution will be calculated independently from VLA 3.6-cm radio images, using tomographic techniques.

Analysis of multi-epoch VLA observations of six planetary nebulae spread over a baseline of five years will be undertaken to measure nebular expansion. These results coupled with optical radial velocity measurements will be used to calculate the distances to these objects.

A survey of CO emission in southern planetary nebulae has revealed a number of new sources. The kinematics of the neutral circumnebular material will be examined for clues to the origin of the bipolar character of many of the visible nebulae.

Studies of novae ejecta are planned, using a combination of radio nova light curves and measurements of images or 2-dimensional visibility functions near or after maximum. The same models used to fit these data will be modified also to fit and describe the optical and infrared light curves and nebular spectra of the same nova ejecta.

A broad program of the study of radio supernovae will continue. In addition to monitoring the radio supernovae SN1979C, SN1980K, and SN1986J, investigations of newly discovered optical supernovae will be made for radio emission.

Thirty-five pulsars were earlier observed at three epochs: 1984, 1986, and 1988, in order to derive radio positions. Results to date show that proper motion accuracies of 0.02" per year are being achieved. The relative motions of the pulsars are determined by comparing their positions with other background quasar radio sources in the same fields, at 20-cm wavelength. The detailed reduction of this project will continue with further refinements.

Neutron stars and black holes attract infall of layers of X-ray emitting gas. The X-radiation is time variable. Using X-ray archive data and a model for the X-ray light curves based upon the spreading infall of gas onto such objects, interpretations of the X-ray light curves of X-ray transients in such objects will be undertaken.

The proper motions of stars will be studied using VLBI techniques, giving a strong improvement over optical techniques. This is made possible by the recent detection of continuum emission from several nearby dMe stars. Millisecond accurate positions can be obtained by comparing the position of the stars with nearby quasars and, over a period of time, accurate proper motions and parallaxes can be determined. Data from several of these experiments will be reduced in AIPS and compared with that of other systems. Besides determining properties of the stars (which can lead to much better astrometric information and distance scales than is possible by optical techniques alone), the VLBI approach provides a good test of the software in AIPS to be used for the VLBA.

Massive stars affect the interstellar medium over ranges much greater than those considered in the projects described so far. In particular, they produce giant HII regions and heat the dust out to large distances. An investigation into the characteristics of heated galactic dust clouds in star-forming regions will be undertaken, using new observations of the continuum emission from the heated dust and observations already made with the IRAM 30-meter telescope. The most accurate method of determining column and even volume densities of the heated gas is by measuring the opacity of the heated dust at millimeter and sub-millimeter wavelengths. Therefore, millimeter-wave maps of these clouds can reveal the physical characteristics of the star-forming regions when combined with far-IR observations made with IRAS.

It is also of interest to investigate the column densities as deduced from molecular emission in these regions. Although molecules give uncertain estimates of the gas column densities because of the difficulties of separating excitation, chemistry, and density effects, it is important to compare these densities with those given by the dust opacities to determine the reliability of the molecular probes. It is hoped to use new observations of the isotopic emission lines of CS to make such a comparison. These data should also reveal the thermal coupling between the gas and dust in the dust clouds.

In light of the newly detected masering radio recombination lines from MWC 349, further investigations of millimeter-wave recombination lines will be made. Of particular interest is the question of whether or not the level populations of atomic hydrogen are sensitive to variations in the UV emission from the stars exciting HII regions and extended stellar atmospheres. This work involves analysis of data now in hand and new observations to be made with the 12-meter telescope.

The small-scale spatial structures of the interstellar medium are well-studied by synthesis maps of neutral hydrogen seen in absorption toward large HII regions. Reduction of VLA data of this type obtained toward the giant HII region complex W43 is planned. Detailed comparisons of the HI and CO distributions should be possible, providing improved estimates of the HI contents and history of molecular clouds.

Studies of the Galaxy

Several large-scale studies of the Milky Way or of its constituents are planned. One is the structure of the neutral galactic halo. We now know that there are significant, though not overwhelming, amounts of neutral material far from the galactic plane. Two questions will be addressed: How did this gas get to such an altitude; and what are its gross morphological properties--i.e., is it in large clouds or a more diffuse drizzle. It has always been assumed that the HI needs some nonthermal support (cosmic rays or magnetic pressure) in addition to the kinetic energy of the clouds to account for the thickness of the HI layer. This argument may need revision, however, for past estimates of the kinetic energy of the HI have used highly indirect estimates of the relevant velocities. This problem will be examined anew, using new HI data and a more modern model for the galactic gravitational potential.

Another global problem is that of the distribution of galactic HII regions. This problem will be re-examined using data from a recently completed new recombination line survey. The key questions here are the extent of confinement of the HII regions to a spiral pattern, and the implications of nebulae with large non-circular velocities. Some additional observations will have to be made in particularly interesting directions, but most of the data are already in hand.

The third large-scale problem is the study of the high galactic latitude cirrus clouds. These clouds have recently been recognized to contain surprisingly dense cores, cores which are gravitationally unstable and which will therefore form stars. It appears that the rate at which they will do so will greatly exacerbate the already difficult problem of why the formation rate of stars in cloud cores capable of forming them is so much lower than the observed rate of star formation throughout the galaxy. Studies of the cirrus cloud cores have been made in several molecules (CO, NH_3, H_2CO, C_3H_2 and others) to understand both the physical conditions and the chemistry. Analysis of these data will continue for what is now a large survey of 56 such cores. In these, the chemistry appears to be deficient, and the current, most likely explanation is that the metallicity in them is low. Systematic maps of several nearby (<100 pc) cirrus clouds will be made in the 6-cm line of H_2CO, which has been established as the best probe for the existence of dense cores. This study will provide the best picture of the small-scale structure of molecular clouds yet available.

The Galactic Center continues to occupy concerted research. Extensive surveys of CO have been made in the Sgr A, B, C, and D source complex. This data will be analyzed. The maps of Sgr A and Sgr C are sufficient complete to allow detailed comparisons between the CO and continuum. A long-term program to monitor the proper motion of the Sgr A source will continue. To date the results have been consistent with a source at rest at the center of the Galaxy. Finally, the Galactic Center remains the test-bed for various theories of nucleosynthesis. Many such theories predict such elements as ^{7}Li and ^{11}B to be greatly overabundant in the Galactic Center as a result of an early active phase. A search for ^{7}Li has been unsuccessful, and analysis of this result is planned. A search for ^{11}B will be made.

Regions of incipient star formation throughout the Galaxy are the subject of continuing studies. Such regions may be largely in the form of very cold dust, until recently undetectable, or may at a later stage of evolution be manifested by water vapor or hydroxyl masers. From studies of galaxies it has been recognized that the dust emission mapped by IRAS excluded a sizable mass of cold dust. Is this cold dust associated with star-forming clouds or with relatively inactive components of the interstellar medium? Studies of temperature sensitive molecules such has DCO^+ have identified several cold cores in the rho Oph molecular complex which have not yet been warmed by nearby stars, and which are largely undetected by IRAS. These cold cores should show up strongly at wavelengths longer than 100 μm. Photometry of the cores at 350 μm is planned. This should provide better mass estimates and aid in understanding the structure of these pre-stellar objects. One such core, L1689S, is very dense (10^6 cm^3) and recent VLA observations show a 2-cm radio source in its center whose spectrum rises toward higher frequencies. Higher resolution VLA observations are planned to prove that this object is not a self-luminous star, as seems unlikely by the IRAS results. Another cold core undetected by IRAS is L1689N, which will also be studied using the OVRO interferometer. A third such core in Ophiuchis, B1, exhibits two peculiar rotating elongated structures not associated with IR sources, which appear to inhibit star formation owing to excessive angular momentum. Observations with the BIMA interferometer are planned to understand this object further.

The massive star-forming region OMC1-KL will be mapped to determine densities and velocities on few arcsecond scales. Maps of several relatively optically thin transitions of H_2CO, obtained with the VLA and BIMA instruments, will be combined in this project. A comprehensive HI emission survey is also planned for the Orion region, to help determine the interactions and interrelations between molecular and atomic gas there. Previous HI surveys are inadequate for this purpose.

A fully sampled, large-scale (30 sq. deg) survey of the first quadrant of the galaxy for water maser emission is well underway, and will be completed. Since such masers are a sign post of star formation, it is anticipated that the numerous previously unknown and weak maser sources found so far will give information as to how star formation is distributed within the Milky Way in a global sense, and within large regions of star formation as well. Several monitoring programs are also underway to observe variations on a monthly basis in either the strength or the velocity of water maser emission associated with IRAS stars, and also from water and ammonia masers associated with galactic HII regions.

Interstellar Molecules and Astrochemistry

Mass loss from super-Li-rich stars has been suggested as a viable source of ^7Li in the interstellar medium, explaining its abundance which is observed to be considerably in excess of the primordial abundance predicted from the big bang. Searches for CO in four super-Li-rich stars in the Northern Hemisphere have yielded two detections, and hence a measure of their mass loss rates. Further objects will be searched in the Southern Hemisphere using the SEST millimeter wave telescope. Current indications are that the mass loss rates are not exceptional for these stars, and hence they are not a viable source of interstellar ^7Li.

An analysis of the NRAO 3-mm spectral survey of Sgr 2B2 and Ori(KL) is underway. This survey detects more than twice as many lines as previous ones. Preliminary results indicate that several of the most complex known interstellar species (CH_3OHCO, $(CH_3)_2O$, CH_3CHO, EtOH, VyCN, EtCN) have much greater abundances than previously thought and will pose challenges to current models for their synthesis. In addition, many observed transitions observed in this and previous surveys and attributed to well-known species appear to be misidentified, so that the number of U-lines may be considerably greater than previously recognized.

The K-band (18-21 GHz) spectral survey undertaken in collaboration with the U. Mass group, is being prepared for publication. The spectral survey of IRC 10216 in the 220-280 and 335-365 GHz regions, undertaken in collaboration with the Herzberg Institute of Astrophysics on the JCMT telescope, will be continued. This latter survey has been granted "long-term status" at the JCMT.

Based on observation of several interstellar phosphorus compounds, a picture of interstellar phosphorus and silicon chemistry has been constructed for dense molecular clouds, utilizing recent laboratory results for the chemistry of these elements. This picture establishes a depletion factor of 1000 for both P and Si in dense clouds and predicts the same for Mg. Efforts to understand Mg ion-molecule chemistry will be undertaken in the laboratory (York University). Identified Mg compounds will subsequently be studied by microwave spectroscopy to facilitate astronomical searches. It is predicted that such compounds will be detectable.

Tentative detections of the first doubly deuterated compounds D_2CO and NHD_2 have been made in interstellar sources. Confirmation will be undertaken. Such compounds test the role of grain processes in the interstellar chemistry of dense clouds.

A likely detection of protonated cyanoacetylene (HC_3NH^+) has been made in the interstellar source DR21OH. Confirmation is planned. The tentative detection gives a ratio HC_3NH+/HC_3N as expected by chemical models, in contrast to HCNH+/HCN which is observed to be ten times too large in SgrB2. Analysis of these ratios in the context of chemical schemes for the synthesis of the important cyanopolyyne family of interstellar molecules will continue.

Searches for several species, newly analyzed in the laboratory, will be made. One is protonated SiO ($SiOH^+$). Current understanding of Si ion-molecule chemistry indicates that this species will be detectable. Another such species is NaO. Little is known of the interstellar chemistry of Na, but arguments indicate that NaO may be the prevalent species.

A tentative detection of the hydronium ion (protonated H_2O, or H_3O^+) has been made by observing a second transition at 364 GHz in SgrB2. The transition at 307 GHz was earlier detected in this source. It is hoped to search for the two remaining accessible lines at 388 and 396 GHz during the next year, using a JPL receiver on the KAO.

A tentative detection of the CH_2 radical will be followed up at the 12-meter telescope and possibly at Nobeyama early next year.

A number of unsuccessful searches for several compounds will be analyzed. Calcium compounds such as CaOH were not detected in circumstellar envelopes despite predictions to the contrary, based on thermochemical equilibrium models. Such models satisfactorily accounted for other observed refractory compounds such as NaCL, KCℓ, AℓCℓ, and AℓF. CaH was not detected in interstellar sources, but little is known of what Ca compounds to expect in these objects. The vinoxy radical (CH_2CHO) was not detected in interstellar sources. This radical is a second good test of Bates' theory of dissociative electron recombination, a process central to ion molecule chemistry of the ISM. The negative result is in fact predicted by one form of the theory. Protonated HCℓ ($H_2C\ell^+$) was not detected in interstellar sources. This species tests current ion-molecule chemistry models of interstellar chlorine chemistry, and was predicted to be at best marginally detectable. Finally, the dimeric species were unsuccessfully searched, including the acetylene dimer $(HCCH)_2$ and the HCN dimer $(HCN)_2$. These dimers are argued to be the most abundant such species, and hence the negative searches establish the best limits on molecule formation processes on grains, which are necessary for the production of dimers.

EXTRAGALACTIC STUDIES

Normal Galaxies

Studies of normal galaxies involve surveys, which attack global problems of these objects, and specific studies of individual galaxies, usually nearby, with the aim of addressing specific questions. We summarize the survey projects first.

The largest survey project ever undertaken at NRAO, namely the 6-cm continuum survey of the sky between declination 0 and 75 degrees (observed with the 300-foot telescope), will be expanded to cover the declination range -45 to 5 degrees using the 140-foot telescope. The resulting maps should have rms noise 12 mJy, rms confusion ~4 mJy, and contain some 15,000 sources stronger than 60 mJy. A total of five-sixth of the celestial sphere will then be covered. A list of the 60,000 discrete sources stronger than 25 mJy from the northern sky (300-foot survey) is in preparation and should be completed early next year.

The 6-cm sky maps have been used to find candidate radio identifications of all UGC galaxies and of all extragalactic sources in the new IRAS Faint Source Catalog in the declination range 5 to 75 degrees. There are about 500 candidates stronger than 25 mJy, of which about half lack aperture synthesis maps and will be observed with the VLA. The confirmed identifications of UGC galaxies will be used to construct independent radio luminosity functions of steep and flat spectrum sources, and these luminosity functions will be used to model cosmological evolution and fit the counts of faint sources (< 0.1 mJy) found in deep VLA maps made at 6 cm. The radio identifications of infrared sources should find nearby "hidden" active galactic nuclei effectively.

A 1.49 GHz atlas of the IRAS Bright Galaxy Sample is nearly complete. The VLA was used in all configurations to map the 330 strongest extragalactic infrared sources. Since their infrared and radio continuum brightness distributions appear to be similar, these high-resolution radio maps can be used as substitutes for the unavailable infrared maps to indicate sizes and precise locations of the infrared emitting regions. The data will be used to study the infrared radio luminosity correlation, distinguish infrared sources heated by starbursts from those powered by compact massive objects, and as inputs for quantitative models describing the evolution of extremely luminous starbursts. Preliminary models based on the infrared and radio continuum data indicate a nearly "universal" initial mass function for these starbursts. Extremely luminous infrared sources ($L > 10^{11}$ Lo) appear to be the most compact (typically $D < 1$ kpc), so these will be mapped with 0.3 arcsec resolution at 8.4 GHz with the VLA. Many of these sources arise in the most intense starbursts known, and they should reveal the processes which limit star formation and ultimately disrupt the star-forming regions.

The VLA survey of nearby E/SO galaxies, carried out in recent years, has yielded many new 6-cm sources deep in these galaxies' nuclei. Current studies are using matched resolution VLA data at 20 cm to establish which galaxies have flat-spectrum cores that are signposts of active nuclei. Such cores may in turn imply the presence of massive black holes in these nearby galaxies.

The 6-cm survey just described involved about 200 points at high galactic latitude and widely separated on the sky. A subset of these images has been searched for background sources at millijansky levels to get new, accurate differential source counts. These new counts are significantly steeper than those at sub-millijansky levels, supporting the emergence of a new population at those lower levels which has been reported recently by others.

Surveys to study the interstellar matter in early type galaxies are also being conducted. The morphological transitions from no disk component (E) to a well defined disk component in the presence of a significant bulge (S0), and on to a similar case with spiral structure (Sa) are in the sample of galaxies under study. Cold (HI, CO, dust), warm (ionized), and hot (X-ray) states of the ISM are included in this analysis. Observations at radio, optical, and X-ray wavelengths are planned. For the last, a proposal for ROSAT time has been submitted. The goal of this work is to understand the origin and fate of such ISM; to search for possible relationships to global properties of the host galaxy; and ultimately to understand why a disk system has cold ISM while a pure non-disk system appears to have such material only if captured. The reverse appears to be the case for the hot ISM.

Basic global properties of a galaxy such as mass, density, angular momentum, and surface brightness are described by two fundamental parameters: size (radius) and rotational velocity (or for some systems, dispersion). These define an R-V plane in which spirals occupy only a small region, i.e., the range of these variables is confined and must clearly reflect initial conditions and possible environmental influences (e.g., tidal truncation and tidal torquing). An extensive R-V data set based on 20-cm measurements and optical diameters is being analyzed. The analysis will be extended to clusters to see if a denser environment changes the R-V relationship. Since both R and V are distance dependent (the latter through the Tully-Fisher relationship), such data may be useful in determining cluster membership and thus yield a more accurate cluster virial mass.

Observations of galaxies in the ultraviolet, 1200-3000 A range, are planned with the imaging telescope of the ASTRO Spacelab mission scheduled for a shuttle flight in April 1990. Several of the experiments during this flight are related to the projects described in the previous two paragraphs. Extensive and unique u-v imagery will be available for analysis. The data cover such diverse areas as searches for low surface brightness galaxies and for white dwarfs in globular clusters.

Extensive spectroscopic and photometric studies of galaxies having double nuclei have been made recently by others. It is planned to map a representative sample of these at the VLA to gain insight into the manner in which interaction affects nuclear activity.

Molecular line studies continue to be important in understanding the ISM of other galaxies. There is currently great interest in the question of the gas and dust content of elliptical and lenticular galaxies. The interest is stimulated in part by the demonstration, through the detection of strong X-ray emission from at least some ellipticals, that such galaxies have large amounts of hot interstellar matter. Interest also stems from the increasingly popular suggestion that many, if not most, early systems are the product of galaxy interaction or merger. Data about the gas content of these galaxies may yield information about the nature of star formation, about the nature of the cooling of the hot gas, and about evidence of a recent interaction (for example, plumes or filaments). A catalog of data from the literature is being prepared, and will be completed. This data base will be supplemented by additional observations of neutral hydrogen and CO in selected galaxies.

Maps taken some time ago of HI and CO in several Seyfert galaxies will be prepared for publication during the coming year, using software which has finally been developed for the purpose.

Several continuum studies aimed at specific galaxies are planned. The 3.6-cm strength of the unresolved radio core of the triple in the Seyfert 1 galaxy NGC 5548 will be monitored. This core is strong enough to detect variability at the level of a few tenths of percent. These radio variability data are being taken as part of an international monitoring effort in conjunction with intensive IUE monitoring. Also, all the radio data will be combined to yield a single, very sensitive image that can be compared with optical images of the extended narrow line region to test excitation models for the emission line gas. Other continuum studies involve the normal spiral galaxies M51, NGC 3504, NGC 5005, NGC 5033, and NGC 5055; the radio nucleus of the normal spiral M81; and several active galaxies (NGC 2911, NGC 3198, NGC 3227, and NGC 4258).

Line studies will also be made in specific galaxies. HI observations with the VLA are planned for the barred spiral galaxy NGC 6764. These will be combined with IRAM and UKIRT observations, allowing the determination of the atomic and molecular distributions along the bar of this galaxy. Interferometric observations will also be made of CO. Among the CO detections of S0 galaxies already reported is that of NGC 4710, known to show radio and far-IR evidence for current star formation. The CO will be imaged with the OVRO interferometer to see if the radio continuum is embedded in the cool gases and if the CO velocity field shows counter-rotation relative to the galaxy's stars, suggesting external capture of the cool gas. Pilot observations have already been made for a large-scale CO survey of our nearest neighbor, M31. Analysis of these data will proceed. Finally, another attempt will be made to map the core of Centaurus A in CO at the JCMT telescope.

Radio Galaxies and Quasars

As with normal galaxies, research in this area tends to divide into that concerned with surveys and that addressed to specific sources or to specific types of structures (jets, twists, halos, etc). In addition, there are the problems of the superluminal sources and of time variations.

The long-term monitoring of the premier superluminal source, 3C 120, will continue. 3C 120 has been observed three times per year since 1982, using the US and European VLBI Networks. Thus far, trajectories have been measured of five superluminal components, and it appears that a new component is emitted at a nearly annual rate. A very large VLBI run on 3C 120 will occur in the fall of 1989, involving over 20 observatories in the US and Europe. This will be the second "World Radio Array" (WRA) experiment, the first being in 1984. The WRA will observe at 20 cm and provide more short baselines than is usual. It will allow the detection of structures larger than the super-luminal knots, but smaller than the jet structures observed by the VLA. It is hoped to resolve motions in this intermediate region of the 3C 120 radio jet. Confirmation of the observed superluminal motions is highly important because such would indicate that the large-scale, powerful radio jets are in fact relativistic.

Another monitoring program is planned to follow the structural changes in the superluminal object 3C 345, in collaboration with CIT. This will follow the evolution of the youngest superluminal components discovered during recent observations. Of primary interest here are the trajectories of components which seem to be markedly different in the immediate vicinity of the central core. Other collaborations with Sao Paulo will continue VLBI study of the quasars 3C 273 and 3C 279, both archetypical superluminal sources. VLBI observations will continue on yet other superluminal objects, particularly NGC 1275, the lobe dominated radio galaxies 3C 111 and 3C 390.3, and the enigmatic quasars 2134+00 and 3C 454.3. The statistics of observed component motions in quasars and radio galaxies is being examined with the goal of trying to understand the apparent overabundance of observed superluminal motion compared with the predictions of conventional (i.e., beaming) as well as non-conventional models. Finally, studies of structural variations of all sorts, but especially superluminal ones, will continue for weak quasar cores, using both the existing VLB network at X-band, and in one *ad hoc* run using NASA's Deep Space Network. The distribution of speeds in samples comprised of such sources provides a direct test of relativistic beaming models and unified schemes.

Time variation studies are also planned using the VLA. The VLA study of "flickering" sources has turned out to be of considerable interest, and a three week monitoring experiment is planned to continue this during re-configuration time at the VLA. This is primarily to study quasi-periodicities in the variation of the quasar 0917+624. Previously, variations of up to 20 percent were found on time scales of about 1.3 days, which are correlated between 2 and 20 cm, with no significant time delay; they are accompanied by polarization changes. There is increasing evidence that this variability is intrinsic, rather than being caused by extrinsic processes as is usually believed. Such variability may well be correlated with optical variations (in several flat spectrum objects), and appears to be a common phenomenon.

A special class of objects receiving much current attention is gravitational lenses. The VLA will be used to examine in further detail several radio sources which earlier observations suggested were promising candidates for gravitational lensing. Particular emphasis will be given to the "clover leaf" configuration quasar H1413+117 which has a similar radio and optical morphology. Lensing models predict time delays among the components which are of the order of a month, so that observations of H1413+117 are especially appropriate as a means of determining the Hubble Constant.

An extensive program to study B3 classical double radio sources in the radio and optical will continue. This study will attempt to extend the knowledge gained from the extensive studies of the 3CR sample to lower flux density levels. Radio mapping of the sample of sources will be completed at 8 GHz to confirm the structural types of the sample and to detect the central components. Using the central component positions, optical identifications of the sample will be completed using deep CCD images from Lowell Observatory. Spectroscopy of the sample at KPNO and IR imaging with the IRTF are also planned for 1990. The long-range goal of the project is to test whether the correlation of radio structure with absolute radio and optical luminosity holds at high redshift and whether the redshift cutoff around 2-3 holds for these fainter sources.

Many observations of the hot spots in a number of double sources have been made with the VLA and the Pie Town VLBA antenna. These observations, at 8 GHz, will give twice the resolution of the VLA in A-configuration and allow detailed comparison at the same resolution with these sources observed at 15 GHz with the VLA. This comparison allows examination of spectral index variations on a scale of about 0.1 arcsecond which helps in understanding electron acceleration and energy loss in the neighborhood of the hot spots. Analysis of these data continues.

Studies of jets continue. The VLA is being used to conduct a critical test of the simple relativistic beaming model for extragalactic radio jets. The internal proper motion of a knot in the asymmetric base of the twin-jet source M84 will be measured. This source is thought to be viewed close to edge-on. If a significantly superluminal knot speed is detected, it will not be explained by the simple beaming model and would cast serious doubt on the model, as Occam's razor demands a single explanation for all superluminal radio jets. The simple twin relativistic jet model also predicts few sub-luminal and asymmetric VLBI sources. Two are already known (3C 84 and 3C 274, both associated with optically bright NGC galaxies), and finding more could cause trouble for the model. Data from a 1989 VLBI experiment on NGC 3894, a nearby E/S0 galaxy, is currently being reduced to determine if it is another example, since a 1981 VLBI image shows asymmetric structure at 6 cm. The 1989 and 1981 VLBI images will be used to measure transverse component speeds. Speeds of only 0.3 c, like those shown by 3C 84 and 3C 274, will be measurable.

Specialized studies are directed at several individual sources. VLA studies of M87 will continue. Observations at 8 GHz are planned to improve the resolution and sensitivity of the images of the filaments in the 2-kpc radio lobes. A full synthesis at 300 MHz is underway. Analysis of 2-cm proper motion results from 1985 and 1989 should be completed during 1990. An extensive set of over 1500 spectra of the H-alpha filaments in M87, obtained in 1989 at the KPNO 4-meter telescope, will be analyzed in 1990.

High resolution polarization studies of several sources will occur. VLBI studies of the polarized structure of the radio galaxy 3C 38 should help determine the structure of the magnetic fields in the jet of this source.

VLA polarimetry of asymmetric VLBI core-jet sources identified with active galaxies and quasars is anticipated. The goal here is to determine accurate rotation measures and intrinsic linear polarization position angles for these time variable sources.

A major VLA study of the radio source Fornax A is now complete and yields a detailed morphology of the filaments, depolarization silhouettes, and galaxy interaction. Detailed analysis of these structures will continue, using the 3-frequency VLA data. Further radio observations (HI) of a dark region in front of the radio lobe will be made to determine if the dark region is in the cluster or in our Galaxy.

Another object of study will be Mkn 501. VLBA and MERLIN data will be acquired to image a dramatic pc-scale twist in the core dominated radio galaxy. This project will serve as a test of the feasibility of doing combined VLBA/MERLIN imaging of sub-arcsecond structures.

VLA/VLBA/MERLIN observations are also planned for a number of sources that should provide a significant increase in the number of calibrators available to all three instruments. The VLA will be used to measure accurate positions for flat spectrum sources from the Green Bank 20 and 6-cm surveys. It will also be determined which of these flat spectrum sources are associated with optically bright galaxies, as such information can be used to form a local radio luminosity function crucial to the interpretation of short-wavelength source counts.

Finally, further study of the extended structure of the QSO PKS0812+020 is planned. Optical spectra are available of gas in the vicinity of the radio jet, and studies of these spectra and of VLA maps of the jet and surrounding regions, will help test theories of the interaction of radio jets with an intra-cluster medium. Analysis of HI maps of the interacting galaxy systems Arp 143 and NGC 2793 will be continued. A program in collaboration with NRL will study the variability of QSO's and active galaxies, using data from the Green Bank interferometer.

There are several survey projects planned for extragalactic sources and fields. An analysis will be made of 150 hours of VLA B, C, and D configuration data at 6 cm to obtain structures and optical identifications on sources as weak as 10 μJy using material obtained with the Palomar 5-meter 4-shooter. VLA observations at 6 cm in the A configuration of the field already observed in B, C, and D configurations will be made to improve the angular resolution to 0.5 arcsec. Analysis will be made of about 100 VLA fields taken in D configuration to obtain information on sources with flux densities in the range 0.5 to 5 mJy. Morphology and optical identifications of a subset of these sources will be examined using material from a KPNO 4-meter deep plate.

Clusters of Galaxies and Cosmological Matters

Measurements of the Sunyaev-Zel'dovich effect will continue. This effect is a distortion of the spectrum of the microwave background due to Inverse-Compton scattering with the hot electrons present in dense clusters of galaxies. At 20 GHz the effect is a decrement in the background radiation temperature of about 1 mK toward the densest and hottest clusters of galaxies. Such small signals have proved hard to detect with single dishes owing to the necessary beam switching methods, so interferometric techniques at higher frequencies, where the effect is stronger, are planned. The BIMA interferometer will be used on the cluster 0016+16 at 86 GHz. Special techniques are being developed to facilitate this, including a tessellating technique to measure the necessary short spacings and the use of CCD cameras installed on each antenna to use stars for offset optical pointing.

Cosmic background fluctuations are important also in deciding the fluctuations inherent in the big bang. This problem is addressed by obtaining extremely sensitive radio continuum observations of "blank" fields. A field of 6x6 arcmin at $\alpha = 14^h$, decl. = 52° has been observed at 6 cm with the VLA. The total integration time is 130 hours and includes the B, C, and D configurations. The radio image has an rms noise of 2.8 μJy with detections of sources above 12 μJy. It is the most sensitive radio image yet made. In 1990 this radio image will be compared with optical images taken with the 4-shooter CCD system at Mt. Palomar, with a limiting detection magnitude of about 28. It is hoped to identify most of the radio sources in the field. It will be the only sample of faint radio sources and galaxies available. Further analysis on Cosmic Background Fluctuations at 6 cm in the angular scale of 3 to 60 arcseconds will also be made from the images. A related project on the CBR fluctuations is planned to obtain limits to the CBR fluctuations between 10 and 60 arcseconds at 8 GHz with the VLA. This frequency is the best one available at the VLA for this experiment because of the low noise HEMT receivers and the fact that the density of confusing sources is much less at 8 GHz than at 5 GHz. Efforts to detect proto-clusters of galaxies through the observation of their redshifted 21-cm emission at a frequency of 333 MHz (z = 3.3) are continuing. The VLA P-band system has been pushed to a sensitivity of better than 3 mJy/synthesized beam for spectral line channels of width 200 kHz. Methods for dealing with interference are proceeding, as is the data analysis of 200 hours of observations already accumulated.

Optical observations of nearby (z = 0.02 to 0.08) dense clusters of galaxies are being made at KPNO, using a tessellating technique to produce wide field pictures from mosaics of CCD frames covering about 12° by 30 arcminutes areas centered on each of three Abell clusters. The goal is to detect diffuse optical light (already measured in Abell 2029 in the R-band) in order to determine the evolutionary history of the clusters through the debris that their formation has left behind. The measurements have achieved a sensitivity of 3×10^{-4} of the night sky level. Special considerations are necessary at these low levels to determine what fraction of the measured diffuse light is scattered light from the central, brightest galaxies in these clusters. V and B band observations will be used to resolve this difficulty.

Cooling flow clusters are of continued importance. Analysis of VLA data on Faraday rotation in the directions of radio sources in cooling flow clusters using 20, 6, and 3.7-cm VLA data will be completed in 1990. Observations to study the Faraday rotation of 3C 75 and 3C 465 with the VLA in order to study magnetic field structures in non-cooling flow clusters should be completed this next year.

A snapshot survey with the VLA at 20 cm of all Abell clusters with measured redshifts less than 0.09 should be completed in 1990. All Abell clusters with radio sources stronger than 200 mJy from the 300-foot 1400 MHz survey will be observed by the end of 1990. Work will continue on a snapshot survey of sources in the direction of Zwicky clusters observed in 1989. A new program for nearby Abell clusters at 300 MHz in the D array to search for very diffuse sources and sources with very steep radio spectra is planned for 1990.

Clusters of galaxies are also being studied at IR wavelengths. Analysis of IRAS data on such clusters is continuing. The impetus is the possible presence of cool material in intracluster space, material perhaps resulting from cooling flows. Extended IRAS radiation may also originate in, and may identify, some of the dark matter known to exist in such clusters.

Finally, major problems of the large-scale structure of the universe and of galaxy evolution may be addressed by the study of the HI line. With it, properties of galaxies will be investigated in a wide range of environments having different galaxian densities, ranging from the Pisces

Perseus Void to the center of the Hydra Cluster. The large-scale structure of the universe as we know it today is based almost entirely on high luminosity, giant galaxies seen at optical wavelengths. It has been acknowledged for some time that the large-scale distribution of dwarf galaxies might be quite different. This issue has become more pressing after huge voids were found that are too large to account for in any conventional theory of galaxy formation. The notion of biased galaxy formation has been introduced, which predicts a separation between luminosity (bright galaxies) and mass (dark matter). Low surface-brightness dwarf galaxies are expected to be more uniformly distributed and should be a better tracer of the mass. So far, however, observational evidence is against a large-scale segregation between giant galaxies and dwarfs, but all surveys have begun with optical catalogues and faint dwarfs are not seen at low brightnesses in such catalogues. A project is planned to search in the HI line with the VLA for a population of low-luminosity dwarf galaxies in the Pisces Perseus supercluster and foreground void by imaging 40 fields. Optical selection effects are therefore avoided, and redshifts will be obtained simultaneously with detections. The results will reveal whether a population of faint HI dwarfs exists with a number density comparable to that of the bright galaxies and what the spatial distribution of such a population is.

The extreme end of galaxian density will be investigated by performing a volume-limited HI survey of the Hydra Cluster of galaxies. This survey is mainly concerned with the effects of the environment on the evolution of galaxies, and it will also give the distribution of dwarfs in a high-density environment. A detailed study will be made of the distribution and kinematics of the HI in the brighter spirals, permitting one to model the interaction with the intra-cluster medium. Rotation curves will be derived from the two-dimensional velocity fields. Combined with high resolution optical data for the inner parts, an ideal data base will be available to investigate statistical differences in the detailed mass distribution of galaxies in clusters versus those in the field.

MISCELLANEOUS

Several scientific programs underway at NRAO are designed to further development of observing techniques, software, or the understanding of systematic effects of the atmosphere and ionosphere upon the reliability of observations, particularly those involving aperture synthesis.

VLBI observations at millimeter wavelengths are technically demanding and the uncertainties in them often poorly understood. Global *ad hoc* observing campaigns are tentatively planned for the technically demanding 7-mm wavelength region in winter 1989/1990 and in late 1990. Observations at this wavelength are now beginning to yield reliable imaging results, and it is hoped to obtain good second epoch images at this wavelength for a half dozen strong sources. Subsequently, the source list will be expanded toward weaker objects. To this end, there are considerations to install a 7-mm receiver at Pie Town.

VLBA-specific requirements for the AIPS system continue to be developed. A fringe rate mapping task is one example of an anticipated development.

A program to study the effects of the turbulent troposphere on radio astronomical imaging will be continued. The study will concentrate on understanding the causes of poor seeing and predicting the onset of bad observing conditions.

Semi-linear methods of image deconvolution are being pursued. Previous improvements to the Steer-Dewdney-Ito method of deconvolution are being reviewed. These improvements have formed the heart of the AIPS program SDCLN, which has been widely used since 1986 October. A multiple resolution method of deconvolution, suggested by several Dutch observers, is also being studied, and will be implemented in AIPS.

Several scientific programs put special emphasis on high dynamic range imaging. For instance, 3C 345 has been observed to better understand the low level structure of this superluminal radio source, and special approaches to its imaging are being undertaken. Work continues on the particularly complex, wide angle source in Cygnus A, with more data being taken at 8.4 GHz and more sophisticated reduction methods being applied, which are expected to better display the jets, and to clarify the rotation measure screen.

Computer imaging has taken several steps forward with the promulgation of the Postscript and X-Windows standards. These standards are under review and the level of impact they should have on the AIPS system is being assessed.

Studies of non-linear coordinate systems in astronomy need to be generalized and extended. The attempt to produce a worldwide consensus on the representation of "World Coordinate Systems" will be continued with this work as a foundation.

Single-dish data analysis and observational techniques continue to be studied and improved. The new multi-feed spectral-line system becoming operational on the 12-meter telescope opens up a range of possible observing strategies and techniques for large-scale mapping. Both theoretical and experimental studies are planned of a number of different observing approaches and data processing schemes, which will be applied to a number of extragalactic objects. The above-mentioned pilot observations of M31 in the CO 1-0 line will serve as a test bed and will be expanded to 2-1 CO observations with the new system.

APPENDIX B

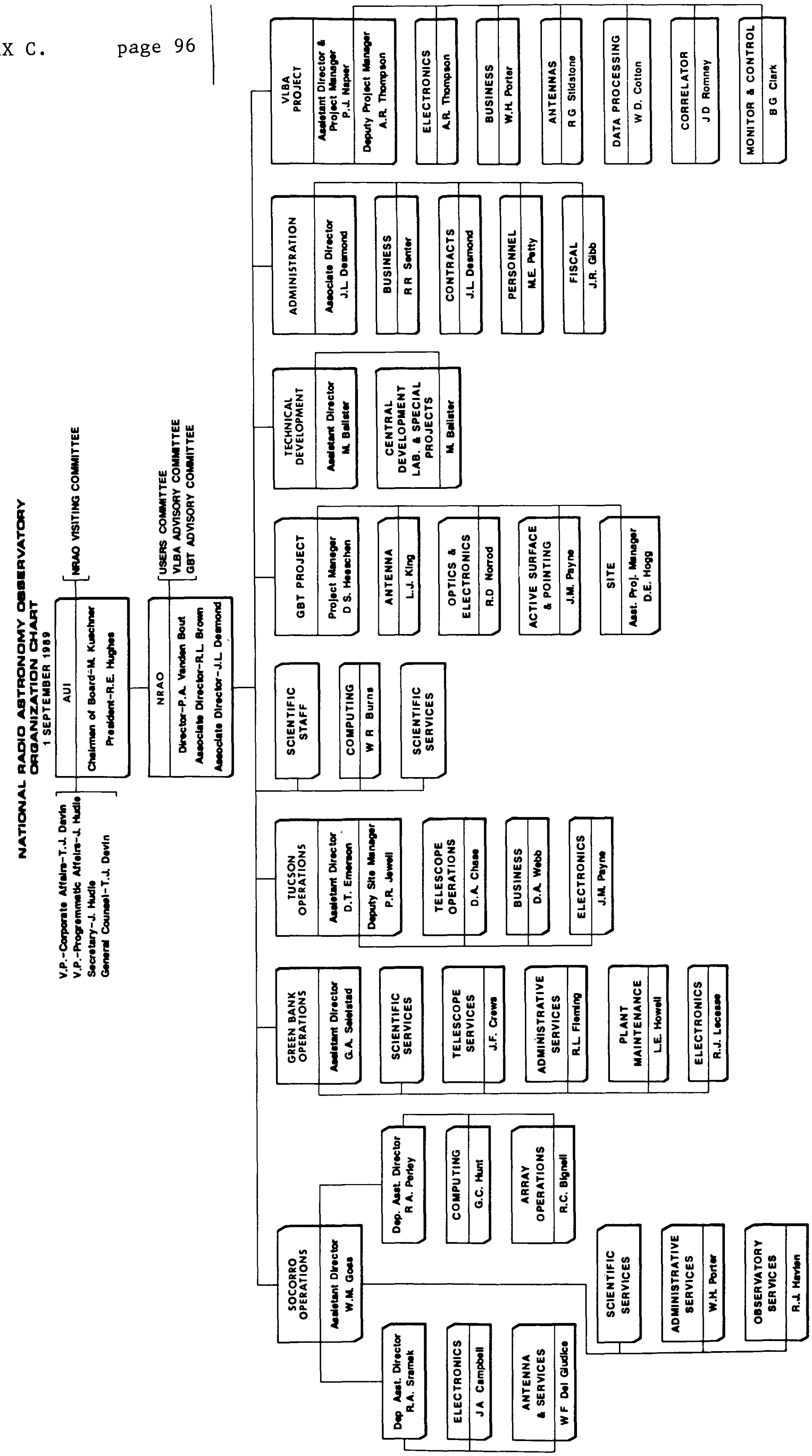
SCIENTIFIC STAFF

(Does not include Visiting Appointments)

T. S. Bastian	SO	Solar/stellar radio physics; radiative processes; plasma astrophysics; particle acceleration; interferometry; image deconvolution and reconstruction
J. M. Benson	CV	Extragalactic radio sources; VLBI image processing
R. C. Bignell	SO	Polarization and imaging of extragalactic radio sources; planetary nebulae; supernovae remnants
A. H. Bridle	CV	Extragalactic radio sources
R. L. Brown	CV	Theoretical astrophysics; interstellar medium; quasar absorption lines
B. G. Clark	SO	VLBA control; software development
J. J. Condon	CV	QSOs; normal galaxies; extragalactic radio sources
T. J. Cornwell	SO	Interferometry; image reconstruction methods; coherence theory; radio-source scintillation
W. D. Cotton	CV	Extragalactic radio sources; interferometry; computational techniques for data analysis
P. C. Crane	SO	Normal galaxies; radio interferometry and aperture synthesis; radio frequency interference
L. R. D'Addario	CV	Theory of synthesis telescopes; superconducting electronics; millimeter wavelength receivers; radio astronomy from space
P. J. Diamond	CV	Spectral line interferometry; VLBI; software development
D. T. Emerson	TU	Nearby galaxies; star-formation regions; millimeter wave instrumentation
J. R. Fisher	GB	Cosmology; signal processing; antenna design
C. Flatters	SO	VLBI polarization studies of extragalactic radio sources

E. B. Fomalont	CV	Interferometry; extragalactic radio sources; relativity tests
F. D. Ghigo	GB	Interacting galaxies; quasars; interferometry
M. A. Gordon	TU	CO; galactic structure; interstellar medium
W. M. Goss	SO	Galactic line studies; pulsars; nearby galaxies
E. W. Greisen	CV	Structure of the interstellar medium; computer analysis of astronomical data
R. J. Havlen	SO	Galactic structure; clusters of galaxies
D. S. Heeschen	CV	Variable radio sources; normal galaxies; QSOs
R. M. Hjellming	SO	Radio stars; X-ray binaries; interstellar medium; millimeter array design and simulation
D. E. Hogg	TU	Radio stars and stellar winds; extragalactic radio sources
P. R. Jewell	TU	Circumstellar shells; interstellar molecules; cometary line emission
W. Junor	SO	Extragalactic radio sources; VLBI
K. I. Kellermann	CV	Radio galaxies; quasars; VLBI
A. R. Kerr	CV	Millimeter wave development
J. W. Lamb	TU	Millimeter wave instrumentation
J. P. Leahy	SO	Extragalactic radio sources
H. S. Liszt	CV	Molecular lines; galactic structure
F. J. Lockman	CV	Galactic structure; interstellar medium; HII regions
R. J. Maddalena	GB	Molecular clouds; galactic structure; interstellar medium
P. J. Napier	SO	Antenna and instrumentation systems for radio astronomy
F. N. Owen	SO	Clusters of galaxies; QSOs; radio stars
S. K. Pan	CV	Development of millimeter wave devices
J. M. Payne	TU	Telescope optics; millimeter-wave receivers; cryogenic systems

R. A. Perley	SO	Radio galaxies; QSOs; interferometer techniques
M. Pospieszalski	CV	Low noise front-ends and amplifiers; theory and measurement of noise in electronic devices and circuits
M. S. Roberts	CV	Properties and kinematics of galaxies
J. D. Romney	CV	Active extragalactic radio sources; VLBI; interferometer imaging
A. H. Rots	SO	Nearby galaxies; spectral line interferometry; data display techniques
G. A. Seielstad	GB	Quasars; active galaxies; VLBI
R. A. Sramek	SO	Normal galaxies; quasars; astrometry
A. R. Thompson	CV	Interferometry; frequency coordination and atmospheric effects; distant extragalactic sources
B. E. Turner	CV	Galactic and extragalactic interstellar molecules; interstellar chemistry; galactic structure
J. M. Uson	SO	Clusters of galaxies; cosmology
P. A. Vanden Bout	CV	Interstellar medium; molecular clouds; star formation
J. H. van Gorkom	SO	Galactic center; nearby galaxies; clusters of galaxies; spectral line interferometry
C. M. Wade	SO	Astrometry; stellar radio emission; minor planets; extragalactic radio sources; VLBA development
R. C. Walker	SO	Extragalactic radio sources; VLBI; VLBA development
D. C. Wells	CV	Digital imaging processing; extragalactic research
A. H. Wootten	CV	Star formation; structure, spectroscopy and chemistry of the interstellar medium in galaxies; circumstellar material
J. Wrobel	SO	Normal galaxies; active galaxies; polarimetry
A. Zensus	SO	VLBI observations of quasars and active nuclei; superluminal motion in compact radio sources


NATIONAL RADIO ASTRONOMY OBSERVATORY
ORGANIZATION CHART
1 SEPTEMBER 1989
V.P.-Corporate Affairs-T.J. Devin
V.P.-Programmatic Affairs-J. Hudie
Secretary-J. Hudie
General Counsel-T.J. Devin
AUI
Chairman of Board-M. Kuschner
President-R.E. Hughes
NRAO VISITING COMMITTEE
NRAO
Director-P.A. Vanden Bout
Associate Director-R.L. Brown
Associate Director-J.L. Desmond
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VLBA ADVISORY COMMITTEE
GBT ADVISORY COMMITTEE
VLBA PROJECT
Assistant Director & Project Manager P.J. Napier
Deputy Project Manager A.R. Thompson
ELECTRONICS A.R. Thompson
BUSINESS W.H. Porter
ANTENNAS R G Stidstone
DATA PROCESSING W D. Cotton
CORRELATOR J D Romney
MONITOR & CONTROL B G Clark
ADMINISTRATION
Associate Director J.L. Desmond
BUSINESS R R Senter
CONTRACTS J.L. Desmond
PERSONNEL M.E. Petty
FISCAL J.R. Gibb
TECHNICAL DEVELOPMENT
Assistant Director M. Balister
CENTRAL DEVELOPMENT LAB. & SPECIAL PROJECTS
M. Balister
GBT PROJECT
Project Manager D S. Heeschen
ANTENNA L.J. King
OPTICS & ELECTRONICS R.D Norrod
ACTIVE SURFACE & POINTING J.M. Payne
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SCIENTIFIC SERVICES
TUCSON OPERATIONS
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Assistant Director G.A. Seielstad
SCIENTIFIC SERVICES
TELESCOPE SERVICES J.F. Crews
ADMINISTRATIVE SERVICES R.L. Fleming
PLANT MAINTENANCE L.E. Howell
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SOCORRO OPERATIONS
Assistant Director W.M. Goss
Dep. Asst. Director R A. Perley
COMPUTING G.C. Hunt
ARRAY OPERATIONS R.C. Bignell
Dep. Asst. Director R.A. Sramek
ELECTRONICS J A Campbell
ANTENNA & SERVICES W F Del Giudice
SCIENTIFIC SERVICES
ADMINISTRATIVE SERVICES W.H. Porter
OBSERVATORY SERVICES R.J. Havlen

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 to 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:

J. A. Baldwin	Cavendish Laboratory
A. Dalgarno	Harvard University
M. H. Haynes	Cornell University
K. J. Johnston	Naval Research Laboratory
R. M. Price	University of New Mexico
A.C.S. Readhead	California Inst. of Technology

NRAO Users Committee

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

The present membership is:

J. Bally	Bell Laboratories
C. L. Bennett	Goddard Space Flight Center
J. H. Bieging	California, Berkeley
J. Bookbinder	JILA/University of Colorado
B. K. Dennison	Virginia Polytechnic Inst. & State Univ.
P. E. Dewdney	Dominion Radio Astrophysical Observatory
J. Dreher	Ames Research Center
G. A. Dulk	University of Colorado
S. T. Gottesman	University of Florida
P. C. Gregory	University of British Columbia
M. P. Haynes	Cornell University
J. N. Hewitt	Princeton University
P. T. P. Ho	Harvard College Observatory
J. M. Hollis	Goddard Space Flight Center
S. Kulkarni	California Inst. of Technology
M. L. Kutner	Rensselaer Polytechnic Institute
A. P. Marscher	Boston University
G. K. Miley	Space Telescope Science Institute
D. O. Muhleman	California Inst. of Technology
R. L. Mutel	University of Iowa
L. J Rickard	Naval Research Laboratory
D. B. Sanders	California Inst. of Technology
D. B. Shaffer	Goddard Space Flight Center
S. M. Simkin	Michigan State University
R. S. Simon	Naval Research Laboratory
J. S. Ulvestad	Jet Propulsion Laboratory
J. M. Weisberg	Carleton College

VLBA Advisory Committee

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

The committee is appointed by the Director. It is composed of scientists and specialists whose interests encompass all areas of radio astronomy and technology of concern to the VLBA. An attempt is also made to maintain in the membership reasonable geographic distribution and representation of the major radio astronomy centers and foreign VLBA projects. The committee meets annually.

The current membership of the committee is:

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

Green Bank Telescope Advisory Committee

Appointed at the inception of the Green Bank Telescope (GBT) project in 1989, this committee will review periodically the design planning for the GBT. Initially the committee will advise the Director on critical design issues facing the GBT project and it will comment on the staffing, decisions, and decision-making process of the GBT design team. The committee may identify alternative design techniques or suggest specific tasks.

The committee is appointed by the Director. It is composed of scientists and engineers representing the range of skills--structural, mechanical, electrical, computational and scientific--needed in the telescope design phase. The committee will first convene in the fall of 1989; thereafter it will meet as called.

Current membership is:

B. F. Burke	Massachusetts Inst. of Technology
C. Heiles	University of California, Berkeley
R. A. Jennings	University of Virginia
J. D. Nelson	University of California, Berkeley
V. Radhakrishnan	Raman Research Institute
J. H. Taylor	Princeton University
P. Thaddeus	Center for Astrophysics
S. von Hoerner	Retired
S. Weinreb	Martin Marietta Laboratories
R. W. Wilson	Bell Labs