NATIONAL RADIO ASTRONOMY OBSERVATORY

LONG RANGE PLAN, 1985-1989

May 17, 1984

NRAO LONG RANGE PLAN 1985-1989

NRAO LONG RANGE PLAN 1985-1989

Page

I. INTRODUCTION

Past advances in radio astronomy have been critically dependent on innovative applications of evolving new technologies to the instruments and techniques used to make radio astronomical observations. Improvements in the sensitivity and resolution of the telescopes and instrumentation used at traditional radio frequencies have stimulated many new discoveries over the years. Improvements in technology have been the driving force behind the slow but steady expansion of radio astronomical research into the higher frequency domain. During the planning period and beyond, the NRAO will continually strive to apply technological improvements to its existing telescopes and instrumentation and to vigorously pursue an expansion of radio astronomical techniques to higher frequencies.

The challenge to the NRAO in the coming half-decade will also be strongly influenced by technological developments in other complementary wavelength domains of astronomical research. In the present era of multiwavelength, interdisciplinary approaches to astrophysical problems, enormous strides in technology have had significant impact throughout the electromagnetic spectrum. For example, space-based gamma-ray and X-ray observations demand longer wavelength, ground-based, follow-up observations, and the NRAO anticipates a continued acceleration of its service to an ever widening user clientele.

II. PLAN OVERVIEW

The Long Range Plan for the 1985-1989 period consists of three principal elements, each of which is a vital component of overall NRAO operation:

- Continued operation of the major observing facilities: the 140-foot and the 300-foot telescopes in Green Bank, the 12-meter telescope at Kitt Peak, and the VLA in New Mexico. In support of these telescopes an active program of receiver development will lead to improvements in the operating parameters of existing radiometers and to the availability of new receivers in previously unsupported wavebands.

- Completion of the VLBA construction followed by its full operation. The construction phase will be completed in 1989, and the array will then be fully operational as a national facility. As necessary, technical improvements resulting from an ongoing development program will be incorporated in the VLBA to assure that the instrument remains at the forefront as a modern, flexible research tool. Plans for the VLBA are described elsewhere.

- Construction and operation of major new initiatives in radio astronomy to reflect the overall growth of the science and the demands that are being confronted in data handling and analysis by the users of our current facilities. Plans include a millimeter array, which will provide U.S. astronomers with a large collecting area, high-resolution instrument at high frequencies. A new, major computer system will dramatically expand the scientific potential of the VLA and impact the capabilities of the VLBA and the millimeter array as well.

III. CONTINUING OPERATIONS AND INSTRUMENTATION

The high caliber of the scientific programs carried out with the NRAO telescopes reflects both the great demand for observing time and the success of the NRAO research equipment development program. The program will continue to be stimulated by a combination of exciting scientific motivation and unpredictable advances in technological capability. The following plan summarizes, by telescope, the major areas of scientific interest to be addressed and the anticipated instrumentation developments that the coming half-decade will bring.

A. THE VERY LARGE ARRAY

By every measure the VLA has been the most powerful and the most scientifically productive instrument that the NRAO has constructed and operated. Since its first use in 1976, in excess of 2000 projects have been proposed and over three-fourths of them have received observing time. Many of its users are not traditional radio astronomers, and their overwhelming demand for the instrument has been a strong endorsement of its capabilities in support of today's problem-oriented, multi-wavelength, interdisciplinary astrophysics. The resolution capability of the VLA has given new life to radio wavelength studies of every class of object which is detectable in the short wavelength, X-ray, uv, optical, and infrared spectral regimes. Direct comparisons of the spectral properties of individual objects are no longer restricted by resolution incompatibilities, and nearly all branches of astronomy have been impacted by VLA observations.

In the study of the galactic environment, the VLA will continue to investigate detailed dynamical and morphological interactions in star-formation regions and molecular clouds. HII regions provide important laboratories in which to probe the physical conditions of the interstellar material, and current studies will be extended to many more regions. In-depth analysis of the structure of compact and ultracompact HII regions and the investigation of OH and H_2CO maser sources promise to reveal much about small-scale, star-formation phenomena throughout the Galaxy.

The significant number of stellar programs carried out with the VLA has been noteworthy and is expected to continue at a high level (approximately 25%). Future high-resolution studies of X-ray stars will search for periodicities and morphological changes. Planetary nebulae, mass-losing stars, and supernovae will continue to receive much attention, especially as the VLA observations are directly comparable with observations with similar resolution in other spectral regimes. This is also true for stellar objects which have not traditionally been of radio interest, such as T Tauri stars, normal A stars, red giants, and symbiotic stars.

Expanded studies of individual extragalactic objects are expected to take advantage of the VLA's ability to provide equivalent angular resolution over a broad wavelength range as it is used in its various standard configurations. Programs requiring this capability are on the increase as the instrument spends greater amounts of time on in-depth studies of individual objects. Very high dynamic-range maps and polarization studies will be required to understand the detailed physics and evolution of radio source structures such as jets and lobes. Dynamical studies of individual galaxies will be compared with numerical model simulations. Deep searches will investigate radio source evolution models and contribute to cosmology studies. Similar progress is expected in the study of clusters of galaxies and the nature of the microwave background radiation.

Many modifications to the VLA system which have already been incorporated during its construction and early operation have significantly impacted the way the instrument has been used and have enormously augmented its scientific productivity. Several additional improvements to the VLA are planned during the remainder of the 1980s which will greatly enhance its capabilities to serve the varied requirements of its ever-widening astronomical clientele. These projects will potentially expand the wavelength coverage of the telescope, upgrade its sensitivity and performance in currently available wavebands, and provide for improved calibration and data-handling hardware.

As a first step toward extending VLA operation to frequencies lower than the current 1.35-1.72 GHz band limit, tests of feed designs and receiver operation on a few antennas are now underway at 327 MHz. Once satisfactory performance is obtained, each antenna will be outfitted for routine operation at this frequency. Eventually 610-MHz receivers are planned for the VLA; however, this will require a large amount of development work since even severer restrictions will be imposed on feed design and location. The prospect of low-frequency VLA observations is attractive for large galactic sources and giant radio galaxies where such large field of view and more complete spectral coverage is essential. These will supplement and extend observations from other radio facilities around the world which already have low-frequency capabilities.

For lower frequency studies, a proposal is being evaluated to permanently site 27 banks of wideband, steerable antennas at all VLA A-array stations. Operating only when the VLA itself is in the "A" configuration, the resolution at 75 MHz will be about 20". Signals from the antenna banks will be conducted by cable to the nearby VLA antennas for amplification and injection into the current waveguide. A special 75-MHz correlator will be provided in the control building. Since the best current resolution at 75 MHz is many arcminutes, the proposed array will enable observations in hitherto unexplored regions of frequency-resolution space to be made. Special interest in cluster halos and other extended sources containing old synchrotron electrons is expected. Further precision in delineating low-frequency flux densities and spectral gradient information in the absence of confusing sources will contribute quite importantly to the study of numerous sources.

Operation of the VLA at frequencies higher than the current 25-GHz upper limit is also under consideration. The possibility of operating the VLA at a frequency as high as 44 GHz will be investigated, using holographic measurements and single-dish efficiency measurements of the VLA antennas. Current expectations are that an efficiency of at least 15% should be attainable. Near 44 GHz the molecular lines of SiO and CS are vitally important for probing the physical conditions of circumstellar envelopes.

At the 6 and 20-cm bands, the need to locate all front-ends in the same cryogenic dewar has given rise to system temperatures which are approximately double the values that could be attained using separate, fully optimized receivers. Feasibility studies for improving the spillover performance of the 20-cm feed and relocating the two receivers are planned as part of a long-term VLA upgrade program. Addition of 2.2-GHz receivers to enhance the frequency-switched, broadband spectrometer capability of the VLA will also be evaluated. The band would be useful for deep detection studies with lower confusion than 1.4 GHz while still maintaining a reasonable field of view. As an extra bonus, the 2.2-GHz receivers would be compatible with planned VLBA frequency coverage.

Currently, the VLA does not have the capability of observing simultaneously with two different frequencies. Studies of rapidly varying sources, such as the sun or flare stars, are therefore seriously constrained. A dichroic reflector system for the 6 and 2-cm wavelength bands has been prototyped and tested satisfactorily on two antennas. Future installation on all antennas is dependent on the development of an automatic mounting system which can minimize geometrical interference with the 1.3-cm and 2-cm receiver feed systems. Dual-frequency observing programs will then be possible.

Other notable deficiences in the current VLA system will require varying degrees of money and manpower to correct and are currently under evaluation. These include modifications to feeds or subreflectors which will improve circular polarization measurements, the addition of an ionospheric measuring device to improve corrections for time variations in the ionospheric Faraday rotation, and development of a system to measure the total precipitable water in a path through the atmosphere to better correct high-frequency observations.

A microwave link is planned between the VLA and the nearest VLBA antenna at Pie Town. Used as an element of the VLA, the Pie Town antenna would effectively double the longest available VLA spacing, thereby improving the resolution by a factor of approximately two. Special, high-resolution mapping projects for source scales intermediate between the VLA and VLBA coverages could then benefit. In addition, the tape-recording system for the Pie Town antenna could be located at the VLA site and thereby reduce operator hours for changing tapes.

The VLA will be used in partial support of the 1988/89 encounter of the Voyager spacecraft with Neptune. The collecting area of the VLA will significantly augment the data rate for pictures from the distant planet and will thereby increase the scientific productivity of the mission appreciably. Feeds and front-ends covering the 8.0-8.8 GHz range will be installed on each

VLA antenna, with the cost being wholly borne by NASA. At the completion of the mission, the receivers will be a permanent addition to the VLA. The additional frequency capability will improve measurements of the spectra of continuum sources and make possible the study of several molecular lines which fall in that frequency interval.

B. THE 300-FOOT TELESCOPE

The 300-foot transit telescope operates principally as a survey instrument, accessing many sources per day as each in turn crosses the instrument's meridian. Sensitivity to faint sources depends on the large collecting area, low-noise receivers, and integration times which span many meridian crossings (up to several months). The availability of this telescope over the years has been a powerful resource for innumerable large-scale surveys for galactic and extragalactic sources of varied character. Future surveys for low-luminosity pulsars, for low-frequency variable sources, and of the velocities and structures of galaxies, clusters, and superclusters will depend on continued improvements to the telescope and receiver systems. Although the type of program carried out on the 300-foot telescope varies little from year-to-year, the wealth of fundamental data that it provides in an environment unrestricted by competition from short-term, limited programs is unparalleled in its contribution to large-scale programs which are otherwise difficult to schedule on other major telescopes in the U.S.

A spectral processor is planned which is a combination spectrometer and signal processor, designed to replace the Mark III autocorrelator and the Nicolet signal averager. It will improve on existing instrumentation in two major areas. Spectral-line observations will have greater resistance to interference since spectral estimates are produced once every 10 microseconds instead of once every 10 seconds as in the autocorrelator. This allows spectral estimates contaminated by broadband or narrowband interference to be excluded from the accumulated spectrum. The spectral processor will also increase the available number of spectral channels, providing 2048 across 40 MHz as compared to 384 across 10 MHz in the Mark III autocorrelator. Secondly, the spectral processor will greatly improve data acquisition capabilities at the 300 foot. As a dedisperser, it will allow high time-resolution studies of average waveforms and single pulses, with full polarization information. Scintillation studies will be possible that employ a wide range of bandwidths, with spectral windows centered on different pulse components.

Investigations which are critically dependent on the broad bandwidth and channel bandwidth flexibility of the spectral processor will make redshift searches for emission from individual galaxies in clusters and superclusters for determining distances, HI contents and total masses. Other fundamental programs include searches for broadband emission from intergalactic neutral hydrogen, protogalaxies in the early universe, and the search for HI absorption lines in QSOs. For pulsar astronomy, the data acquisition flexibility of the spectral processor should greatly improve the analysis of pulse arrival times, pulse shapes, pulse mode-switching and drifting, multiple-frequency polarization effects, and the nature of weak interpulse phenomena.

A new 300-foot telescope receiver is planned which will have the capability to make 5-GHz maps of the entire sky visible from Green Bank. Such a map would be the radio analog of the Palomar Sky Survey to be used by any astronomer to make radio "identifications" or set upper limits to the flux densities of any class of objects. The 7-beam, 14-channel receiver would allow the 300-foot telescope to cover the declination range $0° < \delta < +75°$ in 90 days, resolving the sky into 10^7 beam areas and detecting about $2x10^5$ sources stronger than 10 mJy. Each map would be an historical record of the sky so that successive maps will reveal variable sources. The proposed receiver consists of 7 dual-polarization feeds followed by 14 FET amplifiers, all mounted in a single dewar.

C. THE 140-FOOT TELESCOPE

Significant improvements in the sensitivity of low-noise receivers in the 5-26 GHz, high-frequency range over the past few years have resulted in heightened interest in programs to search for weak transitions of molecular species with the 140-foot telescope. Proposals to make use of the recently implemented low-noise, L-band receiver for OH and HI studies of galactic and extragalactic sources are also on the increase. In the 2-5 GHz range a new receiver optimized for operation around specific spectral-line regions will soon be in operation. Performance at the 9-cm CH lines is expected to be similar to the sensitivity of the new L-band receiver near the lines of OH and HI. The stability and sensitivity of the 140-foot receiver systems continue to support investigations of the properties of the cosmic microwave background radiation. The frequency agility, large collecting area and all-sky coverage of the 140-foot telescope virtually ensure a high demand for its usage into the foreseeable future.

During the course of the next several years additional improvements and modernizations to the 140-foot telescope system are planned which will greatly enhance its operating efficiency. The telescope control computer and analysis computer are both considerably outdated and are badly in need of upgrading. With a new 300-foot telescope control computer soon to be in operation, it is desirable to standardize Green Bank systems as much as possible in terms of software compatibility and manpower effectiveness. Both computers are scheduled for replacement. A copy of the new 300-foot spectral processor will be made for the 140-foot telescope in order to improve interference excision and expand interactive spectral-line observations. Potential experiments in cooperation with VLBA are likely, and improvements for the 140-foot VLBI recording equipment are foreseen in order to standardize it to the VLBA system that is now being developed.

D. THE 12-METER TELESCOPE

The recent resurfacing of NRAO's millimeter-wave telescope has resulted in three major telescope improvements which directly affect the quality of the observations made with it: greater surface accuracy for higher efficiency operation at high frequencies, increased surface area and thereby sensitivity to weak sources, and improved pointing accuracy and stability. The increased competitiveness of the system has given rise to a flood of new proposals which take advantage of its improved angular resolution and expanded wavelength coverage. For the study of the ubiquitous CO molecule in a wide variety of objects, the improved resolution of the telescope at the J = 2-1 line at 230 GHz is critical. Projects are just beginning which probe the detailed morphology and dynamics of the CO molecular components of circumstellar shells, regions of star formation where energetic bipolar outflows are detected, and in a wide variety of external galaxies. Newly sensitive observations of additional transitions of known molecular species in the interstellar medium and in dense molecular clouds will probe more thoroughly the physical conditions in such environs. In addition, prospects are quite good for detecting new species and adding to our understanding of the chemistry of the interstellar medium. More sensitive continuum observations are planned for objects in the solar system, galactic dust clouds and globules. Further improvements in the continuum studies of extragalactic sources, compact objects and QSOs are anticipated which will lead to more refined variability studies as well.

Ongoing improvements in all the 12-meter receiver systems will play an equally important role in the effectiveness of the facility to contribute to the above scientific studies. Progress is expected in a number of instrumental developments to insure that this continues unabated through the 1980s. Receiver sensitivity to the low-intensity, narrow, millimeter spectral-lines which are emitted by cold, spatially extended astrophysical sources is dependent on improvements in Schottky-barrier diodes and SIS junctions which are the critical components of the NRAO millimeter-wave receivers. The NRAO will continue to emphasize work on these devices in parallel with research at other institutions, both for current single-dish work and for eventual use with a millimeter array.

Other instrumental developments include a 345-GHz spectral-line receiver for observations of the J = 3-2 CO transition. This and other important molecular species have transitions which are observable in the 870-micron atmospheric window. An existing mixer will be incorporated in a simple receiver initially to evaluate the performance of the telescope at this frequency.

The observation of extended sources plays an important role in dynamical and morphological studies of regions in the interstellar medium, both galactic and extragalactic. Problems in receiver sensitivity, calibration, and pointing have restricted the efficient use of single-beam instruments for mapping extended sources, however. Several new, multibeam receivers are planned which will alleviate some of these observational inefficiencies. Efficient spectral-line mapping of star-formation regions will be possible with the development of a multibeam CO receiver. Continuum mapping of extended sources will be enhanced by means of a 3x3 bolometer array receiver operating at 0.3 K and having individual channel sensitivity equal to the existing NRAO single-channel bolometer receiver.

Parallel instrumentation improvements will be required in order to fully exploit the capabilities of the new receivers that are planned. SIS mixer devices need to be cooled to 2.5 K or lower and new closed-cycle refrigeration systems need to be developed which avoid the loss and costly replacement of the liquid helium refrigerant. Current multifilter autocorrelator receivers at the 12-meter telescope which are restricted in bandwidth will be replaced by a prototype hybrid filter-bank/digital autocorrelator covering 1-GHz bandwidth with 2048 channels.

E. OTHER PROJECTS

Several major items will be broadly based throughout the Observatory and impact the overall operating efficiency of the existing NRAO facilities. Other projects will be focussed in the Charlottesville Central Development Laboratory and aim specifically toward breakthrough technical advances which will benefit the entire radio astronomy community in their scope.

Continued emphasis will be placed on the development of cooled GaAsFET amplifiers for their reliability, stability, and superb low-noise properties at centimeter wavelengths. As IF amplifiers for millimeter-wave receivers, they improve the sensitivity of almost all observations made at the NRAO. Amplifiers designed at 1.5, 5, 10.7, and 15 GHz are in widespread use at radio installations around the world, and future work will not only expand their design to 0.3, 8.3, and 23 GHz but will be directed toward even further improvements of the FET solid-state device.

A program involving High Electron Mobility Transistor (HEMT) devices is already being supported by NRAO in conjunction with laboratories at JPL, GE, and Cornell. These devices, operating at a physical temperature of 100 K, have noise temperatures lower than GaAsFET's operating at 15 K and promise to significantly impact receiver performance. Developmental work is planned which will employ these devices at 8 and 22 GHz.

Although the majority of the instrumental research and development that is ongoing at the NRAO has been directed towards advancements in millimeter and centimeter-wave receivers, devices, autocorrelators and associated electronics, very little work has gone into improvements of the telescope systems themselves. For this reason a "Future Instrumentation Group" is planned which will recommend long-term improvements to existing radio telescopes and study new ideas for instrumentation in radio astronomy. This small group of engineering scientists and students will have as its first task the investigation of feed designs and reflector modifications to improve the sensitivity of NRAO's present antennas. The majority of the annual \$250k anticipated funding of this group will be for short-term (2 years or less) personnel salaries and travel. University participation in the group's continually changing membership will have the long-term goal of increasing university-based instrument development activities while at the same time producing analytical solutions and recommendations for important problems.

IV. PLANS FOR EXISTING FACILITIES

A. CONSOLIDATION OF CHARLOTTESVILLE FACILITIES

The Charlottesville Edgemont Road building has been the nucleus of the NRAO headquarters operation since 1965 when the NRAO expanded from its West Virginia observing site. As the NRAO staff increased during the VLA planning and development years of the early 1970s, the need for expanded electronics laboratory facilities became acute, and temporary space was leased in an office building approximately one mile away. The leased space, now occupied by the Central Development Laboratory, has recently been expanded to house the Charlottesville VLBA design and planning activities. Space at the Edgemont Road office is still at a premium, with expanded data and image processing operations occupying former electronics laboratories, scientists forced to sit two and three to an office, and the library having no more than two years expansion room. More critical to the fundamental operation and established mission of the NRAO, however, is the artificially imposed separation of technical developmental activities from the hub of scientific activities at Edgemont Road and the resultant absence of daily, informal contacts between the engineers and the staff scientists. A consolidation of the several Charlottesville NRAO activities within an expanded building at Edgemont Road will revitalize the forefront scientific/technological interface that characterizes the mission of a national facility.

In order to accomplish the above goals it is proposed to approximately double the size of the current Edgemont Road building, configuring the extension to accommodate the existing Ivy Road building laboratory space as well as to relieve the current office and library crowding problems. The total cost of construction should be less than $3 million (extrapolating from an existing 1967 plan using the national average CPI). As was done for the current building, the NSF may want to seek a funding agreement with the University of Virginia in order to amortize the cost of the extension over a five or six-year period through payments made from an enhanced NRAO operating budget. Construction in 1987 will be preceded by detailed design work in 1986.

B. CONSOLIDATION OF VLA AND VLBA FACILITIES

The rationale for locating the VLBA Operating Center in Socorro, New Mexico was strongly influenced by the presence of a concentrated group of experienced VLA operations and development engineers and the expectation that the VLBA and the VLA would frequently operate in a combined mode. As the operation of all but the most essential elements of the VLA is transferred from the Plains of San Augustin to Socorro, a new operating facility large enough for both the VLA and the VLBA will be constructed in Socorro. The VLBA portion of the building will be funded from VLBA construction funds, and it is expected that a substantial addition will be needed to house the VLA staff. Only a small percentage of the current VLA still will be required to maintain their permanent location at the VLA site to which they will continue to commute daily from Socorro, Magdelena and Datil. As was done for the Edgemont Road facility in Charlottesville, the NSF may want to seek a funding agreement with New Mexico Tech in order to amortize the cost of the extension over a five or six-year period through payments made from an enhanced NRAO operating budget. A 1986 construction is foreseen.

V. MAJOR NEW INITIATIVES

A. A MILLIMETER ARRAY

The need for high-resolution millimeter-wave observations for continued progress in numerous areas of current astrophysical research has been aptly summarized most recently (April 1983) by the Subcommittee on Millimeter- and Submillimeter-Wavelength Astronomy to the NSF Astronomy Advisory Committee. Future advances in the study of star-formation regions, stellar envelopes, the chemistry and dynamics of the interstellar medium, and the study of the molecular component of our Galaxy and external galaxies are critically dependent on the improved resolution afforded by aperture synthesis telescopes. Such an instrument would also make important contributions to cosmology through studies of fluctuations in the microwave background and the Sunyaev-Zeldovich effect in clusters of galaxies. Work on particle acceleration and emission processes in quasars and radio galaxies would be enhanced, and millimeter VLBI studies of the nuclei of extragalactic objects would be strengthened as well. Studies of evolved, mass-losing stars would improve our understanding of the giant region of the H-R diagram.

Solar-system work would include studies of the upper atmospheres of the giant planets as well as studies of the surface properties of the satellites and asteroids through continuum spectra and the heating and cooling of the surface layers. Global and small-scale studies of the sun at millimeter wavelengths promise to tell us about the chromosphere and the mechanics of particle acceleration in solar flares.

In recognition of these overwhelming scientific justifications and lacking the large, national millimeter-wave facilities, which the Field Committee Report presumed would exist in the early 1980s, the NRAO has initiated an active study to define the specifications of a millimeter array and to assess ongoing technical developments in the field. A proposed plan of action has been drawn up for work on the project over the next few years in preparation for an eventual formal proposal submission and design study. Meanwhile, many of the technical considerations, which are strongly allied to developments on the VLA and VLBA instruments, require minimal dedicated manpower. A committee of non-NRAO scientists has been empaneled to provide a continuing assessment of the early stages of the project and to monitor its program in the light of continuing advances in the rapidly developing field of millimeter astronomy. It is anticipated that the NRAO will be prepared to seek funding for design and construction of the millimeter array on a time scale commensurate with the final funding for VLBA construction (i.e., design beginning in 1988 followed by multiple year funding starting in 1989).

B. A MAJOR COMPUTER SYSTEM

The NRAO has invested a major fraction of its resources over the past decade and a half planning, constructing, and operating the world's largest connected-element, aperture synthesis telescope, the VLA. Soon to begin construction is another aperture synthesis array, the VLBA, and plans have been formulated for a future Millimeter Array. As amply evidenced by experience gained on the VLA and as will similarly effect the newer instruments to be built, the scientific potential of any aperture synthesis instrument is to a large degree constrained by the computer resources that it draws upon.

Even though the VLA has exceeded its design specifications many times over, and, in spite of the consequent increased demand imposed upon its computer system, the VLA has been a spectacularly successful instrument in terms of its scientific productivity. The full potential of the instrument, however, has not yet been tapped. New deconvolution and self-calibration techniques have been developed and tested which clearly provide much greater power to the telescope-computer combination. The major limitation to achieving this goal is an insufficient amount of CPU time.

A few test, highly computer-intensive scientific projects have already been accomplished with the VLA at an enormous cost of computing time. Hundreds of hours of CPU time were required, for example, to construct high dynamic range images of extended radio sources and have revealed spectacular unanticipated morphological complexities. In addition, a rather thorough assessment of the potential computing requirements of many VLA observing projects has been carried out. The estimated computer requirements indicate that a significant number of projects would be limited by the current VLA computer system. Accepting the fact that some scientific projects will always remain computer limited, an analysis of the above estimates still indicates that too much science is limited by the computer in comparison to other limitations.

The NRAO plan addresses the existing VLA computer limitations and the eventual demands of future array operations through a major computer upgrade in 1987. The estimated $10M cost is less than 10% of the inflation adjusted cost of the VLA alone. When considered as an integral part of three arrays several years hence, however, the cost is easily justifiable in terms of the added scientific benefits that will accrue. Although not formulated yet, in detail, the NRAO plan provides for that added computer capability that only a Class 6 computer can provide rather than a simple expansion of present computer capacity.

C. SPACE RADIO ASTRONOMY

Radio astronomy will inevitably have a future in space. Space astronomy has had a very great impact on the fields of X-ray, ultraviolet, optical, and infrared astronomy, and its impact will be even greater once the Space Telescope is functioning. Currently, plans for radio observations from space have been developed primarily within NASA. The fields of submillimeter astronomy and VLBI would benefit greatly with space-borne observing facilities, and both fields are strongly allied with existing NRAO efforts in millimeter-wave and VLBI/VLBA technology.

The VLBI community, consisting mainly of the U.S. and European Networks, are already developing plans for an orbiting VLBI antenna in space. The "QUASAT" program, funded by NASA/ESA and operating a 15-meter antenna in the early 1990's at distances up to 15,000 km above the surface of the earth, will triple the resolution capabilities of existing VLBI experiments, and significantly augment coverage in the uv-plane and the resultant image quality and dynamic range. Potential operation in conjunction with the NRAO VLBA telescope is a critical factor for the justification of QUASAT.

To the extent that NRAO is one of the leading institutions for the development of sensitive low-noise receivers and is taking the lead in developing systems for the VLBA, it will probably be involved in extending radio astronomy into space. The NRAO anticipates that the end of the decade of the 80's will see increasing effort focussed in this area on one or two major projects that are currently unspecified.

VI. APPENDIX

Long-Range Budget and Personnel Projections - 1984-1989

Budget Estimate (millions)	1984	1985	1986	1987	1988	1989
I. OPERATIONS						
Existing Operations	$16.2	$17.0	$18.5	$19.5	$20.5	$21.5
New Operations (VLBA)	-	-	0.5	1.9	3.4	4.9
Total Operations	$16.2	$17.0	$19.0	$20.4	$23.9	$26.4
II. EQUIPMENT						
Research Equipment	$ 1.3	$ 1.2	$ 3.0	$ 3.6	$ 4.2	$ 4.7
Operating Equipment	0.2	0.2	0.2	0.2	0.2	0.2
Total Equipment	$ 1.5	$ 1.4	$ 3.2	$ 3.8	$ 4.4	$ 4.9
Subtotal - Operations and Equpment	$17.7	$18.4	$22.2	$24.2	$28.3	$31.3
III. CONSTRUCTION & DESIGN						
Very Long Baseline Array	$ 2.5	$15.0	$16.3	$17.1	$17.9	-
VLA Building, Socorro	-	-	2.0	-	-	-
Charlottesville Bldg. Addition	-	-	0.2	2.0	-	-
Major Computer System	-	-		10.0	1.0	$ 1.0
Millimeter-Wave Array	-	-	-	-	-	10.0
Space Radio Astronomy	-	-	-	-	-	5.0
Total Construction & Design	$ 2.5	$15.0	$18.5	$29.1	$18.9	$16.0
TOTAL PLAN[1]	$20.2	$33.4	$40.7	$53.2	$47.2	$47.3
PERSONNEL ESTIMATE[2]						
Existing Operations	339	339	349	350	350	350
New Operations (VLBA)	-	-	10	30	50	70
Total Personnel	339	339	359	380	400	420

[1] Does not include USN funds or personnel (10 full time) for operation of Green Bank interferometer ($0.6M in 1984).
[2] Excludes any personnel who may be hired directly into construction projects.