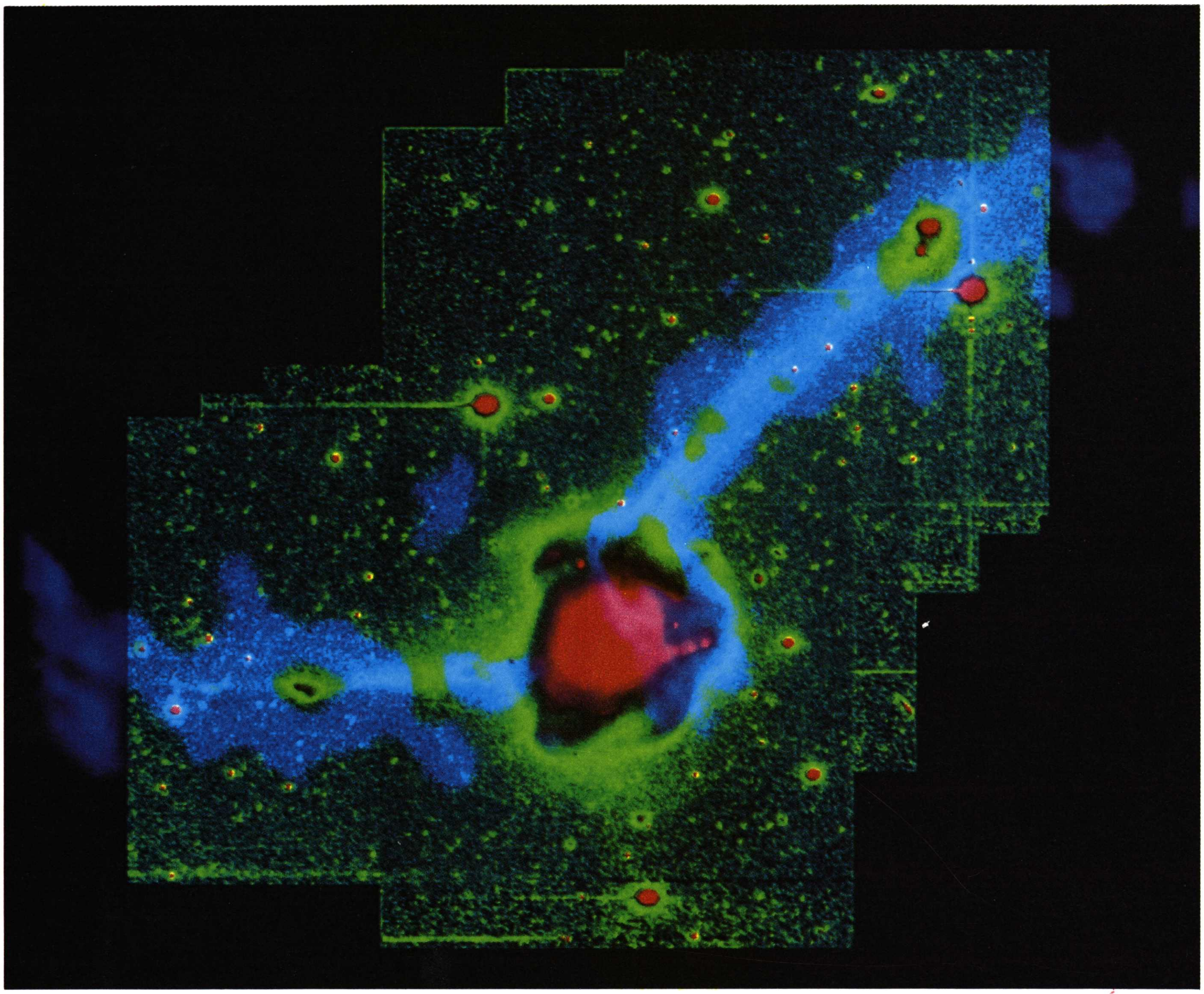
NATIONAL RADIO



ASTRONOMY OBSERVATORY

NRAO

PROGRAM PLAN 1992

Cover: The peculiar galaxy NGC 7252. This galaxy is a result of a recent merger, or collision, of two galaxies. The starlight from the merged galaxy is shown as red in this image, light from stars scattered by the force of the collision, or stars unrelated to the galaxy, is shown as green and the radio emission from neutral atomic hydrogen gas is indicated by blue shading. This image demonstrates that when galaxies collide their gas is removed; the final merged system is nearly devoid of gas.

The radio image was made with the NRAO Very Large Array radio telescope. The optical image was obtained at the CTIO 4m telescope.

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NATIONAL RADIO ASTRONOMY OBSERVATORY

CALENDAR YEAR 1992

PROGRAM PLAN

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I. INTRODUCTION

The Committee recommends that the National Science Foundation increase the operations and maintenance budgets of the national observatories to an adequate and stable fraction of their capital cost, thereby repairing the damage caused by a decade of deferred maintenance.

With these words the report of the Astronomy and Astrophysics Survey Committee, the "Bahcall Report," summarizes its highest priority recommendation for ground-based astronomical research in the next decade. The statement is a recognition that the NSF investment in capital facilities, the astronomy infrastructure, can be expected to yield the greatest scientific returns only when those facilities are provided with adequate and reliable operations funding. While this has not been the case for the past seven years, the Bahcall Committee recommendation for "appropriate remedial actions [to increase] the operations, maintenance, and refurbishment budgets for the [national] observatories" has been translated into a specific augmentation in the NSF appropriation by the current Congress. Such increased operations support is critical to the NRAO. The 1992 Program Plan presented here incorporates $7.3M of funding augmentation to begin the restoration of the National Radio Astronomy Observatory. The 1992 spending plan for the augmentation is outlined in Section II.

Nineteen ninety-one was a watershed year for radio astronomy and for the NRAO. After decades of effort, and instrumentation development, radio spectroscopic observations have now become possible in the most distant reaches of the universe. Both HI and CO have been observed in galaxies--protogalaxies or perhaps pre-galaxies--at redshifts greater than two. The ramifications of the result that localized concentrations of atomic hydrogen, and even carbon monoxide, have condensed out of the Hubble flow when the universe was less than 20 percent of its present age and size will have a profound effect on cosmological models and will stimulate intense competition for observing time on the NRAO telescopes. A representative sample of this and other research proposed in 1992 is outlined in Section III.

All three major telescope systems operated by the NRAO will be in increased demand: the 27 element Very Large Array (VLA) synthesis telescope located on the Plains of San Agustin near Socorro NM; the 12 meter millimeter-wave telescope on Kitt Peak AZ; and the 140 foot telescope in Green Bank WV. These instruments are described in more detail in Section IV. In 1992 we expect that more than 850 individual scientists from nearly 200 institutions will conduct their research with these NRAO facilities.

The NRAO is engaged in two major construction projects which are summarized in Section V. Construction of the Very Long Baseline Array (VLBA) will be completed in 1992 and the instrument, operated previously in an interim form for scientific observations, will prepare for full operation in 1993. Meanwhile, the first steel supporting members of the Green Bank Telescope (GBT) will be erected and assembled in the spring of 1992. The GBT construction schedule is also given in Section V.

Among the few equipment initiatives for the decade of the 1990s recommended by the Bahcall Committee for construction by the NSF are two very important to the NRAO. The Millimeter Array (mmA) proposal is currently under review by the NSF; the extension of the capabilities of the VLA so as to bridge the gap to the VLBA is an element of the long range development plan for these facilities. Both these projects are summarized in Section VI.

Three sections of the Program Plan emphasize different ways that the NRAO collaborates with universities and other observatories to mutual benefit: Section VII describes work done at the NRAO for the U.S. Naval Observatory and in conjunction with NASA. Section VIII describes efforts by the NRAO to develop the next generation of imaging software in active collaboration with astronomers and programmers worldwide. It also includes a discussion of a cooperative effort to develop the mmA. The variety of educational initiatives at the NRAO are presented in Section IX.

The final three sections of the Program Plan include the 1992 preliminary financial plan, the long range budget and personnel projections for the subsequent five years, and the research equipment plan. Appendices to the Plan include a summary of the 1992 scientific program planned by the NRAO staff, a list of the staff and their principal research interests, an organization chart, and a list of various committees that provide advice and assistance to the Observatory.

II. RESTORING THE NRAO INFRASTRUCTURE

1. Overview

The most visible evidence of a deteriorating infrastructure at the NRAO, an example highlighted by the Bahcall Committee's report, is the state of the railway track system used to transport the antennas of the Very Large Array (VLA) among its four different array configurations. Major components of the system need to be replaced and improved, and the level of continuous maintenance required to keep the system in good repair has never been achieved. As a result, the system continues to slowly decline in reliability, and safety considerations mandate slow and inefficient operations. But the VLA railway tracks are only the highly visible "tip of the iceberg," an important part of a much larger problem.

Not only are the physical plant needs of the NRAO much larger than the VLA railway track problems, the concept of infrastructure itself is larger than physical plant maintenance. The report of the Bahcall Committee recognizes this by including in the "restoration of the infrastructure" instrumentation upgrades, enhancement of computing resources, and strengthening of technical development staff and equipment. It is the entire infrastructure from the present physical plant to the ability to develop the means for scientists to better utilize those facilities that must be restored. The effects of several years of very restricted operations funding at the NRAO have percolated throughout the entire scope of Observatory activities to such an extent that a substantial increase in base funding is required to restore the facilities and, equally important, the staff of the Observatory. The table below gives the requirements in four broad areas for NRAO to provide to the U.S. scientific community the services expected from their National Observatory and to rectify the effects of the technical stagnation imposed by the lack of funds of the recent past.

Infrastructure Requirements

	Required Addition to Annual Budget
Physical Plant Restoration	1.2M$
Computing Resources	1.0
Research, Operating, and Test Equipment	1.5
VLA Upgrade (VLA Total 36 M$)	3.6
Annual Total	7.3M$
Book Value of NRAO Facilities*	123.0M$
Escalated Value (approx.)	200.0M$
Current Annual Budget for Infrastructure (1990)	5.0M$

*Does not include the Very Long Baseline Array or Green Bank Telescope. Value shown is as of date purchased.

2. NRAO Physical Plant

The problem of restoring the physical plant is not amenable to quick fixes. The NSF investment in capital facilities is sufficiently large, at least $200M, that it requires an annual investment in maintenance as long as the facilities are operated. Today we can enumerate the specific maintenance needs and estimate the cost. But having addressed these specific problems, we cannot expect the maintenance needs of the NRAO facilities to be eliminated. Tomorrow the maintenance problems will be different, but they certainly will be present. Maintenance funding is a continuing need.

Summarized in the table below is the plan to restore the NRAO physical plant. A short description of the individual items follows the table. The important point is not the pressing maintenance problems which we today write in this table, but the magnitude of the need for increased funding, about $1.2M a year, we can foresee as long as the NRAO facilities are operated.

Restoring the NRAO Physical Plant
(equipment, materials and supplies, and subcontracts)

	1991 Spending (est)	5-Year Plan Cost to Complete	Annual Expense	Annual Addition Needed
PHYSICAL PLANT				
VLA Rail Ties	$35k	Continuing	$300k	$ 265k
VLA Track Intersections		2000	400	400
VLA Power Distribution System	50	850	170	120
VLA Waveguide System	25	300	60	35
Telescope Repair and Paint	40	600	120	80
Environmental Safeguards	10	275	55	45
Buildings and Roads	25	625	125	100
Machine Tools	25	350	70	65
Electric Power Conditioning		100	20	20
Utilities and Communications	20	200	40	20
Vehicles and Overhaul	30	400	80	50
TOTAL				$1200k/yr

The VLA Rail Ties. The VLA rail track system consists of two standard gauge railroad tracks which run along each 13-mile arm of the array. There are about 80 miles of (single) track in the system. The combined weight of the transporter plus the antenna is about 300 tons. With 24 wheels on four trucks, this gives a loading of 50,000 pounds on each of the 12 axles, a high but not unusual load in the railroad industry. The track system currently has about 800,000 feet of (single) rail on the main line and 46,000 feet in the antenna spurs. There are 190,000 ties and 72 intersections. The entire track system was constructed with used materials. The rail, for example, dates from 1902 to 1956.

Since the VLA began full operation in 1980, the rail system has received regular inspection and whatever upkeep was mandated by safety considerations. Now, at roughly ten years of age for much of the system, more major maintenance is required. The main, but not the only, problem is a deterioration of the rail ties. This has become serious because the rate of deterioration has accelerated beyond what would normally be expected. In particular, those ties that came from wet regions of the U.S. are deteriorating rapidly in the dry conditions of New Mexico.

Rail maintenance is now done by a four-man VLA rail crew augmented by seasonal help. In the past year a tie extractor (purchased with NASA/JPL funding) and a surplus ballast tamper have been added to the rail maintenance equipment. Tie replacement is continuing at 1000-3000 ties per year. Improving the condition of the rail system requires that at least 6000 ties per year be replaced.

VLA Track Intersections. During operations the VLA antennas rest on concrete foundations 100 feet from the main rail line. Each station is connected to the main line by a short spur rail line and a track intersection. These deteriorating intersections are the weakest elements in the system. They are being redesigned and need to be rebuilt.

Other maintenance items in the track system besides the ties and intersections are: replacement of clogged ballast; reconstruction of the U.S. 60 highway crossing; realigning, gauging, and upgrading antenna spur lines; replacing bad rail sections; repairing and smoothing joints; and cleaning and dressing ballast, and ultrasonic testing of all rail.

VLA Power Distribution System. Electrical power is supplied to the antennas of the VLA by buried cable running along the arms--three cables per arm, one for each phase, operating at 12.45 kV. These cables were installed between 1974 and 1980. The type of cable selected was highly recommended and in wide use at that time throughout the U.S. by electric utility companies. The extruded polyethylene insulation on these cables is now known to be subject to failures which increase rapidly in rate with cable age. Experience with the cable at the VLA is following the industry-wide pattern.

Polyethylene cable deteriorates with age owing to a process known as "treeing." A "tree" is a growing channel which propagates through the insulation, probably due to ion or electron bombardment. The number and size of trees in a cable are primarily a function of time in service, operating electric field strength, and the presence of manufacturing impurities. As treeing progresses, the dielectric strength of the insulation deteriorates until voltage surges due to switching transients or nearby lightning strikes break down the insulation and the resulting arcing produces a ground fault. The only solution is to replace the power cables. Steps to slow the cable degradation and minimize the disruption of operations will allow the cable to be replaced over several years. The total cost is estimated to be approximately $1.35M. About 25 percent of the cost has been borne by NASA as part of the Voyager/Neptune encounter project, and all cable has been replaced to the ends of the C-configuration at NASA expense. NRAO will have completed a roughly equal amount of cable replacement with NSF funds at the end of 1991, leaving 320,000 feet of cable to be installed. The work is done in-house with a three person crew, using a trencher to excavate a trench, lay the cable, by hand, in a bed of sand at the bottom of the trench, and cover with clean sand and fill dirt. At present installation rates it would take six to seven years to finish recabling. Funds to double the installation rate are included in the infrastructure restoration plan.

VLA Waveguide System. The VLA IF signals, local oscillator, and monitor signals for the VLA antennas are all multiplexed on a signal carried by circular waveguide along the arms of the wye to the antennas. The waveguide is buried and access is via a series of widely spaced manholes. There are more than 100 manholes, each of which was constructed with the clever and inexpensive expedient of stacking concrete burial vaults with their bottoms removed. However, after ten years the soil pressure has bowed the sides of the vaults to the extent that it is unsafe to access many of the manholes. They are being replaced with a proper design at a cost of $3k each.

On-going Maintenance at the NRAO. Other continuing maintenance needs at the VLA comprise a long list of significant but smaller items: overhaul of antenna transporters and installation of new transporter control systems, overhaul of electrical generators and upgrading of electrical power system controls, bringing fuel storage tanks into compliance with new environmental regulations, replacement of machinery and selected vehicles, and improvement of painting facilities. The VLA site road system is badly in need of maintenance.

Maintenance requirements at Green Bank are related to environmental/health considerations. The sewage treatment plant is being modernized. The water tower has been repaired and painted inside and out, but a water filter system must be installed. Asbestos must be removed from the older buildings. Various buildings require new roofs. Superficial cracks in the concrete of the 140 Foot Telescope pedestal must be grouted and sealed, and the telescope must be painted. Housing needs maintenance.

Within two or three years the fabric covering on the 12 Meter Telescope dome must be replaced. The estimated cost approaches $400k. Other 12 Meter Telescope needs include electrical power conditioning upgrades, adding a sun screen to the dome to prevent damage by the sun and wind, and repaving the road.

3. Engineering Infrastructure--Research and Operating Equipment

The design and construction of new instrumentation for the NRAO telescopes involves a concerted effort by those involved with basic research and development of microwave and millimeter-wave devices as well as by those expert at fabricating reliable instrumentation, and by systems engineers. It also requires hardware and (expensive) laboratory test equipment. Restoring the NRAO engineering infrastructure involves augmentation of both staff and equipment. The yield of the investment is more sensitive and more capable telescope instrumentation that will expand the potential of the NRAO instruments, make possible new science and make more effective use of the large investment the telescope facilities represent.

As with the maintenance program, the equipment modernization of a research facility is a continuing activity. In the table below, and in the descriptions which follow, the present activities at the NRAO are summarized. When these activities are complete, new instrumentation activities will begin. The goal is to establish, and maintain, an appropriate new instrumentation program. In the past few years this has not been possible, and the new equipment program at the NRAO has seriously atrophied.

The specific spending plan for Research Equipment in 1992 is presented in tabular form in Section X of this Preliminary Program Plan.

Restoring the NRAO Research and Operation Equipment

	Annual Spending Needs k$	1991 Spending (est) k$	Annual Addition Needed* k$
Millimeter-Wave Device Development	575	125	450
HFET Amplifier Development	600	225	375
Cryogenic Refrigerator Development	50		50
Digital Spectrometer Development	290	40	250
Interference Protection	60	10	50
Telescope Pointing and Optics	85	10	75
Test Equipment	175	75	100
Operations Equipment	250	100	150
TOTAL			1500

* Continuing needs

Millimeter-Wave 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. In the immediate future this work will lead to more sensitive receivers on the 12 Meter Telescope; in the long-term the development is crucial for the mmA.

The near-term goal for 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.

Observations have begun with a 4.2 K system that can handle eight insertable SIS mixer/feed/amplifier assemblies. The telescope version has coverage throughout the 1 mm and 3 mm windows. With the development planned in the previous table, complete coverage of all the windows between 70 and 360 GHz will be achieved with this receiver in the near future.

HFET Amplifier Development. Development of cryogenic Heterostructure Field Effect Transistor (HFET) 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.

HFET 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 the next five years will focus on development of broader band amplifiers for various applications at all NRAO sites. We will also start work on a prototype amplifier at 86 GHz for the VLBA and mmA.

Cryogenic Refrigerator Development. The superconducting millimeter-wave mixers must to be cooled to 4 K or less. In fact, their sensitivity continues to improve with decreasing temperature down to at least 2.5 K. To realize the sensitivity inherent in these devices requires the development of a closed-cycle, reliable, low-maintenance refrigerator. Several possible, but quite different, options exist and will need to be evaluated and tested over several years time.

Digital Spectrometer Development. The expected new generation of SIS and HFET receivers will be very broadband, sensitive devices. When available, the bandwidth of these receivers will far exceed that of the backend spectrometer or continuum receivers at all telescopes. Such a disparity will mean that much data gathered with great sensitivity will not be analyzed. To reconcile the capabilities of the telescope system a new generation of digital/analog correlation spectrometers will be developed. Again, there are several technical options that will first need study and evaluation.

Interference Protection. The sensitivity of the 327 MHz and 75 MHz systems on the VLA are limited by radio-frequency interference locally generated in the B-rack at each antenna. This problem is particularly severe for the more compact arrays. RFI shielding of the LO rack in the vertex room has proved effective and four antennas have been equipped. In order to improve the sensitivity of 327 MHz, the complete array will be required to be outfitted with these RFI shields.

Telescope Pointing and Optics. With the VLA antenna insulation completed, the next largest contribution to the pointing errors is the tilts of up to 20 arcseconds in the azimuth axis of some antennas at certain azimuth angles. This effect is possibly caused by deformations or perturbations in the azimuth bearings. This and other problems such as an antenna tilt caused by a constant wind force could be corrected by an active correction scheme utilizing electronic tilt-meters mounted on the antenna structure. Two antennas are equipped with tilt-meters, and engineering studies indicate that improved tilt-meters are required. That design is complete and further testing is required.

In order to improve the pointing on the 12 Meter Telescope, we will implement the following: real-time monitoring of movements of the focus assembly using a laser and quadrant detector; improved focus mount offering more freedom of movement and more precise control; increased monitoring instrumentation, such as inclinometers, strain gauges, and temperature sensors; replacement of feed legs with a carbon-fiber design giving less temperature dependence and less aperture blockage; and a sun screen to reduce thermal distortions of the telescope during daytime operation. We have started experiments with an auxiliary optical pointing system, observing stars optically as an aid to better understanding the pointing characteristics of the telescope. We intend to expand on this theme, to give a higher level of automation, with the possibility of offset guiding on optical stars to give accurate tracking of weak radio sources.

Test Equipment. The only test and laboratory equipment NRAO has been able to buy for the last seven years has either come by way of the VLBA construction or from NASA or the U.S. Naval Observatory. It has been little, but it has been invaluable. This equipment is vital to an ongoing R&D effort, and the preservation of NRAO's effort has been totally dependent on these sources lying outside the base program. Test equipment is expensive: a single item of major test equipment can easily cost $50k to $100k.

NRAO acquired a network analyzer in 1986 costing about that or a little more as part of the NASA-funded Voyager/Neptune encounter project. It made possible the research program on HFET amplifiers. The astounding success of these amplifiers has had a profound effect on all radio astronomy, driving out of use the unstable parametric amplifiers and complex and expensive maser amplifiers. Amplifiers that are as good as desired are actually routine at lower frequencies now, besides being inexpensive, reliable, and inexpensive to maintain. Without that single item of test equipment, this would not have been possible.

Operations Equipment. For the past several years, funding of operating equipment has been nonexistent. In an effort to meet the minimum budgetary needs in research equipment and regular operations, it has been necessary to postpone indefinitely the purchase of operating equipment. In addition, we have had to delay the replacement of existing obsolete equipment. This approach to funding leads to higher maintenance costs, more frequent down time, and inconvenient and inefficient use of our personnel resources. The plan presented attempts to reverse this trend in operating equipment funding. Over the next several years, with adequate funding, we will be able to provide the infrastructure to meet the increasing demands of our users for office, library, living quarters, and shop equipment.

4. Computing Resources

The long-standing problem of inadequate computing at the VLA in particular, and the NRAO in general, remains unsolved. The cause of the problem is worth review.

Since the original design goals were specified in 1969, the power of the VLA for imaging radio sources has increased steadily. The following table gives the changes in selected image parameters.

Development of VLA Imaging Power

	Goal 1969	Achieved 1980	Achieved 1990
Speed (images per day)	3	200	200
Image Size--Routine (pixels)	128x128	512x512	1024x1024
Image Size--Maximum (pixels)	512x512	1024x1024	4096x4096
Spectral Line Channels (full array)	--	8	512
Dynamic Range--Routine	100:1	500:1	2000:1
Dynamic Range--Maximum	100:1	2000:1	100,000:1
Maximum Sensitivity (mJy)	0.1	0.05	0.005
Resolution (arcseconds)	1	0.1	0.07

Each increase shown in the above table has required computing resources beyond those originally anticipated. The growth in demand for computing resources has outstripped our ability to provide them within the annual operating budgets of NRAO. Only a small fraction of the scientific investigations that are exciting but exceptionally computer intensive can now be supported. The operation of the VLBA is expected to increase the computing demand by 65 percent over the demands of the VLA alone. In order to rectify this situation, the NRAO submitted to the NSF in September 1987 a proposal, "Array Telescope Computing Plan," which creates a joint VLA/VLBA computing environment suitable for the needs of both arrays.

The essence of the plan is the recognition that the imaging burden of the synthesis arrays covers a broad spectrum: some observations require only modest computing resources while others may require the full power of a large supercomputer. Given this distribution, the design of the appropriate computing facility for VLA/VLBA imaging incorporates hardware resources which span the same spectrum from the modest to the very powerful. Doing this is cost effective and leads us to a hardware plan for a computing facility which is a combination of computers, of varying computational capacity, loosely coupled together.

The software plan for the proposed computing system has three elements:

- A rewriting of AIPS into a new system called AIPS++ for use at NRAO and export to other facilities, including supercomputer centers and user home institutions for the reduction of array and single-dish data;
- Research in data processing, including new algorithm developments that will be incorporated into AIPS++;
- Code optimization for efficient use of the machines available.

In 1988 the Array Telescope Computing Plan was reviewed by the NSF Division of Astronomical Sciences and received highly favorable reviews but it could not be funded in the then restrictive funding climate. In 1990 the NRAO submitted an addendum to the Array Telescope Computing Plan which reaffirms the needs and goals of the plan and reassesses the plan for software and algorithm development.

The Array Telescope Computing Plan is a proposal to redress a problem of long-standing. It emphasizes, and we restate in the table below, the continuing need to augment and replace computing hardware at regular intervals. Furthermore, not only is the distinction between radio astronomy "instrumentation" and "computer" being blended (modern telescope instruments have dedicated computers for their control), but the computers themselves, whatever their function, are part of larger networks. The infrastructure--disk servers, networks, display devices--is important. Algorithms must be developed to enable the astronomer to exploit the computing resources. These needs are never satisfied with finality, rather, a continuing effort at an appropriate level is an indispensable function of the National Observatory.

Restoration of Computing Resources at the NRAO
(both purchases and personnel)

	Annual Spending (need) ($k)	1991 Spending (est) ($k)	Annual Addition Needed ($k)
Real Time Control	100	40	60
Computer Engines	150	-	150
Interactive Graphics Engines	150	-	150
Imaging Workstations	120	20	100
Disk Storage and Archive	100	20	80
Image Recorders and Display	85	-	85
Networking & Communications	200	25	175
Algorithm Development	200		200
Total			$1000k

5. Telescope Upgrades

When the VLA went into operation in 1980, it gave an improvement in resolution, sensitivity, speed, and image quality of more than two orders of magnitude. Since that time, the VLA has been an extraordinarily productive scientific instrument, and has been used by more than 1200 astronomers for a wide variety of investigations, including solar system, galactic, and extragalactic research. However, as a result of technological advances during the past decade, much of the instrumentation is seriously out of date and major replacement and upgrading of the instrumentation is needed to realize the potential of the investment in the VLA.

Recognizing the scientific potential of the VLA equipped with more modern instrumentation, the Report of the Radio Astronomy Panel of the Bahcall Committee emphasizes the need for a comprehensive upgrade.

The operation and maintenance of the VLA needs to be brought to a level appropriate to its broad scientific impact and great capital investment, and the seriously out of date instrumentation needs to be replaced with modern low-noise radiometers, fiber optic transmission lines, and a modern broad-band correlator. These upgrades will improve the sensitivity by up to an order of magnitude, improve the frequency coverage and spectral resolution, and increase the maximum allowable image size.

The significant instrumentation improvements mentioned here form the basis of the plan to upgrade the VLA. It can easily be funded incrementally over a decade and yet be useful at each stage of its development. The table below outlines the essence of the VLA upgrade, assuming the work extends over ten years.

Telescope Upgrades - A Ten-Year Plan

	Cost to Complete	10-Year Plan: Annual Funding
Receiver Sensitivity	\$ 8.0M	\$0.8M
New Frequencies	8.0	0.8
Fiber Optics IF System	9.0	0.9
Broadband Correlator	11.0	1.1
TOTAL	\$36M	\$3.6M

Receiver Sensitivity. New receivers based on cooled low noise HFET amplifiers are needed to lower the system temperature at all bands except 3.6 cm where these devices already exist. The proposed receivers are based on designs already implemented at the VLBA.

New Frequencies. Three new observing bands, at 610 MHz, 2.7 GHz, and 43 GHz, are being considered for the VLA, and one at 86 GHz for the VLBA. The 610 MHz and 2.7 GHz bands are intended to fill in the gaps in existing coverage, while the 43 GHz system will improve the resolution by a factor of two. The additional frequencies are important for continuum studies of spectra as well as the effect of Faraday rotation and depolarization which are tied to: specific critical frequency regimes that are determined by source physics; for pulsar work where the critical frequencies of observation are determined by the spectra and dispersion; and for unique spectral lines such as SiO at 43 GHz.

Fiber Optics IF Transmission System. In order to distribute 2 GHz of bandwidth from each antenna (two polarizations, each with 1 GHz), the current waveguide transmission system needs to be replaced with a modern fiber optics link. This will also permit future expansion to even wider bandwidths, and will allow inclusion of signals from other, more widely dispersed antennas. For the first stage, a fiber optics link will replace the waveguide connection between the VLA antennas and it will connect the Pie Town VLBA antenna to the VLA correlator.

Broad Band Correlator. The VLA provides a maximum bandwidth of 100 MHz, obtained by a pair of separately tuned, 50 MHz wide bandwidths. These bandwidths were set by technological limitations current some 15 years ago, and cannot be greatly expanded. In conjunction with greatly improved IF transmission capability, a full 1 GHz bandwidth in each polarization can now be implemented. A 2 GHz capability is also possible in the future.

Modern correlator design based on the FX approach, used successfully by the VLBA, is especially suited to arrays with large numbers of elements, such as the VLA. With an FX correlator and good spectral resolution, it should also be feasible to delete narrow-band RFI and thus exploit the full bandwidth of the IF system.

III. 1992 SCIENTIFIC PROGRAM

1. Very Large Array

The VLA is the fundamental research instrument of choice for ground-based, high resolution, centimeter wavelength astronomy for an ever-expanding population of the world's astronomers. Although the VLA is used for over 400 projects annually, there are an equal number of meritorious proposals that cannot be accommodated in its heavy schedule. The demand for VLA time is widespread across all astronomical subdisciplines from solar physics to cosmology.

During 1992 solar physicists are planning to carry out several multi-wavelength coordinated observing campaigns of the sun where the VLA will be the primary radio instrument. The VLA will give radio wavelength support simultaneous with a major campaign to study solar flare physics with a long duration Antarctic balloon-borne X-ray experiment. The multi-wavelength data will be critical for understanding microflares, flare particle acceleration, and the "super hot" flare plasma component. In another simultaneous campaign, VLA observations will support Gamma Ray Observatory (GRO) and Japanese Solar A high-energy/high-time resolution observations of solar activity. Solar A images of the morphology and brightness of lower lying magnetic loops will be directly compared with simultaneous decimetric VLA observations of bursts produced by energetic electrons in the middle corona.

Planetary investigations are planned for Venus, Jupiter, Saturn, and Uranus. Observations of Venus at 1.3 cm in spectral line mode will undertake the difficult task of determining the Venusian atmospheric water vapor abundance. Towards Jupiter, P-band observations of the scintillation or scattering of background radio sources will provide a novel method of investigating Jupiter's extended magnetosphere in detail. Multi-wavelength VLA observations of Uranus will improve on earlier determinations of its atmospheric microwave spectrum and possible variations in its brightness temperature distribution that will test the "warm pole" model. The VLA/Goldstone radar echo technique will again be applied to the rings of Saturn. The magnitude and polarization characteristics of the echo will be used to constrain the physical properties of the ring particles.

Observations of stars and their near environment at radio wavebands will be undertaken by many VLA investigators. A new class of photometrically variable stars, presumably star-spot related, will be the subject of a continuing VLA survey of chromospherically active stars. Additional radio detections are required for improved statistical studies of chromospheric activity, and the brightest stars will be useful for radio astrometry, as well. A detailed multi-wavelength campaign will study spatial structures and flares on the eclipsing RS CVn system AR Lacertae, which is an ideal laboratory for the eclipse mapping technique. The coordinated efforts of the Hubble Space Telescope (HST), International Ultraviolet Explorer, and Ginga (the Japanese X-ray satellite) will join the VLA observations. A coordinated multi-band effort will also be directed towards the magnetic cataclysmic variable, AE Aquarii, with the goal of characterizing its flaring activity in order to test the hypothesis that the flares may be associated with disruption of the accretion disk near the magnetized white dwarf. In contrast, the isolated white dwarf GD356, with an 11 million gauss magnetic field and evidence for strong chromospheric activity, will be investigated for continuum radio emission as a diagnostic of alternative models of the system. The outflow from the Mira variable, R Aquarii, will be observed with the VLA and compared to HST [OIII] images, astrometry, and high-resolution speckle interferometry Hα images in order to better understand potential excitation mechanisms which power the outflow. A coordinated optical and VLA radio monitoring program of the X-ray binary LSI+61°303 will investigate its orbital spectral evolution as a test of suggested models of the system. The VLA will be used to examine three globular clusters containing X-ray sources detected by the German Roentgen Satellite (ROSAT) to test for the presence of accreting neutron stars. In other globular clusters VLA data will help to pinpoint cluster X-ray sources in order to aid optical identifications for follow-up studies.

Pulsar studies with the VLA continue to break new ground. Very high-time resolution measurements of "giant" pulses from the Crab pulsar will be obtained in order to establish characteristics such as polarization and dynamic spectra for comparison with recent data from the GRO and the Green Bank 140 Foot Telescope. Fast pulsar timing experiments of millisecond pulsars will complement similar studies at Arecibo and provide invaluable tools for the study of astrometry, binary star evolution, cosmology, gravitation physics, and timekeeping metrology. Quiescent low mass X-ray pulsars (LMXP) will be searched for evidence of pulsar activity linking LMXP's to millisecond pulsars. Neutral hydrogen absorption measurements towards six inner Galaxy pulsars will help determine kinematic distances and place constraints on the distribution of diffuse ionized gas in our Galaxy. Further observations at 327 MHz will be used to accumulate statistical information on the pulsar content and pulsar parameters of globular clusters. The proper motion of the very young pulsar in the supernova remnant G5.4-1.2 will be determined as a test of the asymmetric explosion model of its origin.

Stars in the later stages of evolution will be the target of several VLA programs. Observations of the water vapor maser line will trace mass motions in circumstellar shells during the pulsation and mass loss phases of late type stars. The carbon star, V Hydra, in transition to a planetary nebula, will be observed in order to search for time variability and to determine its spectral and morphological characteristics. For the planetary nebula, NGC 6302, VLA second epoch observations will be carried out to detect angular expansion and to determine a distance. Known supernovae will be monitored in the galaxies M83 and Markarian 297 as part of long-term studies to determine their statistical properties, light curves, and spectral indices. Over 100 nearby galaxies will be regularly monitored as part of a long-term probe of the radio properties of supernovae to provide a framework for numerous studies of their evolution and standard luminosity characteristics.

The study of galactic supernova remnants (SNRs) with the VLA offers exciting opportunities to make detailed comparisons between observation and theory. Four young remnants have been chosen as a test bed for the study of small-scale SNR structures which should lead to an understanding of filaments and electron acceleration mechanisms. For IC 443, VLA observations of shocked HI gas will constrain models of energy transport to the interstellar medium from SNRs. SN1006 is targeted for high resolution observations of its shell thickness and expansion. Finally, the remnant Cas A will serve as a background source for critical studies of the intervening interstellar medium using the carbon recombination lines.

The high resolution and sensitivity of the VLA make it a powerful tool for the investigation of star formation regions throughout the Galaxy. The final phase of a galactic plane survey of ultra-compact HII regions will be completed in order to statistically study the rate of massive star formation, the contribution of massive stars to the total energy budget of the galaxy, and their general environmental impact throughout the galaxy. Multi-epoch studies of some ultra-compact HII regions will probe the dynamics of their expansion or contraction. In other cases, a search for H_2O maser emission will test the bow shock hypothesis in the outflows of newly formed massive stars. Multi-frequency observations of outflow sources in the ρ Oph star forming region and in the L723 molecular cloud will help to clarify the nature of their power sources and improve the angular resolution of existing images of the outflow features. Deep observations will be made of two regions containing many infrared sources near LkHα 101 to probe for radio emitting young stellar objects and to compare the radio luminosity function of the region to that for the ρ Oph regions. Neutral hydrogen observations of the bipolar flow of the DR21 HII region will help determine the kinematics and magnetic field in the neutral gas surrounding the outflow. An attempt will also be made to detect dust emission from circumstellar disks associated with young stellar objects. If successful, the detections will afford unprecedented resolution of such systems.

The general interstellar medium will be the focus of several VLA projects. The VLA will play a critical role in a study of the relationship between various phases of the ISM toward globular clusters. The VLA HI absorption spectra toward background continuum sources will be used in conjunction with other wavelength data and the measurement of globular cluster pulsars. An attempt will also be made to detect the 327 MHz atomic deuterium line in absorption against Cas A.

Detailed radio features in the immediate vicinity of the galactic center will be imaged at dynamic ranges of up to 70,000:1 at several wavelengths in order to establish their intensity and spectral index distribution as part of a study of their physical relationship to one another. Recombination line studies seek to establish the kinematics of the features, as well, and to search for ultra-high velocity emission components. Determination of the velocity field very close to Sgr A* will help to differentiate its gravitational or non-gravitational origin and potentially generate a direct estimate of the mass of the central object. OH absorption line measurements toward Sgr A will attempt to confirm and extend earlier VLA Zeeman measurements of large magnetic fields in the milligauss range which occur in the circumnuclear disk in comparison to the overall interstellar field of a few microgauss. Simultaneous H110α and H138β recombination line observations of the inner galaxy will be mosaiced in order to clarify conflicting determinations of the temperature gradient from recent radio and infrared measurements. The galactic center star forming region Sgr B1/B2 will be extensively studied at higher resolution in order to gain detailed information about the many ultracompact HII regions that are concentrated there. An accurate assessment of the star formation parameters, electron densities, mass function, etc., is critical to the global comparison of star formation throughout the Galaxy as a whole.

Coordinated VLA-Granat-GRO (Granat is the Russian gamma-ray satellite) observations of the compact source of positrons near the galactic center will be carried out in order to study its strong variability and to clearly identify the source for additional correlative analysis. The source of the 511 keV positron-electron annihilation line will also be searched for the existence of positronium recombination lines. A positive detection would immediately give information about the position, velocity extent, and physical conditions within the region of formation and annihilation of positronium.

Many investigations of normal galaxies will be undertaken with the VLA in pursuit of a wide variety of goals, which include the physics of individual galaxies and their components as well as the kinematics and evolutionary consequences of galaxy-galaxy interactions. Several morphologically distinct galaxies with ring structures such as NGC 5122 or the Cartwheel, possibly related to galaxy encounters or wave induced star formation, will be studied in the HI spectral line in order to determine important parameters that are necessary for the correlation of kinematics, masses, star formation histories, and morphologies. The most probable models will be tested by the observations. In many instances the VLA will produce the first available high resolution, multi-frequency data for direct comparison to existing optical and infrared databases. In nearby galaxies, such as NGC 1808, it may be possible to understand in detail the gas kinematics near the active nucleus. The structure of the interstellar medium in nearby dwarf galaxies will be investigated to see if the HI "holes" discovered in UGC 4305 are a general phenomenon resulting from stellar wind and supernova driven shocks in these gas rich galaxies. High resolution HI maps of the dwarf irregular DDO 47 will be obtained in order to study its organized spiral arm pattern and possible connection to a nearby companion galaxy.

Galaxies exhibiting starburst activity as a result of the presence of intense, active star formation regions will be observed with the VLA. The numerous compact sources in the central portions of NGC 253 and M82 will be studied for variability behavior in order to determine supernova rates, identify HII regions, and differentiate the spectral properties of the sources to better understand galaxy evolution. The halo or bipolar outflow structures of some starburst galaxies will be imaged in the radio for direct comparison to optical and X-ray databases to test existing galactic superwind models. Polarization observations should also yield magnetic field configurations and provide necessary data to eventually evaluate the role that magnetic fields play in the starburst phenomenon.

VLA studies of Seyfert galaxies are required to fully understand the physics of the nuclear AGN phenomenon and its relationship to the circumnuclear region. NGC 3393 will be observed with the VLA as part of a detailed infrared, optical, and ultraviolet investigation of the morphology, kinematics, and energetics of the galaxy. For NGC 1068, a detailed comparison of multifrequency VLA, molecular (CO) and Hα observations will provide data for studying the nature and origin of the ring that is present in its circumnuclear disk. Short observations of several spiral galaxies will be carried out in a search for compact flat spectrum cores that may be related to the Seyfert phenomenon in other galaxies.

Many general studies of classical radio galaxies will be carried out with the VLA. High quality VLA images will be directly compared to optical data for several southern radio galaxies that have extra-nuclear uv continuum emission. The data will help differentiate young stars, scattered light, or synchrotron emission as the origin of the continuum. A sample of 3C radio sources will be studied in order to determine the spatial relationship between radio structure, depolarization, spectral variation, and extended emission-line gas in radio galaxies and quasars. Snapshot observations of a Molonglo sample of optically identified objects will be obtained in order to investigate the evolution of the radio luminosity function of radio sources and the relation between radio galaxies and quasars.

Specific radio source studies will focus on understanding the physics of individual sources in regions such as the radio lobes, hot spots, jets, and nuclei. A sample of high power sources will be examined for the presence of radio jets in comparison to lobe asymmetries in spectral index and depolarization to ultimately test the Doppler boosting/projection effect hypothesis for the appearance of radio source structures. Sources with extended jets but no lobe hotspots will be compared with other sources to determine if the effect is intrinsic to the physics of the jets or is due to Doppler beaming. The statistics of jet/counterjets in a sample of 3CR sources will also be investigated as a test of the unified beaming scheme for radio galaxies and quasars. In 3C 273 and 3C 279 second epoch VLA images will be evaluated in a search for superluminal motions in their kiloparsec-scale jets as clear evidence for relativistic speeds and beaming outside of the core parsec scales detected by VLB techniques. A detailed multiwavelength VLA-HST investigation of the optical jet in 3C 66B should put useful constraints on jet particle acceleration mechanisms.

Radio sources in the cluster and supercluster environment continue to be important VLA targets. VLA observations of Parkes radio sources in several rich southern clusters are intended to improve the statistical database, from which to analyze cluster cooling flow environments, luminosity functions, etc., in comparison to the well studied northern sample. A complete sample of radio sources near the centers of rich clusters will be used to determine morphologies and size distributions in a study of the evolution and properties of individual radio sources and as a test of standard models for the creation of jets and radio lobes. Head-tail sources in poor clusters and narrow angle tail galaxies in the outskirts of rich clusters will constrain the analysis of the kinematics of the cluster galaxy population and to understand the dynamics of radio jets. Three irregular galaxies in Abell 1367 have extremely peculiar radio properties and will serve as probes of the dynamical interaction between the galaxies and the intracluster medium. A complete sample of distant X-ray selected clusters will be observed to determine the evolution of the radio galaxy population with cosmic time. Similar studies will be extended to radio galaxies in loose group environments where there is evidence that encounters between galaxies initiate star formation or lead to HI deficiencies in cluster spirals.

The VLA is uniquely suited for many studies of quasars and BL Lac objects. Several quasar samples will be observed in order to improve the statistical basis from which to make radio-optical comparisons. An optically complete sample of 95 quasars with mean redshift equal to 3.4 will be observed in order to differentiate the properties of low-z and high-z quasars if the early epoch quasars are characteristically different from their low-z counterparts. High resolution radio images will be completed for another large quasar sample and will allow the degree of distortion of the radio structure to be analyzed as a function of power and redshift and also compared to a sample of radio galaxies. Samples of intermediate redshift quasars in and out of rich and poor cluster environments will be compared directly to other morphological studies for low-z radio galaxies and for high-z quasars, and the statistical differences may constrain the mechanism for fuelling quasar activity. The radio properties of the highest redshift ($z > 4$) quasars will be studied in order to plan a future radio survey for such quasars, which are currently all optically detected. VLA observations in the P-band will search for highly redshifted HI absorption corresponding to the optically detected damped Lyman alpha line with the intent of understanding the physics and evolution of gaseous HI in the early universe. Recently detected Lyman alpha companions to distant ($z \sim 3$) quasars offer the opportunity for the VLA to carry out a morphological and polarization study of quasar evolution related to it specific environment. The radio emission properties of these sources should discriminate faint radio galaxies from potentially exciting primeval galaxies with active star formation present.

The detection of HI absorption at $z = 3.4$ against a radio galaxy with an optical redshift only slightly higher than the absorption redshift will be followed up in several ways. Higher velocity resolution observations will be attempted in order to discriminate the clumpiness of the absorption. Any detected velocity-space structure in the absorption could mean that fragmentation of the absorbing material (protocluster?) already occurred at an earlier epoch. A similar search for other HI absorption against galaxies or QSOs at redshifts near 3.3 will also be undertaken.

Deep radio surveys with the VLA will be carried out towards two of the ROSAT deep survey fields. The radio observations will put firm limits on non-QSO contributions to the X-ray background and help to discriminate models seeking to unify the radio and optical properties of QSOs. Known gravitational lens systems will receive continued VLA monitoring in order to both constrain the individual gravitational lens models themselves and to contribute to methods for determining the Hubble constant.

A search for new bright BL Lac objects will use VLA observations as a follow-up to a sample of bright unidentified X-ray sources from the Einstein "Slew Survey." The joint X-ray/radio method is 80 percent efficient for objects seen at both wavebands and the effort promises to increase the number of known BL Lac objects many fold in order to improve statistical studies of their extreme AGN behavior. The arcsecond scale radio structure of seven X-ray selected BL Lac objects will be imaged to directly test whether the X-rays in these objects are beamed or are isotropic. The VLA will participate in a large international effort to monitor multiwavelength variability events in the BL Lac object PKS 2155-304 as a test of the standard synchrotron self-Compton jet model. High dynamic range images of BL Lac objects and flat spectrum radio galaxies will test the microlensing hypothesis for BL Lacs and augment the relational database of X-ray and radio selected objects.

2. Interim VLBA

The VLBA is rapidly nearing completion as construction remains only on one or two of the ten sites. Astronomical observations with the completed antennas, once they are operable, however, are necessarily limited. Priority must be placed on the effort to complete the project and to thoroughly check its performance before it is dominated by astronomical observations. Inherent in the current situation is the requirement of maintaining schedule flexibility during the break-in period. Although there have been numerous requests to use available VLBA antennas for specific scientific proposals, few have been accommodated to date. Excellent proposals continue to be received and several are detailed here.

The VLBA is an ideal instrument for pulsar astrometry and can be used to investigate and understand the positional differences which have been found between the positions derived from pulsar timing analysis and those found from interferometric techniques. Pulsar space velocities are also important and require multi-epoch observations. Phase referenced VLBI observations of radio stars have been proposed to provide a crucial link between the Hipparcos optical frame and the radio VLBI celestial frame at the milliarcsecond level.

The shortest VLBA baselines will provide ideal spatial frequency coverage for detailed investigations of non-thermal radio activity in luminous OB stars where the emission is generated at many stellar radii above the stellar surface. OH and H_2O maser emission observations of the post-AGB object OH 17.7-2.0 should provide a detailed image of the circumstellar shell structure. The milliarcsecond images should help to diagnose potential bipolar morphology and the nature of high velocity features in the OH spectrum. The VLBA will facilitate the measurement of interstellar scattering produced by the Cyg OB1 interstellar bubble and help to test mechanisms for the generation of turbulence in such regions.

Extragalactic programs seeking VLBA observing time range from observations of megamaser galaxies to the study of the energetics of the nuclear cores of distant radio galaxies. VLBA observations can examine the picture of an unsaturated megamaser amplifying an intense continuum background in the megamaser galaxy IRAS 17208-0014. The flat-spectrum core of one of the most distant radio galaxies known (0902+34, $z = 3.395$) is a proposed VLBA target. Detection of the nucleus would be a unique opportunity to relate the parsec-scale radio characteristics of the nucleus with the morphology of the surrounding gas which it is actively photoionizing. For a complete sample of compact double radio sources, VLBA observations are proposed to obtain accurate radio spectra for the individual components appearing over parsec scales. The aim is to better discriminate the physical and dynamical processes that occur in the compact regions in the context of relativistic beaming models.

As the instrument nears completion during 1992, the number of astronomical proposals carried out on the VLBA should rise significantly.

3. 12 Meter Telescope

Millimeter-wave, single dish telescopes are used by astronomers to address many fundamental astrophysical questions. Such telescopes excel in problems requiring sensitivity to low brightness, extended emission, and to multi-species, multi-transition molecular line investigations. The Observatory has undertaken an aggressive program of technology development at the 12 Meter Telescope to enhance the capabilities in these areas: for weak emission, a complement of high-sensitivity SIS receivers is under development; to speed the observation of highly extended emission complexes, multi-beam imaging receivers are being built; and to supply the frequency agility required for multi-line studies, sensitive receivers have been completed or are under construction for all the usable wavebands at the 12 Meter ranging from 68 to 360 GHz.

Millimeter-wave telescopes are sensitive to emission from cold, interstellar gas, to short-wavelength bremsstrahlung radiation, and to long wavelength emission from cold dust. Because of the sensitivity to cold material, millimeter-wave science is invaluable in the study of galactic structure, and unique in the study of star formation processes. Much of the research undertaken with the 12 Meter Telescope will concentrate in these two areas.

In the area of star formation, researchers will combine millimeter-wave techniques with new infrared techniques to develop a more complete picture of the steps and chronology of the star formation process. For example, 12 Meter Telescope users will compare images of CO emission with IR camera images of the molecular cloud surrounding LkHα 101 to search for age segregation in the associated star cluster.

Making use of the frequency agility of 12 Meter Telescope receiver systems, astronomers will use the emission from various molecules to determine the physical conditions of star forming regions. Most studies of interstellar clouds now make routine use of several CO isotopes, often in at least two rotational transitions. Other species serve as thermometers. Thus, ratios of [DCO+] to [$H^{13}CO^{+}$] will be used to measure the temperatures of cold cores in clouds such as ρOph. Other molecules, such as CS, will be used as sensitive densitometers. With CS, visiting astronomers at the 12 Meter Telescope will search this year for small, dense cloud clumps that may be indicative of proto-brown dwarfs.

Studies of large-scale galactic structure can be extremely time consuming when using the small beams of high frequency radio telescopes. The 230 GHz, 8 beam receiver and future multi-beam receivers will facilitate most studies of this sort, and make others feasible when they were heretofore practically impossible. These multi-beam receivers are the millimeter-wave equivalent of imaging cameras used in the optical and infrared. Such systems will, for example, allow many globules, Barnard clouds, and Sharpless objects to be imaged quickly. The 8 beam receiver is currently being upgraded with more sensitive SIS mixers, and is expected to be back in service this year.

In addition to observations of galactic star forming regions, astronomers will use the 12 Meter Telescope to study the cloud structure and interstellar medium of external galaxies. Because of the perspective offered by our view from afar, external galaxies can provide information on galactic structure that is not apparent by studies of our own galaxy. Many external galaxies including M31, M33, and M83 are close enough to allow detailed structures to be resolved and studied. Here again, astronomers will make heavy use of the multi-beam system and the low-noise, single-beam systems to allow fast mapping even when high sensitivity is required.

Many specific problems in our understanding of external galaxies will be addressed by 12 Meter Telescope research. For example, a study will be conducted in how star formation proceeds in M33, a low mass spiral with a low surface density of gas.

The sensitive new receivers will also allow the study of numerous distant galaxies of cosmological significance. In one case, observations of various transitions of CO and CI will be made of the highly redshifted ($z = 2.286$) infrared object IRAS 10214+4724, a possible proto-galaxy. In addition, a sensitive search for CO in a sample of powerful radio galaxies will be conducted. This study will provide a critical test of the hypothesis that gas rich galaxies fuel powerful extragalactic radio sources.

The 12 Meter Telescope has a rich tradition in the study of astrochemistry, which should continue in the coming years. The high sensitivity and frequency agility of the new generation of SIS receivers will greatly aid in these studies. The emphasis in the coming years will likely be on refractory and light metallic compounds such as AlO, and on ions such as $HNSi^+$ and SO^+.

The 12 Meter Telescope is a versatile instrument used for projects ranging beyond those described above. Each year the 12 Meter Telescope is used for studies of continuum emission from quasars and galaxies, and sometimes from dust in our own galaxy. As well, the 12 Meter supplies a crucial baseline in millimeter-wave VLBI experiments, which are now becoming routine and highly productive scientifically. The 12 Meter is also used for studies of planetary atmospheres, including the earth's. Because of the sensitivity and high velocity resolution available, 12 Meter observations of planetary atmospheres have become competitive with the results obtained from planetary fly-bys.

4. <u>140 Foot Telescope</u>

One of the great virtues of the 140 Foot Telescope was highlighted once again in 1991: its nearly continuous frequency coverage with sensitive receivers at all bands permits unique exploratory observations from which new discoveries spring. The most recent surprising discovery was the detection of a methanol (CH_3OH) maser transition at a frequency of 6.6 GHz. The molecule's spectral line is second in strength only to some water maser lines, and it is found in many regions of the galaxy. Not only will future studies assist in understanding the maser phenomenon itself, but also they will provide new probes of star forming regions. Observations in 1992 will extend the search for methanol masers to external galaxies.

The fact that a line of such strength escaped detection for so long, even though many radio telescopes operated well at 6.6 GHz, hints at a wealth of research opportunity in the field of centimeter wavelength spectroscopy. The 140 Foot Telescope will therefore continue to be active in this area. Searches for several new molecules will continue, among them propadienone H_2C_3O, cyclic C_3D, and the butatriene carbene H_2CCCC. New molecules are still being discovered at the rate of four to five per year, about half of which the 140 Foot Telescope has recently been detecting. Of late the discoveries have only deepened the mystery about interstellar molecule formation, because the new species are increasingly complex and exotic. It should come as no surprise that a proposal is in hand to search the 4,0-3,1 methanol transition at 28.3 GHz to see whether maser emission is present. The capability for observations at frequencies in the 25-35 GHz band was newly installed on the 140 Foot Telescope, a development that has resulted in other new proposals as well.

Some mapping observations of galactic regions will also be undertaken. Methylidyne (CH), for example, may be a better tracer of molecular gas than CO in low density ($\leq 10^3$ cm^{-3}) regions. Accordingly one of these regions, MBM16, in a high latitude translucent cloud will be mapped with a goal of understanding the cloud's dynamical behavior. Another region to be mapped is the Cepheus-Cassiopeia molecular cloud complex, this time in neutral hydrogen for studying the structure and motion of the diffuse gas there.

Extragalactic spectroscopic observations will consume a greater proportion of telescope time than in the past. One study will probe the gas in the dust lane and nuclear region of the powerful radio galaxy Centaurus A by intercomparing several molecular transitions. Another will study the intergalactic medium by searching for stimulated radio recombination line emission in the directions of quasars and AGN galaxies. If such emission is found, follow up observations will search for time variability. Formaldehyde (H_2CO) observations of external galaxies will be used to determine whether the molecule can be used as a thermometer of a galaxy's radiation field. Specifically, will comparison of the 6 and 2 cm transitions reveal candidate regions where searches for molecular transitions at millimeter wavelengths will be successful?

As in the past, several extragalactic neutral hydrogen observations will be scheduled. Basic aims are to map the distribution of matter on the largest scales possible and to study the effect of environment on galaxy formation. For mapping out to $z = 0.025$, a sample of Sc galaxies has been selected in the southern sky outside the Arecibo limits and where optical data already exist. The sample will be used to investigate possible deviations from uniform Hubble flow in addition to providing information about the spatial distribution. With respect to galaxy formation, one proposal will search for HI emission from low surface brightness, dwarf galaxies. Do dwarfs and giants have similar spatial distributions is one question to be answered. A different category of hydrogen observations searches for absorption features. In one such program, HI absorption will be looked for against quasars with strong continuum emission in a redshift range inaccessible to optical searches, $z = 0.4\text{-}0.9$. Any disk systems found in this way will illuminate our understanding of the condensation process of intervening matter over long spans of evolutionary time. An even more exotic use of HI absorption spectroscopy will search for evidence of a gravitationally lensing galaxy in front of the quasar pair: 2345+007. These and other such programs rely on the frequency excision property of the spectral processor. They can therefore only be conducted at Green Bank.

The demand for 140 Foot Telescope time devoted to pulsar observations continues to increase, a product of the breakthroughs that continue to occur in this field of research. Two regular monitoring programs aim to make accurate timing measurements. One focuses on the highest accuracy attainable, with the hope that a small properly distributed array of high-accuracy clocks can be a reference frame both for studying solar system dynamics and for searching for gravitational waves. The other timing observations are in conjunction with the GRO. Gamma ray signals are too sparse to submit to power spectrum analysis in search of regular pulses, but a search can be made at a specific pulse periodicity if that is provided by radio observations.

Two other pulsar monitoring programs probe the interstellar medium. One measures dynamic spectra, that is, two-dimensional frequency vs. time distributions of pulse intensities determined at various epochs. The goals are to measure the amplitude of refractive scintillations, to determine statistical scintillation velocities, to study the frequency of occurrence of interferometric fringing--from interstellar turbulence, and to measure proper motions. The other such program repeatedly measures HI absorption spectra in the emission of pulsars. If changes occur, they can be related to other interstellar phenomena, such as variable dispersion measures, decorrelation bandwidths and decorrelation times.

Very Long Baseline Interferometry (VLBI) will utilize about 20-25 percent of the available telescope time. Nearly all of the programs will be scheduled by the VLBI Network. However, the 140 Foot Telescope's sensitivity also leads it to be used in special non-Network experiments. Once per year, for example, the 140 Foot Telescope is tied into the Crustal Dynamics Network as a check on the internal stability of the North American tectonic plate. The telescope is also requested for a special project mapping low power radio galaxies, since Green Bank fills a gap between VLBA antennas and Italian VLBI antennas.

The 140 Foot Telescope, with its low noise, 30 GHz, wideband receiver, will be used in an attempt to detect anisotropies in the Cosmic Microwave Background Radiation on 5-10 arcminute scales. The advantages of the 140 Foot Telescope include system stability and nearly gaussian noise statistics.

IV. MAJOR USER FACILITIES

1. Very Large Array

Status of Present System

More than 625 scientists used the VLA for their research work in 1990 and a similar or larger number will have done so in 1991. Demand for the VLA arises both from the multi-wavelength nature of contemporary astronomical research and from the flexibility of the telescope. With regard to the former, it is now widely recognized that radio observations provide unique insight into a variety of astronomical objects that may be used to complement the information gained with telescopes operating at visible, infrared, or X-ray wavelengths. Or, it may be the focus of one's research with complementary data provided from observations at other wavelengths. For either case, the fact that the angular resolution and field of view of the VLA is nearly identical to that achievable with modern detectors at other wavelengths means that all the data can be merged with no ambiguity. This provides a very comprehensive research capability.

Present Instrumentation

The VLA consists of twenty-seven 25 meter antennas arranged in a wye configuration, nine antennas on each 13 mile arm of the wye. The antennas are transportable along double rail track and may be positioned at any of 72 possible stations. In practice, the antennas are rotated among four standard configurations which provide a maximum baseline along each arm of 0.59, 1.95, 6.39, and 21.0 km, respectively. Reconfigurability provides the VLA with variable resolution at fixed frequency.

The VLA supports six frequency bands, remotely selectable; the five upper bands by means of subreflector rotation. When the VLA became fully operational in 1981, receiving systems were supported at 1.4, 5.0, 14.4, and 22.5 GHz, with the fundamental amplification at all four frequencies occurring via a 5 GHz parametric amplifier--1.4 GHz was preceded by a parametric upconversion to 5 GHz, whereas both 14.4 and 23 GHz were mixed down to 5 GHz for amplification. Since 1981, most of these systems have undergone major improvements. Presently,

- 1.4 GHz amplification is done at the signal frequency with a cryogenic GaAsFET developed at the NRAO Central Development Laboratory (CDL);
- 5.0 GHz amplifiers are nearly all CDL GaAsFETs;
- 14.4 GHz amplification is done at the signal frequency with CDL GaAsFET amplifiers;
- 23 GHz amplifiers are CDL HFET units. In addition, two new frequency bands have been installed;
- 8 GHz HFET amplifiers have been added to all antennas. This X-band system was constructed with funding provided by NASA/JPL in support of the Voyager 2 encounter with Neptune;
- 327 MHz prime focus FET receivers were installed.

The table below summarizes the parameters of the VLA receiver system.

VLA Receiving System

Frequency (GHz)			T_{sys} (K)	Amplifier
0.308	-	0.343	150	GaAsFET
1.34	-	1.73	60	Cooled GaAsFET
4.5	-	5.0	60	Cooled GaAsFET
8.0	-	8.8	35	Cooled HFET
14.4	-	15.4	110	Cooled GaAsFET
22.0	-	24.0	180	Cooled HFET

The VLA receives two IFs with full polarization capability in all continuum and spectroscopic bandwidths ranging from 50 MHz to 195 kHz. Within certain total bandwidth limitations, 512 channel spectroscopy is supported in all bands.

Future Plans - Electronics

When the VLA went into operation in 1980, it gave an improvement in resolution, sensitivity, speed, and image quality of more than two orders of magnitude. Since that time, the VLA has been an extraordinarily productive scientific instrument, used by more than 1200 astronomers for a wide variety of investigations, including solar system, galactic, and extragalactic research. However, as a result of technological advances during the past decade, much of the instrumentation is needed to keep the VLA at its current leading position among the world's radio astronomy facilities.

When designed in the mid-1970s, the VLA used state-of-the-art technology. Over the last fifteen years, however, there have been major advances in receiver sensitivity, correlator design, and the transmission of broadband signals which have already been incorporated into other new radio telescopes such as the VLBA, the Australia Telescope, and the Nobeyama millimeter interferometer. In its current configuration, the VLA can still observe radio sources which are two orders of magnitude fainter than have been observed by any other radio telescope. By using modern low noise radiometers, fiber optic transmission lines, and a broad bandwidth correlator, it will be possible to gain another order of magnitude improvement in sensitivity. New receivers are also needed at wavelengths not presently covered in order to extend both the spectral coverage and the range of sensitivity to low surface brightness observations.

The program to modernize the VLA electronics amounts to a major overhaul of the entire receiving instrumentation. It is described in Section II of this Preliminary Program Plan as one of the steps needed to restore the Observatory infrastructure. The first step, in 1992, is to complete the upgrade of the VLA L-band receivers to HFET instrumentation in individual cryostats. Ten antennas remain to be completed. The remainder of the ten-year program to restore the VLA is outlined in Section II.

2. 12 Meter Telescope

The NRAO 12 Meter Telescope is the only U.S. millimeter wavelength telescope operated full-time as a national facility. More than 150 visiting astronomers make use of the telescope annually in support of their research endeavors.

The proposal pressure of the 12 Meter has increased dramatically as a result of its new complement of SIS receivers. From 70-270 GHz, in all the available atmospheric windows, the 12 Meter Telescope offers 4K SIS receivers with lower noise figures (better sensitivity) than any other instrument in the world. The capability at 70-90 GHz is in special demand owing to the discovery that galaxies at high redshift are rich reservoirs of molecular gas. At the 12 Meter Telescope searches can be conducted for the CO (J = 1-0) line at redshifts from $z = 0$ to $z = 0.65$ with one receiver. This new scientific capability is a useful, and surprising, complement to the Galactic astrochemical studies for which the 70-115 GHz SIS receiver was primarily intended. It also illustrates the richness of the millimeter-wave sky still to be explored with the proper instrumentation.

Present Instrumentation

The basic specifications of the 12 Meter Telescope, its size, receivers, and spectrometers are given below:

Telescope Specifications

Diameter: 12 meters
Astrodome with slit
Pointing accuracy 5"
Effective surface accuracy: 50-60 μm rms
Aperture efficiency: 49% at 70 GHz
45% at 115 GHz
25% at 230 GHz
15% at 345 GHz

As many as four receivers are mounted simultaneously at offset Cassegrain foci on the telescope. Receiver selection is by means of a rotating central mirror and can be accomplished in minutes.

Receiver List

Frequency Range (GHz)	Mixer	SSB Receiver Temperature (K) (per polarization channel)	
68-116	SIS	60-90	
130-170	SIS	<200	Note 1
200-260	SIS	200	
270-310	Schottky	1200-1500	Note 2
330-360	Schottky	1800-2200	Note 2
Eight-Beam Receiver			
220-240	8 SIS	400	

Note: All single beam receivers have two orthogonal polarization channels. Receiver temperatures include all receiver optics.

Note 1: A new frequency band for the 12 Meter Telescope.
Note 2: Soon to be replaced by a SIS system.

The following filter bank spectrometers are maintained so that the astronomer will have access to the proper frequency resolution for a particular astronomical observation.

Filter Bank List

Resolution (kHz) Per Channel	Number of Channels	Number of Filter Banks
25	256	1
30	128	1
100	256	1
250	256	1
500	256	1
1000	256	2
2000	256	2

Note: All filter banks except the 25 and 30 kHz units can be divided into two 128-channel sections to accept two independent IF channels. The 25 kHz filters use the spectrum expander.

To enhance the telescope's spectroscopic capability and to accommodate the 8 beam receiver, a hybrid filter bank/autocorrelator is available. Its instrumental parameters are as follows:

- 8 independent IF sections;
- 1536 spectral channels (can be split into 8 sections)
- maximum total bandwidth options:

  1 x 2400 MHz

  2 x 1200 MHz

  4 x 600 MHz

  8 x 300 MHz

- frequency resolution (per channel): variable in steps of two continuously between 1.56 MHz and 24 kHz.

Instrumentation Plans

Most millimeter-wave spectroscopic studies of star formation, interstellar chemistry, galactic and extragalactic composition, etc., require observations of a number of molecules in a number of traditions, occurring at many different frequencies. These studies can be carried out most expeditiously, and most thoroughly, if high sensitivity receivers are available for all the atmospheric windows, and if a high speed imaging capability is available at the most important wavelengths. Together, these requirements define the focus of the long range plans for the 12 Meter Telescope.

All the developments described here are of immediate relevance to the 12 Meter Telescope, and most are equally relevant to the mmA.

One Millimeter Imaging SIS System

Millimeter-wave telescopes inevitably have small beams and, hence, with the usual single beam system, true imaging of large fields is particularly difficult and time consuming. For large scale imaging, the smaller diameter of the 12 Meter Telescope compared, e.g., with the IRAM 30 meter telescope in Spain, is no disadvantage. We plan to provide a powerful imaging system at our optimum wavelength of 1.3 mm.

To this end, the 8 feed Schottky mixer receiver system was made available to users during the 1989-1990 observing season. The system was a great success in spite of some compromises made in its implementation--the hybrid spectrometer was not yet operating with the full versatility of its original design and the telescope control system severely limited the efficiency of the system. The 12 Meter Telescope now operates under a completely new control system using modern hardware, and the hybrid spectrometer will be completed in 1992.

The 8-feed Schottky system is being upgraded to use SIS mixers, thereby giving state-of-the-art sensitivity in all feeds. This upgraded system should become available to observers in 1992. We plan to have a 32 feed SIS system operational during 1994. The keys to this development are the backend electronics and the data analysis and display capabilities.

Recent development in LSI chips, where a combination of high speed (1 GHz) samplers and ECL logic with multiplexed CMOS logic, give hope for a short development cycle for a new generation of digital correlator. We hope to prototype wide bandwidth digital cards using this new technology in the first part of 1992. Of course, this puts severe demands on the computer hardware and software. The telescope control system has been completely replaced with a modern design which offers great flexibility for future developments. Already, remote observing, controlling the 12 Meter Telescope over area network has been demonstrated and is expected to become a more common mode of operation in a few years. During 1992 and 1993, we will be concentrating on improving observing techniques of the telescope and developing and implementing new observing techniques. The data acquisition rate will have increased by between one and two orders of magnitude. The postprocessing environment will become a network of modern workstations. We have begun to build this network with existing funds, but a great deal of new computer hardware and software development will be required in the next three to four years.

3. 140 Foot Telescope

NRAO Green Bank is making a major transition driven by the GBT. NRAO responsibilities for this new instrument include implementation of the monitor and control system, the adjustable surface, two precision pointing systems, the data analysis hardware and software, and all the electronics instrumentation. These many tasks require contributions from every employee in Green Bank, most of whom were previously focused on improving the capabilities of the 140 Foot Telescope. Consequently, for the first time in the history of the 140 Foot Telescope, no improvements or additions to its capabilities are planned if they are useful to that telescope only. Two caveats qualify this significant shift in emphasis, however. One is, no gap can be permitted in the field of single-dish radio astronomy, or the user community for whom the GBT is being built will dwindle. Hence NRAO is committed to maintaining the 140 Foot Telescope at its present capability and to supporting the users of it. The second caveat is that some developments for the GBT will require testing. The 140 Foot Telescope can serve as an appropriate test bed, with the likelihood that its capabilities in fact will increase.

An obvious example of a new development aimed ultimately for the GBT where the 140 Foot Telescope also reaps benefits is data analysis. No abstract testing of software algorithms is as valuable as the throughput of real telescope data. Likewise, computer networks are optimally tested by weaving them into active systems. Especially important to the GBT will be the ability to observe remotely, with as close to the same capabilities at off site locations as on site. This requires a good interface between the Local Area Network in Green Bank and the wide area networks that are serving the entire U.S. Experience acquired using the 140 Foot Telescope in this manner will be directly applicable to the GBT. Clearly, the data analysis capabilities necessary to the success of the GBT will initially be improvements realized by 140 Foot Telescope users.

The computing capabilities in Green Bank will be strengthened by extending the Local Area Network (LAN). By the end of 1991, most of one floor of the Jansky Laboratory will be fully wired. In 1992 we plan to extend network coverage to the electronics laboratory as well. The greater number of users on the expanded network will require a more powerful server. We plan to use a Sun Sparc2 class machine, backed up with the Database Server-option.

Users of the 140 Foot Telescope may also have access to an improved 750-1000 MHz receiver. This is so because the prime focus receiver for the GBT will incorporate several new concepts, all of which need testing. The major change is that heterodyning will not take place in the receiver box mounted at the focal point. Instead, the rf signal, always < 1.2 GHz for prime focus operation on the GBT, will be carried on optical fibers to the control room itself, where it can be mixed down to an intermediate frequency. Rather than shakedown this new approach on the GBT itself, it seems prudent to do so in advance on the 140 Foot Telescope. A spinoff advantage to the user of developing this new receiver is that it should be lower noise than the one it replaces due to advances in technology since the last one was built.

Other receiver improvements will be made to the Cassegrain receiver system. The heart of this system is a pair of masers that operate in the band 18-25 GHz. A series of upconverters permits the same masers to amplify other bands between approximately 5 and 7 GHz, 8 and 11 GHz, and 12 and 16 GHz. Continuing improvements in HFET technology now allow lower noise amplifiers to be constructed for these three lower bands. Since cooled HFET amplifiers will be used on the GBT, it is important that NRAO push their development by installing them on the 140 Foot Telescope first. In addition to the lower noise, users will also benefit by the elimination of gaps in frequency coverage of the present Cassegrain system and by the greater reliability that transistor amplifiers possess.

A few other GBT features will be tried first on the 140 Foot Telescope. But these may be more useful to the GBT than to the 140 Foot Telescope. One such example is that the way the GBT's Monitor and Control devices interface to instrumentation can be tested first on an existing telescope. Another example may test how the ground reference system of laser distance-ranging devices improves knowledge of a telescope's orientation or pointing.

V. MAJOR CONSTRUCTION PROJECTS

1. Very Long Baseline Array

NRAO's 1992 budget plan for VLBA construction is labeled BD79N01. This plan is in "current dollars"; that is, the 1991 figures are in 1991 dollars and the 1992 figures are in 1992 dollars. We need $8.714M in new funds in 1992. It is currently planned that this will provide sufficient funds to complete all construction work on the VLBA Project. The major activities remaining to be completed in 1992 include completion of the assembly of the tenth antenna in Hawaii, outfitting of the St. Croix and Hawaii antennas, construction of the last ten tape recorders, purchase of the large supply of operating tape, installation and completion of the correlator in the Array Operations Center (AOC), and installation of the last receivers at all sites.

So that this work can be completed in a timely and economic way, we request advanced funding of $4.5M of the $8.714M new funds to be available as soon as possible after 1 October 1991. This advanced funding will be used to purchase the postprocessing computers, initiate the last phase of the tape recorder construction contract at Haystack, and complete the Array Operations Center repayment to New Mexico Institute of Mining and Technology.

Antennas and Sites

The construction status of the individual sites is as follows:

Pie Town, NM - Operational

Kitt Peak, AZ - Operational

Los Alamos, NM - Operational

Fort Davis, TX - Operational

North Liberty, IA - Operational

Owens Valley, CA - Operable and participates in Network observations on an a "best efforts" basis until fully staffed in late 1991.

Brewster, WA - Operable and participates in Network observations on a "best efforts" basis until fully staffed in late 1991.

Hancock, NH - Antenna erection was completed in July 1991. Electronic outfitting is underway and scheduled for completion in December 1991.

St.Croix, VI - Antenna erection is essentially complete. Outfitting is scheduled to start in October 1991. Operability is scheduled for April 1992.

Mauna Kea, HI - The construction of the antenna foundation and control building is scheduled for completion in October 1991. Antenna erection is scheduled to start in October 1991, and outfitting should be complete before the end of 1992.

Sites and Antennas
(in order of antenna erection →)

Activity	PT	KP	LA	FD	NL	OV	BR	HN	SC	MK
Select site	#	#	#	#	#	#	#	#	#	#
Acquire site	#	#	#	#	#	#	#	#	#	#
Develop site	#	#	#	#	#	#	#	#	#	#
Construct control building	#	#	#	#	#	#	#	#	#	+
Construct antenna foundation	#	#	#	#	#	#	#	#	#	+
Fabricate antenna	#	#	#	#	#	#	#	#	#	#
Erect antenna	#	#	#	#	#	#	#	+	+	
Accept antenna	#	#	#	#	#	#				
Outfit antenna	#	#	#	#	#	#	#			
Station operational	#	#	#	#	#	#	#			

Codes: + started; # complete

Electronics

The year 1992 will see the completion of all construction of the electronic receiving system for the VLBA. Front ends for all frequency bands except 2.3, 14, and 43 GHz will be completed by the end of 1991. The last 2.3 GHz front end will be completed early in 1992. The 14 GHz front ends will be the last to be completed and will take until about mid-year. All electronics racks will be completed by the end of 1991 with the exception of the last Data Acquisition Rack, which will take until February. Approximately 100 modules of various types will remain to be assembled in 1992, to expand the system to the full number of baseband channels and to provide the complement of spares required for maintenance. This work will be completed during the third quarter of 1992. Outfitting of the last two antennas, those at St. Croix and Mauna Kea, are scheduled to take place in 1992. Outfitting at St. Croix will be largely completed during the first quarter of the year, but at Mauna Kea it will extend through the fourth quarter. Final units to be installed on most antennas will include the 14 GHz front ends and the modules for the pulse calibration system. Completion of documentation and retrofits will be other tasks for 1992.

Data Recording

VLBA recorders through serial #21 (including two parts kits assembled at the AOC) have been shipped from Haystack Observatory. Deliveries from third production run (of eleven) through serial #32 are expected to start in November 1990, with shipment intervals of approximately two weeks. A unit from the second run was also delivered for a one year loan starting August 1991 to the Astro Space Center in the USSR to allow their staff to develop the necessary interfaces to ground stations for the Radioastron satellite, as well as earth based VLBI antennas in the Soviet Union. An order to Haystack for a fourth and last run of 11 recorders is expected to be placed in October

1991. Eight recorders are scheduled for a production run at the AOC in 1991 and 1992 in addition to the two already mostly assembled at the AOC. The total number of VLBA recorders to be produced by Haystack and NRAO is now 51.

Field tests of samples of thin tape from various manufacturers were performed in 1991. These tapes were mixed into VLBI and JPL/GSFC Network tape supplies for participating observatories and processing sites. Durability, magnetic, and mechanical performance were monitored. Extensive laboratory tests were also performed at Haystack Observatory under various tape speeds and various values of other transport parameters. A recommendation from Haystack on the choice of the first large operational tape purchase is expected early 1992.

Site Equipment

	PT	KP	LA	FD	NL	OV	BR	HN	SC	MK
Receivers & Feeds:										
330 / 610	#	#	#	#	#	+	-	+	-	-
1.5 *	#	#	#	#	#	#	#	+	+	+
2.3	#	#	#	#	#	-	-	+	+	-
4.8 *	#	#	#	#	#	#	#	+	+	+
8.4 *	#	#	#	#	#	#	#	+	+	+
15	#	-	-	-	-	-	-	-	-	-
23 *	#	#	#	#	#	#	#	+	+	-
43	#	+	+	-	-	-	-	-	-	-
S/X Dichroic	#	#	#	#	#	-	-	+	-	-

Codes: * Initial installation frequency band;
- Fabrication or procurement started;
+ Fabrication or procurement completed;
# Installed and operational.

(continued)

	PT	KP	LA	FD	NL	OV	BR	HN	SC	MK
Other Electronics:										
Front End (A) Rack	#	#	#	#	#	#	#	+	+	+
LO/IF (B) Rack	#	#	#	#	#	#	#	+	+	+
Master LO (C) Rack	#	#	#	#	#	#	#	+	+	+
Data Acq. (D) Rack	#	#	#	#	#	#	#	+	+	+
Recorder 1	#	#	#	#	#	#	+	+	+	+
Recorder 2	#	+	#							
Maser	#	#	#	#	#	#	#	+	+	+
Timing Receiver	#	#	#	#	#	#	#	+	+	+
Weather Station	#	#	#	#	#	#	#	+	+	+
Control Computer	#	#	#	#	#	#	#	+	+	+

Codes: * Initial installation frequency band;
- Fabrication or procurement started;
+ Fabrication or procurement completed;
# Installed and operational.

Monitor and Control

The on-line software system for the VLBA stations is now in a moderately mature state, although significant enhancements remain to be added. These include: automatic control of observe file distribution, automatic tape reversal/track allocation, major improvements to the monitor data logging system (especially for logging calibration data), better active diagnostic routines for checking the hardware, and security features to attempt to control both accidental and malicious interference with the operation of the array.

The array is now connected primarily by the Internet, although some stations had a long teething period to make the communications work reliably. This effort must still be expended in 1991 for the Hancock site and, in 1992, for the last two stations--the island sites. A communications backup plan must also be decided upon and implemented.

Only in 1992 will we begin the use of the Ingres database system to store observing log data, and provide the interface to the VLBA correlator system. It is probable that the database usage will be such that we shall need to purchase an additional Sun Spark station to provide the power necessary for efficient database access.

Correlator

Nearly all major hard- and software modules in the correlator and its playback interface are complete, and system integration is well advanced. System-level checkout of the hardware components has started, and will continue at least through the end of 1991. Progress in the hardware integration and checkout is expected to permit joint checkout with the control software by the beginning of the fourth quarter of 1991.

The major task remaining before the correlator can be considered complete is verification of performance in its many functional modes, which is expected to last through the first quarter of 1992. A few components must also be completed: the digital output filter, which has been designed and is currently under construction; the output archive and distribution subsystems, where single units of the required computer peripherals have been procured for evaluation, but must be complemented; and the job control and scheduling tasks, which range from partially designed to partially coded.

It is planned to move the completed and substantially tested correlator to Socorro early in the second quarter of 1992, where work will continue in bringing the system into routine operation.

Postprocessing

The request for proposals for the VLBA computer procurement has been sent out. It is expected that equipment will be purchased early in 1992.

Since the correlator is planned to be in operation in early 1992, it is expected large amounts of data will be flowing from the correlator into and through the postprocessing package shortly thereafter. To prepare for this, the software necessary to read the data from the correlator has been written and currently undergoing extensive tests. The VLBA software group is writing a set of routines to verify the operation of both the correlator and the postprocessing package.

We plan to start writing routines to enable users to perform astrometry and phase-referencing projects with the VLBA. This is a major undertaking but is necessary to enable users to utilize the full power of the VLBA. Much effort will also be expended in making the user interface to the VLBI programs friendlier for the neophyte users.

Revised Budget for the VLBA Construction Project

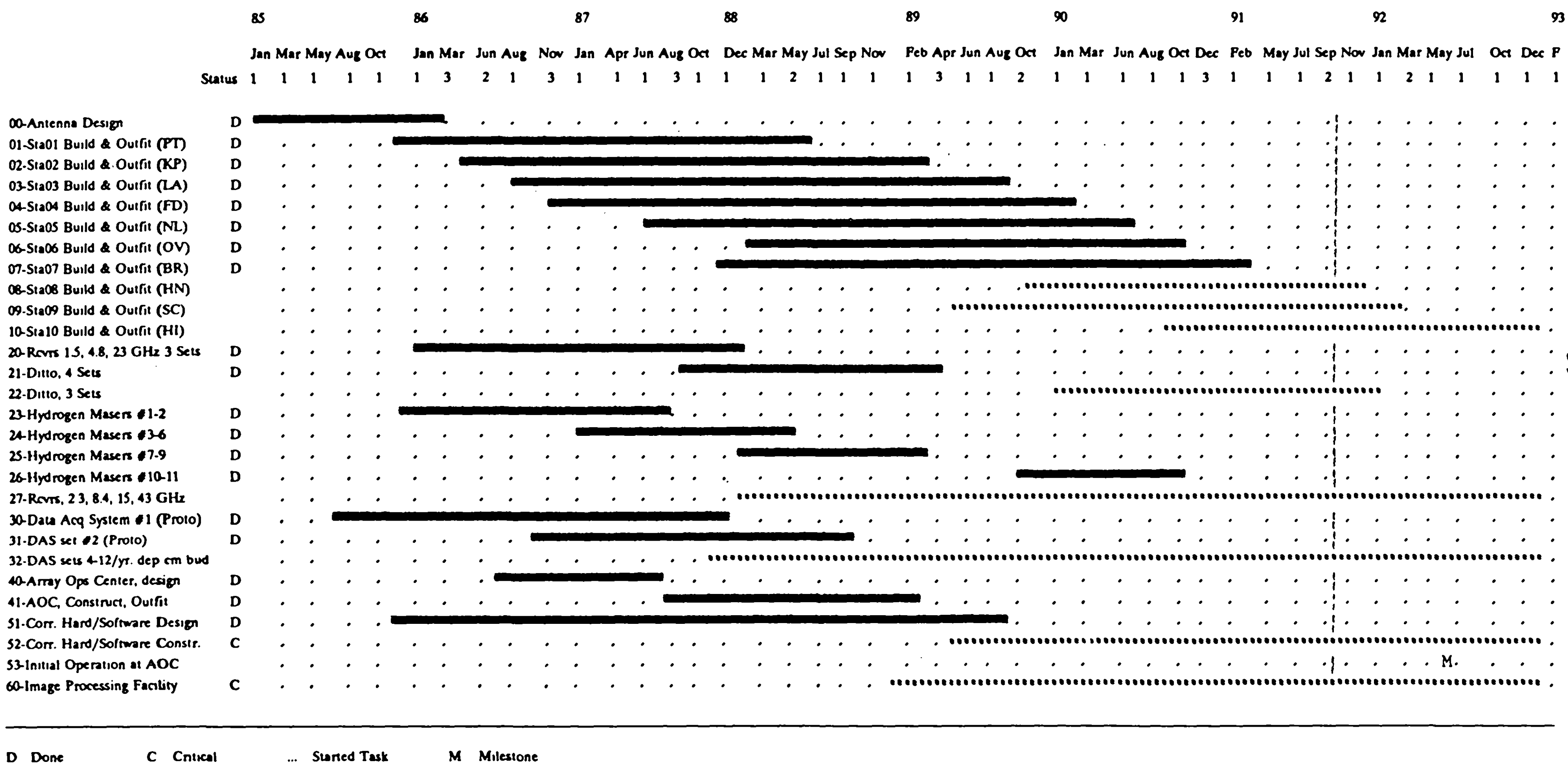
The concluding construction budget and schedule for the VLBA project are shown in the tables below. The $8.714M in new funds will complete construction of the VLBA.

VLBA BUDGET AND COST ESTIMATE (Current $)

	1983, 4	1985	1986	1987	1988	1989	1990	1991	1992	TOTALS
ANT STARTS/INSTLS		1/1	3/1	2/2	2/1	2/2	0/1	0/2		
SITES	32	194	2,204	1,605	1,171	2,036	2,914	269	325	10,750
ARRAY OPNS CTR	0	0	33	19	41	1,414	1,525	349	795	4,176
ANTENNAS	1,088	2,460	6,540	5,180	5,090	5,734	832	1,387	401	28,712
ELECTRONICS	537	1,573	1,652	2,045	1,277	2,201	2,093	2,224	801	14,403
DATA RECORDING	298	424	4	906	1,242	1,092	1,558	2,065	2,473	10,062
MONITOR, CONTROL	63	94	317	549	376	596	462	163	44	2,664
CORRELATOR	322	133	197	370	895	619	657	712	488	4,393
POST PROCESSING	0	0	0	75	61	97	147	200	3,000	3,580
SYST ENGINEERING	54	86	76	24	0	0	0	0	0	240
MISC & SPARES	0	0	0	16	122	560	213	477	0	1,388
PROJ MGT & SUPPORT	272	374	606	657	590	510	514	476	387	4,386
OPNS TRAINING	0	12	49	26	0	0	0	0	0	87
EXPENDITURES	2,667	5,350	11,674	11,472	10,865	14,859	10,915	8,322	8,714	84,837
CONTINGENCY	N/A	N/A	N/A	N/A	N/A	N/A	N/A	61	0	0
NEW FUNDS, Current $	2,806	9,000	8,552	11,400	11,600	11,800	10,700	10,265 (1,882)	8,714	84,837

1992 VLBA FINANCIAL PLAN

	Effort	Salaries & Wages	Benefits (@ 28.5%)	Materials & Services	Travel	Contract Charges	Total
Sub-Project	Man-months	$k	$k	$k	$k	$k	$k
Sites	0	0	0	225	0	100	325
Antennas	60	162	47	130	62	0	401
Electronics	114	361	105	118	37	180	801
Data Recording	9	33	10	1069	5	1356	2473
Monitor & Control	0	0	0	44	0	0	44
Correlator	54	216	63	142	67	0	488
Data Processing	18	40	10	2950	0	0	3000
System Engineering	0	0	0	0	0	0	0
Array Oper. Center	0	0	0	795	0	0	795
Spares	0	0	0	0	0	0	0
Project Management	30	142	42	183	20	0	387
Operations Training	0	0	0	0	0	0	0
Planned Commitments	285	954	277	5656	191	1636	8714
New Funds, 1992							8714
Net Contingency, $k							0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Jan Mar May Aug Oct Jan Mar Jun Aug Nov Jan Apr Jun Aug Oct Dec Mar May Jul Sep Nov Feb Apr Jun Aug Oct Jan Mar Jun Aug Oct Dec Feb May Jul Sep Nov Jan Mar May Jul Oct Dec F
Status
00-Antenna Design D
01-Sta01 Build & Outfit (PT) D
02-Sta02 Build & Outfit (KP) D
03-Sta03 Build & Outfit (LA) D
04-Sta04 Build & Outfit (FD) D
05-Sta05 Build & Outfit (NL) D
06-Sta06 Build & Outfit (OV) D
07-Sta07 Build & Outfit (BR) D
08-Sta08 Build & Outfit (HN)
09-Sta09 Build & Outfit (SC)
10-Sta10 Build & Outfit (HI)
20-Rcvrs 1.5, 4.8, 23 GHz 3 Sets D
21-Ditto, 4 Sets D
22-Ditto, 3 Sets
23-Hydrogen Masers #1-2 D
24-Hydrogen Masers #3-6 D
25-Hydrogen Masers #7-9 D
26-Hydrogen Masers #10-11 D
27-Rcvrs, 2.3, 8.4, 15, 43 GHz
30-Data Acq System #1 (Proto) D
31-DAS set #2 (Proto) D
32-DAS sets 4-12/yr. dep cm bud
40-Array Ops Center, design D
41-AOC, Construct, Outfit D
51-Corr. Hard/Software Design D
52-Corr. Hard/Software Constr. C
53-Initial Operation at AOC
60-Image Processing Facility C
M.
D Done
C Critical
... Started Task
M Milestone

2. Green Bank Telescope

The end of CY 1991 will see the completion of the first major construction milestone in the tangible implementation of the GBT. By mid-November 1991, the telescope foundation is scheduled for completion, including the center pintle area as well as the 210 foot diameter track ring wall. The antenna contractor, Radiation Systems, Inc., (RSI), also may elect to proceed with construction of the antenna assembly pad and tower crane foundation this calendar year; however, those items are not required to meet the program schedule and their construction may be delayed until the spring of 1992.

The telescope design and analysis will continue throughout 1992. The structural design, alidade, elevation assembly, access and lifts, electrical layout, servo system, and surface panels and subreflector designs are currently underway. The design of the equipment rooms, optical positioning mechanisms and mechanical furnishing will begin later in 1991. The contractor's formal sixty percent design review is scheduled for January 1992. The ninety percent review is scheduled for September 1992, looking toward the final design delivery in November 1992.

Tooling fabrication and antenna fabrication will begin in the fall of 1991 and continue throughout 1992 and beyond. The installation of the large antenna structure on the completed foundation at Green Bank will begin in the spring of 1992. Note that the antenna erection is scheduled to be underway prior to delivery of the final antenna design. This overlap in the schedule is necessitated by the need to defeat the effects of Green Bank's potentially harsh winter weather on the construction schedule, as well as the effects of inflation on the buying power of the fully pre-funded project. The fact that NRAO has a fully developed conceptual design of its own, is exercising close design collaboration with RSI, and has an extensive oversight program for the fabrication and construction by RSI, mitigates the risks which might be associated with this schedule.

Development of the active surface will continue through 1992. The actuators which will position the active surface have been selected after having endured a rigorous test program which included an accelerated life test, static load test, backlash test, exposure to the Green Bank environment and a physical (tear down) inspection. The first shipment of the 2213 actuator assembly packages, which includes the actuator, motor, linear variable differential transformer and associated hardware and electrical wiring, will be delivered early in 1992. Deliveries will continue through 1992 and into early 1993. RSI will be installing the actuator assemblies on the reflector structure as the growth of the telescope reaches the appropriate phase.

During 1991, a laser ranging system suitable for the active surface control of the GBT has been demonstrated. This system is capable of measuring a range of 120 meters with an accuracy of 50 μm. The instrument can measure five such ranges per second. During 1992, the completion of three instruments configured in a similar manner to the proposed system for use on the GBT is expected. These instruments will be used to measure the positions of nine retroreflectors on a test fixture that will replicate the arrangement of the panels, retroreflectors, actuators and LVDT's that will be used on the GBT. This test arrangement of panels will be movable in order to simulate the thermal and gravitational deformations that will be encountered in actual operation on the telescope. If the metrology system correctly measures these disturbances and the surface correction actuators move to maintain the correct surface shape, then the concept will have been convincingly demonstrated.

The program for generating pointing corrections using an autocollimator system to measure movements of the elevation angle will continue in 1992. To date it has been demonstrated that a commercially available instrument has the required accuracy. The program will continue with the development of various stabilized platforms that will be needed for application on the telescope.

During 1991, the Electronics and Optics group concentrated on plans and systems designs for the receivers and LO systems, on interfaces with the antenna contractor, on prototype designs for feeds and polarizers, and on the hardware design required for holographic antenna measurement system. A coherent receiver plan has been developed providing continuous coverage from 0.3 to 50 GHz, microwave tests were completed on several synthesizers as candidates for use in the LO systems, feed designs for the Gregorian and prime focus receivers are well under way with some being fabricated, and the construction of the correlator required for holography began. This work allows us to shift emphasis during 1992 to more detailed design work, procurement and evaluation of prototype components, and the start of construction of some of the remaining equipment. During 1993, the construction work will significantly increase to be completed in 1994 in preparation for outfitting the antenna in late 1994.

Also during 1992, completion of designs for the feeds and polarizers to be used in the highest priority receivers is scheduled, allowing the detailed design of those receivers to proceed. Particular attention will be paid to the design of the LO and IF systems to provide the performance and flexibility demanded, with close interaction with the monitor and control group expected. Procurement of certain critical items, either long lead items or those necessary to define the equipment designs, will occur. Examples are some of the receiver polarizers and LO synthesizers. Purchase of some bulk items, such as the cryogenic tubing to be installed on the antenna, will occur early to minimize cost to the project. Construction of the holography hardware will be completed and more extensive tests will be done on the fiber optic IF system which was installed on the 140 Foot

Telescope in 1991. By late 1992, several of the highest priority receivers should be under construction.

By the end of CY 1991, the monitor and control group will have defined and prototyped the monitoring facilities, identified the system safety and integrity issues and completed the initial iteration of architecture and subsystem definitions and their interfaces including physical locations, subsystem to architectural mappings, shared structures, state and packet functional definitions and periodicity. As well, the first version of the system requirements will be completed along with the initial description of primitives for the core monitor and control system , and the VLBA card and IEEE-488 drivers and interfaces.

Monitor and control efforts in 1992 will include further definition of the hardware interfaces, full description of inter-CPE packets, prototyping of the internal interface to core monitor and control system, standard configuration of the GBT VxWorks and completion of the monitoring facilities. The data collator will be prototyped, as will the backend organizer, fast process-control-variables sampling and the laser surface control interface.

With the increase of both the contractor's design/construction program and the internal development of the pointing, electronics and monitor and control systems, it will be necessary for the project team to grow in number from its current level of 14 employees up to 21 employees. New positions will include a field antenna construction engineer, two electronics engineers and a technician and three computer programmers or software designers.

By CY 1993, the telescope structure will begin to emerge as RSI's installation activities advance into full swing. The NRAO project team will be fully staffed and all the various systems will be under development. Examples include the electronics, active surface system, monitor and control systems and software development, and interfaces with the computer-controlled devices and the telescope drive system.

The telescope installation will be completed in mid-1994. Outfitting and acceptance testing will occupy the latter part of 1994, looking toward final acceptance, operations, and first astronomical observations early in 1995.

VI. MAJOR NEW INITIATIVES

1. The Millimeter Array

While the report of the Bahcall Committee, "The Decade of Discovery in Astronomy and Astrophysics," makes a number of prioritized recommendations, the overriding theme projected for the decade of the 1990's is the opportunity presented to us to exploit new technology for the exploration of the thermal sky. The three highest priority large programs recommended by the Survey Committee--the Space Infrared Telescope Facility (SIRTF), the IR-optimized 8 meter telescope on Mauna Kea, and the Millimeter Array--address a common set of scientific questions and do so with comparable capabilities, especially sensitivity and angular resolution. Together these instruments will provide astronomers of the next decade with an appropriate suite of complementary facilities from which we can expect significant progress, discoveries, to be made in our understanding of the formation and evolution of stars, galaxies, and the large-scale structure of the universe.

The external peer review of the mmA proposal has been completed by the Foundation. This process involved both a mail review of the written proposal as well as a presentation made to a "site visit" NSF group. Nearly thirty astronomers participated in one or the other of these reviews, each of whom has written an independent review for the Foundation. In the fall the NSF Astronomy Division Advisory Committee will be presented with a review of the project.

In the meantime work on many aspects of the design of the Array continues. At a mmA community meeting held in January in Tucson, the point was made that were significant mmA development funds to be available early, it is desirable that experienced university based staff and students participate in, and be funded to do, mmA related development. In response to this recommendation a NRAO/university mmA Joint

Development Group (JDG) has been formed to carry out many tasks related to the design and evaluation of mmA systems. In the near term the JDG will concentrate on those areas with the potential for having the greatest cost impact on the Array. The JDG is described more fully in Section VII.

Site selection and acquisition will continue to receive particular emphasis in the next few months as it, more than any other single mmA activity, will set the time scale for Array construction. The Forest Service estimates that the environmental process, in its manifold requirements, will occupy nearly four years. Owing to this long time scale, we will begin the Environmental Impact Statement (EIS) work on both the candidate mmA sites, the one in the Magdalena mountains NM, and the one near Springerville AZ. We have completed the atmospheric monitoring work on both sites (both 225 GHz tipping radiometers were run for the same ten-month period) and will compare and evaluate the data over the next few months. While the radiometer data shows subtle differences between the two sites, it is nevertheless clear that both sites will support the scientific program of the mmA. Consideration of site logistical and operational issues is beginning.

The construction cost and the construction schedule for the mmA have been reconsidered in light of the need to complete several years of development work prior to commencing major construction. The estimate of the project cost, $120M (1990 dollars), is unchanged from that given in the mmA proposal. The revised project schedule is shown below.

mmA Project Schedule

1991	Site Selection (Primary and Secondary)	$0.1M
1992	Site Construction Layout Environmental Impact Survey Antenna Design Electronics Development Algorithm Development	1.0M
1993	EIS Antenna Design Electronics Development Algorithm Development	3.0M
1994	Forest Service Procedures Prototyping-Electronics and Antenna Algorithm Development	5.0M
1995	Site Preparation Prototyping	11.0M
1996	Construction	25.0M
1997	Construction	25.0M
1998	Construction	25.0M
1999	Construction Interim Operations	25.0M
2000	Full Operation	

2. VLA-VLBA Connection

A plan to bridge the gap in angular resolution between the maximum achievable by the VLA, ~0".1, and the minimum provided by the VLBA, ~0".01, was endorsed by the report of the Astronomy and Astrophysics Survey Committee as one of the recommended moderate programs. Connection of the two arrays will increase the resolution of the VLA at all frequencies; improve the dynamic range, field of view, and extended source sensitivity of the VLBA; and give a scaled array capability at 0".1 resolution for all frequencies from 300 MHz to 22 GHz.

The VLA/VLBA connection will be accomplished with a phased plan which includes the following three steps:

- Placing four VLBA recorders at the VLA so that the antennas at the ends of the wye arms can be used as independent VLBA telescopes;
- Constructing four new VLBA antennas (at Dusty, Bernardo, and Vaughn NM and at Holbrook AZ) for measurement of short VLBA spacings;
- Providing fiber optic links from the VLA to the four new antennas as well as to the VLBA antennas at Pie Town and Los Alamos. These six outrigger antennas would then be used as part of the VLA. The VLA correlator will be expanded from 27 to 33 stations to accommodate the additional baselines.

Together, these improvements will provide a greatly enhanced imaging capability and brightness sensitivity over a wide range of frequency. The scientific applications will include observations of the sun and planets, radio emission from stars, novae, protoplanetary nebulae and stellar winds, as well as from star forming regions, active galactic nuclei and quasars. The VLA/VLBA connection is a long-term goal of the Observatory--beyond the five year budget and personnel schedule presented in Section XII.

3. Submillimeter Telescope

Recent initial results from the effort to develop a laser metrology system for the GBT have been very promising and, if they continue to be successful, they could form the basis for the construction of a large aperture, submillimeter telescope by employing an active surface. A national submillimeter facility that builds on the pioneering work of the Caltech Submillimeter Observatory and Univ. of Arizona/MPI Submillimeter Telescope is a logical step in long-range national plans for this spectral region. NRAO will keep abreast of developments in submillimeter astronomy, become involved in the technology required where possible, and appropriate, and foster opportunities for collaboration in submillimeter astronomy, with the long-term goal of establishing a national facility.

VII. WORK FOR OTHERS

1. USNO Operations

In 1992 NRAO will continue to operate two telescope systems for the U.S. Naval Observatory (USNO) in Green Bank WV. The primary system uses one 85 foot telescope as a VLBI station in the NAVNET system of stations. NAVNET determines the earth's (variable) rotation rate and, with less accuracy, the position of the pole. It uses one to three antennas at distant locations in addition to the 85 Foot Telescope, all equipped to operate simultaneously at 2.3 and 8.4 GHz. Several upgrades to the VLBI station in Green Bank were implemented in 1991. The recording MkIII terminal was replaced by a VLBA data acquisition system. The wider bandwidths this system is able to record provide greater sensitivity to the observations. In addition, frequency dependent effects introduced by earth's atmosphere are better calibrated when the span of frequencies is enlarged. The receiver was modified to provide the broader bands sent to the VLBA recorder. In addition, improved phase calibration generators were installed.

The geodetic observations do not use all hours of every day. The time not used for VLBI is devoted to pulsar timing observations. Some 100 pulsars are observed as often as possible at 610 MHz. A 327 MHz receiver will be added in 1992. The goals are to monitor for changes in their periods, especially for discontinuous jumps, and for variations in pulse amplitudes. The amplitude variations are attributed to interstellar scintillation. Thus, the timing observations reveal fundamental physics of neutron stars, while amplitude observations probe the interstellar medium.

Two other 85 foot antennas are linked by fiber optics as a single baseline interferometer. This interferometer also operates at 2.3 and 8.4 GHz simultaneously. It observes a few hundred 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.

Major upgrades of the facilities NRAO operates on behalf of USNO are being discussed for implementation in 1992. At the time of preparation of this Program Plan, however, the discussions had not concluded. Possible projects include a master clock System, new antenna for NAVNET to replace the 85 Foot Telescope, and a joint-use control building.

2. Green Bank OVLBI Earth Station

The Green Bank Orbiting VLBI Earth Station will be one of several such stations around the world that will provide communication links to and from the two orbiting VLBI satellites now scheduled for launch. These are Radioastron, to be launched by the USSR around July 1994; and VSOP, to be launched by Japan around February 1995.

The Green Bank station is a NASA funded project of the NRAO, started in 1990 and scheduled for completion of its implementation phase at the end of 1993. This will be followed by an operations phase which will last for the duration of the OVLBI missions, probably until about 1998. After that, the station will be available to support future OVLBI missions.

The two spacecraft are functionally similar. Each carries a 10 meter diameter antenna and front ends for several radio astronomy bands, commonly used for VLBI. The combination of either spacecraft and an appropriately equipped earth station constitutes a radio telescope equipped for VLBI, very much like those on the ground. At ground VLBI stations, all major components are located in close proximity and are typically linked by fixed cables. In the orbiting case, important components must be located on the ground--in particular, the high density recorders and high stability oscillator--and linked to the orbiting components by a variable length radio path.

Each spacecraft is to be in a highly elliptical, high inclination orbit, but Radioastron will be at a much higher altitude than VSOP; the periods will be approximately 24 hours and 6 hours, respectively. Furthermore, Radioastron's apogee will remain over the northern hemisphere for most of its lifetime, with the result that it will be visible from Green Bank for the majority of nearly every orbit, and sometimes for more than 80 percent of its orbit. VSOP's visibility from any fixed earth station will vary widely, from less than one hour to more than four hours. Especially for VSOP, a worldwide network of earth stations is needed. NASA is planning stations at Goldstone, Madrid, and Canberra (supporting both spacecraft); Japan at Kagoshima (VSOP only); and the USSR at Ussuriysk (Radioastron only).

The Green Bank earth station is built around a 13.7 meter diameter antenna which was formerly part of the NRAO radio link interferometer. It has been restored to operation on the Green Bank site. The surface has been holographically measured and reset for operation at 15 GHz as required for OVLBI. In 1992 it will be provided with the ancillary instrumentation (transmitter, receiver, and hydrogen maser frequency standard) needed for data transfer from the two spacecraft. A staff of five engineers and technicians is involved in the 1992 implementation effort.

3. OVLBI Science Support

As one element of a synthesis telescope, the orbiting VLBI radio antenna is used in concert with ground antennas, all of which observe the same radio source simultaneously. After the data are taken and recorded, the data tapes are played back and correlated at a central facility. The scientific return from an OVLBI spacecraft therefore is contingent upon ground support in a number of ways--co-observations, correlation, data processing, and imaging. In return for access to the spacecraft by U.S. scientists, NASA has negotiated with the foreign space agencies to provide the requisite ground support. Since the NRAO will operate the only dedicated VLBI array in the world at the time the spacecraft are launched, NASA has asked for NRAO involvement with the two space missions.

NRAO participation in OVLBI science support will consist of the following:

- Co-observation with the VLBA for as much as 30 percent of the scheduled VLBA time for an initial period;
- Correlation of all data taken when the VLBA is used for co-observation;
- Modification of the VLBA correlator to accommodate the higher fringe rates of OVLBI and the larger delays resulting from errors in the orbit determination;
- Modification of the VLBA software in AIPS++ to make it suitable for the special needs of OVLBI;
- Support of OVLBI users at the AOC in Socorro.

The NRAO OVLBI science support activities, planning and operation, will require four to six full-time staff. NASA funding passed through NSF by interagency transfer will bear the cost.

VIII. COLLABORATIVE WORK

1. AIPS++

In June 1991, thirty scientists and programmers, representing almost all major radio telescopes in the world, met at NRAO to consider the rewrite of AIPS. At that meeting it was decided that the rewrite should be done as a joint effort between the various radio astronomy organizations represented at the meeting, using the C++ programming language. This would make it possible for the new package, AIPS++, to be employed also for other projects, such as the 12 Meter Telescope, 140 Foot Telescope, the GBT, and mmA projects.

The participating organizations are: the Australia Telescope; Jodrell Bank Observatory; the Herzberg Institute, Canada; the Berkeley-Illinois-Maryland Array; and the Netherlands Foundation for Research in Astronomy. They will each send one senior software designer to Charlottesville for the first half year of 1992 to join with five NRAO staff to design and partially implement AIPS++. The participating organizations have committed a further one and a half man-year each to this effort. We expect a first order working system to be available by the middle of 1993.

2. mmA Joint Development Group

Design of the Millimeter Array has been a cooperative venture between the NRAO and interested millimeter-wave astronomers for nearly a decade. The concept of the array as a fast imaging instrument capable of precision operation at frequencies as high as 360 GHz and capable of providing images at 0."1 angular resolution, equivalent to that achievable by the HST or SIRTF, was a result of a series of scientific workshops held at the NRAO. The realization of the concept--40 transportable antennas of 8 meters diameter located on a high altitude site--was the instrument recommended by the 1991 report of the Astronomy and Astrophysics Survey Committees.

The mmA concept is currently in the development phase, meaning that various technical options are being explored as alternative ways of achieving particular mmA scientific goals. Much of this work is explorative and iterative. No synthesis telescope, at any wavelength, has ever been designed to have, for example, complete frequency coverage over more than a decade of bandwidth. Can broadband receivers be built that are as sensitive as the best current narrow band receivers while at the same time be simple, reproducible, and reliable? The answers to questions like this, crucial to the cost and operation of the mmA, require a significant allocation of development resources.

The development phase of the mmA will benefit by the attention of experienced millimeter-wave instrumentalists whether they be at the NRAO or in the university community. In an attempt to marshall the efforts of the widest body of expertise to the exploration of mmA design options, a joint NRAO/university development group (JDG) has been organized. The participants in this group include those associated with the Caltech OVRO interferometer, the participating universities of the Berkeley-Illinois-Maryland Array, and the scientists at the Five College Radio Observatory. Technical questions to be addressed by the JDG, and the resources devoted to these questions, will be determined by the NRAO mmA working groups. Annually, the scope and progress of the JDG work will be reviewed by an oversight committee to assure that the work is consistent with the scientific goals of the mmA and that the technical integrity of the project is not compromised.

With the funding provided in 1992, the NRAO and the members of the mmA Joint Development Group will begin work in the following areas:

SIS Receivers: Amplifiers developed at the NRAO Central Development Laboratory will be used on the 12 Meter Telescope and on the OVRO array antennas.

At OVRO the SIS mixers will be used in experimental tests of sideband separation techniques.

HFET Amplifiers: Cooperative work between the Central Development Laboratory and the University of Massachusetts will seek to realize broadband 3 mm HFET amplifiers with noise temperatures competitive with the best SIS mixers. Prototype amplifiers will be tested in astronomical observations on the 12 Meter Telescope and on the UMass FCRAO antenna.

Fiber Optic Signal Transmission: The University of Maryland in cooperation with the Green Bank digital group will install optical fiber IF transmission cables to one of the BIMA antennas located 500 m distant from the center of the array. Stability tests will be conducted.

Broadband Local Oscillator Sources: The mmA will need a local oscillator that is tunable over an extremely wide band and which is mechanically simple. Prototype sources will be developed and evaluated at OVRO and the CDL.

Cryogenics: The mmA SIS receivers will require 4K cryostats with several hundred milliwatts of cooling capacity. Presently, on the 12 Meter Telescope and elsewhere, this is achieved by using a standard Gifford-McMahon refrigerator to reach 15K, followed by a Joule-Thompson circuit to reach 4K. The latter stage is troublesome--it passes gas through a narrow orifice which plugs easily with contaminants--and requires a separate compressor. Experiments are underway at Berkeley to use the Gifford-McMahon stage alone to achieve the required 4K cooling capacity. This work has the potential to lower the receiver cost of the mmA and improve the reliability.

Antenna Design: The mmA antenna is a high performance structure that is fully exposed to the environment. Thermal effects will be the principle cause of degraded performance. Ways to circumvent, or compensate for, thermal gradients across exposed antennas will be studied at OVRO and BIMA.

Control Software: The mmA will be used by astronomers as a real-time instrument. Its rapid imaging capability provides an opportunity for the astronomer to create an observing program on the fly: if, that is, he or she has a display of the data image as it comes in. The software to provide such a tool will be developed first for the VLA, OVRO, and BIMA with the JDG collaboration and consultation.

Analysis Software: As the AIPS++ project develops, the specific needs of the mmA will be a cornerstone of this software effort. Participation by millimeter-wave astronomers and programmers in the AIPS++ definition will ensure the utility of this program for the mmA. Participants from the JDG university groups at Maryland, Illinois, and Caltech will join the AIPS++ effort in Charlottesville.

IX. EDUCATION

Although the distinction between research and education is at the most fundamental level artificial, nevertheless it is possible to point to a number of programs at the NRAO specifically designed to broaden and enhance the educational background of students and their teachers. These include opportunities for undergraduate students to participate in on-going scientific, engineering, or computer science projects, opportunities for graduate students to conduct research under the direction of NRAO staff scientists, and opportunities for recent PhD recipients to collaborate with scientists having mutual research interests at the NRAO. The scope, purpose, and cost of such programs are briefly outlined below. Not included here are a wide variety of activities, also educational, which are focused on individuals other than those enrolled at academic institutions. Public education is one example of an activity missing from this summary but conducted at the NRAO nonetheless at our visitors centers. The educational programs presented here are those designed to benefit students.

1. Secondary Science Teachers Institute

NRAO-Green Bank has operated summer education institutes for precollege science teachers for five years now. The first three years, 1987-89 inclusive, were funded by the National Science Foundation. The year 1990 was funded by the Claude Worthington Benedum Foundation, and NSF funding resumed in 1991. The second NSF grant extends through 1993 and supports a program called Learning to Investigate the Universe. The program invites 25 participants, selected from a national pool of applicants, to join five mentors, i.e., participants in previous Green Bank institutes, for a period of two intensive weeks at the Observatory; two such groups attend each summer. During the course of the year following attendance at an institute, the teachers meet again to share the curriculum developments that occurred as a result of their participation.

The guiding principle of the institutes is to learn science by doing science. For this purpose, a 40 foot transit telescope, with a 21 cm continuum receiver, is made available. To our knowledge, use of a radio telescope is unique. Five groups of five teachers plus one mentor each tackle a research project. That is to say, each group defines a problem it wishes to address, devises an observing strategy for addressing it, gathers and interprets the data, and presents the results and conclusions to a seminar of other participants. The educational value lies in experiencing actual measurements, not in the particular answer determined. Another value is working on a problem for which the answer is unknown. Training exercises in science are often unrealistic simply because everyone knows what answer is supposed to be found.

There are additional complementary aspects to the program. In line with the theme of hands-on science, the teachers build a device of some kind, one with which they can return to their classrooms. Furthermore, a mini-course in astronomy is presented. This course provides an overview within which the research project makes sense. It also acquaints those teachers who are not from the physical sciences with necessary background information. The course is enriched by the appearance of guest lecturers, each a specialist in some area of radio astronomy or of science education. Their main goal is to provide teachers with examples of the latest developments near the research frontier, to shorten the time delay between when such discoveries are made and when they appear in standard textbooks. A final major component of the institutes is led by science educators from West Virginia University, with whom NRAO jointly operates the program. This component aims at assisting teachers extract specific classroom lessons from their experience here.

Less formal, but crucial to the success of the program, are the contacts with the telescope users in Green Bank. The teachers get to watch and study how a scientist conducts his or her investigations at the 140 Foot Telescope. Ample opportunity exists to discuss with various scientists what motivated them to enter their profession, what they recommend to students considering entering a scientific or technical profession, why they chose the research project they are pursuing, and what they hope to learn. Often, some enduring contacts are established on individual bases, permitting teachers subsequently to contact experts with questions that occur to them.

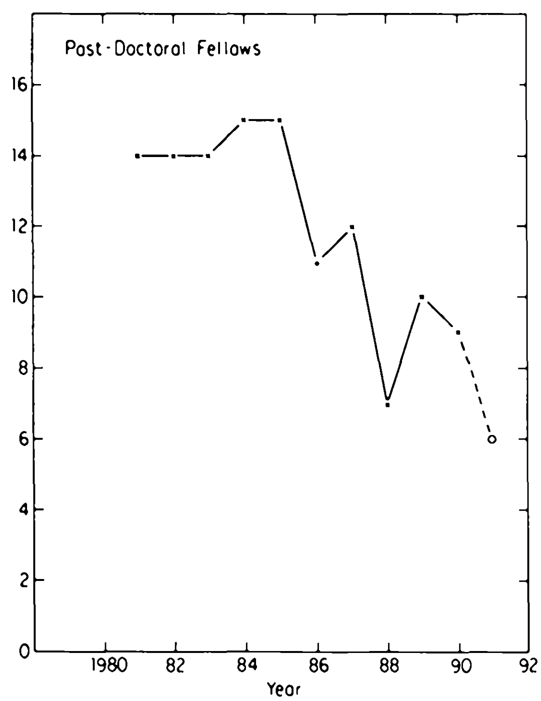
Enough experience has been acquired to demonstrate the value of some intangible benefits. One is the opportunity for highly motivated teachers from all regions of the country to exchange their own ideas with each other. The setting in Green Bank is particularly appropriate, because all participants not only go through the formal programs together, but also they live and eat in the same on-site facility. The other intangible benefit upon which many participants have commented is that they are treated as professionals and as colleagues with the scientists, engineers, and programmers at NRAO.

2. Postdoctoral Fellows

At the NRAO postdoctoral appointees are given Jansky Fellowships with a term of two years, that may be extended an additional year. In the selection process recent graduates are given preference to those who are applying for their second postdoc position. In principle, Jansky Fellowships are available not only to those in radio astronomy but they are also available to recent PhD recipients in engineering and computer science. In practice the stipend of a Jansky Fellowship, while very competitive with the stipend offered postdoctoral astronomy appointees at other observatories and universities, is nearly $20,000 less than the starting salary of PhD engineers and computer science professionals. For this reason all recent Jansky Fellowships have gone to astronomers.

Jansky Fellows are given the freedom to define their own research program; they are not asked to serve as apprentices to NRAO staff scientists.

At the end of 1991, we expect six Jansky Fellows at the Observatory, one located in Tucson and five in Socorro. Nearly ten postdoctoral positions were lost in the budget reductions of the last six years. Building the number of postdocs at the Observatory back to the levels of the early 1980's is an important component of rebuilding the infrastructure.

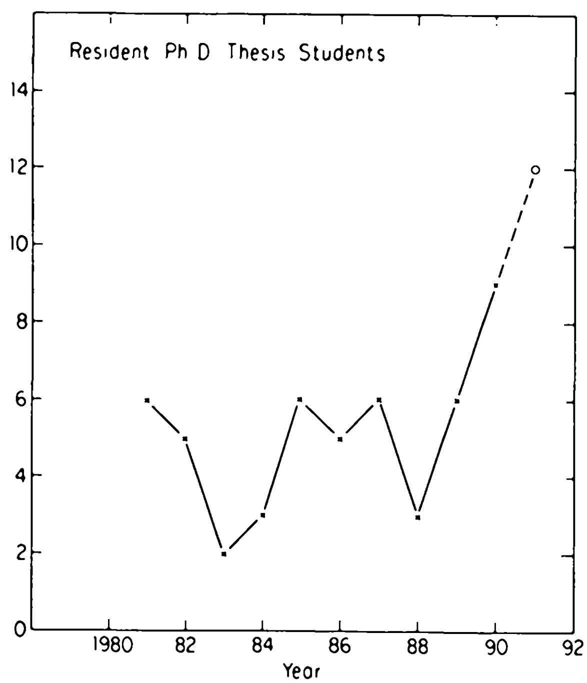


The number of postdoctoral fellows at NRAO since 1980.

3. Resident PhD Thesis Students

As astronomy becomes a more problem oriented discipline, and less divided by observing wavelengths, radio astronomical observations play an important role in a wide variety of astronomy PhD theses. Some of the universities awarding those degrees have few, or no, radio astronomers to guide student research in radio astronomy. To rectify the situation, train students in the techniques of radio astronomy specifically needed for the individual students' research, the NRAO staff scientists collaborate with university astronomers in the supervision of PhD thesis students. The students spend as long as twenty-four months in residence at the NRAO taking data, reducing it, and writing their theses--all with the guidance of NRAO staff scientists.

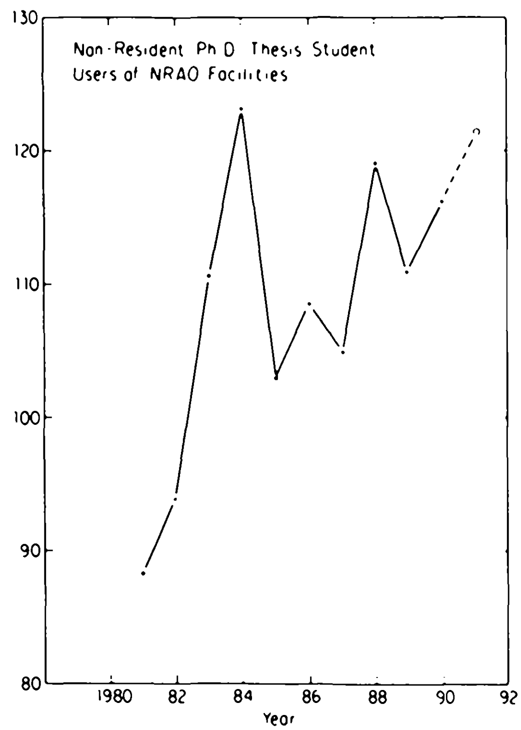
A resident PhD thesis student receives an annual salary from the NRAO of $15,000. Presently there are twelve resident PhD thesis students at the NRAO doing research in astronomy, microwave engineering, and computer science. This program principally benefits the student, but it has a salutary effect as well for the NRAO staff supervisor.



The number of students in residence at the NRAO for the purpose of doing PhD research projects.

4. Non-Resident PhD Thesis Students

More than one hundred PhD thesis students use the NRAO facilities each year for their research. While these individuals receive no direct salary support from the NRAO, their stay of one to a few weeks at the Observatory is supported directly by a housing subsidy (in Socorro), travel reimbursement, computer time, and supplies; and it is indirectly supported by assistance from the NRAO scientists and staff as needed. Many of the one hundred twenty-five students using NRAO facilities this year will receive their introduction to radio astronomy from staff scientists.



The annual number of PhD students using NRAO facilities.

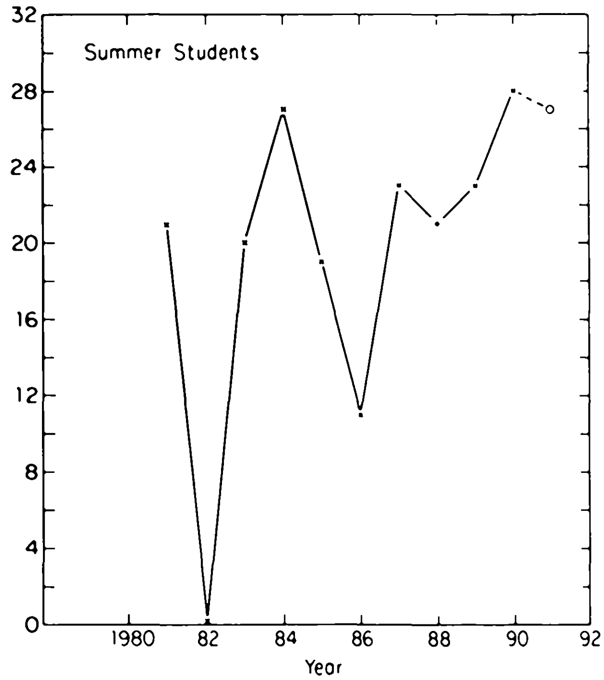
5. Summer Students

For thirty years the NRAO has offered summer appointments to students interested in broadening their exposure to radio astronomy. The students work as collaborators with NRAO staff scientists on on-going research projects. They are also invited to participate in a seminar on radio astronomical instrumentation and observational techniques. Many of the former NRAO summer students are now established researchers. In this sense the summer student program has been very successful indeed.

One of the strengths of the early program was its emphasis on students who had made a commitment to radio astronomy: the only students admitted to the program were graduate students in radio astronomy, engineering, or computing. One of its weaknesses was that it was funded out of contract funds and, when funding was tight, the program was constrained. In 1982 there was no summer student program at all.

In 1987 the NSF funded a program for summer student research opportunities called Research Experiences for Undergraduates (REU). The NRAO has annually supported eighteen to twenty summer students every year since 1987. All these students are, of course, undergraduates and as such have not made a commitment to radio astronomy nor do they, usually, have the research skills of graduate students. Many students are exploring radio astronomy as a career option, others are simply looking for summer employment.

Each year since 1987 we have supplemented the REU program supporting a few graduate students, bringing the total number of summer students to nearly thirty. Approximately half this number are astronomy students; the remainder are in engineering and computing. Thirty summer students nearly saturates the capacity of the sixty NRAO PhD staff to supervise student activities. If we add to the thirty summer students the twelve resident PhD thesis students, nearly three-fourths of the NRAO PhD staff (astronomers, engineers, and computer scientists) are engaged with student research.



The number of summer students at the NRAO

6. Cooperative Education Students

The co-op student program is a mechanism designed to involve undergraduate engineering and computer science students in radio astronomy instrumentation at an early and impressionable point in their academic career. Co-op students, in alternate semesters, attend classes and work in an industrial setting. On return visits the co-op student needs little initiation into the mechanics of the work place and can work very effectively as a result. The co-op program is designed to benefit the student by providing him or her with an opportunity to work on the design and construction of telescope instrumentation that will be used by visiting astronomers. The practical aspect of the experience, the need to balance instrument performance with maintainability and integrate the whole into a larger framework, has been noted as especially valued by the students.

Presently there are three co-op students at the Observatory, all of whom are microwave engineers--one student each in Green Bank, Tucson, and at the Central Development Laboratory. We intend to expand this program in the future if funds can be found, possibly writing a proposal for the funds to the Foundation.

7. Special Educational Programs

Synthesis Imaging Workshops

One important measure of the success of the VLA is the number of scientists who use the telescope each year, viz., nearly six hundred. That so many people could use it speaks to its operational ease and convenience. This is surprising because the principles of aperture synthesis are subtle. Apparently the VLA can and is used successfully by people lacking a thorough understanding of the instrument. At the same time users seeking to push the VLA to its limits recognize that one needs to understand its subtleties. We attempt to communicate this information to users, particularly student users, by workshops held in Socorro on synthesis imaging.

The third synthesis imaging workshop was held in June 1991. More than one hundred fifteen students (mostly graduate students) attended the workshop, the third in six years. Thirty-one NRAO staff scientists developed the theory and application of aperture synthesis in various lectures that were given over a ten-day period. The third synthesis workshop was held in June 1991. Thirty-one NRAO staff scientists developed the theory and application of aperture synthesis in various lectures that were given over a ten-day period. The proceedings of the 1991 workshop, as for the two prior workshops, will be published.

Topical Symposia: The 1992 VLBI School

In 1992 it will have been twenty-five years since the technique of VLBI was first used in astronomy. Since the NRAO played a major role in the development of VLBI and will see that effort culminated, also in 1992, with the completion of the VLBA, the NRAO will commemorate the event by sponsoring a summer school on VLBI.

For twenty-five years VLBI has been perceived as an arcane branch of radio astronomy capable of leading to considerable insight but the practice of which was limited to a few dedicated individuals. The VLBA promises to make VLBI readily accessible to the large number of users accustomed to observing with the VLA. In order to accelerate the process, the NRAO will encourage graduate students and others to attend a summer school on the theory and practice of VLBI, with specific reference to the capabilities of the VLBA. We expect 50-100 graduate students to attend for approximately ten days.

X. EQUIPMENT PLANS

1. 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 composite image on the cover of this Program Plan illustrates the point. The pale green emission shown extending to great distance from the nucleus of the galaxy NGC 7252 is a tidal tail of atomic gas stripped from the galaxy disk by the close encounter of a companion galaxy to NGC 7252. Such encounters are evidently a common occurrence to galaxies even in quite loose clusters, and they have profound effects on the rate of subsequent galaxy evolution. Images of faint HI such as this require the most sensitive receiving equipment and the imaging capability of an instrument such as the VLA. Improvement of the 21 cm receivers on the VLA has been a principal thrust of the NRAO Research Equipment plan for the past two years. The image on the cover and its implications are among the many rewards of the continuing effort to improve the NRAO observing equipment.

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/or computing techniques is maintained at each observing site as well as at the Central Development Laboratory in Charlottesville. Each of those 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.

The 1992 NRAO Program Plan includes $1500k for Research and Operating Equipment slated to come from supplemental funds set aside by Congress to restore the U.S. astronomical infrastructure. A program for application of these funds to the RE needs of the Observatory is given in Section II. A more detailed breakdown is shown in the table below.

2. Operating Equipment

In order to satisfy the recent budgetary requirements of Observatory operations, it was necessary to defer funding of Operating Equipment for the past several years. Deferring these costs has taken its toll on the Observatory. Since 1989, only $111,000 of new funds has been allocated to Operating Equipment. It has been necessary to supplement Operating Equipment by transferring funds from normal operations. This stop-gap measure is not a solution to the problem, but a temporary measure to maintain operations. This delay in funding has resulted in increased costs associated with the maintenance and repair of existing equipment in an effort to prolong its useful life. Although prolonging the useful life of this equipment is helpful, modern equipment is significantly more efficient, technologically advanced, and much less expensive to maintain.

Our 1992 Operating Equipment requirements are estimated at $345,000. This is the amount necessary to allow for the replacement of equipment that is obsolete with parts difficult to locate, equipment where the maintenance costs exceed the cost of replacement, and for the purchase of equipment necessary to conform with new regulatory requirements. Some items absolutely cannot be delayed for an additional year. Together they total $150k, and this figure is included in the Program Plan. This is not the request; it is the minimum.

Included in the request for Operating Equipment funds in 1992 are improvements to the electrical system at the VLA, replacement of an outdated Bridgeport Mill at the VLA, and the purchase of used, heavy equipment necessary to assist with infrastructure improvements. During the period 1993-97 funds will be required to replace the in-ground fuel tanks at Kitt Peak. An above-ground fuel tank will bring NRAO in compliance with new environmental regulations now being imposed. By 1995 approximately $200k will be necessary to replace the machine shop equipment in the Central Development Laboratory. A CNC mill/lathe will replace the existing equipment, which is over twenty-five years old. With higher demands placed on precision and the technological advancement in science, the existing equipment will be unable to meet the needs of the Observatory. Also, building improvements such as installing air conditioning in the Green Bank Jansky Lab and cafeteria, where temperatures this summer reached 100 degrees, are needed to improve working conditions.

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

	1992 Needs k$	1992 Minimum k$
Maintenance and Shop Equipment	130	60
Vehicles	115	40
Office and Library Equipment	60	20
Living Quarters Furnishings	0	0
Building Equipment	10	10
Observatory Services	30	20
	345	150

Research and Operating Equipment

($ in thousands)

	Expenditure 1991 (est)	Expenditure 1992
Laboratory and Test Equipment	100	100
Miscellaneous Projects	60	100
Very Large Array		
1.3-1.7 GHz Improvement	200	225
23 GHz Repackage	-	80
RFI Shields	-	50
Array Computing	60	60
12 Meter Telescope		
SIS Receivers	45	90
Spectrometer Development	60	70
Control/Analysis Computing	20	40
140 Foot Telescope		
Cassegrain Receiver	20	25
Prime-Focus Receiver	15	30
Analysis Computing	15	40
Common Development		
Millimeter Device Development	135	250
HFET Amplifier Development	25	100
Computational Imaging	85	90
Operations Equipment	25	150
Total	865	1500

XI. 1992 PRELIMINARY FINANCIAL PLAN
by Budget Category
(NSF Funds, $ in thousands)

	New Funds	Uncommitted Carryover of 1991 Funds	Total Available for Commitment	Commitments Carried Over From 1991 Funds	Total Available for Expenditures
Operations					
Personnel Compensation	$14,694		$14,694		$14,694
Personnel Benefits	4,262		4,262		4,262
Travel	780		780		780
Material & Supply	6,764		6,764	150	6,914
Management Fee	550		550		550
Common Cost Recovery/CDL Device Revenue	(350)		(350)		(350)
Total: Operations	26,700	0	26,700	150	26,850
Design & Construction					
VLBA	8,714	100	8,814	1,000	9,814
GBT	0	14,727	14,727	48,000	62,727
Total: Design & Construction	8,714	14,827	23,541	49,000	72,541
Total Operations and Design & Construction (NOTE 1)	$35,414	$14,827	$50,241	$49,150	$99,391
Infrastructure					
Phys. Plant Restoration & Maint.	$1,200		$1,200		$1,200
Research & Operating Equipment	1,500		1,500		1,500
Computing Resources	1,000		1,000		1,000
VLA Upgrade	3,600		3,600		3,600
Total Infrastructure	7,300	0	7,300	0	7,300
New Initiatives					
Millimeter Array	1,000		1,000		1,000
Total Infrastructure & New Initiatives	8,300	0	8,300	0	8,300
TOTAL NSF PLAN	$43,714	$14,827	$58,541	$49,150	$107,691

(NOTE 1) NSF New Funds request is $33.4M. The shortfall is $35.4M - $33.4M = $2.0M

October 1, 1991

XI. 1992 PRELIMINARY FINANCIAL PLAN
by Site / Project
(NSF Funds, $ in thousands)

	Personnel	Salaries, Wages & Benefits	Materials, Supplies & Services	Travel	Total
Operations					
General & Administrative	25	$1,331	$913	$134	$2,378
Research Support	59	3,496	575	258	4,329
Technical Development	20	983	291	18	1,292
Green Bank Operations	72	3,194	449	75	3,718
Tucson Operations	29	1,614	526	50	2,190
Socorro Operations	120	5,130	2,527	71	7,728
VLBA Operations	87	3,208	1,483	174	4,865
Management Fee			550		550
Common Cost Recovery/ CDL Device Revenue			(350)		(350)
Total Operations	412	$18,956	$6,964	$780	$26,700
Design and Construction					
VLBA	9	$1,091	$7,473	$150	$8,714
Total Operations and Design & Construction	421	$20,047	$14,437	$930	$35,414
Infrastructure					
Phys. Plant Restoration & Maint.	8	$260	$940	$0	$1,200
Research & Operating Equipment	0	0	1,500	0	1,500
Computing Resources	5	240	750	10	1,000
VLA Upgrade	3	90	3,440	70	3,600
Total Infrastructure	16	$590	$6,630	$80	$7,300
New Initiatives					
MMA	2	$100	$860	$40	$1,000
TOTAL NSF	439	$20,737	$21,927	$1,050	$43,714

XII. LONG RANGE PLAN
(NSF Funds, $ in millions)

	1992	1993	1994	1995	1996	1997
Operations						
Base Operations	$21.835	$23.145	$32.590	$34.945	$37.041	$39.263
VLBA Operations	4.865	7.600				
Total Operations	26.700	30.745	32.590	34.945	37.041	39.263
Design & Construction						
VLBA ($85M)	8.714	-	-	-	-	
Total Operations and Design & Construction	$35.414	$30.745	$32.590	$34.945	$37.041	$39.263
Infrastructure						
Phys. Plant Restoration & Maint.	$1.200	$1.200	$1.300	$1.300	$1.300	$1.500
Research & Operating Equipment	1.500	1.500	1.500	1.500	1.600	1.600
Computing Resources	1.000	1.000	1.000	1.000	1.000	1.000
VLA Upgrade	3.600	3.600	3.600	3.600	3.600	3.600
Total Infrastructure	$7.300	$7.300	$7.400	$7.400	$7.500	$7.700
New Initiatives						
Millimeter Array ($120M)	1.000	3.000	5.000	11.000	25.000	25.000
VLA-VLBA Link ($31M)	-	-	-	-	-	5.000
Total New Initiatives	1.000	3.000	5.000	11.000	25.000	30.000
Total NSF	$43.714	$41.045	$44.990	$53.345	$69.541	$76.963

PERSONNEL PROJECTION (Full Time - Year End Ceiling)

	1992	1993	1994	1995	1996	1997
Base Operations	325	336	457	472	474	476
VLBA Operations	87	97				
VLBA Construction	9	-	-	-	-	-
Infrastructure	16	16	16	16	16	16
GB Telescope Construction	23	25	25	-	-	-
Millimeter Array	2	5	9	12	24	40
VLA-VLBA Link	-	-	-	-	-	5
Work for Others	20	20	15	15	15	15
Personnel Total	482	499	522	515	529	552

APPENDIX A

NRAO SCIENTIFIC STAFF ACTIVITIES FOR THE YEAR 1992

The NRAO permanent staff will investigate a number of topics in a variety of research areas during 1992, as described below. Visiting scientists will collaborate in some of this research.

1. The Sun

Although the sun reached the nominal maximum of its activity cycle in mid-1989, it continues to produce considerable numbers of flares. The fast snapshot imaging mode of the VLA was used with great success in December 1990 to reveal previously unseen phenomena in impulsive solar flares. The most spectacular example was a radio burst showing both narrow band and broadband pulsations. These data are now being analyzed in detail. Considerable effort will be devoted in the coming year to modelling the pulsations in terms of nonlinear mechanisms.

The problem of the structure and evolution of solar active regions will be thoroughly analyzed and modified using the microwave and soft X-ray emission of a solar active region complex observed on September 1-4, 1988. The data base is the most complete of its kind: it includes soft X-ray images of the active region in the Fe XVII line and high dynamic range radio maps at 3.6, 6, 20, and 90 cm over a four-day period. The motivation of the work is to reconcile the X-ray and radio observations with a single model of the thermal bremsstrahlung emission from the active region which will involve detailed modelling of the differential emission measure and the inhomogeneous structure of the coronal medium. Based on the results of this work, follow-up studies are planned for early 1992, when the array configuration and the availability of complementary instrumentation will be optimal for active region studies.

Finally, analysis will begin of the high resolution images of the full disk of the sun at wavelengths of 850 and 1250 microns obtained from the Caltech Submillimeter Observatory in support of the solar eclipse of July 11, 1991. Radiation at these wavelengths originates in the low chromosphere where the effects of nonradiative heating in the solar atmosphere are first beginning to manifest themselves. The millimeter/submillimeter wavelength regime is ideally suited for studying this poorly understood layer of the sun's atmosphere. Because the continuum forms in thermal equilibrium, it suffers from few of the interpretive difficulties that spectral lines do.

2. Stars and Stellar Remnants

Stellar Radio Emission

The presence of nonthermal radio emission is a discriminating characteristic of the collapsed remnant of evolved stars--pulsars and X-ray binaries, for example--while thermal radio emission, either in the continuum or in molecular spectral lines, is a signature of young stars or those shedding their outer envelope as they evolve along the giant branch. Both classes of objects will be studied.

The analysis of the complete, three (or more) frequency light curves of the classical radio novae Hercules 1987, Cygni 1986, and Hercules 1991 will be completed. Her 87 and Her 91 were the fastest radio novae yet observed, whereas Cyg 86 was on the other extreme with a long lifetime before reaching the optically thin decay phase, exhibiting the most extreme velocity and density gradients across the shell ever observed. Any new novae observed at high frequencies, near maximum in their radio light curves, should be resolvable with the VLA A-array, allowing systematic studies of the evolution of the two-dimensional structure of nova ejecta. This resolution effect was seen in Hercules 1991, but it had decreased to a flux level of 1 mJy at that time, so the ideal case where the source is both strong and resolved has not yet been found. New novae and X-ray transients will be examined for radio emission and promising ones will be observed systematically.

VLA observations of radio emission from nearby stars will be used to determine the stellar proper motions and parallax. For each star a background radio source within 10' must be located, and its position determined, so that the VLA observations can be made as differential measurements and hence extremely high accuracy can be achieved.

Similar differential astrometric VLA observations of pulsars will be used in a comparison of pulsar proper motions and VLA positions with those obtained from pulse timing techniques. Differences in the two fundamental reference frames, the VLA quasar based celestial frame and the pulsar solar system ephemeris based frame, will be related to the uncertainties in our understanding of the mass distribution in the solar system.

The study of pulsars and their supernovae progenitors will encompass several different approaches. The first is a study of the pulsar-supernova remnant connection. Of the 450 known pulsars and the 150 catalogued supernova remnants, there are surprisingly few established associations. A multi-frequency approach has been adopted to search for new associations. The VLA, ROSAT, 140 Foot Telescope, and Arecibo are being used. The goal is to learn about the distribution of initial periods and magnetic fields for young pulsars as well as learn about their beaming fraction. Follow-up work on the recent new association (G5.4-1.2 and PSR157-24) will also be carried out at the VLA.

A second avenue is a study of pulsar wind generated nebulae around energetic and high-velocity pulsars. How the relativistic pair loaded wind is generated, its composition, and how is propagates and interacts with the surrounding medium are poorly understood. New searches for wind nebulae will be carried out as well as follow-up observations of the recently discovered termination shock of the Vela pulsar.

The study of recent supernovae themselves will be the focus of two research programs. The decay of the radio emission from the radio supernovae SN1979C, SN1980K, and SN1986J will continue to be monitored as a way of constraining the evolution of the supernova envelope. In addition, light curves will be compiled for two new radio supernovae, SN1988Z and SN1990B. Searches for radio emission from supernovae discovered in 1992 will also be made as the opportunity arises.

In several important ways, the initial search for extragalactic supernovae is better done at radio than at optical wavelengths. Radio emission, of course, is not attenuated by interstellar dust as is visible light. This fact provides the motivation for a systematic VLA search for optically obscured supernovae in a large sample, ~150, of nearby galaxies. Observations will be made at regular intervals in 1992.

Emission Nebulae

Nebular emission lines may arise in material recently expelled from the atmosphere of an asymptotic giant branch star or they may arise in gas located near a stellar source of excitation. Both cases may be studied for information about the nature of interstellar gas.

Excitation of the expelled circumstellar envelope of the Be star MWC 349 will be investigated by observations of the millimeter-wave recombination line emission. The variation of the intensity and velocity of these lines, perhaps periodic, is related to overflow of the Roche lobe and hence is a probe of the mass distribution in the MWC 349 system. The process of mass expulsion in an evolving star will be imaged directly through VLBA observations of 43 GHz SiO maser emission.

The ionized expelled envelopes of evolved stars, planetary nebulae, will be studied by means of VLA recombination line images in order to determine the structure and dynamics of the envelope. The distance to six planetary nebulae will be directly established by a comparison of two VLA images taken several years apart. The combination of the apparent increase in the angular diameter of the nebular shells together with the velocity of expansion, determined from the recombination line emission, for instance, will provide the distance. Further constraints on the evolution of planetary nebulae will be provided by images at two wavelengths which together will trace the optical depth in the nebula and by variations in the flux density with time which reflect changes in the mean density of the nebula.

Star Formation

Stars form in condensations within molecular clouds; these condensations are usually called cloud cores. A census of dense cores is complete for only a very few cloud complexes. The tally is fairly complete in the ρOph dense cloud complex where plans are made to better determine the properties of these cores. A cold starless core--L1689N--has been mapped in a deuterated ammonia line with the OVRO interferometer; reduction should shortly be finished. These maps will show just how far the gravitational evolution of this core has proceeded and answer questions such as...is it collapsing? does it rotate? is it flattened? has a readily discernible property halted its evolution? In contrast, a nearby similar core may have formed a star. A high resolution map of 2 cm formaldehyde emission in L1689S shows an elongated structure with suggestive velocity segregation. It is not clear yet whether this structure is a disk, but its major axis aligns well with all of the other known disks and subcore structures in the ρOph cloud. High resolution maps in the ammonia line should clarify whether the structure is a true protostellar disk. A core which has formed a star--several in fact--has been mapped with the Hat Creek millimeter interferometer, revealing a very compact but bright source of SO molecules coincident with one, but not both, of a pair of young stars. The abundance enhancement of sulfur oxides could derive from an enhancement of sulfur or oxygen as the young stars heat nearby grains.

Many stars are binaries, yet little is known about how they form, or how their parent cores differ from those which give rise to single stars. The contention that the IRAS 16293 source is in fact a very young binary has been proven this year with new Owens Valley interferometer (OVRO) maps at 2.6 and 1.3 mm. Mapped on arcsecond scales, the continuum source is clearly double, but neither component is well-resolved, so it remains unclear whether a disk envelops the components. Further observations of continuum and formaldehyde emission at 1.3 mm are planned with the OVRO to determine if the second object is a star, whether both components originated in a common protostellar disk, or whether separate disks envelop the components. Similarly, a more widely separated source in NGC 1333 appears to be a young binary. High resolution ammonia studies will reveal the structure of dense material enveloping the young stars.

The newly formed, recently luminous, stars provide a source of excitation for the remnant gas in their vicinity left over from the star formation process. The hottest young stars will ionize that gas giving rise to ultracompact HII regions, the dynamics of which will be analyzed by their recombination line emission and the evolution of which will be followed by images of the continuum radio emission. Newly formed stars of somewhat lower temperature, but still very highly luminous, will heat and excite the molecular material in their vicinity. These stars can be observed through their excitation of OH and H_2O maser emission in the gas surrounding them. Observations with the VLA and VLBA of the Zeeman splitting of the molecular maser emission lines will be used to estimate the strength and orientation of the magnetic field in the gas from which stars have formed. First theoretical predictions of how the magnetic field relates to the star formation process will be tested.

3. The Interstellar Medium

Observations with the VLBA will be used to study the turbulent electron density layer in the interstellar medium. The measured sizes of OH/IR stars will be interpreted in terms of a scatter broadening and this, in turn, will be studied as a function of location in the galaxy. An attempt will be made to resolve the question of whether the unusual scattering in the direction of the galactic center is related to distributed matter along the line of sight or whether it is attributable to a localized region near the galactic center itself.

The large-scale distribution of diffuse neutral and ionized interstellar gas will be probed by HI absorption observations toward high dispersion measure pulsars.

4. Molecules and Astrochemistry

The chemical, kinematic, and density structure of interstellar molecular clouds can be probed on the scale of milliarcseconds by means of observations of CO absorption toward background continuum sources. The goal is to compare the CO optical depth directly with that inferred by cloud models.

A spectral survey is planned covering the 140-175 GHz region with the 12 Meter Telescope and new SIS receivers. This is an aftermath of the just completed analysis of the NRAO 3 mm spectral survey, which revealed much new information about molecular abundances, the degree of similarity of chemistry in Sgr B2 and OMC-1, etc. The details of these results suggest many new areas of interest at 2 mm, and why the 12 Meter Telescope is well-matched to this problem.

A paper has just been completed on the astrochemistry of refractory elements, which predicts that Mg compounds will be detectable once laboratory information is available, and that the PO molecule will be detectable in cold dark clouds. A search is planned for several other refractory element species, using the new 2 mm SIS receivers at the 12 Meter Telescope; very large increases in the sensitivity over previous searches are obtainable.

SiH_2 is the most likely photodissociation product of silane (SiH_4) as the latter reaches the outer envelope of the circumstellar dust shell in IRC 10216. Silane cannot be detected in the outer envelope by IR methods, yet some form of Si must reach the outer envelope to explain the exotic species SiC_2, SiC_4 recently detected there at millimeter wavelengths. The problem bears on the highly important astrochemical question of whether or not the so-called refractory species such as those of Si are highly depleted by adsorption onto grains.

Ortho/para abundance ratios and relative excitation can be used to determine if ortho and para forms of molecules are equilibrated on grain surfaces or not. Excitations in the equilibrated case can also determine if they were formed on grains or merely adsorbed and desorbed. Analysis of the 3 mm NRAO spectral survey has suggested that ortho-para forms of H_2CCO, H_2CS, NH_2CN are equilibrated (as expected for closed-shell species) while those of CH_2CN, C_3H_2 (radicals) are not. Further observations are proposed of these species to determine much more accurately the excitations and, hence, to decide the central question in astrochemistry of the role of grains.

5. Studies of the Galaxy

In 1992 observations will be made in an attempt to understand the large scale of the structure of the galaxy and of the location and nature of specific objects in the galaxy.

Understanding the nature of interstellar gas well displaced from the galactic plane is one key to an understanding of energetic phenomena in the disk of the galaxy. For several years observations have been made of diffuse HI emission in the galactic halo with a goal of comparing halo HI properties to those of halo heavy-element gas observed in the ultraviolet.

All the data are now in place and the analysis is almost complete. One feature of the data that bears further examination is the variation in elemental abundances with distance from the galactic plane, and with peculiar velocity at high galactic latitudes. It appears that the present data confirm the Routly-Spitzer abundance effect, which is attributed to shock acceleration of clouds leading to a reduced elemental depletion in them. An effect of this sort is probably also needed to explain the observed Ti II abundances, which increase monotonically with distance from the plane even as the total gas density is dropping off rapidly.

High velocity hydrogen clouds in our galaxy have been recognized for close to thirty years but are still poorly understood. As fundamental a parameter as their distance(s) is unknown. The detection of such clouds in other galaxies would severely limit the proposed explanations of these clouds which in our galaxy cover some ten percent of the sky.

A pilot observational study at Arecibo and at the VLA has shown that such clouds can be detected in other galaxies. At least a half dozen galaxies have been detected with the signature of high velocity hydrogen. The route is now open to the explanation of these clouds in our own galaxy as well as in other systems. A significant effort in the coming year will be devoted to gathering, analyzing, and interpreting data on the high velocity HI phenomena in galaxies.

Observation of high velocity HI clouds in the galaxy will be made at high resolution using a 50-pointing mosaic of VLA data. The short spacing data will be provided by complementary observations made with the 140 Foot Telescope. These mosaics, the first ever to be made of high velocity clouds, will permit an analysis of the cloud dynamics to be made.

On a much smaller scale the nature of the compact radio source at the Galactic Center, Sgr A^*, will be constrained in two ways. First, the flux variations, observed for several years, will be interpreted in terms of intrinsic variations and variations attributable to refractory interstellar scattering. The former places a useful lower limit on the source size. The second limit that will constrain Sgr A^* is knowledge of its luminosity. Here one estimate of the mechanical luminosity comes from study of the extreme high velocity gas, -190 km s^{-1}, rotating and expanding about Sgr A Observations of CO will be used to establish the size of the high velocity region from which its energetics can be determined. The combination of parameters, source size and energetics, are needed if alternatives to the description of Sgr A^* as a black hole are to be unambiguously excluded.

Finally, the mass of the Milky Way galaxy will be estimated in a creative way by means of a determination of the orbits of its gravitationally bound, companion, dwarf spheroidal galaxies. VLA astrometric observations of radio sources in the dwarf galaxies will be compared with the positions of background radio sources. This, together with the radial velocity information and the known distance gives a precise measure of the companion's orbit about the Milky Way and from this the mass of the Galaxy.

6. Normal Galaxies

Observations are planned in 1992 to explore the nature and properties of the largest galaxies in the universe, the central galaxies of clusters, and the smallest, the dwarf galaxies.

Optical observations will be made of the most massive galaxies in clusters of galaxies using a tessellating technique that has been developed in order to produce wide field pictures from mosaics of CCD frames covering about 1° 30' areas centered on each one of four Abell clusters. The goal is to detect diffuse optical light 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 better than 10^{-4} of night sky level in the R band. After subtraction of the contamination from bright stars, an extended, highly elliptical, halo of diffuse light has been detected in the cluster Abell 2029 in the R band. The total luminosity of the central galaxy with this halo exceeds 10^{12} $L_{\odot}$ in this band. The halo is detected as well in the B and V bands. No color gradients are detected. The halo is smooth (to better than 3%) in all bands and this is an indication of a well relaxed old system. Data from two different years agree to better than 5×10^{-5} of the night sky level (R band). R, V, and B data have now been obtained as well for clusters A566, A1656, and A2065. These data will be analyzed in the coming months. More observations will be made in order to better determine the faint-end luminosity function in these clusters to better constrain the make-up of the detected diffuse light.

The Sculptor group galaxy NGC 253 contains a very active nucleus. This system was at the heart of a publication on the analysis of radio absorption spectra in which it was shown that a high resolution 21 cm study of this system is badly needed. In 1992 VLBA and MERLIN continuum observations will be carried out on this galaxy in order to determine the flux density of the flat spectrum source in the nucleus of NGC 253. This data will also be analyzed to determine if the nuclear source could be used for phase referencing the observations of other small continuum sources in the central region of NGC 253. These other sources are believed to be very compact supernovae remnants.

Observations of the Sb Seyfert galaxy NGC 1068 will be made with the VLA to image HI and radio continuum emission. The goal is to relate the characteristics of the disk of the galaxy with the activity in the nuclear region. Here the HI VLA images will be compared to CO images recently obtained at the OVRO millimeter wave interferometer.

Radio recombination lines have also been sought in Seyfert galaxies. Beyond the Magellanic clouds, radio recombination lines had been detected before in only two extragalactic sources, namely M82 and NGC 253. Although theoreticians showed that prospects for detecting recombination lines from galaxies and quasars are quite good, searches toward several extragalactic sources did not yield any new detections. Six Seyfert II and starburst galaxies using the best VLA X-band receivers have been used to detect H92α from two of six galaxies, IC 694 and N3628. The search will be extended to more candidate sources.

Dwarf galaxies will be observed both to determine their properties and as probes of their environment. In a prior observation HI clouds near HII galaxies (also known as extragalactic HII regions or Blue Compact Dwarf galaxies) were found to be common. This supports the idea that BCDs have recently undergone an interaction with a companion cloud which has most likely triggered the violent burst of star formation which we witness today. In the coming year further high resolution VLA HI observations will be made of those systems in which companion cloudlets were detected.

A second project on HII galaxies focusses on the radio continuum properties of these objects. Radio continuum observations were made of a small sample of HII galaxies recently. Surprisingly, it was found that the radio spectra at the longer wavelengths flattens. Although there are many mechanisms which could contribute the most likely cause is free-free absorption. In order to constrain the modelling of the radio spectra Hα imaging of the sample of dwarfs will be obtained to provide an independent estimate for the thermal flux density.

Data on a sample of blue compact dwarf galaxies in the Virgo cluster will be taken in the 21 cm line in order to determine a kinematical inclination and through the Tully-Fisher relation a distance to these galaxies. Optical data and the HI data will be combined for this analysis.

Radio continuum observations of several galaxies are planned to investigate the origin and propagation of cosmic rays and the magnetic field in galaxies. This will require multi-frequency, multi-array, polarimetric VLA observations.

7. Radio Galaxies and QSOs

In a complete VLA survey of Abell Clusters, 479 radio galaxies were identified. This sample will be used in several ways in 1992.

It will be used to study the evolution of radio galaxies. The goal is to construct an analog to the HR diagram for radio galaxies. The diagram will consist of the absolute radio luminosity, absolute optical luminosity of the parent galaxy, and radio linear size. Currently available data show the existence of interesting relations between pairs of these variables. Basically sources are expected to grow in luminosity and size with time and die off slowly. The observations can be used to test the theory and to constrain observationally the evolution of the sources.

Higher resolution VLA data is being obtained to allow estimates of the sizes. CCD photometry also is being obtained to measure the magnitudes of the galaxies.

The sample will be used to test the proposal that FR I (twin jet) radio galaxies are the parent objects of BL Lac sources. This idea will be evaluated by looking for nonthermal nuclei in the galaxies in the survey. The primary technique of this test will be to measure the magnitude of the 4000 angstrom break in the spectra of the galaxies. Using this technique, the same one being used to identify BL Lac objects in X-ray surveys, we expect to be able to detect nonthermal cores one hundred times fainter than classical

BL Lac and thus detect the phenomena, if it exists, over a wider range of luminosity and beaming angles than has been achievable in other searches. If the proposal is correct one to ten percent of the galaxies should be true BL Lac objects and many more will be detected at lower luminosities.

The radio survey will be compared with the ROSAT X-ray survey in collaborative effort with the Germans. Theory suggests that there should be a close correlation in the external environment of a radio galaxy and its other properties. Radio sources in rich clusters seem more distorted than those not known to be in dense environments, but it is not clear that luminosity in the radio correlates in the expected way. The situation will be clarified by comparing the two unbiased surveys in detail.

Observations, existing and planned, will be used to establish statistical properties of extragalactic radio jets and to investigate correlation with other observable features of extended radio sources.

- The statistics of both jet and counterjet prominence in "classical double" sources, and their relation to asymmetries in the lobes and to the prominence of other compact structures, will be used to test "unified models" of radio galaxies and quasars. New VLA observations are planned to increase the quality and quantity of the database that is available for such work.
- VLA, MERLIN, and WSRT imaging of a complete sample of nearby 3CR radio sources will be assembled into a computer readable database, in a joint project with workers at the Netherlands Radio Astronomy Laboratory and Netherlands Foundation for Research in Astronomy. This complete "3CR Atlas" will be distributed to individuals and institutes, to assist research into the properties of nearby strong extragalactic sources.

- Studies of the internal structure of "partial jets" in extragalactic sources will be used to help discriminate between steady-state and intermittent-flow models of these structures. To this end, the knots in the partial jet of 3C 219 will be studied at high resolution with the VLA. The VLA will also be used to search for evidence in 3C 219 of the possible radio bow-shock predicted by the intermittent flow model.

The velocities of the kiloparsec-scale extragalactic jets remain perhaps the most important unknown parameter in our understanding of these objects. Monitoring of motions in the M87 jet using 2 cm VLA data will continue. New observations taken in the summer of 1991 will be analyzed and compared with previous epochs. Additional observations have been proposed for late 1992. For the jets in 3C 273 and 3C 279, third and fourth epoch VLA observations were recently made and will be analyzed to search for motions in those jets. A study of the feasibility of measuring velocities in all known jets is underway, and will be concluded.

Efforts to understand particle acceleration and the magnetic field structure of the M87 jet will continue. Total intensity and polarization data from the Hubble Space Telescope and the VLA, both with 0.21 arcseconds resolution, will be compared. New HST observations have been proposed for 1992 to obtain higher signal-to-noise ratio images in both total intensity and polarization. (These new HST observations will also be used to measure proper motions in the M87 jet independently of the VLA measurements.)

An attempt will also be made to determine the velocity of the jet in Centaurus A. Using high fidelity multi-configurational imaging with the VLA and cross-correlational analysis between images of different epochs, the theoretical uncertainty in the measurement of transverse motion in about ten features in the inner jet is between 0.5c and 0.10c. This potential wealth of dynamical information will allow a detailed study of the flow of the synchrotron emitting material as well as a determination of the pattern velocity of the jet. To date, there is not even a VLBI determination of the pattern velocity for Cen A owing to its southern declination and the slow start of southern hemisphere VLBI. The agreement of outer jet morphology with hydrodynamical jet simulations implies that FR I jets are moving subsonically (nonrelativistically). However, Cen A's one-sided inner jet suggests relativistic beaming. It is quite possible that the inner jet is relativistic but rapidly decelerates to sonic velocities about 1 kpc from the core. Such behavior would be apparent in the VLA images. If this were the case, the inner relativistic jet would be hidden from the VLA in the unresolved core in almost every other FR I radio galaxy.

When the jets in Centaurus A, and other radio galaxies, terminate a bright "hot spot" is seen. A sample of nearby, luminous objects with prominent hot spots has been observed with the VLA at X-band, all configurations. These data will be used to understand the phenomenon that causes the supersonic, possibly relativistic, jet to terminate.

8. Parsec-Scale Radio Jets

Radio jets observed closest to the nuclei of radio galaxies are often found to be one-sided. the conventional wisdom has it that this morphology is a result of a relativistic beaming; the intrinsic source morphology is a symmetric twin nuclear jet. Several observations to be made with the VLBA will test this idea.

- Measurements will be made of the internal proper motion of a knot in the asymmetric base of the twin-jet source M84, thought to be viewed close to edge-on. If a significantly superluminal knot speed is detected, then it could 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 subluminal 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. A 1989 VLBI experiment indicates that NGC 3894, a nearby E/SO galaxy, is another example. 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 0.3c, like those shown by 3C 84 and 3C 274, will be measurable.
- Worldwide VLBI observations will be used to search for relativistic motions in the nuclear jet of Cygnus A.

A sample of powerful lobe dominated 3CR radio galaxies has been defined using the same selection criteria used to define the Hough-Readhead sample of lobe dominated quasars. In addition, a redshift range of 0.3-1.0 has been set so that the radio galaxies have approximately the same luminosity and redshift distribution as the quasar sample. Comparison of the morphologies and eventually the internal velocities within the quasar and radio galaxy samples will be an important test of grand unified schemes which seek to unify quasars and radio galaxies based on their orientation relative to our viewing angle.

Frequent VLBA monitoring of a few bright sources, representative of large classes of objects, are also planned to continue. In particular, between 1979 and 1988, the parsec scale structure of 3C 120 was monitored with VLBI. Preliminary results show that new components appear about once per year and travel away from the core at about 2.5 milliarcseconds per year, an apparent speed of about four times that of light. These data will provide a unique opportunity to study the evolutionary history of many superluminal components in a single source. It should help us determine which characteristics are constant and which can vary from one component to another.

Preliminary detections have been made of superluminal motions in 3C 120 on scales of 50 to 100 parsecs. These detections were based on two epoch observations with 18 cm VLBI. In late 1989, the third epoch VLBI observations were made in an attempt to confirm the motions on the 50 to 100 parsec scales. These data have now been correlated and will be analyzed over the next year.

9. Radio Surveys

The 4.85 GHz seven beam receiver was used on the 140 Foot Telescope in 1990 to make a sky survey covering $0^h < \alpha < 20^h$, $-45° < \delta < +5°$. These data have been mapped and a list of the $> 10^4$ sources stronger than S ~ 65 mJy from the maps will be produced.

The 4.85 GHz sky maps made with data from the 300 Foot Telescope were used to identify the 347 UGC galaxies in the declination range $+5° < \delta < +75°$ that are stronger than S = 25 mJy. High resolution (FWHM ~ 1.5 arcsec) 1.49 GHz VLA maps have already been made for half of them and the remaining half of this complete sample will soon be mapped. The high resolution maps will be used to distinguish starbursts from "monsters" powering the radio sources. CCD images of galaxies containing monsters will be obtained at Kitt Peak to determine whether the monsters at the radio core positions coincide exactly with the optical nuclei of these galaxies and to measure the orientations of the inner isophotes relative to the radio jet/lobe axes. A program to observe a complete sample of the stronger radio cores with the VLBA will be started.

The final use of the 1.49 GHz VLA maps will be to provide spectral indices $\alpha(1.49,4.85)$ for the sample of UGC galaxies stronger than 25 mJy at 4.85 GHz. Redshifts are already available for nearly all of the galaxies, so it will be possible to determine the local luminosity function at 4.85 GHz for the first time. This is also the first sample with enough flat spectrum sources to determine the local spectral index distribution of flat spectrum sources. This 4.85 GHz local luminosity function and spectral index distribution will be used to model the radio source counts and spectral index distribution at this frequency. It should be possible to determine the evolution of flat and steep spectrum radio sources independently for the first time.

VLA observations will be used to study the brightness distribution of all the PG quasars, with particular attention to PG 1700+518, a BAL quasar with unusually strong radio emission. The uniform sample of PG quasars will be used to examine the systematic change in radio properties with distance and luminosity. Of particular interest will be to search for the expected $(1+z)^{-4}$ dependence of the brightness temperature.

10. Cosmological Studies

The gravitational lens 2016+112 is being periodically observed with the VLA to measure variations in the brightness of the images. The intent is to use these observations to determine the path length difference between images of the background quasar and, from that, distance to the lens and the background QSO independent of the redshift. If successful these observations will yield an estimate of the Hubble constant.

The question of the origin of the heavy element quasar absorption line system will be addressed in three ways. The first way is through HI 21 cm spectral line observations with the VLA of systems in which a high redshift quasar projects close (on the sky plane) to a low redshift galaxy. Spectra of the quasars in these systems occasionally reveal absorption by gas associated with the foreground galaxy. Observations of such systems provide vital and unique information on the parent galaxy population of quasar absorption line systems, and on the relationship between the absorbing clouds and their parent galaxies. The second way is a compilation of HI imaging surveys of voids and clusters of galaxies and of interacting galaxies. These data will be used to determine the mean free path length to absorption as a function of HI column density in the local universe, which can then be compared to the values at higher redshift derived from optical spectroscopy of quasars. The third way is a search for HI emission from intermediate redshift quasar absorption line systems using the 140 Foot Telescope in Green Bank to test the ideas that galaxies may still be forming at fairly low redshift and that quasar absorption line systems are associated with these forming galaxies.

The microwave background will be the subject of two comprehensive studies.

- Limits will be determined to the 3.6 cm fluctuations in the CMB on angular scales of 60".
- Measurements will continue of the Sunyaev-Zel'dovich effect, a distortion of the spectrum of the microwave background due to Inverse-Compton scattering with the hot electrons that are present in dense clusters of galaxies. At a frequency of 20 GHz, the effect is a decrement in the temperature of the background radiation of about -1 mK in the direction of the densest and hottest clusters of galaxies. Due to the beam-switching schemes that must be used with single dish telescopes at these levels of sensitivity, the measured decrements are about -0.4 mK as the reference beams are affected by the Sunyaev-Zel'dovich distortion. Such small signals have to be confirmed by observations at other frequencies, especially so due to the past history of the observations of this effect as observers have failed to reproduce other observers' results. The observations will use the BIMA millimeter interferometer to observe the Sunyaev-Zel'dovich effect in the cluster 0016+16 at a frequency of 86 GHz. The observations will be made using a tessellating technique to measure the necessary short spacings. Test observations have uncovered some systematic effects which are dominated at this time by

pointing errors which depend on ambient temperature. Work is in progress at University of California, Berkeley towards eliminating this temperature dependence. CCD cameras installed on each antenna will be used in order to determine and monitor pointing using stars. It is not yet clear what will be the next limiting systematic effect. The observing strategy will be decided after better understanding the problems involved with the measurement.

Finally, further searches will be made for proto-clusters of galaxies through the observation of their (redshifted) 21 cm emission at a frequency of 333 MHz, thus probing a redshift of about 3.3. The VLA P-band system has been pushed to a sensitivity of better than 1 mJy/synthesized beam for spectral channels of width 100 kHz. A number of tests located sources of systematic errors (interference, a pointing error of about 8.5 arcminutes on all antennas) and ways have been found to correct them or eliminate their effects. The achieved sensitivity corresponds to a 1 σ value of about 5×10^{12} $M_{\odot}$, somewhat dependent on the values of key cosmological parameters. One of the observed fields contains a protocluster with 3×10^{14} $M_{\odot}$ of neutral hydrogen which is seen in emission. Absorption at a redshift of $Z = 3.4$ is seen towards a radio galaxy at about the same redshift. Higher resolution data will be acquired in order to study the degree of fragmentation and structure of this system. Observations of other fields are planned as well.

A second method used successfully to study protogalaxies at high redshift is to search for CO in emission. In 1991, CO ($J = 3$-2) emission was detected in the IR luminous galaxy IRAS F10214+4724 at a redshift of 2.2867. The enormous gas content of this galaxy suggests that (1) galaxies condense out of the Hubble flow very early; (2) the gas is enriched by several generations of star formation within the first 17 percent of the age of the universe, and (3) the conditions necessary for star formation--

molecular clouds, dust, and a source of excitation--at the present epoch exist as well at high redshift and may be studied well with the next generation of millimeter-wave synthesis telescopes. Studies of CO and other species at high redshift will continue in 1992.

11. Astrophysical Theory and Applied Studies

A comprehensive theoretical and observational study of the spiral galaxy NGC 5364 will begin in 1992. The investigation will focus on the effects of viscosity and vorticity on the dynamical properties of gaseous galaxies where it is suspected that both the large scale dynamics and the spiral patterns are quite significantly affected by hydrodynamic forces. A long-term program for applying hydrodynamic and density wave theory to the best observational information on a number of grand-design spirals is being planned. The first steps will be to propose high velocity and spatial resolution observations of NGC 5364 and to begin understanding the theory well enough to develop a reasonably comprehensive computer code of galaxy dynamics. Over the past year it has been learned that (1) bulk viscosity can have an important effect on the rotational pattern of a galaxy, (2) vorticity is quite significant in disk galaxies, (3) HI maps of disk galaxies must be made with a resolution of about 3 km/s or better to resolve the velocity dispersion profile at each point in a galaxy, and (4) there is enough small-scale structure with high brightness temperature in external galaxies to make B Array VLA observations very important to this study. NGC 5364 was selected for the first observations because it is a relatively simple two-armed spiral of the right angular size to be well resolved with the VLA without mosaicing.

A detailed theoretical study will begin into the chemical evolution of planetary nebulae. This project involves the integration of a complex chemical network throughout the lifetime of a simulated nebula. The nebula is expected to evolve with expansion from a highly shielded circumstellar envelope in which ion-molecule chemistry dominates, to a diffuse gas dominated by photon processes. Grain processing will be carefully examined. In addition, a comprehensive calculation of the thermal balance will be made. The possible effects of large molecules will also be included. Modeling of molecular emission from a spherical nebula is to be done at various epochs in the evolution of the PN. As required, an extensive visual, infrared, and millimeter wavelength observational program will be carried out simultaneously. The observations will be used to test and refine the chemical models.

A similar computer model will be developed to simulate the exposure of molecular clouds to ultraviolet radiation which can result in the formation of photodissociation regions which are rapidly evolving. Earlier work on steady-state photodissociation regions will be extended to a fully time dependent approach. Detailed models of photodissociation regions in sites of star formation will be calculated. A complete treatment of heating and cooling processes in the medium will be included. Emphasis will be placed on observable diagnostics. New observations will be required at far infrared, submillimeter, and millimeter wavelengths. The effects of large molecules on the chemistry and thermal balance of these regions will also be examined.

APPENDIX B

SCIENTIFIC STAFF

(Does not include Visiting Appointments)

P. J. Andre Star formation; molecular clouds; pre-main sequence stars; circumstellar disks; magnetic field

T. S. Bastian - Solar/stellar radiophysics; radiative processes; plasma astrophysics; particle acceleration; interferometry; image deconvolution and reconstruction

A. Beasley - Radio galaxies; synthesis imaging techniques

J. M. Benson - Extragalactic radio sources; VLBI image processing

R. C. Bignell - Polarization and imaging of extragalactic radio sources; planetary nebulae; supernovae remnants

J. A. Biretta - Active galaxies; quasars; VLBI techniques

A. H. Bridle - Extragalactic radio sources

E. Brinks - Interstellar medium in nearby galaxies; HI studies of galaxies; star-forming dwarf galaxies

R. L. Brown - Theoretical astrophysics; interstellar medium; quasar absorption lines

W. R. Burns - Information theory and signal processing

C. L. Carilli - Extragalactic radio sources; formation of galaxies

B. G. Clark - VLBA control; software development

J. J. Condon - QSOs; normal galaxies; extragalactic radio sources

J. Conway - Polarization of extragalactic sources; VLBI techniques

T. J. Cornwell - Interferometry; image reconstruction methods; coherence theory; radio source scintillation

W. D. Cotton - Extragalactic radio sources; interferometry; computational techniques for data analysis

P. C. Crane - Normal galaxies; radio interferometry and aperture synthesis; radio-frequency interference

L. R. D'Addario - Theory of synthesis telescopes; superconducting electronics; millimeter wavelength receivers; radio astronomy from space

P. J. Diamond - Spectral line interferometry; VLBI; software development

K. S. Dwarkanath - Physics of extragalactic radio sources; the interstellar medium

D. T. Emerson - Nearby galaxies; star formation regions; millimeter wave instrumentation

J. R. Fisher - Cosmology; signal processing; antenna design

C. Flatters - VLBI polarization studies of extragalactic radio sources

E. B. Fomalont - Interferometry; extragalactic radio sources; relativity tests

D. A. Frail - Interstellar medium; pulsars; supernova and nova remnants; radio stars

R. W. Garwood - Galactic 21 cm line absorption; interstellar medium; high redshift 21 cm line absorption

F. D. Ghigo - Interacting galaxies; extragalactic radio sources; interferometry

B. Glendenning - Starburst galaxies; scientific visualization

M. A. Gordon - CO; galactic structure; gas rich galaxies; interstellar medium

W. M. Goss - Galactic line studies; pulsars; nearby galaxies

E. W. Greisen - Structure of the interstellar medium; computer analysis of astronomical data

R. J. Havlen - Galactic structure; clusters of galaxies

D. S. Heeschen - Variable radio sources; normal galaxies; QSOs

R. M. Hjellming - Radio stars; radio and X-ray observations of X-ray binaries; interstellar medium

D. E. Hogg - Radio stars and stellar winds; early-type galaxies

M. A. Holdaway - Image reconstruction methods; VLBI polarimetry

P. R. Jewell - Circumstellar shells; interstellar molecules; cometary line emission

W. Junor - Extragalactic radio sources; VLBI

K. I. Kellermann - Radio galaxies; quasars; VLBI

A. R. Kerr - Millimeter-wave development

J. W. Lamb - Millimeter-wave instrumentation

G. I. Langston - Gravitational lenses; computational techniques for synthesis imaging

W. B. Latter - Physics of interstellar clouds; theoretical astrophysics

H. S. Liszt - Molecular lines; galactic structure

F. J. Lockman - Galactic structure; interstellar medium; HII regions

R. J. Maddalena - Molecular clouds; galactic structure; interstellar medium

P. J. Napier - Antenna and instrumentation systems for radio astronomy

F. N. Owen - Clusters of galaxies; QSOs; radio stars

S. K. Pan - Development of millimeter-wave devices

J. M. Payne - Telescope optics; millimeter-wave receivers; cryogenic systems

R. A. Perley - Radio galaxies; QSOs; interferometer techniques

M. Pospieszalski - Low noise front-ends and amplifiers; theory and measurement of noise in electronic devices and circuits

D. Puche - Kinematics of spiral galaxies; dark matter; groups and clusters dynamics

M. S. Roberts - Properties and kinematics of galaxies

J. D. Romney - Active extragalactic radio sources; VLBI; interferometer imaging

M. Rupen - HI emission from normal galaxies; galaxy formation

C. J. Salter - Extragalactic radio sources; galactic continuum emission; SNR

G. A. Seielstad - Quasars; active galaxies; VLBI

R. A. Sramek - Normal galaxies; quasars; astrometry

A. R. Thompson - Interferometry; frequency coordination and atmospheric effects; distant extragalactic sources

B. E. Turner - Galactic and extragalactic interstellar molecules; interstellar chemistry; galactic structure

J. M. Uson - Clusters of galaxies; cosmology

P. A. Vanden Bout - Interstellar medium; molecular clouds; star formation

C. M. Wade - Astrometry; stellar radio emission; minor planets; extragalactic radio sources; VLBA development

R. C. Walker - Extragalactic radio sources; VLBI; VLBA development

D. C. Wells - Digital image processing; extragalactic research

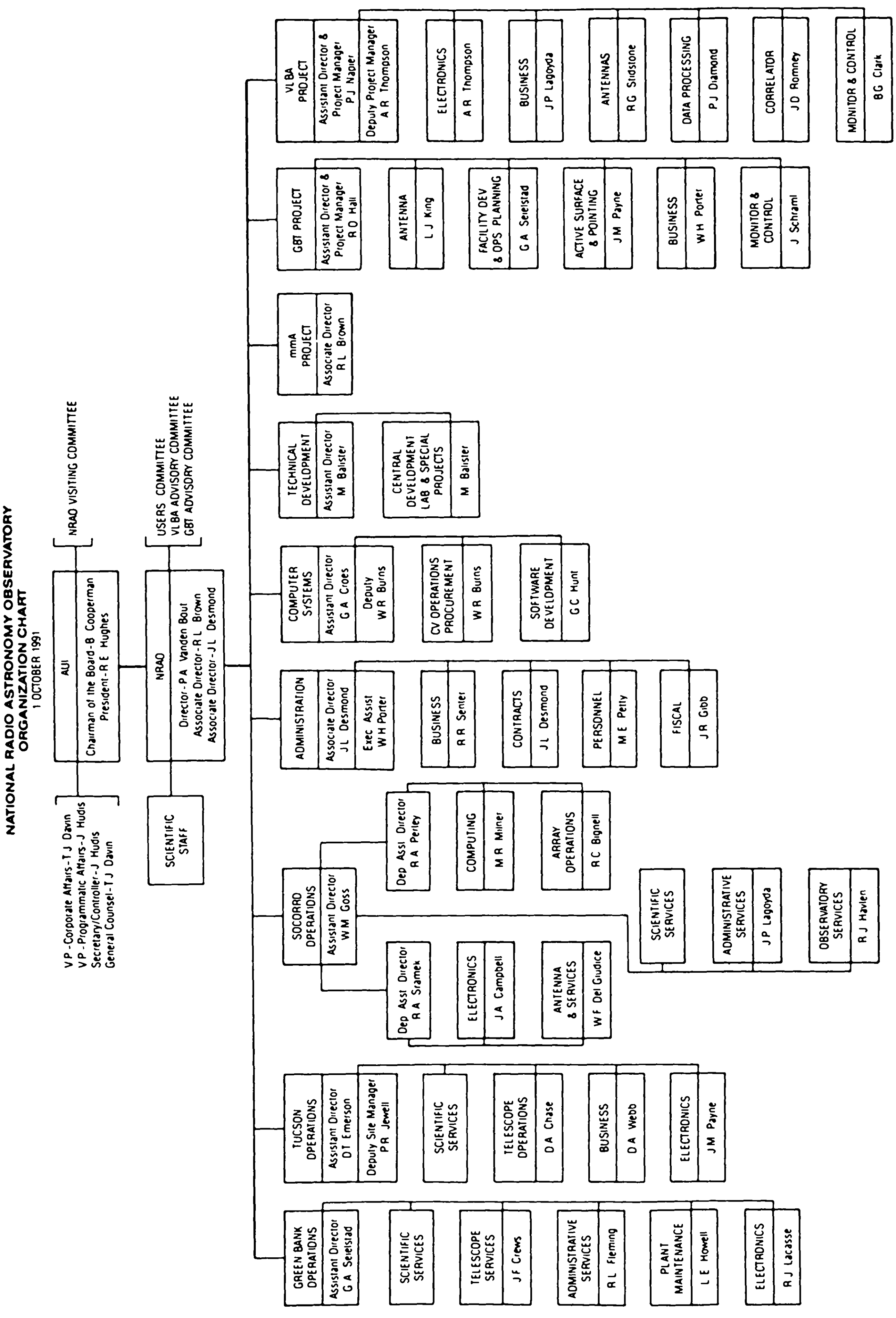
A. H. Wootten Star formation; structure, spectroscopy and chemistry of the interstellar medium in galaxies; circumstellar material

J. M. Wrobel - Normal galaxies; active galaxies; polarimetry

Q.-F. Yin - Normal galaxies; imaging techniques

A. Zensus - VLBI observations of quasars and active galactic nuclei; compact radio jets and superluminal motion in compact radio sources

J.-H. Zhao - Radio jets; galactic center; interstellar medium; clusters of galaxies; recombination lines


NATIONAL RADIO ASTRONOMY OBSERVATORY
ORGANIZATION CHART
1 OCTOBER 1991
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VP-Programmatic Affairs-J Hudis
Secretary/Controller-J Hudis
General Counsel-T J Davin
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NRAO
Director-P A Vanden Bout
Associate Director-R L Brown
Associate Director-J L Desmond
USERS COMMITTEE
VLBA ADVISORY COMMITTEE
GBT ADVISORY COMMITTEE
GREEN BANK OPERATIONS
Assistant Director G A Seielstad
SCIENTIFIC SERVICES
TELESCOPE SERVICES
J F Crews
ADMINISTRATIVE SERVICES
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L E Howell
ELECTRONICS
R J Lacasse
TUCSON OPERATIONS
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Deputy Site Manager P R Jewell
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TELESCOPE OPERATIONS
D A Chase
BUSINESS
D A Webb
ELECTRONICS
J M Payne
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R G Sidstone
DATA PROCESSING
P J Diamond
CORRELATOR
J D Romney
MONITOR & CONTROL
B G Clark

APPENDIX D

NRAO COMMITTEES

1. AUI 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:

D. C. Backer	California, Berkeley
F. N. Bash	University of Texas
R. Hills	Cavendish Laboratory
F. J. Low	Steward Observatory
R. M. Price	University of New Mexico
A.C.S. Readhead, Chairman	California Inst. of Technology
P. Thaddeus	Center for Astrophysics
J. A. Tyson	Bell Laboratories

2. 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 or June.

The present membership is:

C. L. Bennett	Goddard Space Flight Center
J. H. Bieging	Univ. California, Berkeley
F. H. Briggs	University of Pittsburgh

E. B. Churchwell	University of Wisconsin
B. K. Dennison	Virginia Polytechnic Inst. & State Univ.
P. E. Dewdney	Dominion Radio Astrophysical Observatory
R. J. Dewey	Jet Propulsion Laboratory
G. A. Dulk	University of Colorado
N. Duric	University of New Mexico
C. R. Gwinn	University of California, Santa Barbara
J. N. Hewitt	Princeton University
P. T. P. Ho	Harvard College Observatory
S. Kulkarni	California Inst. of Technology
M. L. Kutner	Rensselaer Polytechnic Institute
A. P. Marscher	Boston University
C. R. Masson	Center for Astrophysics
L. J Rickard	Naval Research Laboratory
F. P. Schloerb	Institute for Astronomy
D. B. Shaffer	Goddard Space Flight Center
S. M. Simkin	Michigan State University
R. S. Simon	Naval Research Laboratory
R. Taylor	University of Calgary
J. Turner	University of California, Los Angeles
J. S. Ulvestad	Jet Propulsion Laboratory
A. E. Wehrle	California Institute of Technology
J. M. Weisberg	Carleton College
D. Woody	California Institute of Technology
L. M. Ziurys	Arizona State University

3. VLBA Advisory Committee

The VLBA Advisory Committee periodically reviews 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 advises 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 will meet for the last time in November 1991.

The current membership of the committee is:

D. C. Backer	University of California, Berkeley
R. S. Booth	Onsala Space Observatory
Y. Chikada	Nobeyama Radio Observatory
R. D. Ekers	Australia Telescope
C. G. Fanti	Istituto di Radioastronomia, Bologna
K. J. Johnston	Naval Research Laboratory
R. Porcas	Max-Planck-Institut fur Radioastronomie
A. Readhead	California Institute of Technology
M. J. Reid	Center for Astrophysics
D. B. Shaffer	Interferometrics
A. Whitney	Haystack Observatory

4. Green Bank Telescope Advisory Committee

Appointed at the inception of the Green Bank Telescope (GBT) project in 1989, this committee reviews periodically the design planning for the GBT. Initially the committee advised the Director on critical design issues facing the GBT project: staffing, decisions, and decision-making process of the GBT design team. The committee may identify alternative design techniques or suggest specific tasks. Construction review and proposed instrumentation are future areas of concern to the Committee.

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 for the telescope design and construction.

Current membership is:

C. Heiles	University of California, Berkeley
R. A. Jennings	University of Virginia
J. D. Nelson	University of California, Berkeley
V. Radhakrishnan	Raman Research Institute
S. von Hoerner	Independent Telescope Consultant
S. Weinreb	Martin Marietta Laboratories
R. W. Wilson	Bell Labs

Addendum 1

To

National Radio Astronomy Observatory

Calendar Year 1992

Program Plan

NATIONAL RADIO ASTRONOMY OBSERVATORY

EDGEMONT ROAD · CHARLOTTESVILLE, VIRGINIA 22903-2475
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September 17, 1991

Dr. Ludwig Oster
Division of Astronomical Sciences
National Science Foundation
1800 G Street NW
Washington, DC 20550

Dear Ludwig:

I am writing to provide you with background information for the upcoming meeting of the Division of Astronomical Sciences to discuss the 1992 budget. None of this is news, but you may find a new summary useful.

At the level of the budget request, NRAO would have a severe problem, worse than in any previous year I can recall. The main cause is the collision between the need to maintain VLBA construction, if it is to be completed in 1992, and the need to build up VLBA operations, if it is to be fully operational in 1993. Both of these requirements could have been more easily accommodated had NRAO's base operations budget received adequate increases over the past seven years. But, as you well know, the base program has not even kept pace with inflation. The result, highlighted in the Bahcall Report, is that the entire infrastructure of ground-based astronomy, including the Observatory, needs to be restored. Without that restoration, we are simply too stretched to manage the request level with reasonable options.

Were we forced to operate at the request level, the unreasonable options available include: canceling the entire instrumentation program, ordering a layoff, delaying completion of VLBA construction, slowing down the buildup of VLBA operations, and continuing the present low levels of investment in long-term maintenance, computing, development of new technology, graduate and postdoctoral education, and user support. No single option will produce the budget reduction required to meet the request level; a combination of several, perhaps all, would be necessary. While unreasonable, these options are at least in principle possible. I know of no practical possibilities for actually closing a facility. I hope it is obvious that the need for a 1992 budget larger than the level requested of Congress is a desperate one.

The objectional nature of some of these options is obvious. Eight years is long enough for any construction project, including the VLBA. Not operating finished VLBA sites is embarrassing in the extreme. Why did we build it? But what is so objectionable to further constricting the base program? A review of the extent to which that has already happened and why it cannot continue is in order.

As of today, NRAO has 283 full-time employees for the base program, that is, all NSF-supported activities exclusive of construction and VLBA operations. This level of staffing is identical to that of 12 years ago in 1979, before completion of the VLA, which now accounts for about half of the base program. This impacts every activity of the Observatory. Asking fewer people to do more might look like an increase in efficiency, but it has long-range consequences when it leads to low morale. The latter is an especially real danger at NRAO in that staff compensation lags far behind competing institution--universities, national laboratories, and private enterprise.

The need to repair and increase the maintenance of the Observatory's physical plant has been made so often I need not repeat it here. If the budget situation in 1992 is no better than 1991, it will mean no basic change is possible in this area. We will continue to attack first only those problems where safety is an issue and deal with the rest as best we can.

Computing hardware and software systems at NRAO have long needed improvement. We are making good progress on software under G. Croes's leadership. We expect the purchase of hardware with VLBA construction funds will assume capacity for that instruments needs. Much more needs to be done, however, at all sites including the VLA.

Our instrumentation program has been cut to a bare minimum. Had the Research Equipment program been funded for the last seven years as it had for the seven years prior to that, the VLA would already be upgraded. That is, the receiver systems would be the best possible, a wide bandwidth IF system would be in place, and a new correlator would have been prototyped. As things stand the VLA is operating at 10 percent of the power it could have. This is but one example.

The technical development that must precede any new telescope instrumentation is also proceeding at far too low a level. We are woefully short of test equipment and resources to invest in HFET and SIS rf technology and new digital techniques. This <u>is</u> the long-range future of NRAO.

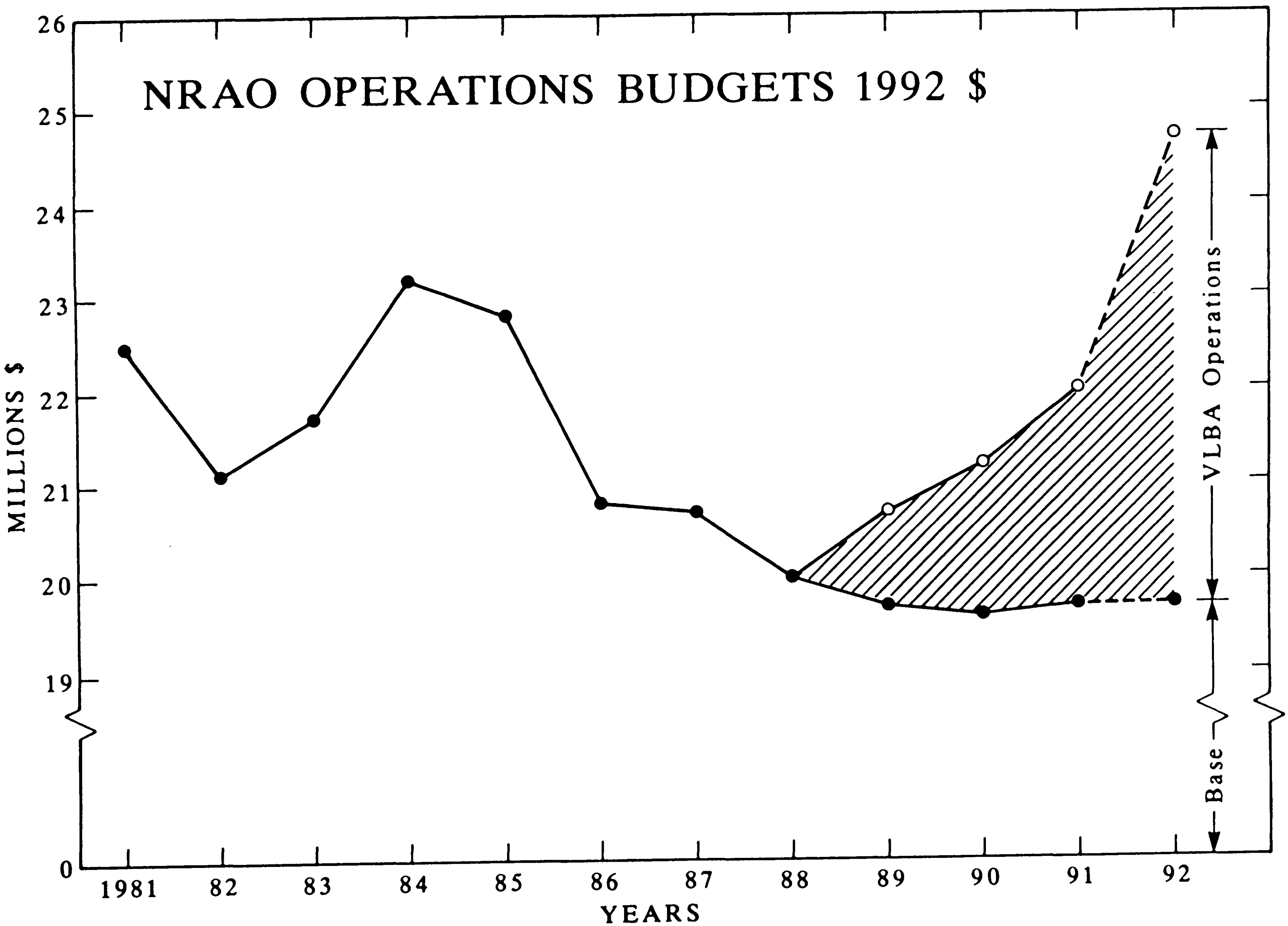
Our support of our user community is severely restricted by present budgets. We have never completely eliminated travel and page charge support, believing that it was critical to maintain minimum levels in an era of inadequate grant support. But we could do more for our users and their students if we had more resources.

Finally, let me remind you that we need on 1 October 1991: an advance from 1992 funds of $600k for VLBA operations and $4.5M for VLBA construction. Also, we expect to receive funds for the Green Bank Secondary Science Teachers Institute and the REU program for 1992. These are, of course, above and beyond the amount for NRAO in the request level budget.

Sincerely,

Paul

Paul A. Vanden Bout
Director


NRAO OPERATIONS BUDGETS 1992 $
MILLIONS $
0
19
20
21
22
23
24
25
26
1981
82
83
84
85
86
87
88
89
90
91
92
YEARS
Base
VLBA Operations

NRAO 1992 BUDGET PROBLEM (M$)

	1992 Request	1991 NRAO Plan[1]
Total Budget	33.4	31.0
Less VLBA Construction	8.7	10.3
Less VLBA Operations[2]	5.0	1.6
Net Available for Base Program Operations	19.7	19.1
Actual Base Survival Budget[3]	21.7	
Shortfall	2.0	

Notes

1. NRAO Plan is <u>after</u> "NSF taxes"; these have not been deducted from 1992 request figures and will increase shortfall accordingly.

2. Actual amount to be spent in calendar year 1991 is 1.6M$ plus an advance from 1992 funds of 0.6M$ for a total of 2.2M$. Accordingly, in calendar year 1992 we will spend 5.0M$ less the advance to 1991, or 4.4M$.

3. Elements contributing to the shortfall: inclusion of research equipment funds, loss of common cost recovery funds from work for others, inflation, and return to operations budgets of certain VLBA construction personnel.

09/17/91

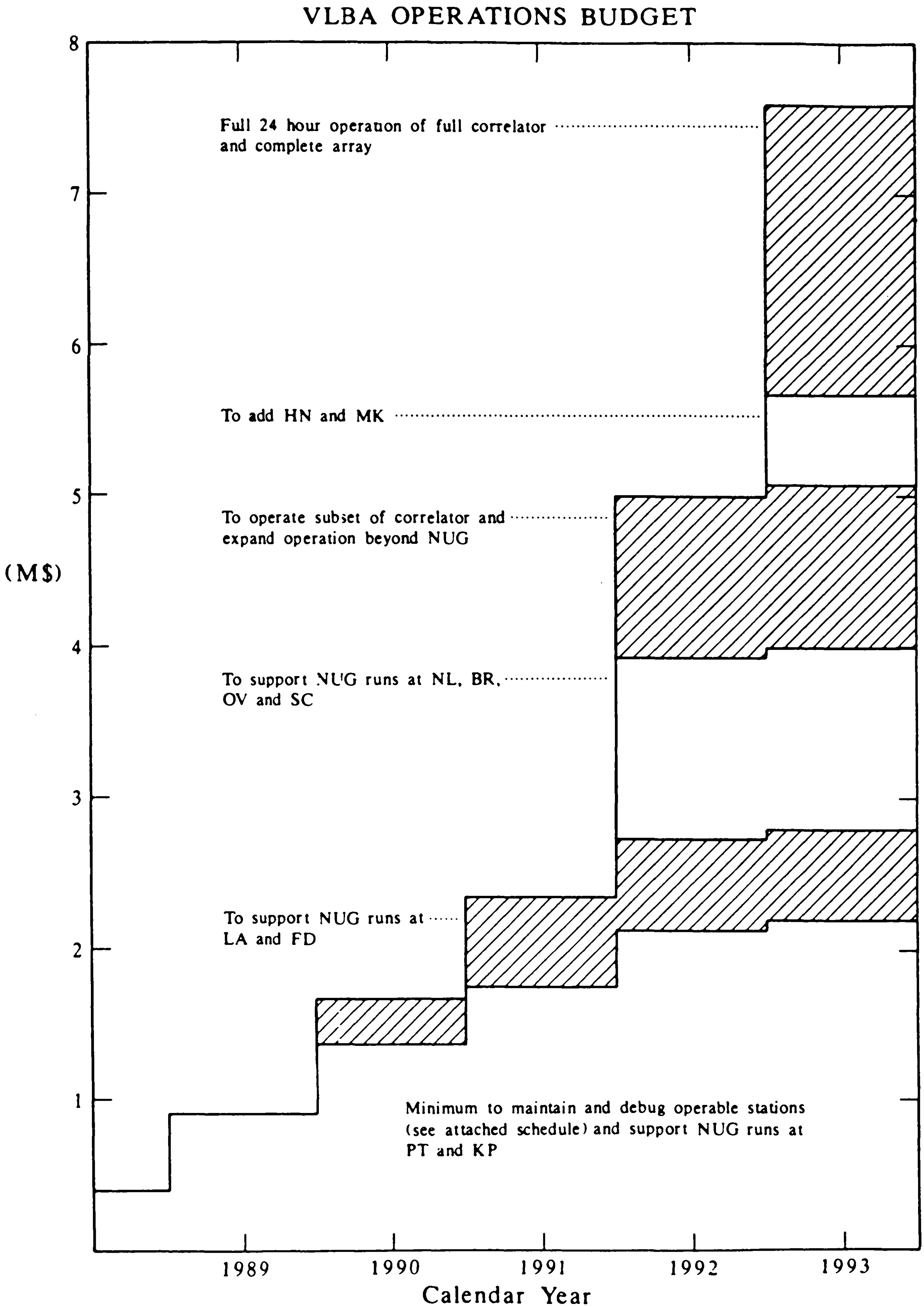
NRAO BUDGET OPTIONS - 1992

Extend VLBA construction into 1993

Slow down the building of VLBA operations

Observatory-wide layoff of personnel

Cancel Observatory instrumentation program



VLBA OPERATIONS BUDGET
8
7
6
5
4
3
2
1
(M$)
Full 24 hour operation of full correlator and complete array
To add HN and MK
To operate subset of correlator and expand operation beyond NUG
To support NUG runs at NL, BR, OV and SC
To support NUG runs at LA and FD
Minimum to maintain and debug operable stations (see attached schedule) and support NUG runs at PT and KP
1989
1990
1991
1992
1993
Calendar Year

INFRASTRUCTURE REQUIREMENTS
NATIONAL RADIO ASTRONOMY OBSERVATORY

	Required Addition to Annual Budget
Physical Plant Restoration and Maintenance	1.2M$
Computing Resources	1.0
Research, Operating, and Test Equipment	1.5
VLA Upgrade (VLA Total 36M$)	3.6
Annual Total	7.3M$
Book Value of NRAO Facilities*	123.0M$
Replacement Value	~200.0M$
Current Annual Budget for Infrastructure (1990)	< 5.0M$

*Does not include the Very Long Baseline Array or Green Bank Telescope. Value shown is as of date purchased.

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FINAL

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20-Jan-92

Benefit Rate 29.50%

Description	Employees @ Y/E	Man Years	Salaries	Benefits (Net of VLBA OPS)	Materials & Services	Travel	Comm. & Utilities	Bldg Rent & Maint	Computer Maint	C.C.R.	Income	Total New Funds Operating Costs	Carryover from 1991	Total New Funds & Carryover
Director's Office	6	6.0	433,000		50,000	75,000						558,000	4,748	562,748
Fiscal	13	12.5	365,000		240,000	35,000			9,000			649,000	11,998	660,998
Business Office	7	8.3	272,000		220,000	8,000						500,000	903	500,903
Management Fee					550,000							550,000		550,000
Sick Leave Buy-Back			28,000									28,000		28,000
Other				4,142,685			130,000	310,000			(5,000)	4,577,685		4,577,685
G & A - NSF	26	26.8	1,098,000	4,142,685	1,060,000	118,000	130,000	310,000	9,000	0	(5,000)	6,862,685	17,649	6,880,334
Scientific Staff	33	32.0	1,648,000		20,000	180,000						1,848,000	682	1,848,682
Student Support	0	18.0	282,000		10,000	15,000						307,000		307,000
				PLUG	56,809							56,809		56,809
Computing	8	7.0	363,000		130,000	15,000			95,000			603,000	19,591	622,591
Software Development	8	8.0	369,000		65,000	25,000						459,000		459,000
AIPS ++					45,000							45,000		45,000
Scientific Services	4	4.8	140,000		250,000	3,000						393,000	23,834	416,834
Other (MMA)					250,000							250,000		250,000
												0		0
Research Support - NSF	53	69.8	2,802,000	0	826,809	238,000	0	0	95,000	0	0	3,961,809	44,107	4,005,916

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20-Jan-92

Benefit Rate 29.50%

Description	Employees @ Y/E	Man Years	Salaries	Benefits (Net of VLBA OPS)	Materials & Services	Travel	Comm. & Utilities	Bldg Rent & Maint	Computer Maint	C.C.R.	Income	Total New Funds Operating Costs	Carryover from 1991	Total New Funds & Carryover
Central Development Lab	20	17.0	711,000		128,000	16,000						855,000	3,244	858,244
Total Technical Develop.	20	17.0	711,000	0	128,000	16,000	0	0	0	0	0	855,000	3,244	858,244
GB - Telescope Services	19	19.8	660,000		42,000	3,000						705,000	4,117	709,117
GB - Electronics	16	15.5	664,000		65,000	10,000						739,000	3,902	742,902
GB - Plant Maintenance	13	14.0	322,000		70,000	2,000						394,000	14,091	408,091
GB - Admin. Services	8	11.2	262,000		95,000	2,000						359,000	3,741	362,741
GB - Scientific Services	5	4.7	211,000		49,000	8,000						268,000	7,990	275,990
GB - Computing	4	4.0	179,000		50,000	10,000			5,000			244,000		244,000
GB - Teachers Enhance. Prgm	1	1.3	31,000	9,000	269,591	2,000						311,591	513	312,104
GB - Other							270,000				(170,000)	100,000		100,000
USNO Upgrade										(32,000)		(32,000)		(32,000)
USNO Operations										(236,000)		(236,000)		(236,000)
												0		0
Green Bank - NSF	66	70.5	2,329,000	9,000	640,591	37,000	270,000	0	5,000	(268,000)	(170,000)	2,852,591	34,354	2,886,945

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20-Jan-92

Benefit Rate 29.50%

Description	Employees @ Y/E	Man Years	Salaries	Benefits (Net of VLBA OPS)	Materials & Services	Travel	Comm. & Utilities	Bldg Rent & Maint	Computer Maint	C.C.R.	Income	Total New Funds Operating Costs	Carryover from 1991	Total New Funds & Carryover
TU - Operations & Maint	14	14.8	520,000		120,000	18,000						658,000	8,649	666,649
TU - Electronics	13	13.0	557,000		150,000	18,000						725,000	7,668	732,668
TU - Computing	2	2.0	80,000		60,000	5,000			35,000			180,000		180,000
TU - Othsr							50,000	81,000			(10,000)	121,000		121,000
TU - Miscellaneous												0		0
Tucson - NSF	29	29.8	1,157,000	0	330,000	41,000	50,000	81,000	35,000	0	(10,000)	1,684,000	16,317	1,700,317
SOC - Scientific Services	9	9.7	427,000		35,000	21,000						483,000	2,020	485,020
SOC - Antenna & Services	41	43.7	1,123,000		543,000	13,000						1,679,000	12,853	1,691,853
SOC - Computing	16	15.5	621,000		75,000	5,000			190,000			891,000	5,093	896,093
SOC - Electronics	29	29.7	1,066,000		230,000	13,000						1,309,000	3,457	1,312,457
SOC - Array Operations	9	9.0	288,000		25,000	2,000						315,000	450	315,450
SOC - Admin Services	11	11.0	271,000		240,000	14,000						525,000	1,238	526,238
SOC - Observatory Service	4	4.0	103,000		95,000	3,000						201,000	5,228	206,228
SOC - Other							1,046,000	100,000			(59,000)	1,087,000		1,087,000
SOC - Miscellaneous												0		0
												0		0
VLA - NSF	119	122.6	3,899,000	0	1,243,000	71,000	1,046,000	100,000	190,000	0	(59,000)	6,490,000	30,339	6,520,339

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20-Jan-92

Benefit Rate 29.50%

Description	Employees @ Y/E	Man Years	Salaries	Benefits (Net of VLBA OPS)	Materials & Services	Travel	Comm. & Utilities	Bldg Rent & Maint	Computer Maint	C.C.R.	Income	Total New Funds Operating Costs	Carryover from 1991	Total New Funds & Carryover
VLBA OPS - Sci. Services	7	6.0	250,000		25,000	14,000						289,000		289,000
VLBA OPS - Antenna & Serv	6	5.5	153,000		90,000	25,000						268,000	1,238	269,238
VLBA OPS - Computing	10	6.7	262,000		45,000	20,000			30,000			357,000	5,144	362,144
VLBA OPS - Electronics	39	34.2	1,022,000		135,000	25,000						1,182,000	4,779	1,186,779
VLBA OPS - Array Ops	13	8.5	255,000		70,000	15,000						340,000	5,632	345,632
VLBA OPS - Admin Services	5	5.5	136,000		149,000	10,000						295,000	729	295,729
VLBA OPS - Observatory Svcs					10,000	1,000						11,000		11,000
VLBA - Other							375,000	65,000				440,000		440,000
												0		0
Total VLBA OPS - NSF	80	66.4	2,078,000	0	524,000	110,000	375,000	65,000	30,000	0	0	3,182,000	17,522	3,199,522
CCR/Device Revenue										(732,000)	(25,000)	(757,000)		(757,000)
Total NSF Operations	383	402.[illegible]	14,074,000	4,151,685	4,752,400	631,000	1,871,000	556,000	364,000	(1,000,000)	(269,000)	25,131,085	163,532	25,294,617
Operating Equipment					0							0		0
Research Equipment					750,000							750,000	178,029	928,029
VLBA Construction	15	27.5	1,096,000	323,320	6,779,680	250,000						8,449,000	3,938,401	12,387,401
TOTAL - NSF FUNDING	408	430.4	15,170,000	4,475,005	12,282,080	881,000	1,871,000	556,000	364,000	(1,000,000)	(269,000)	34,330,085	4,279,962	38,610,047

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20-Jan-92

Benefit Rate 29.50%

Description	Employees @ Y/E	Man Years	Salaries	Benefits (Net of VLBA OPS)	Materials & Services	Travel	Comm. & Utilities	Bldg Rent & Maint	Computer Maint	C.C.R.	Income	Total New Funds Operating Costs	Carryover from 1991	Total New Funds & Carryover
Work for Others/Operations														
USNO Operations	7	8.0	296,000	87,320	100,280	3,000	30,000			315,000		831,600	161,698	993,298
NASA UV Imaging Telescope	0	0.0			20,027							0	20,027	20,027
NSF Observ. So. Supernova	0	0.0			3,102							0	3,102	3,102
NASA Time Var.	0	0.0			20,602							0	20,602	20,602
NASA OVLBI Science	4	4.5	187,000	55,165	415,835	35,000				193,000		886,000	3,362	889,362
NASA OVLBI W17.388	0	0.0			2,178							0	2,178	2,178
TOTAL - Work for Others/Operations	11	12.5	483,000	142,485	562,024	38,000	30,000	0	0	508,000	0	1,717,600	210,969	1,928,569
Work for Others - Equipment														
USNO Operations	0	0.0										0	0	0
Design & Work in Process														
USNO Interferometer Addition	1	1.0	40,000	11,800	518,198					42,400		0	612,398	612,398
GBT Project - Operations	23	22.3	987,000	291,165	13,683,420	60,000						0	15,021,585	15,021,585
NASA - OVLBI Earth Station	5	5.0	228,000	67,260	697,740	16,000				241,000		1,250,000	281,652	1,531,652
USNO - VLBI Hawaii					224,886	16,000				208,200		0	449,086	449,086
Total - Design & Work in Process	29	28	1,255,000	370,225	15,124,244	92,000	0	0	0	491,600	0	1,250,000	16,364,721	17,614,721

XI. 1992 Preliminary Financial Plan
Table 1
(NSF Funds, $ in thousands)

	Personnel	Salaries, Wages & Benefits	Materials, Supplies & Services	Travel	Total
Operations					
General & Administrative	25	$1,331	$913	$134	$2,378
Research Support	59	3,496	575	258	4,329
Technical Development	20	983	291	18	1,292
Green Bank Operations	72	3,194	449	75	3,718
Tucson Operations	29	1,614	526	50	2,190
Socorro Operations	120	5,130	2,527	71	7,728
VLBA Operations	87	3,208	1,483	174	4,865
Management Fee			550		550
Common Cost Recovery/ CDL Device Revenue			(350)		(350)
Total Operations	412	$18,956	$6,964	$780	$26,700
Design and Construction					
VLBA	9	$1,091	$7,473	$150	$8,714
Total Operations and Design & Construction	421	$20,047	$14,437	$930	$35,414
Infrastructure					
Phys. Plant Restoration & Maint.	8	$260	$940	$0	$1,200
Research & Operating Equipment	0	0	1,500	0	1,500
Computing Resources	5	240	750	10	1,000
VLA Upgrade	3	90	3,440	70	3,600
Total Infrastructure	16	$590	$6,630	$80	$7,300
New Initiatives					
MMA	2	$100	$860	$40	$1,000
TOTAL NSF	439	$20,737	$21,927	$1,050	$43,714

October 1, 1991

XI. 1992 Preliminary Financial Plan

Table 2

(NSF Funds, $ in thousands)

	New Funds	Uncommitted Carryover of 1991 Funds	Total Available for Commitment	Commitments Carried Over From 1991 Funds	Total Available for Expenditures
Operations					
Personnel Compensation	$14,694		$14,694		$14,694
Personnel Benefits	4,262		4,262		4,262
Travel	780		780		780
Material & Supply	6,764		6,764	150	6,914
Management Fee	550		550		550
Common Cost Recovery/CDL Device Revenue	(350)		(350)		(350)
Total: Operations	26,700	0	26,700	150	26,850
Design & Construction					
VLBA	8,714	100	8,814	1,000	9,814
GBT	0	14,727	14,727	48,000	62,727
Total: Design & Construction	8,714	14,827	23,541	49,000	72,541
Total Operations and Design & Construction (NOTE 1)	$35,414	$14,827	$50,241	$49,150	$99,391
Infrastructure					
Phys. Plant Restoration & Maint.	$1,200		$1,200		$1,200
Research & Operating Equipment	1,500		1,500		1,500
Computing Resources	1,000		1,000		1,000
VLA Upgrade	3,600		3,600		3,600
Total Infrastructure	7,300	0	7,300	0	7,300
New Initiatives					
Millimeter Array	1,000		1,000		1,000
Total Infrastructure & New Initiatives	8,300	0	8,300	0	8,300
TOTAL NSF PLAN	$43,714	$14,827	$58,541	$49,150	$107,691

(NOTE 1) NSF New Funds request is $33.4M. The NRAO shortfall is $35.4M – $33.4M = $2.0M

October 1, 1991

XII. LONG RANGE PLAN
(NSF Funds, $ in millions)

	1992	1993	1994	1995	1996	1997
Operations						
Base Operations	$21.835	$23.145	$32.590	$34.945	$37.041	$39.263
VLBA Operations	4.865	7.600				
Total Operations	26.700	30.745	32.590	34.945	37.041	39.263
Design & Construction						
VLBA ($85M)	8.714	-	-	-	-	-
Total Operations and Design & Construction	$35.414	$30.745	$32.590	$34.945	$37.041	$39.263
Infrastructure						
Phys. Plant Restoration & Maint.	$1.200	$1.200	$1.300	$1.300	$1.300	$1.500
Research & Operating Equipment	1.500	1.500	1.500	1.500	1.600	1.600
Computing Resources	1.000	1.000	1.000	1.000	1.000	1.000
VLA Upgrade	3.600	3.600	3.600	3.600	3.600	3.600
Total Infrastructure	$7.300	$7.300	$7.400	$7.400	$7.500	$7.700
New Initiatives						
Millimeter Array ($120M)	1.000	3.000	5.000	11.000	25.000	25.000
VLA-VLBA Link ($31M)	-	-	-	-	-	5.000
Total New Initiatives	1.000	3.000	5.000	11.000	25.000	30.000
Total NSF	$43.714	$41.045	$44.990	$53.345	$69.541	$76.963

PERSONNEL PROJECTION (Full Time - Year End Ceiling)

	1992	1993	1994	1995	1996	1997
Base Operations	325	336	457	472	474	476
VLBA Operations	87	97				
VLBA Construction	9	-	-	-	-	-
Infrastructure	16	16	16	16	16	16
GB Telescope Construction	23	25	25	-	-	-
Millimeter Array	2	5	9	12	24	40
VLA-VLBA Link	-	-	-	-	-	5
Work for Others	20	20	15	15	15	15
Personnel Total	482	499	522	515	529	552

Addendum 2

To

National Radio Astronomy Observatory

Calendar Year 1992

Program Plan

Porter

NATIONAL RADIO ASTRONOMY OBSERVATORY

520 EDGEMONT ROAD CHARLOTTESVILLE, VIRGINIA 22903-2475
TELEPHONE 804 296-0211 TWX 910 997-0174 FAX 804 296-0278

January 21, 1992

Dr. Ludwig Oster
Division of Astronomical Sciences
National Science Foundation, Rm. 618
1800 G Street NW
Washington, DC 20550

Dear Ludwig:

The enclosed financial tables replace those in the Preliminary Program Plan for 1992. These tables have been revised to reflect the final allocation of new NSF funds for 1992, that is, $34.465M. That total amount contains $8.449M for VLBA construction, but does not include funds for the Research Experiences for Undergraduates or the Teachers Enhancement Program.

While this budget is a welcome increase over past budgets, it still does not provide enough funds to both address our infrastructure problems, effectively operate the Observatory, complete VLBA construction, and continue to build up VLBA operations. Our original budget estimate of $35.4M would have accomplished this.

The financial plan we are submitting will stretch out staffing for VLBA operations and begin to seriously address the infrastructure problems. To continue these two efforts throughout the year, it will be necessary to receive an advance of at least $1.0M in FY 93 funds in October 1992. Please confirm that NSF intends to advance these funds in early FY 93.

A plan for the first five years of infrastructure restoration at the NRAO is enclosed.

Sincerely,

Paul

Paul A. Vanden Bout

XII. LONG RANGE PLAN
(NSF Funds, $ in millions)

	1992	1993	1994	1995	1996	1997
Operations						
Base Operations	$21.025	$23.059	$32.499	$34.839	$36.929	$39.145
VLBA Operations	3.991	7.600				
Total Operations	25.016	30.659	32.499	34.839	36.929	39.145
Design & Construction						
VLBA ($85M)	8.449	-	-	-	-	-
Total Operations and Design & Construction	$33.465	$30.659	$32.499	$34.839	$36.929	$39.145
Infrastructure						
Phys. Plant Restoration & Maint *	$1.000	$0.900	$0.945	$0.880	$0.800	$0.900
Research & Operating Equipment	0.800	1.500	2.000	2.000	2.000	2.200
Computing Resources *	0.200	0.700	0.500	0.500	0.500	0.500
VLA Upgrade	0.000	1.000	2.000	3.000	3.600	3.600
Total Infrastructure	$2.000	$4.100	$5.445	$6.380	$6.900	$7.200
New Initiatives						
Millimeter Array ($120M)	0.000	1.000	5.000	11.000	25.000	25.000
VLA-VLBA Link ($31M)	-	-	-	-	-	5.000
Total New Initiatives	0.000	1.000	5.000	11.000	25.000	30.000
Total NSF **	$35.465	$35.759	$42.944	$52.219	$68.829	$76.345

PERSONNEL PROJECTION (Full Time - Year End Ceiling)

	1992	1993	1994	1995	1996	1997
Base Operations	312	325	425	450	455	460
VLBA Operations	82	92				
VLBA Construction	15	-	-	-	-	-
Infrastructure	6	8	8	8	8	8
GB Telescope Construction	23	21	21	-	-	-
Millimeter Array	-	5	9	12	24	40
VLA-VLBA Link	-	-	-	-	-	5
Work for Others	18	15	15	15	15	15
Personnel Total	456	466	478	485	502	528

* Incremental to operation funds spent in 1991 and to be continued in 1992.

** Includes $1.0M in advanced 1993 funding.

XII. LONG RANGE PLAN
(NSF Funds, $ in millions)

	1992	1993	1994	1995	1996	1997
Operations						
Base Operations	$21.025	$23.059				
			$32.499	$34.839	$36.929	$39.145
VLBA Operations	3.991	7.600				
Total Operations	25.016	30.659	32.499	34.839	36.929	39.145
Design & Construction						
VLBA ($85M)	8.449	-	-	-	-	-
Total Operations and Design & Construction	$33.465	$30.659	$32.499	$34.839	$36.929	$39.145
Infrastructure						
Phys. Plant Restoration & Maint *	$1.000	$0.900	$0.945	$0.880	$0.800	$0.900
Research & Operating Equipment	0.800	1.500	2.000	2.000	2.000	2.200
Computing Resources *	0.200	0.700	0.500	0.500	0.500	0.500
VLA Upgrade	0.000	1.000	2.000	3.000	3.600	3.600
Accelerated Program **	0.000	2.041	1.855	0.920	0.400	0.100
Total Infrastructure	$2.000	$6.141	$7.300	$7.300	$7.300	$7.300
New Initiatives						
Millimeter Array ($120M)	0.000	1.000	5.000	11.000	25.000	25.000
VLA-VLBA Link ($31M)	-	-	-	-	-	5.000
Total New Initiatives	0.000	1.000	5.000	11.000	25.000	30.000
Total NSF ***	$35.465	$37.800	$44.799	$53.139	$69.229	$76.445

PERSONNEL PROJECTION (Full Time - Year End Ceiling)

	1992	1993	1994	1995	1996	1997
Base Operations	312	325				
			425	450	455	460
VLBA Operations	82	92				
VLBA Construction	15	-	-	-	-	-
Infrastructure	6	8	8	8	8	8
GB Telescope Construction	23	21	21	-	-	-
Millimeter Array	-	5	9	12	24	40
VLA-VLBA Link	-	-	-	-	-	5
Work for Others	18	15	15	15	15	15
Personnel Total	456	466	478	485	502	528

* Incremental to operation funds spent in 1991 and to be continued in 1992.

** These funds would accelerate the infrastructure restoration to the level proposed ($7.3M).

*** Includes $1.0M in advanced 1993 funding.

XI. 1992 Financial Plan by Site / Project (NSF Funds, $ in thousands)

	Personnel	Salaries, Wages & Benefits	Materials, Supplies & Services	Travel	Total
Operations					
General & Administrative	26	$1,422	$954	$118	$2,494
Research Support	53	3,629	922	238	4,789
Technical Development	20	921	128	16	1,065
Green Bank Operations	65	2,976	476	35	3,487
Tucson Operations	29	1,498	486	41	2,025
Socorro Operations	119	5,049	2,520	71	7,640
VLBA Operations	82	2,692	1,189	110	3,991
Management Fee			550		550
Common Cost Recovery/ CDL Device Revenue			(1,025)		(1,025)
Total Operations	394	$18,187	$6,200	$629	$25,016
Design and Construction					
VLBA	15	$1,419	$6,780	$250	$8,449
Total Operations and Design & Construction	409	$19,606	$12,980	$879	$33,465
Infrastructure					
Phys. Plant Restoration & Maint.*	6	$90	$900	$10	$1,000
Research & Operating Equipment	0	0	800	0	800
Computing Resources *	0	0	200	0	200
VLA Upgrade	0	0	0	0	0
Total Infrastructure	6	$90	$1,900	$10	$2,000
New Initiatives					
MMA	0	$0	$0	$0	$0
TOTAL NSF	415	$19,696	$14,880	$889	$35,465

* Incremental to operation funds spent in 1991 and to be continued in 1992.

** Includes $1.0M in advanced 1993 funding.

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XI. 1992 Financial Plan by Budget Category (NSF Funds, $ in thousands)

	New Funds	Uncommitted Carryover of 1991 Funds	Total Available for Commitment	Commitments Carried Over From 1991 Funds	Total Available for Expenditures
Operations					
Personnel Compensation	$14,043		$14,043		$14,043
Personnel Benefits	4,143		4,143		4,143
Travel	629		629		629
Material & Supply	6,676		6,676	164	6,840
Management Fee	550		550		550
Common Cost Recovery/CDL Device Revenue	(1,025)		(1,025)		(1,025)
Total: Operations	25,016	0	25,016	164	25,180
Design & Construction					
VLBA	8,449	0	8,449	1,604	10,053
GBT	0	15,021	15,021	49,082	64,103
Total: Design & Construction	8,449	15,021	23,470	50,686	74,156
Total Operations and Design & Construction	$33,465	$15,021	$48,486	$50,850	$99,336
Infrastructure					
Phys. Plant Restoration & Maint. *	$1,000		$1,000		$1,000
Research & Operating Equipment	800		800		800
Computing Resources *	200		200		200
VLA Upgrade	0		0		0
Total Infrastructure	2,000	0	2,000	0	2,000
New Initiatives					
Millimeter Array	0		0		0
Total Infrastructure & New Initiatives	2,000	0	2,000	0	2,000
TOTAL NSF PLAN **	$35,465	$15,021	$50,486	$50,850	$101,336

* Incremental to operation funds spent in 1991 and to be continued in 1992.

** Includes $1.0M in advanced 1993 funding

January 22, 1992

NATIONAL RADIO ASTRONOMY OBSERVATORY

REBUILDING THE INFRASTRUCTURE

A PLAN FOR THE FIRST FIVE YEARS

January 1992

I. OVERVIEW

"Restoring the infrastructure" is the Bahcall Committee's *highest* priority for ground-based astronomy. This is to be accomplished by increasing "the operations and maintenance budgets of the national observatories to an adequate and stable fraction of their capital cost..." What is meant by the term *infrastructure* and what are the specific needs at NRAO?

The most visible evidence of a deteriorating infrastructure at the NRAO, an example highlighted by the Bahcall Committee's report, is the state of the railway track system used to transport the antennas of the Very Large Array (VLA) among its four different array configurations. Major components of the system need to be replaced and improved, and the level of continuous maintenance required to keep the system in good repair has never been achieved. As a result, the system continues to slowly decline in reliability, and safety considerations mandate slow and inefficient operations. *But the VLA railway tracks are only the highly visible "tip of the iceberg," an important part of a much larger problem.*

The physical plant needs of the NRAO are not only much larger than the VLA railway track problems, the concept of *infrastructure* itself is larger than physical plant maintenance. The report of the Bahcall Committee recognizes this by including in the restoration of the infrastructure instrumentation upgrades, enhancement of computing resources, and strengthening of technical development staff and equipment. It is the entire infrastructure from the present physical plant to the ability to develop the means for scientists to better utilize those facilities that must be restored.

It must also be recognized that restoring and maintaining the infrastructure is a *continuing* activity. This is not a one-time, short-term effort. Today's list of physical plant problems requiring attention will be replaced by another in a few years. Today's computing facilities will be rendered obsolete and inadequate by tomorrow's technology and the demands of new science. The possibilities to extract better use from facilities with upgraded instruments depend on a continuing program of developing technology.

A summary of NRAO infrastructure requirements is given in four broad categories in Table 1 below, where the annual additional funding required is given.

TABLE 1

INFRASTRUCTURE REQUIREMENTS

Physical Plant Restoration and Maintenance	1.2M$
Engineering Infrastructure/Research, Operating, and Test Equipment	1.5
Computing Resources	1.0
VLA Upgrade	3.6
Annual Total	7.3M$

*Includes the Very Long Baseline Array and Green Bank Telescope. Value shown is as of date purchased.

II. PHYSICAL PLANT RESTORATION AND MAINTENANCE

The effects of several years of very restricted operations funding at the NRAO have percolated throughout the entire scope of Observatory activities to such an extent that many years of increased funding will be required to restore the facilities, and equally important, the staff of the Observatory. Section VI gives a schedule for the first five years. During the course of this program major items are completed in a progression of balanced priorities that will enable the NRAO to provide to the U.S. scientific community the services expected from their National Observatory and to rectify the effects of the funding-imposed technical stagnation of the recent past. Major items are described here and in Sections III-V.

The problem is not amenable to simple fixes. The NSF investment in capital facilities is large, and we must plan to spend a few percent of this investment each year on maintenance as long as the facilities are operated. Today we can enumerate the specific maintenance needs and estimate the cost. But having "solved" these specific problems we cannot expect the maintenance needs of the NRAO facilities to be eliminated or even reduced. Tomorrow the maintenance problems will be different, but they certainly will be present.

The VLA Rail Ties. The VLA rail track system consists of two standard gauge railroad tracks which run along each 13-mile arm of the array. There are about 80 miles of (single) track in the system. The combined weight of the transporter plus the antenna is about 300 tons. With 24 wheels on four trucks, this gives a loading of 50,000 pounds on each of the 12 axles, a high but not unusual load in the railroad industry. The track system currently has about 800,000 feet of (single) rail on the

main line and 46,000 feet in the antenna spurs. There are 190,000 ties and 72 intersections. The entire track system was constructed with used materials. The rail, for example, dates from 1902 to 1956.

Since the VLA began full operation in 1980, the rail system has received regular inspection and whatever upkeep was mandated by safety considerations. Now, at roughly ten years of age for much of the system, more major maintenance is required. The main, but not the only, problem is a deterioration of the rail ties. This has become serious because the rate of deterioration has accelerated beyond what would normally be expected. In particular, those ties that came from wet regions of the U.S. are deteriorating rapidly in the dry conditions of New Mexico.

Rail maintenance is now done by a four-man VLA rail crew augmented by seasonal help. In the past year a tie extractor (purchased with NASA/JPL funding) and a surplus ballast tamper have been added to the rail maintenance equipment. Tie replacement is continuing at 1000-3000 ties per year. Improving the condition of the rail system requires that at least 6000 ties per year be replaced, with 10,000 per year a goal. At 6000 ties replaced per year, any given tie is replaced every 30 years.

VLA Track Intersections. During operations the VLA antennas rest on concrete foundations 100 feet from the main rail line. Each station is connected to the main line by a short spur rail line and a track intersection. These deteriorating intersections are the weakest elements in the system. They need to be redesigned and rebuilt.

Other maintenance items in the track system besides the ties and intersections are: replacement of clogged ballast; reconstruction of the US 60 highway crossing; realigning, gauging, and upgrading antenna spur lines; replacing bad rail sections; repairing and smoothing joints cleaning and dressing ballast; and ultrasonic testing of all rail.

VLA Power Distribution System. Electrical power is supplied to the antennas of the VLA by buried cable running along the arms--three cables per arm, one for each phase, operating at 12.45 kV. These cables were installed between 1974 and 1980 The type of cable selected was highly recommended and in wide use at that time throughout the U.S. by electric utility companies. The extruded polyethylene insulation on these cables is now known to be subject to failures which increase rapidly in rate with cable age. Experience with the cable at the VLA is following the industry-wide pattern.

Polyethylene cable deteriorates with age owing to a process known as "treeing." A "tree" is a growing channel which propagates through the insulation, probably due to ion or electron bombardment. The number and size of trees in a cable is primarily a function of time in service, operating electric field strength, and the presence of manufacturing impurities. As treeing progresses, the dielectric strength of the insulation deteriorates until voltage surges due to switching transients or

nearby lightning strikes break down the insulation and the resulting arching produces a ground fault. The only solution is to replace the power cables. Steps to slow the cable degradation and minimize the disruption of operations will allow the cable to be replaced over several years. The total cost is estimated to be approximately $1.35M. About 25 percent of the cost has been borne by NASA as part of the Voyager/Neptune encounter project, and all cable has been replaced to the ends of the C-configuration at NASA expense. NRAO will have replaced a roughly equal amount of cable with NSF funds at the end of 1991, leaving 400,000 feet of cable to be installed. The work is done in-house with a three person crew, using a trencher to excavate a trench, lay the cable, by hand, in a bed of sand at the bottom of the trench, and cover with clean sand and fill dirt. At present installation rates it would take six to seven years to finish recabling. Funds to double the installation rate are included in this plan.

VLA Waveguide System. The VLA IF signals, local oscillator, and monitor signals for the VLA antennas are all multiplexed on a signal carried by circular waveguide along the arms of the wye to the antennas. The waveguide is buried and access is via a series of widely spaced manholes. There are more than 100 manholes, each of which was constructed with the clever and inexpensive expedient of stacking concrete burial vaults with their bottoms removed. However, after 10 years the soil pressure has bowed the sides of the vaults to the extent that it is unsafe to access many of the manholes and they must be rebuilt with an improved design.

VLA Antenna Azimuth Bearings. In 1991 an antenna was taken out of service for several months due to problems with its azimuth bearing. A large stand was constructed to enable the removal and replacement of these bearings in the antenna assembly building. The faulty bearing is being studied by the manufacturer. Depending on the results of that study, future routine overhaul of VLA antennas may require azimuth bearing replacement or rebuilding.

VLA Antenna Transporter Overhaul. The two transporters used to reconfigure the VLA require new hydraulic control systems and replacement or overhaul of major subsystems. This is the consequence of normal use and aging of the systems.

On-going Maintenance at the NRAO. Other continuing maintenance needs at the VLA comprise a long list of significant but smaller items: overhaul of antenna transporters and installation of new transporter control systems, overhaul of electrical generators and upgrading of electrical power system controls, bringing fuel storage tanks into compliance with new environmental regulations, replacement of machinery and selected vehicles, and improvement of painting facilities. The VLA site road system is badly in need of maintenance.

Maintenance requirements at Green Bank are related to environmental/health considerations. The sewage treatment plant must be modernized. The water tower has been repaired and painted inside and out, but a water filter system must be installed. Asbestos must be removed from the older buildings. Various buildings require new roofs. External cracks in the concrete of the 140-foot telescope pedestal must be grouted and sealed.

Within two or three years the fabric covering on the 12-meter telescope dome must be replaced. Other 12-meter telescope needs include electrical power conditioning upgrades, adding a sun screen to the dome to prevent damage by the sun and wind, repaving the road, and installation of an above ground fuel tank.

III. ENGINEERING INFRASTRUCTURE--RESEARCH AND OPERATING EQUIPMENT

The design and construction of new instrumentation for the NRAO telescopes involves a concerted effort by those involved with basic research and development of microwave and millimeter-wave devices as well as by those expert at fabricating reliable instrumentation, and by systems engineers. It also requires hardware and (expensive) laboratory test equipment. Restoring the NRAO engineering infrastructure involves augmentation of both staff and equipment. The "output" of the investment is more sensitive and more capable telescope instrumentation that will expand the potential of the NRAO instruments, make possible new science and make more effective use of the large investment the telescope facilities represent.

As with the maintenance program, the equipment modernization of a research facility is a continuing activity. In the table below, and in the descriptions which follow, the present activities at the NRAO are summarized. When these activities are complete, new instrumentation activities will begin. The goal is to establish, and maintain, an appropriate new instrumentation program. In the past few years this has not been possible, and the new equipment program at the NRAO has seriously atrophied.

<u>Millimeter-Wave Device Development</u>: 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. In the immediate future this work will lead to more sensitive receivers on

the 12-meter telescope; in the long-term the development is crucial for the Millimeter Array

The near-term goal for 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.

Observations have begun with a 4.2 K system that can handle eight inserts which include SIS mixer/feed/amplifier assemblies. The telescope version has coverage throughout the 1 mm and 3 mm windows. With the development planned in Table 3, complete coverage of all the windows between 70 and 360 GHz will be achieved with this receiver in the near future.

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.

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 the next five years will focus on development of broader band amplifiers for various applications at all NRAO sites. We will also start work on a prototype amplifier at 86 GHz for the VLBA and MMA.

Cryogenic Refrigerator Development. The superconducting millimeter-wave mixers need to be cooled to 4 K or less. In fact, their sensitivity continues to improve with decreasing temperature down to at least 2.5 K. To realize the sensitivity inherent in these devices requires the development of a closed-cycle, reliable, low-maintenance refrigerator. Several possible, but quite different, options exist and will need to be evaluated and tested over several years time.

Digital Spectrometer Development. The expected new generation of SIS and HEMT receivers will be very broadband, sensitive devices. When available, the bandwidth of these receivers will far exceed that of the backend spectrometer or continuum receivers. Such a disparity will mean that data gathered with great sensitivity will go unanalyzed. To reconcile the capabilities of the telescope system a new generation of digital/analog correlation spectrometers will be developed. Again, there are several technical options that will first need study and evaluation.

Interference Protection. The sensitivity of the 327 MHz and 75 MHz systems on the VLA are limited by radio-frequency interference locally generated in the B-rack at each antenna. This problem is particularly severe for the more compact arrays. RFI shielding of the LO rack in the vertex room has proved effective and four antennas have been equipped. In order to improve the sensitivity of 327 MHz, the complete array will be required to be outfitted with these RFI shields.

Telescope Pointing and Optics. With the VLA antenna insulation completed, the next largest contribution to the pointing errors is the tilts of up to 20 arcseconds in the azimuth axis of some antennas at certain azimuth angles. This effect is possibly caused by deformations or perturbations in the azimuth bearings. This and other problems such as an antenna tilt caused by a constant wind force could be corrected by an active correction scheme utilizing electronic tilt-meters mounted on the antenna structure. Two antennas are equipped with tilt-meters, and engineering studies indicate that improved tilt-meters are required. That design is complete and further testing is required.

In order to improve the pointing on the 12-meter telescope, we will implement the following: real-time monitoring of movements of the focus assembly using a laser and quadrant detector; improved focus mount offering more freedom of movement and more precise control; increased monitoring instrumentation, such as inclinometers, strain gauges, and temperature sensors; replacement of feed legs with a carbon-fiber design giving less temperature dependence and less aperture blockage; and a sun screen to reduce thermal distortions of the telescope during daytime operation. We have started experiments with an auxiliary optical pointing system, observing stars optically as an aid to better understanding the pointing characteristics of the telescope. We intend to expand on this theme, to give a higher level of automation, with the possibility of offset guiding on optical stars to give accurate tracking of weak radio sources.

Test Equipment. The only test and laboratory equipment NRAO has been able to buy for the last seven years has either come by way of the VLBA construction or from NASA or the U.S. Naval Observatory. It has not been much but it has been invaluable. This equipment is vital to an ongoing R&D effort, and the preservation of NRAO's effort has been totally dependent on these sources lying outside the base program. Test equipment is expensive: a single item of major test equipment can easily cost $100k these days.

NRAO acquired a network analyzer in 1986 costing about that or a little more as part of the NASA-funded Voyager/Neptune encounter project. It made possible the research of Sandy Weinreb and Marian Pospieszalski on HEMT amplifiers. The astounding success of these amplifiers has had a profound effect on radio astronomy, driving out of use the unstable parametric amplifiers and complex and expensive maser amplifiers. Amplifiers that are as good as desired are actually routine at lower frequencies now, are inexpensive, reliable, and inexpensive to maintain.

Without that single item of test equipment, this would not have been possible.

Operations Equipment. For the past several years, funding of operating equipment has been nonexistent. In an effort to meet the minimum budgetary needs in research equipment and regular operations, it has been necessary to postpone indefinitely the purchase of operating equipment. In addition, we have had to delay the replacement of existing obsolete equipment. This approach to funding leads to higher maintenance costs, more frequent "down" time and inconvenient and inefficient use of our personnel resources. The plan presented attempts to reverse this trend in operating equipment funding. Over the next several years, with adequate funding, we will be able to provide the infrastructure to meet the increasing demands of our users for office, library, living quarters, and shop equipment.

IV. SCIENTIFIC INFRASTRUCTURE/COMPUTING RESOURCES

The long-standing problem of inadequate computing at the VLA in particular, and the NRAO in general, remains unsolved. The cause of the problem is worth review.

Since the original design goals were specified in 1969, the power of the VLA for imaging radio sources has increased steadily. The following table gives the changes in selected image parameters.

Development of VLA Imaging Power

	Goal 1969	Achieved 1980	Achieved 1990
Speed (images per day)	3	200	200
Image size--Routine (pixels)	128x128	512x512	1024x1024
Image size--Maximum (pixels)	512x512	1024x1024	4096x4096
Spectral Line Channels (full array)	--	8	512
Dynamic Range--Routine	100:1	500:1	2000:1
Dynamic Range--Maximum	100:1	2000:1	100,000:1
Maximum Sensitivity (mJy)	0.1	0.05	0.005
Resolution (arcseconds)	1	0.1	0.07

Each increase shown in the above table has required computing resources beyond those originally anticipated. The growth in demand for computing resources has outstripped our ability to provide them within the annual operating budgets of NRAO. Only a small fraction of the scientific investigations that are exciting but exceptionally computer-intensive can now be supported. The operation of the VLBA is expected to increase the computing demand by 65 percent over the demands of the VLA alone. In order to rectify this situation, the NRAO submitted to the NSF in September 1987

a proposal, "Array Telescope Computing Plan," which creates a joint VLA/VLBA computing environment suitable for the needs of both arrays.

The essence of the plan is the recognition that the imaging burden of the synthesis arrays covers a broad spectrum: some observations require only modest computing resources while others may require the full power of a large supercomputer. Given this distribution, the design of the appropriate computing facility for VLA/VLBA imaging incorporates hardware resources which span the same spectrum from the modest to the very powerful. Doing this is cost effective and leads us to a hardware plan for a computing facility which is a combination of computers, of varying computational capacity, loosely coupled together.

The software plan for the proposed computing system has three elements:

- Continued support of AIPS for use at NRAO and export to other facilities, including supercomputer centers and user home institutions;

- Research in image processing;

- Development of a new data analysis system, aips++.

In 1988 the Array Telescope Computing Plan was reviewed by the NSF Division of Astronomical Sciences and received highly favorable reviews but it could not be funded in the then restrictive funding climate. In 1990 the NRAO submitted an addendum to the Array Telescope Computing Plan which reaffirms the needs and goals of the plan and reassesses the plan for software and algorithm development.

The Array Telescope Computing Plan is a proposal to redress a problem of long-standing. It emphasizes, and we restate in Table 4 below, the continuing need to augment and replace computing hardware at regular intervals. Furthermore, not only is the distinction between radio astronomy "instrumentation" and "computer" being blended (most modern telescope instruments have dedicated computers for their control), but the computers themselves, whatever their function, are part of larger networks. The infrastructure--disk servers, networks, display devices--is important. Algorithms must be developed to enable the astronomer to exploit the computing resources. These are needs without a "solution," rather a continuing effort at an appropriate level is an indispensable function of the National Observatory.

V. UPGRADE OF THE VLA

When the VLA went into operation in 1980, it gave an improvement in resolution, sensitivity, speed, and image quality of more than two orders of magnitude. Since that time, the VLA has been an extraordinarily

productive scientific instrument, and has been used by more than 1200 astronomers for a wide variety of investigations, including solar system, galactic and extragalactic research. However, as a result of technological advances during the past decade, much of the instrumentation is seriously out of date and major replacement and upgrading of the instrumentation is needed to keep the VLA at its current leading position among the world's radio astronomy facilities.

Recognizing the scientific potential of the VLA as upgraded with modern instrumentation, the Report of the Radio Astronomy Panel of the Astronomy and Astrophysics Survey Committee emphasizes the need for a comprehensive upgrade of the VLA.

> *The operation and maintenance of the VLA needs to be brought to a level appropriate to its broad scientific impact and great capital investment, and the seriously out of date instrumentation needs to be replaced with modern low-noise radiometers, fiber optic transmission lines, and a modern broad band correlator. These upgrades will improve the sensitivity by up to an order of magnitude, improve the frequency coverage and spectral resolution, and increase the maximum allowable image size.*

The significant instrumentation improvements mentioned here form the basis of the plan to upgrade the VLA. It can easily be funded incrementally over a decade or more and yet be useful at each stage of its development.

<u>Receiver Sensitivity</u>. New receivers based on cooled low noise HEMT amplifiers are needed to lower the system temperature at all bands except 3.6 cm where these devices already exist. The proposed receivers are based on designs already implemented at the VLBA.

<u>New Frequencies</u>. Three new observing bands, at 610 MHz, 2.7 GHz, and 43 GHz, are being considered for the VLA, and one at 86 GHz for the VLBA. The 610 MHz and 2.7 GHz bands are intended to fill in the gaps in existing coverage, while the 43 GHz system will improve the resolution by a factor of two. The additional frequencies are important for continuum studies of spectra as well as the effect of Faraday rotation and depolarization which are tied to specific critical frequency regimes that are determined by source physics. The additional frequencies are also needed for pulsar work where the critical frequencies of observation are determined by the spectra and dispersion; and for unique spectral lines such as SiO at 43 GHz.

<u>Fiber Optics IF Transmission System</u>. In order to distribute 2 GHz of bandwidth from each antenna (two polarizations, each with 1 GHz), the current waveguide transmission system needs to be replaced with a modern fiber optics link. This will also permit future expansion to even wider bandwidths, and will allow inclusion of signals from other, more widely

dispersed antennas. For the first stage, a fiber optics link will replace the waveguide connection between the VLA antennas and it will connect the Pie Town VLBA antenna to the VLA correlator.

Broad-Band Correlator. The VLA provides a maximum bandwidth of 100 MHz, obtained by a pair of separately tuned, 50 MHz wide bandwidths. These bandwidths were set by technological limitations current some 15 years ago, and cannot be greatly expanded. In conjunction with greatly improved IF transmission capability, a full 1 GHz bandwidth in each polarization can now be implemented. A 2 GHz capability is also possible in the future.

Modern correlator design based on the FX approach is especially suited to arrays with large numbers of elements, such as the VLA. The VLBA correlator could provide 1024 channels of spectral resolution in each of the eight pairs of IF's being returned from the antennas. Full polarization will be available with the same number of channels, except with perhaps a reduction to 512 channels when using the full 1 GHz bandwidth. With an FX correlator and good spectral resolution, it should also be feasible to delete narrow-band rfi and thus exploit the full bandwidth of the IF system.

VI. COST ESTIMATES AND SCHEDULES

	1991	1992	1993	1994	1995	1996
Physical Plant: Repair, Maintenance, and Upgrade						
Very Large Array						
Rail System:						
Ties and supplies	30	400	200	200	200	200
Ultrasonic rail test		30				
Track survey						25
Interchanges			125	125	125	125
Clean ballast			125			
Restock ballast					50	
Rail replacement	15				200	100
Rebuild switches				30	30	
Road crossings					50	50
Front end loader		50				
Back hoe and compactor		55				
Tie puller		85				
Dump truck		60				
Rail vehicle				50		

	1991	1992	1993	1994	1995	1996
Power Cable:						
Cable	38	220	220	220		
Connectors and supplies	6	25	25	25		
Waveguide:						
Manhole rebuilding	24	40	40	40	40	40
Antennas:						
Bearing replacement and transporter overhaul	135	100	100	100	100	100
Miscellaneous:						
Lathe	5					35
Transporter axles	43	30				
Wye monitor system		35				
Water tank		15				
Machine tools			30			
Fuel tank upgrade			15			
Focus rotation mounts					25	25
Metal shear					30	
Tractor						100
Fork lift					80	
Generator overhaul					50	50
Cherry picker				200		
Road repairs						220
Materials Cost	296	1145	820	1000	1030	1070
Personnel Costs (FTE):						
Rail system	6	6	6	6	6	6
Power cabling	½	1	1	1		
Waveguide manholes	2½	4	4	4	4	4
Antenna	2	2	2	2	2	2
Total FTE	11	13	13	13	12	12
Labor Cost @ 25k$/FTE	275	325	325	325	300	300
Total VLA Costs	571	1470	1145	1325	1330	1370

<u>Green Bank</u>

	1991	1992
Sewage Plant	30	
Antenna Test Range	8	
Painting - 140 ft	5	
Housing Repairs	5	
Shop Roof		30

	1991	1992	1993	1994	1995	1996
Jansky Lab Basement		40				
140 ft Concrete Grouting			50			
Sewer Pipe Replacement				30		
Air Conditioning				100		
Repair 300 ft Control Building					50	
Total	48	70	50	130	50	
Labor (k$)	15	30	55	60	60	60
Total Green Bank Costs	63	100	105	190	110	60
Tucson						
Dome Door Repairs		20				
UPS Upgrade		10				
Paving and Drainage				24		
Fuel Tank Replacement				6		
Diesel Generator					40	
Dome Fabric Replacement			300			
Total		30	300	30	40	
Labor (k$)						
Total Tucson Costs		30	300	30	40	
Total for Physical Plant Repair Maintenance, and Upgrade	634	1600	1500	1545	1480	1430
Eng. Infrastructure/Res. & Oper. Equip.	500	900	1500	2000	2000	2000
Sci. Infrastructure/Computing Resources		500	700	1000	1000	1000
VLA Upgrade			1000	2000	3000	3600
Total Infrastructure	1134	3000	4700	6545	7480	8030

Table 1 listed infrastructure requirements in broad categories totalling 7.3M$ incremented to 1991 spending. That is, a total of roughly 8.4M$ is required annually. The schedule presented above shows an approach to that level of investment over a five year period.

1993 BUDGET ASSUMPTIONS

1) Salaries calculated at 6% above 1992 rate.
2) All positions in the 1993 personnel projection will be funded.
3) Benefits calculated at the rate of 30%.
4) Advanced funding of $1.0M deducted from accelerated program total of $2.041M.
5) Millimeter Array Funded at $1.0M.
6) Teachers Enhancement Program not included in this budget projection.

	1992		1993 (guess)
Base	21,025 ~~25.616~~	→	21,000
RE/OE	1.000	→	1.000
	22.025 ~~26.016~~		22.0
VLBA o/s	3.991	→	6.000
	~~30.007~~ 26.016		28.0
	+ infrastructure 1.00		+ infrastructure

C:\LOTUS\93BUDGT\93BUD817.WK1 Benefit Rate 30.00%

18-Aug-92

SCENARIO #1

Description	Employees @ Y/E	Man Years	Salaries	Benefits (Net of VLBA Ops)	Materials & Services	Travel	Comm. & Utilities	Bldg Rent & Maint.	Computer Maint.	C.C.R.	Income	Total New Funds Operating Costs
Director's Office	6	6.0	456,553		63,000	79,000						598,553
Fiscal	14	13.5	410,472		350,000	32,000			10,000			802,472
Business Office	7	8.3	282,602		231,000	9,000						522,602
Management Fee					600,000							600,000
Sick Leave Buy-back			30,000									30,000
Other				5,094,101	**PLUG** 548,100		137,000	310,000			(10,000)	6,079,201
G & A - NSF	27	27.8	1,179,627	5,094,101	1,792,100	120,000	137,000	310,000	10,000	0	(10,000)	8,632,828
Scientific Staff	32	33.0	1,850,180		21,000	168,000						2,039,180
Student Support	0	21.0	293,339		11,000	16,000						320,339
Computing	8	8.3	417,994		136,500	16,000			100,000			670,494
Software Development	10	10.0	456,118		68,000	26,000						550,118
AIPS ++					0							0
Scientific Services	4	4.5	145,220		273,000	4,000						422,220
Millimeter Array	4	4.0	200,000		740,000							940,000
Research Support - NSF	58	80.8	3,362,851	0	1,249,500	230,000	0	0	100,000	0	0	4,942,351
Central Development Lab	22	22.0	993,118		126,000	17,000						1,136,118

C:\LOTUS\93BUDGT\93BUD817.WK1 Benefit Rate 30.00%

18-Aug-92

SCENARIO #1

Description	Employees @ Y/E	Man Years	Salaries	Benefits (Net of VLBA Ops)	Materials & Services	Travel	Comm. & Utilities	Bldg Rent & Maint.	Computer Maint.	C.C.R.	Income	Total New Funds Operating Costs
GB - Telescope Services	20	20.9	651,993		54,000	4,000						709,993
GB - Electronics	19	19.0	839,824		83,000	11,000						933,824
GB - Plant Maintenance	12	13.5	307,131		84,000	3,000						394,131
GB - Admin. Services	9	10.5	279,896		110,000	3,000						392,896
GB - Scientific Services	6	6.0	307,697		16,000	12,000						335,697
GB - Computing	3	3.0	140,344		52,000	11,000			6,000			209,344
GB - Teachers Enhancement Prgm												0
GB - Infrastructure	1	1.0	45,580									45,580
GB - Other					50,000	**PLUG**	289,000				(160,000)	179,000
USNO Upgrade										(31,000)		(31,000)
USNO Operations										(235,000)		(235,000)
Green Bank - NSF	70	73.9	2,572,465	0	449,000	44,000	289,000	0	6,000	(266,000)	(160,000)	2,934,465
TU - Operations & Maint.	14	14.8	553,963		147,000	24,000						724,963
TU - Electronics	13	13.0	589,924		163,000	19,000						771,924
TU - Computing	2	2.0	87,450		63,000	6,000			37,000			193,450
TU - Other					25,000		53,000	85,000			(10,000)	153,000
TU - Miscellaneous					50,000	**PLUG**						50,000
Tucson - NSF	29	29.8	1,231,337	0	448,000	49,000	53,000	85,000	37,000	0	(10,000)	1,893,337

C:\LOTUS\93BUDGT\93BUD817.WK1 Benefit Rate 30 00% SCENARIO #1

18-Aug-92

Description	Employees @ Y/E	Mar Year	laries	Benefits (Net of VLBA Ops)	Materials & Services	Travel	Comm. & Utilities	Bldg Rent & Maint.	Computer Maint.	C.C.R.	Income	Total New Funds Operating Costs
SOC- Scientific Services	9	10.5	492,743		32,000	22,000						546,743
SOC- Antenna & Services	46	49.5	1,469,229		504,000	14,000						1,987,229
SOC - Computing	15	15.0	642,931		79,000	16,000			217,000			954,931
SOC - Electronics	30	30.8	1,183,846		194,000	14,000						1,391,846
SOC - Array Operations	9	9.0	297,872		21,000	3,000						321,872
SOC - Admin. Services	10	10.0	265,569		231,000	5,000						501,569
SOC - Observatory Services	4	4.9	146,685		100,000	4,000						250,685
SOC - Other					125,000	**PLUG**	1,077,000	105,000			(41,000)	1,266,000
VLA - NSF	123	129.7	4,498,875	0	1,286,000	78,000	1,077,000	105,000	217,000	0	(41,000)	7,220,875
VLBA OPS - Scientific Services	10	10.0	423,084		35,000	26,000						484,084
VLBA OPS - Antenna & Services	7	7.0	186,785		127,000	46,000						359,785
VLBA OPS - Computing	10	10.0	392,836		92,000	52,000			35,000			571,836
VLBA OPS - Electronics	46	47.0	1,513,694		184,000	46,000						1,743,694
VLBA OPS - Array Ops	15	14.5	426,578		104,000	17,000						547,578
VLBA OPS - Admin. Services	7	8.1	199,088		161,000	12,000						372,088
VLBA OPS - Obser. Services					12,000	1,000						13,000
VLBA OPS - Other					750,000	**PLUG**	420,000	190,000				1,360,000
Total VLBA OPS - NSF	95	96.6	3,142,065	0	1,465,000	200,000	420,000	190,000	35,000	0	0	5,452,065

C:\LOTUS\93BUDGT\93BUD817.WK1 Benefit Rate 30.00%

18-Aug-92

SCENARIO #1

Description	Employees @ Y/E	Man Years	Salaries	Benefits (Net of VLBA Ops)	Materials & Services	Travel	Comm. & Utilities	Bldg Rent & Maint.	Computer Maint.	C.C.R.	Income	Total New Funds Operating Costs
CCR/Device Revenue										(553,000)		(553,000)
Total NSF Operations	424	460.6	16,980,338	5,094,101	6,815,600	738,000	1,976,000	690,000	405,000	(819,000)	(221,000)	31,659,039
Infrastructure Increment:												
Charlottesville					100,000							100,000
Green Bank					200,000							200,000
Tucson					100,000							100,000
Socorro					500,000							500,000
VLA Upgrade					1,000,000							1,000,000
Accelerated Program					2,041,000							2,041,000
LESS: Advanced Funding					(1,000,000)							(1,000,000)
Operating Equipment					300,000							300,000
Research Equipment					1,200,000							1,200,000
												0
Computing					700,000							700,000
												0
TOTAL NSF FUNDING	424	460.6	16,980,338	5,094,101	11,956,600	738,000	1,976,000	690,000	405,000	(819,000)	(221,000)	36,800,039

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August 18, 1992

1993 BUDGET PROJECTIONS
SCENARIO #1

Description	Salaries	Benefits	Materials & Services	Travel	Comm & Utilities	Bldg Rent & Maint.	Computer Maint.	C.C.R.	Income	New Funds Operating Costs	Comments
General & Administrative	1,179,627	5,094,101	1,792,100	120,000	137,000	310,000	10,000	0	(10,000)	8,632,828	Includes $548k Plug
Research Support	3,362,851	0	1,249,500	230,000			100,000			4,942,351	Includes $1.0M MMA
Central Development Lab	993,118	0	126,000	17,000						1,136,118	
Green Bank Operations	2,572,465	0	449,000	44,000	289,000		6,000	(266,000)	(160,000)	2,934,465	Includes $50k Plug
Tucson Operations	1,231,337	0	448,000	49,000	53,000	85,000	37,000	0	(10,000)	1,893,337	Includes $50k Plug
Socorro Operations	4,498,875	0	1,286,000	78,000	1,077,000	105,000	217,000	0	(41,000)	7,220,875	Includes $125k Plug
VLBA Operations	3,142,065	0	1,465,000	200,000	420,000	190,000	35,000	0	0	5,452,065	Includes $750k Plug
Common Cost Recovery								(553,000)		(553,000)	
Sub-Total	16,980,338	5,094,101	6,815,600	738,000	1,976,000	690,000	405,000	(819,000)	(221,000)	31,659,039	
Infrastructure Increment:											
Charlottesville			100,000							100,000	
Green Bank			200,000							200,000	
Tucson			100,000							100,000	
Socorro			500,000							500,000	
VLA Upgrade			1,000,000							1,000,000	
Accelerated Program			1,041,000							1,041,000	
Operating Equipment			300,000							300,000	
Research Equipment			1,200,000							1,200,000	
Computing			700,000							700,000	
TOTAL - NSF FUNDING	16,980,338	5,094,101	11,956,600	738,000	1,976,000	690,000	405,000	(819,000)	(221,000)	36,800,039	

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August 18, 1992

1993 BUDGET PROJECTIONS

SCENARIO #2

Description	Salaries	Benefits	Materials & Services	Travel	Comm & Utilities	Bldg Rent & Maint.	Computer Maint.	C.C.R.	Income	New Funds Operating Costs	Comments
General & Administrative	1,179,627	5,094,101	1,494,100	120,000	137,000	310,000	10,000	0	(10,000)	8,334,828	Includes $250k plug
Research Support	3,362,851	0	749,500	230,000			100,000			4,442,351	Includes $500k MMA
Central Development Lab	993,118	0	126,000	17,000						1,136,118	
Green Bank Operations	2,572,465	0	449,000	44,000	289,000		6,000	(266,000)	(160,000)	2,934,465	Includes $50k plug
Tucson Operations	1,231,337	0	448,000	49,000	53,000	85,000	37,000	0	(10,000)	1,893,337	Includes $50k plug
Socorro Operations	4,498,875	0	1,286,000	78,000	1,077,000	105,000	217,000	0	(41,000)	7,220,875	Includes $125k plug
VLBA Operations	3,142,065	0	1,015,000	200,000	420,000	190,000	35,000	0	0	5,002,065	Includes $300k plug
Common Cost Recovery								(553,000)		(553,000)	
Sub-Total	16,980,338	5,094,101	5,567,600	738,000	1,976,000	690,000	405,000	(819,000)	(221,000)	30,411,039	
Infrastructure Increment											
Charlottesville			100,000							100,000	
Green Bank			200,000							200,000	
Tucson			100,000							100,000	
Socorro			500,000							500,000	
VLA Upgrade			1,000,000							1,000,000	
Accelerated Program			1,041,000							1,041,000	
Operating Equipment			300,000							300,000	
Research Equipment			1,200,000							1,200,000	
Computing			700,000							700,000	
TOTAL - NSF FUNDING	16,980,338	5,094,101	10,708,600	738,000	1,976,000	690,000	405,000	(819,000)	(221,000)	35,552,039	

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August 18, 1992

1993 BUDGET PROJECTIONS
SCENARIO #3

Description	Salaries	Benefits	Materials & Services	Travel	Comm & Utilities	Bldg Rent & Maint.	Computer Maint.	C.C.R.	Income	New Funds Operating Costs	Comments
General & Administrative	1,179,627	5,094,101	1,244,100	120,000	137,000	310,000	10,000	0	(10,000)	8,084,828	Less $548k Plug
Research Support	3,362,851	0	549,500	230,000			100,000			4,242,351	Includes $300k MMA
Central Development Lab	993.118	0	126,000	17,000						1,136,118	
Green Bank Operations	2,572,465	0	399,000	44,000	289,000		6,000	(266,000)	(160,000)	2,884,465	Less $50k Plug
Tucson Operations	1,231,337	0	398,000	49,000	53,000	85,000	37,000	0	(10,000)	1,843,337	Less $50k Plug
Socorro Operations	4,498,875	0	1,161,000	78,000	1,077,000	105,000	217,000	0	(41,000)	7,095,875	Less $125k plug
VLBA Operations	3,142,065	0	715,000	200,000	420,000	190,000	35,000	0	0	4,702,065	Less $750k plug
Common Cost Recovery								(553,000)		(553,000)	
Sub-Total	16,980,338	5,094,101	4,592,600	738,000	1,976,000	690,000	405,000	(819,000)	(221,000)	29,436,039	
Infrastructure Increment:											
Charlottesville			100,000							100,000	
Green Bank			200,000							200,000	
Tucson			100,000							100,000	
Socorro			500,000							500,000	
VLA Upgrade			1,000,000							1,000,000	
Accelerated Program			1,041,000							1,041,000	
Operating Equipment			300,000							300,000	
Research Equipment			1,200,000							1,200,000	
Computing			700,000							700,000	
TOTAL - NSF FUNDING	16,980,338	5,094,101	9,733,600	738,000	1,976,000	690,000	405,000	(819,000)	(221,000)	34,577,039	

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August 18, 1992

1993 BUDGET PROJECTIONS

SCENARIO #4

Description	Salaries	Benefits	Materials & Services	Travel	Comm & Utilities	Bldg Rent & Maint.	Computer Maint.	C.C.R.	Income	New Funds Operating Costs	Comments
NSF OPERATIONS-Sub Total	16,980,338	5,094,101	4,592,600	738,000	1,976,000	690,000	405,000	(819,000)	(221,000)	29,436,039	
Infrastructure Increment:											
Charlottesville			100,000							100,000	
Green Bank			200,000							200,000	
Tucson			100,000							100,000	
Socorro			500,000							500,000	
VLA Upgrade			1,000,000							1,000,000	
Accelerated Program			1,041,000							1,041,000	
Operating Equipment			100,000							100,000	Less 200k
Research Equipment			800,000							800,000	Less 400k
Computing			300,000							300,000	Less 400k
TOTAL - NSF FUNDING	16,980,338	5,094,101	8,733,600	738,000	1,976,000	690,000	405,000	(819,000)	(221,000)	33,577,039	

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August 18, 1992

1993 BUDGET PROJECTIONS
SCENARIO #5

Description	Salaries	Benefits	Materials & Services	Travel	Comm & Utilities	Bldg Rent & Maint.	Computer Maint.	C.C.R.	Income	New Funds Operating Costs	Comments
NSF OPERATIONS-Sub Total	16,980,338	5,094,101	4,592,600	738,000	1,976,000	690,000	405,000	(819,000)	(221,000)	29,436,039	
Infrastructure Increment:											
Charlottesville			100,000							100,000	
Green Bank			200,000							200,000	
Tucson			100,000							100,000	
Socorro			500,000							500,000	
VLA Upgrade			1,000,000							1,000,000	
Accelerated Program			0							0	Less 1.041M
Operating Equipment			100,000							100,000	Less 200k
Research Equipment			800,000							800,000	Less 400k
Computing			300,000							300,000	Less 400k
TOTAL - NSF FUNDING	16,980,338	5,094,101	7,692,600	738,000	1,976,000	690,000	405,000	(819,000)	(221,000)	32,536,039	

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August 18, 1992

1993 BUDGET PROJECTIONS
SCENARIO #6

Description	Salaries	Benefits	Materials & Services	Travel	Comm & Utilities	Bldg Rent & Maint.	Computer Maint.	C.C.R.	Income	New Funds Operating Costs	Comments
NSF OPERATIONS-Sub Total	16,980,338	5,094,101	4,592,600	738,000	1,976,000	690,000	405,000	(819,000)	(221,000)	29,436,039	
Infrastructure Increment:											
Charlottesville			100,000							100,000	
Green Bank			200,000							200,000	
Tucson			100,000							100,000	
Socorro			500,000							500,000	
VLA Upgrade			0							0	Less 1.0M
Accelerated Program			0							0	Less 1.041M
Operating Equipment			100,000							100,000	Less 200k
Research Equipment			800,000							800,000	Less 400k
										0	
Computing			300,000							300,000	Less 400k
TOTAL - NSF FUNDING	16,980,338	5,094,101	6,692,600	738,000	1,976,000	690,000	405,000	(819,000)	(221,000)	31,536,039	

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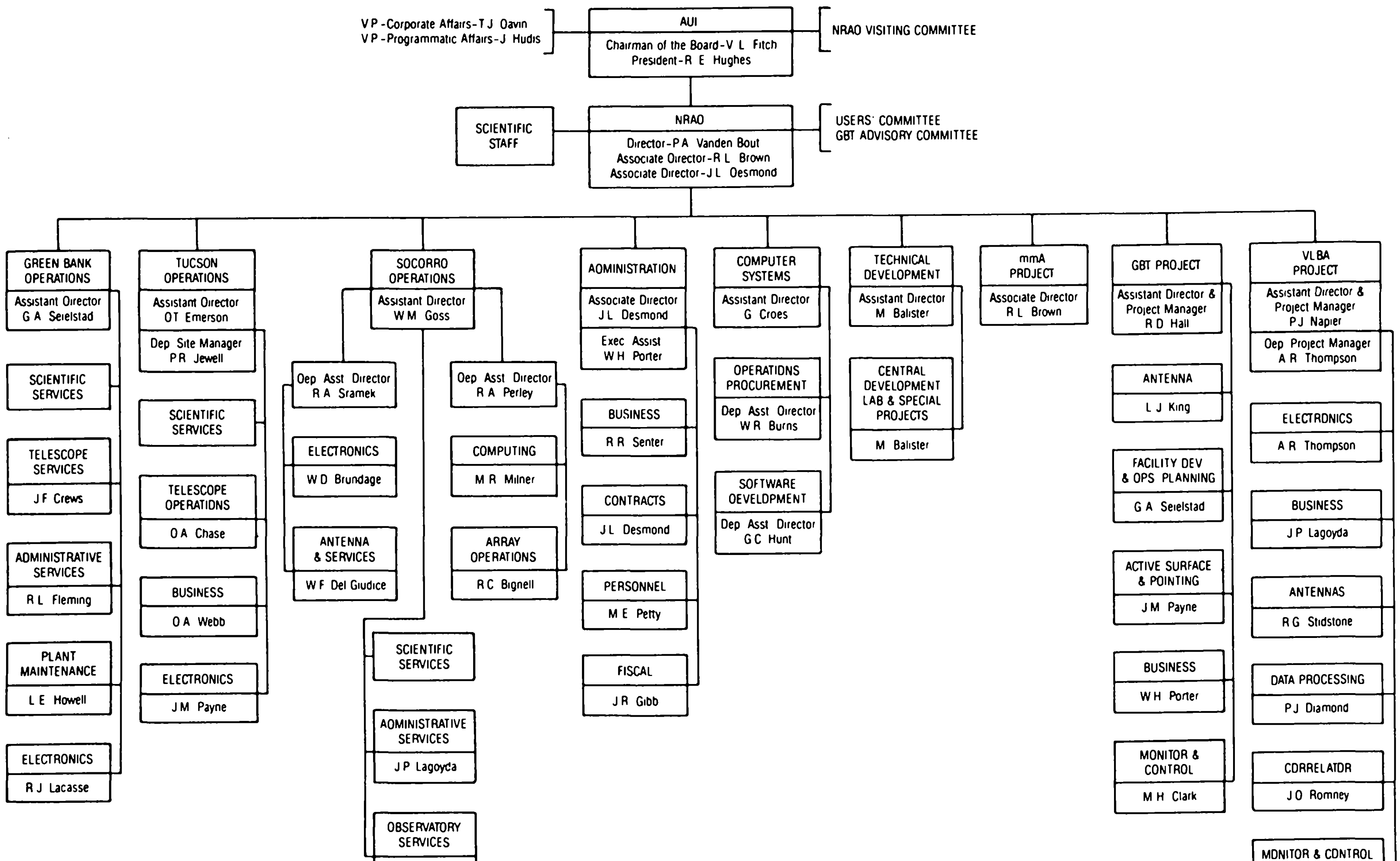
August 18, 1992

1993 BUDGET PROJECTIONS

SCENARIO #7

Description	Salaries	Benefits	Materials & Services	Travel	Comm & Utilities	Bldg Rent & Maint.	Computer Maint.	C.C.R.	Income	New Funds Operating Costs	Comments
NSF OPERATIONS-Sub Total	16,980,338	5,094,101	4,592,600	738,000	1,976,000	690,000	405,000	(819,000)	(221,000)	29,436,039	
Infrastructure Increment:											
Charlottesville			100,000							100,000	
Green Bank			100,000							100,000	Less 100k
Tucson			100,000							100,000	
Socorro			300,000							300,000	Less 200k
VLA Upgrade			0							0	Less 1.0M
Accelerated Program			0							0	Less 1.041M
Operating Equipment			100,000							100,000	Less 200k
Research Equipment			800,000							800,000	Less 400k
Computing			300,000							300,000	Less 400k
TOTAL - NSF FUNDING	16,980,338	5,094,101	6,392,600	738,000	1,976,000	690,000	405,000	(819,000)	(221,000)	31,236,039	

NATIONAL RADIO ASTRONOMY OBSERVATORY
ORGANIZATION CHART
1 FEBRUARY 1992



*Acting