THE FIRST 7 YEARS OF VLA OPERATIONS

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VLA 1980-1987

Ver: VLAp1 – A4-7

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1. INTRODUCTION

1.1. End of Construction

During the final years of its construction the Very Large Array was used increasingly for astronomical observations with the final transition from the construction phase into full operations coinciding with my appointment as Site Director for VLA Operations in October 1980. In this report I have collected and summarized highlights of the operation of the VLA from then until the end of my involvement with the VLA in February 1988.

The VLA concept was dominated by a simple and clear theme, to obtain images of the radio sky with resolution and detail comparable to that of ground-based optical photography. The first column of table 1.1 summarizes these design goals as set out in the proposals submitted to the NSF to build the VLA. During the construction it was possible to take advantages of technical developments in electronics, computing and antenna design to improve the performance within the original budget and to eventually exceed almost every design goal by very significant factors as indicated in column 2 of Table 1.1.

TABLE 1.1 PERFORMANCE DESIGN GOALS FOR VLA

	Goal (1967)	Achieved(1980)
Resolution	1"	0".1
Sensitivity	10^{-3}-10^{-4} JY	5 x 10^{-5} Jy
Sidelobes	-20 dB	-30 dB
Field of View	1' to 10'	1' to 30'
Wavelengths	5, 11 cm	1.2, 2, 6, 20cm
Declination Range	-20° to +90°	-40° to +90°
Speed	3 images/day	100 images/day
Spectral Line	Not to design out	256 channels
Map Size	~100 x 100 pixels	512 x 512 (routine) 4096 x 4096 (max)

For the first 2 years after construction funding (see budget section) was adequate to initiate various programs to further enhance the capability of the VLA. During the same period enormous strides were made in the processing algorithms, resulting in a current capability (Table 1.2) vastly exceeding any original expectations. Imaging quality is now superior to that of the best ground-based optical telescopes, sensitivity to weak sources improved by more than four orders of magnitude compared with the pre-VLA era in radio astronomy. Will this trend continue? Not unless budgets are increased to again allow the vigorous research development programs and to maintain a slowly aging instrument.

TABLE 1.2 VLA PERFORMANCE - 1982-1986
Improvement Factor over 1967 Design Goal

Parameter	1982	1986	
Resolution	10	25	
Sensitivity	2	10	
Dynamic Range	10	1200	
Field of View	3	9	
Wavelengths	2	3	
Speed	30	60	
Image Size	25	1600	(Number of pixels)
Declination range increased from	-20° → +90°	-40° → +90°	

1.2. Chronological History

The chronological history of the construction of the VLA (1972-1980) can be found in the "National Radio Astronomy Observatory VLA Program Completion Report", Exhibit 13, by Jack Lancaster (July 1982). Appendix I continues the chronological history of the VLA, and eventually the VLBA, since 1980. As you can see the VLA did not come to life as a static completed instrument but it, and its organization, have been continually evolving. An additional more detailed chronological history of VLA computing going back to 1972 is given in Appendix II and discussed in section 8.

2 ORGANIZATION

2.1. Management Structure

Figures 2.1 - 2.3 show the slow evolution of this management structure. The plant maintenance and antenna divisions were merged when Forrest Wells retired in December 1982 and a new Engineering and Services division was formed. This was very ably led by Les Temple until his death in March 1985. Since that time Bill delGiudice has lead this division. The structure remained relatively stable until changes were required to accommodate the VLBA construction in 1985. Peter Napier, who had been Deputy Site Manager, then moved into the VLBA project and Dick Sramek took over this role.

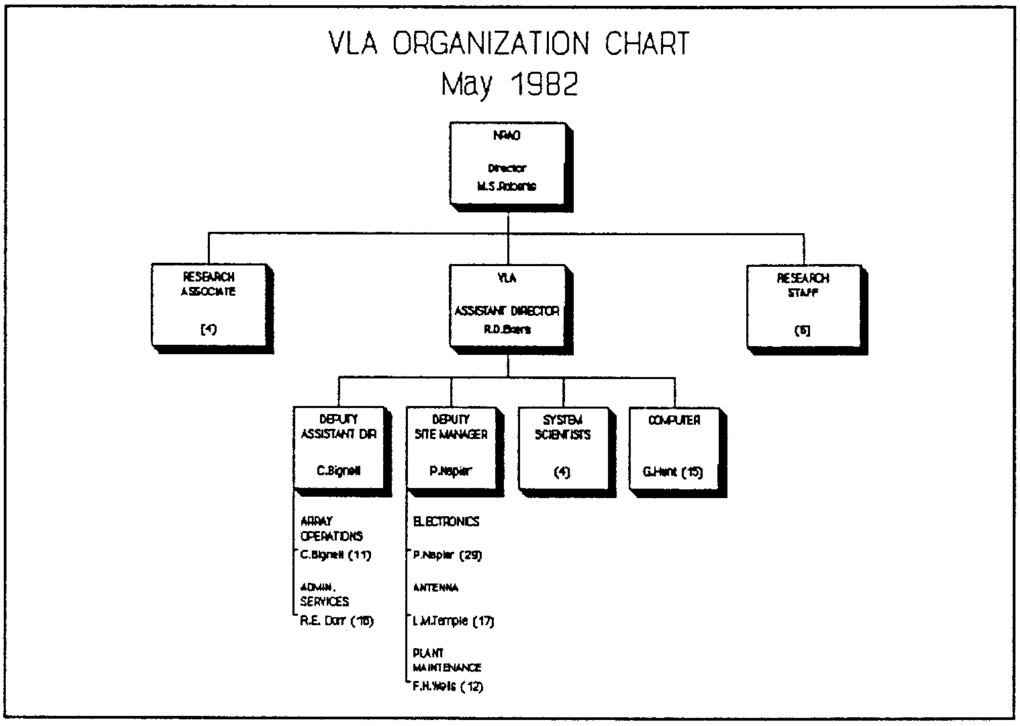

FIGURE 2.1 VLA Organization Chart - May 1982

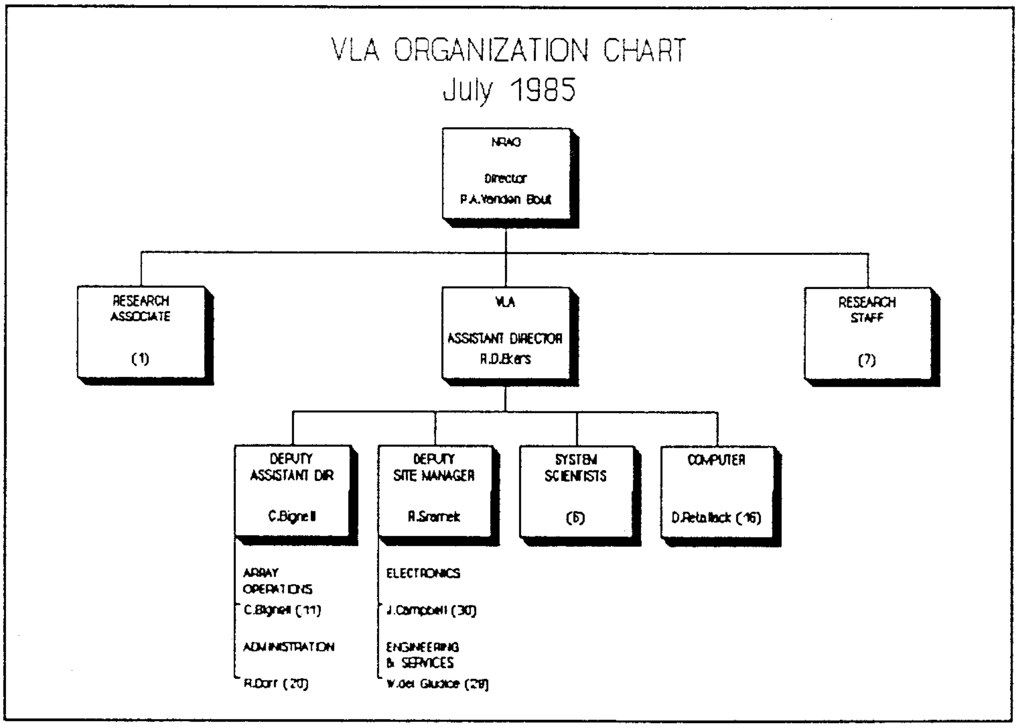

FIGURE 2.2 VLA Organization Chart - July 1985

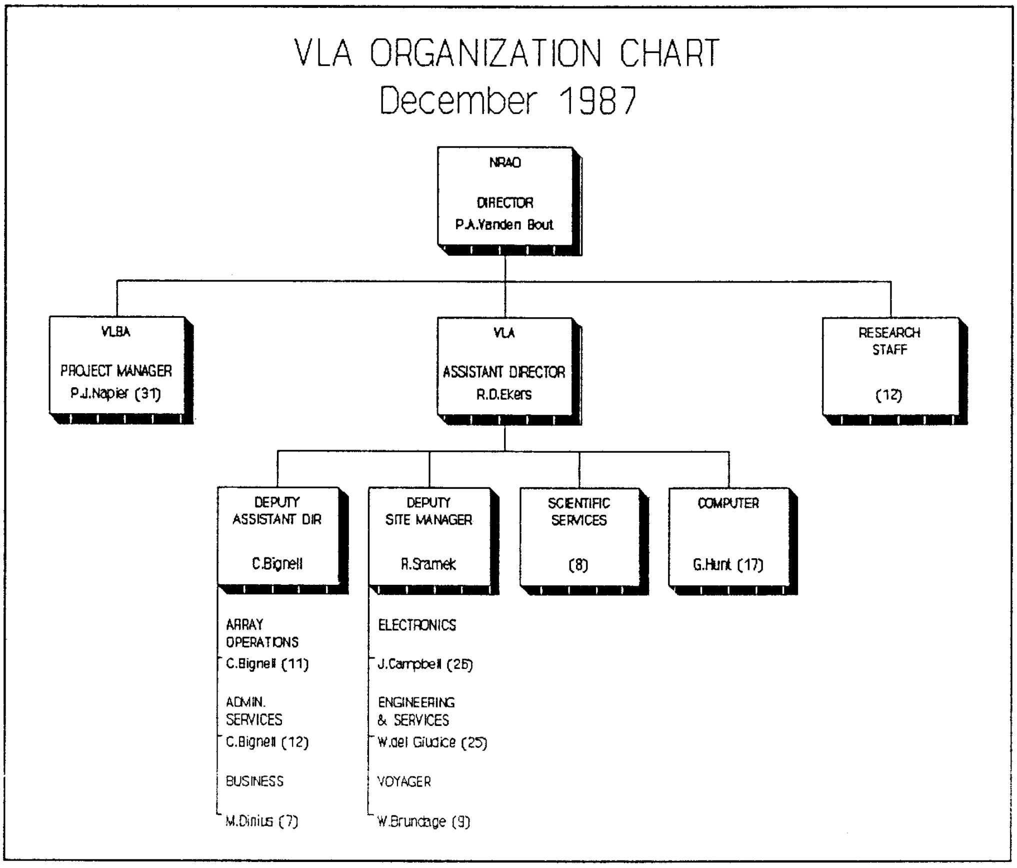

FIGURE 2.3 NM/NRAO Organization Chart - Dec 1987

The Business division was moved from the Socorro Office to the site in September 1982. Despite the disadvantages of additional travel time the net impact of this move was very positive with much enhanced interaction between the Business division (especially Purchasing) and the other divisions.

Unlike the other NRAO sites the VLA continued with the quite successful structure set up for construction in which all divisions (except fiscal) reported to the VLA Director rather than back to the Charlottesville divisions. The distance and size of the VLA divisions made this preferable. Coordination with the Electronics and Computer divisions based in Charlottesville was by Division Heads and Group Leaders. In Electronics this was completely successful. In Computing significant divergence occurred. Whether a single more coherent computing policy would have been better remains unclear.

The main management coordination tool for VLA operations has been the weekly Monday Coordination Meeting, adapted from its successful predecessor set up by Jack Lancaster for the VLA construction. This meeting provided as the main inter-divisional communication in addition to tracking key dates and obtaining feedback on progress. It is a regular short meeting with a clearly defined agenda. We added an additional meeting of division heads starting in 1986 with the need to resolve the increasingly difficult budgetary questions and to provide a forum for resolution of cross divisional problems which were also becoming more acute as the VLBA construction load and responsibility increased without any corresponding increase in manpower.

2.2. Policy

The overall policy for the operation of the VLA is an implementation of NRAO's policy on operating a National facility. Simply stated my interpretation was to provide the best possible astronomical research facility and to make it readily accessible to the user community. The success of this operation to be judged by the quality of the resulting science.

From time to time special policy issues evolve which are relevant to a particular instrument. The following are documented examples.

2.2.1. Access to VLA Archive Data

Raw data for all VLA observations are routinely archived; we have some requests for the use of this data. Although we normally try to channel such requests through the original observing team, this is not always practical. Consequently, we have defined an NRAO policy on the extent to which an observing team has exclusive use of the raw data obtained as part of their VLA observation.

Eighteen months after the end of a VLA observation the raw (uncalibrated visibility data) will be made available to other users on request. The end of an observation is defined to be after the last VLA configuration requested, either in the original proposal or in a direct extension of the original proposal.

NRAO Newsletter No. 13
1983 August 1

2.2.2 Target of Opportunity Observing at the VLA

It is occasionally important to be able to bypass the normal scheduling procedures in order to obtain a VLA observation on a shorter time scale then made possible through the normal peer review and scheduling procedure. Various categories of observations fall into this class; observation of a transient or an unpredicted event for which important information would be lost if an observation is delayed, observations of extremely exciting or unusual discoveries where the VLA observation could play a crucial role in the development of ideas or other observations, and situations where a very small VLA observation could provide information critical for the design or success of some other experiment, an observation that is important but requires such a trivial amount of telescope time (e.g. few minutes) that the overhead of the full scheduling mechanism is out of proportion with respect to the impact of the observation on the VLA schedule.

Requests for such observations are handled by the Site Director in the following way: An assessment is made of the priority which should be given to the observation and the need for by-passing the normal scheduling system. The request is cross-checked with existing requests or observations in order to avoid conflict of interest.

The VLA is scheduled in advance for 100% of the time with no explicit allowance for director's discretionary time. However this schedule does include observations related to instrumental tests (2-5%). Small target of opportunity observations which have been deemed important to schedule on short notice are taken out of this time. This does not imply that test observations are considered less important than normal scientific experiments, it is just that the flexibility available in scheduling and re-scheduling such tests makes this the most practical mechanism.

If the observation requested is for a non-trivial amount of observing time we still request that the observer provide a written statement of the intent and scope of the target of opportunity observation.

NRAO Newsletter No. 23,
May 1, 1985

2.2.3. Open Access Policy

Although the National Radio Astronomy Observatory is funded wholly by the U. S. government, observing time is granted on the basis of the most promising research, without regard to the national affiliation of the investigators. Believing astronomical research to be an international endeavor of interest to all, NRAO urges other observatories to subscribe to a policy of open access.

Standard letter from Scheduling Committee

3. BUDGET AND STAFFING LEVELS

3.1. Operations and Research Equipment Budgets

Figure 3.1 shows the evolution of the main components of the operating and research equipment budgets at the VLA. All budget numbers are converted to constant 1987 $'s using standard inflation rates. The research equipment budget (known as the OOE budget before 1984) is included and is treated in the same way as the operating budget. The trends are clear and well known. Apart from an initial few years of healthy operating and research equipment budget, the next five years had either constant or declining funding. Furthermore this occurred as the new instrument started to age and maintenance costs started their inevitable rise. Other costs such as the utilities (see Figure 3.1) also increased at a rate much faster than inflation so that even the energy saving measures that were implemented could not fully offset the impact. The long term result was the erosion of an initially substantial research equipment budget and the continual postponement of money for long term maintenance on the misguided belief that each bad year was surely abnormal and that a return to adequate funding would follow. A prime example of the effect of decisions to defer maintenance has been the deterioration of the VLA rail track to the point where massive inputs of money are now needed to continue to operate the array safely at its highest resolution (see section 10.4). The impact of the continual reduction in research equipment funds is yet to be felt. We are now reaping the benefits of development projects to improve in sensitivity and frequency coverage which were initiated three to four years ago. With the exception of the changes necessary for Voyager support (see section 4.1) the VLA is no longer embarking on new projects of this scope.

TABLE 3.1 VLA PERSONNEL

VLA Division	1981	1982	1983	1984	1985	1986	1987	1988$
Scientific Services	6	6	7	8	8	7	8	10
Basic Research	9	6	9	8	8	9	12	12
Operations	12	10*	10	11	12	11	11	17+
Computer	13	15	15	17	17	16	17	17
Business	15	16	20#	20	20	19	19	7+
Site & Ant	29	30	28#	27	27	26	25	29+
Electronics	28	27	28	27	28	26	26	26
Total	112	110	117	118	120	114	118	118 $
Voyager								9
VLBA								31

* Technicians transferred from operations to electronics
# Guards transferred from Site to Business
+ Guards, janitors transferred from Business to Site; cafeteria, temporarily transferred to operations
$ Before the February 1988 reduction in force by 4 positions.

Table 3.1 shows the distribution of staff among the VLA divisions and its evolution in time. For simplicity plant maintenance and antenna division numbers are already combined in 1981. Basic research staff based in Socorro are included here although they are part of the Charlottesville budget.

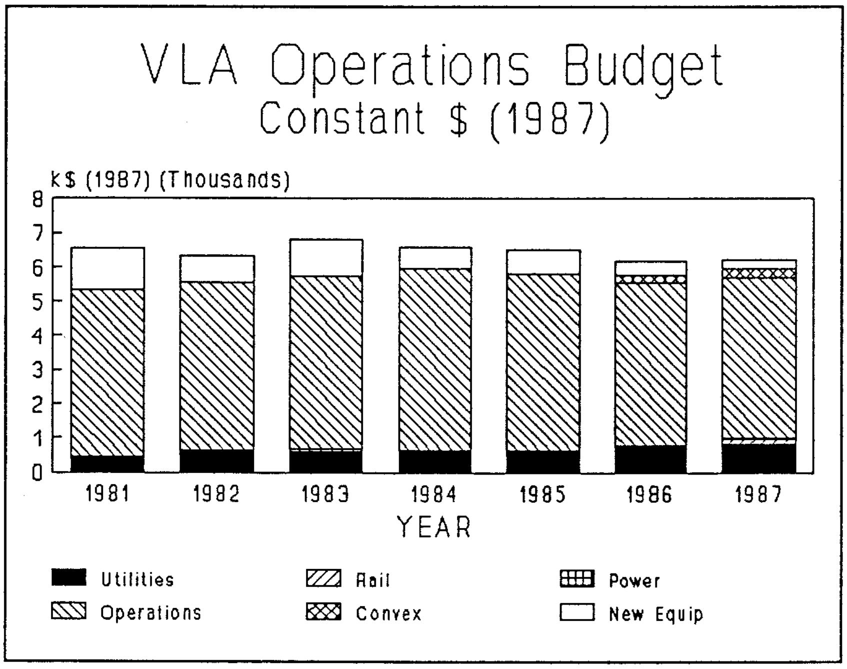

FIGURE 3.1 VLA operations and research equipment Budget

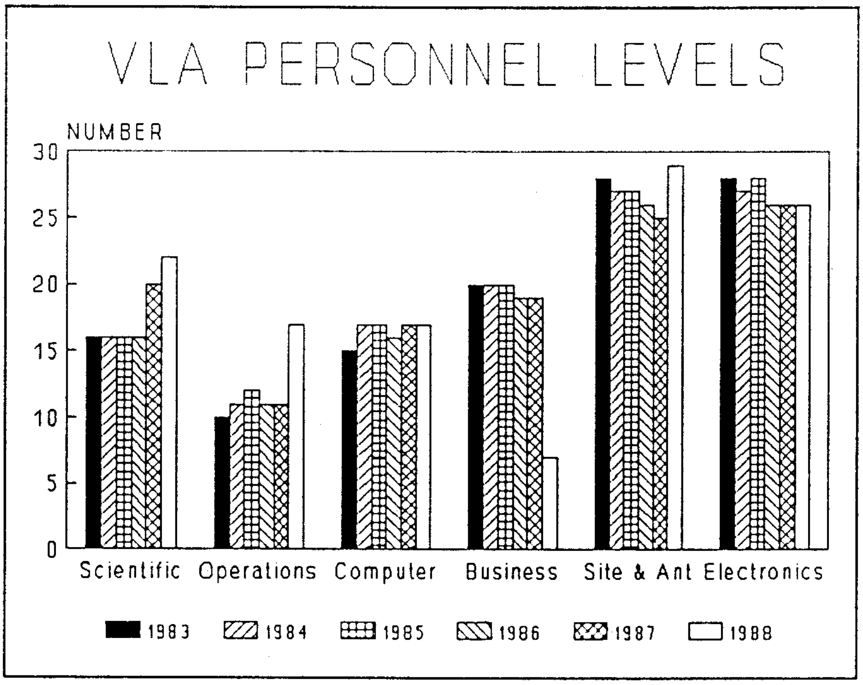

FIGURE 3.2 VLA Personnel

3.2. Staffing Levels

Figure 3.2 shows how these personnel levels have changed with time. If corrections are made for the inter-divisional transfers indicated in the footnotes to Table 3.1., the following trends can be noticed. Slow increase in total scientific staff, results from increasing number of NRAO post-doctoral positions transferred to the VLA. The Computer division has slowly increased in size while both Site and Antenna and Electronics have declined. These changes reflect the increasing complexity and priority given to the VLA computing problem. However constraints on total manpower result in the unfortunate decrease in the other two areas. This is made even worse than the table and figures indicate since some additional VLA manpower was made available for VLBA construction which had not been manned at the level anticipated. Additional manpower provided through the NASA contract to support the Voyager Neptune Encounter (section 4.1) is not included in the figure.

4. MAJOR PROJECTS

4.1. VLA Support for Voyager 2 - Neptune Encounter

In February 1982, Dr. Bruce Murray, Director Jet Propulsion Laboratory proposed that NRAO consider use of the VLA for telemetry reception from the Voyager 2 encounter with Neptune in August 1989. As a result of a successful technical evaluation of this possibility NSF and NASA agreed to a management plan "Management Plan for the VLA-GDSCC Telemetry Array Project", JPL D-2087 which directed the implementation and operation of the VLA in support of the Voyager spacecraft. Bill Brundage came from Green Bank to the VLA in 1985 to lead the Voyager team.

A major spinoff of this project has been the equipping of the VLA at an additional frequency at 8.7 GHz. Use of HEMT amplifiers developed by Sandy Weinreb and Mike Ballister at the Central Development Laboratories in Charlottesville resulted in a lower system temperature than any other VLA system.

4.2. VLBA

The decision to locate the VLBA Operations Center in Socorro to be operated jointly with the VLA results in significant saving in construction and operation budgets. However the impact of this major construction project on the VLA has been very significant, especially as it has occurred during a period of decreasing VLA budget and manpower resources.

4.3. Array Operations Center (AOC)

The decision to locate the VLBA operations center in Socorro was coupled to the decision to shift the center of activity of the VLA from the plains of San Agustin to the new Array Operations Center. Without this move the full integration of VLA and VLBA would not be possible. Three options for the location of the joint VLA/VLBA AOC in New Mexico were considered; Albuquerque, Socorro and the Plains of San Agustin. With a location in Albuquerque it would have been very difficult to fully integrate the VLA and the VLBA. A major part of the VLA technical support would have had to stay on the plains and communication from Albuquerque would be impractical. Locating the VLBA AOC with the VLA on the plains of San Agustin would have minimized impact on the VLA operations but would have involved the VLBA staff in the additional 2 hour commute per day. Socorro was felt to be a workable compromise. In a memo from Ekers and Napier (October 27, 1983) it was argued "that in this scenario we have to make significant changes to the current VLA operation and we must balance the effects of this against the advantages obtained for the VLBA operation. Although the operation of the VLA from Socorro involves a split in the main working location of the VLA staff this perturbation is the smallest of the perturbations involving split locations. The effect in this case is minimized because the majority of the VLA staff lives and commute from Socorro and this gives us a natural way to keep up a high level of communication. In this option about 40 of the current VLA staff would still be permanently assigned to work on the Plains of San Agustin".

The AOC was jointly funded by the NSF (VLBA construction budget) and the State of New Mexico and is located on the campus of the New Mexico Institute of Mining and Technology.

The move to the new center in 1988 involved significant restructuring of VLA operations and management.

4.4. A Major New National Radio Astronomy Facility; The Millimeter Array

The "MM Array Study vols 1 & 2" January 1988 involved substantial input from VLA staff. It also stimulated research into areas such as large image mosaicing which have now become important research tools for VLA observing.

5. SCIENCE WITH THE VLA

5.1. VLA Time Allocation Procedure

The time allocation procedure used at the VLA is similar to the NRAO procedures used at other NRAO facilities. The proposals are submitted to the NRAO, with an observing application form (Appendix III). Each proposal is refereed by at least two and usually three anonymous referees who are selected by the NRAO director from the VLA user community and serve for two years. There are separate referees for the following subject areas; solar, planetary, stellar, galactic, extragalactic. Referees see all proposals in their subject area. Two of the referees are theoreticians and they are asked to comment on proposals in any category. The referees give a scientific merit rating, an indication of the fraction of time to be allocated, and are encouraged to provide written comments. About two thirds of the referee reports include such comments.

Each quarter all proposals (about 200) and referee reports are reviewed by a small NRAO scheduling committee, which includes the site director. The referees' ratings are considered advisory to this committee which also takes into account additional technical constraints which may not be known to the referees. In the majority of cases the time allocation decision is based on the average referee rating. Detailed time allocations are coupled to the generation of an actual observing schedule for the quarter. Hence the fraction of time allocated is dependent on the requested LST range and other special requirements. The oversubscription rate and hence the fraction of time allocated varies considerably with LST.

Proposals are rejected rather than retained for later consideration if: 1) they are more than two quarters old with adequate consideration for suitable configurations; 2) there is a consensus among the referees that the proposal isn't worth doing; 3) when a proposal which has the same aims or same objects has already been scheduled or observed; or 4) They will be out of date by the time the VLA returns to a suitable configuration.

The results of the time allocation, including the referees ratings and essentially all their comments, are automatically sent back to the proposer. If a proposer wishes to resubmit the proposal debating the referee comments he is free to do so. Most of the proposal administration, including collation and dissemination of referee reports, has been computerized by Barry Clark.

Loss of time due to failure or weather is sufficiently small (< 5%) that we can usually reschedule most of the lost time.

The VLA director occasionally bypasses the normal allocation procedures for situations requiring rapid response, but this is unusual and involves a very small fraction of the total time (< 1%).

The VLA is oversubscribed in time by a factor of 2 to 3. It operates 24 hours per day and useful programs can be as short as an hour. More than five hundred separate proposals were scheduled and completed in 1986.

5.1.2. Comment on Time Allocation Procedure

As always, the peer review provided by the refereeing system discriminates against the less conventional programs. This is slightly offset by the referees being advisory to the director. On the positive side this system is generally considered very fair. The procedure of automatically reporting the referees ratings and comments to the proposers has been well accepted and is very successful. This feedback has in some instances resulted in significantly better proposals being submitted. The extremely short time scale with which we schedule (submission deadline is less than three months before time is allocated) is hard for our administration but is considered valuable by the observing community.

We do not allocate reward time to instrumentalists or to our other scientific support staff. The slight edge they already have as a result of understanding the instrumental possibilities better than the average user is sufficient to enable them to compete successfully for time.

5.2. Proposal Statistics

The amount of observing time available on the VLA (approximately 5 times that for an optical observatory only operating on clear nights) and its speed, result in a very large number of scheduled proposals (Table 5.1, 5.2).

TABLE 5.1 PROPOSAL STATISTICS

Number of Proposals	1981	1982	1983	1984	1985	1986	1987*
Requested	420	475	599	559	601	686	439
Scheduled	312	399	482	480	509	519	479
Rejected	108	76	117	79	92	167	
Fraction scheduled[#]	74%	84%	80%	86%	85%	76%	

[#] No detailed statistics have been computed for the fraction by time rather than number but the reduction of time allocated for accepted proposals is about 50% reducing the fraction of time scheduled by time to 50% of this value.

*From 1987 the method of counting proposals was changed to give consistent counts as we went from the quarter to trimester system. Differences are related to the way multiple configuration proposals, and proposals spanning multiple periods are counted.

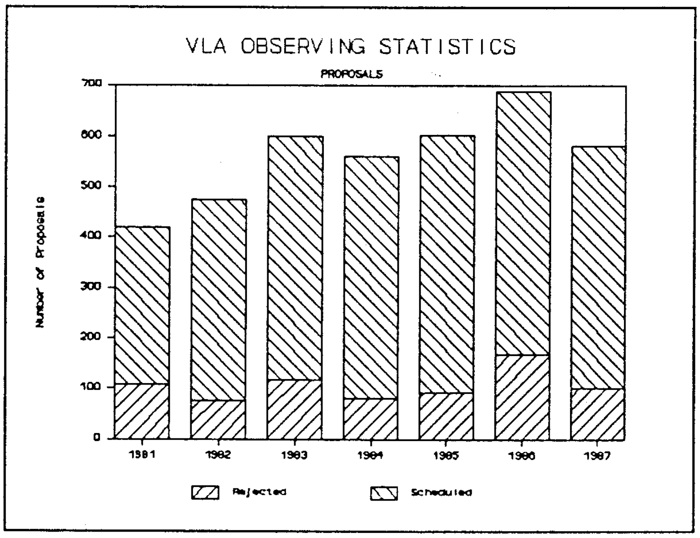

FIGURE 5.1 Scheduled Proposals

TABLE 5.2 OBSERVING TIME (HR)

	1981	1982	1983	1984	1985	1986	1987
Astronomical	5236	6279	6485	6574	6693	6546	6463
Test/cal.	2595	2422	2209	1128	1073	1274	1242
Maintenance				1002	932	892	1001
VLB (1 ant)	342	342	528	546	678	384	
VLB (27 ant)	90	276	336	324	264	300	
Ave time per observation (hrs)			11.7	10.4	9.9	10.9	11.1
Ave time per proposal (hrs)	16.8	15.7	13.5	13.7	13.1	12.6	13.5

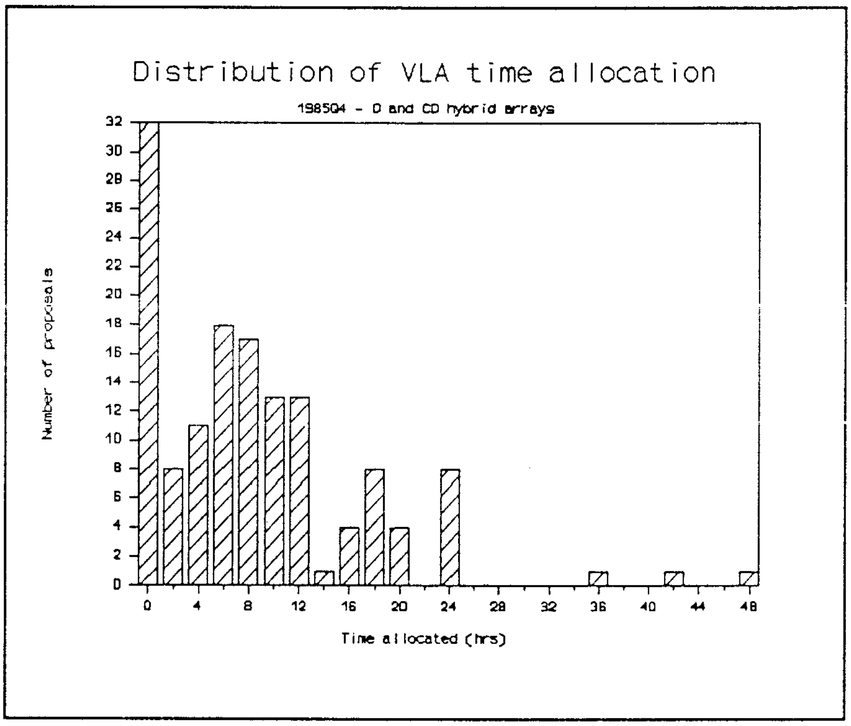

FIGURE 5.2 Distribution of VLA Time Allocated Per Proposal

Figure 5.2 shows the distribution of time allocated per proposal at the VLA during the last quarter of 1985 (D and CD hybrid arrays).

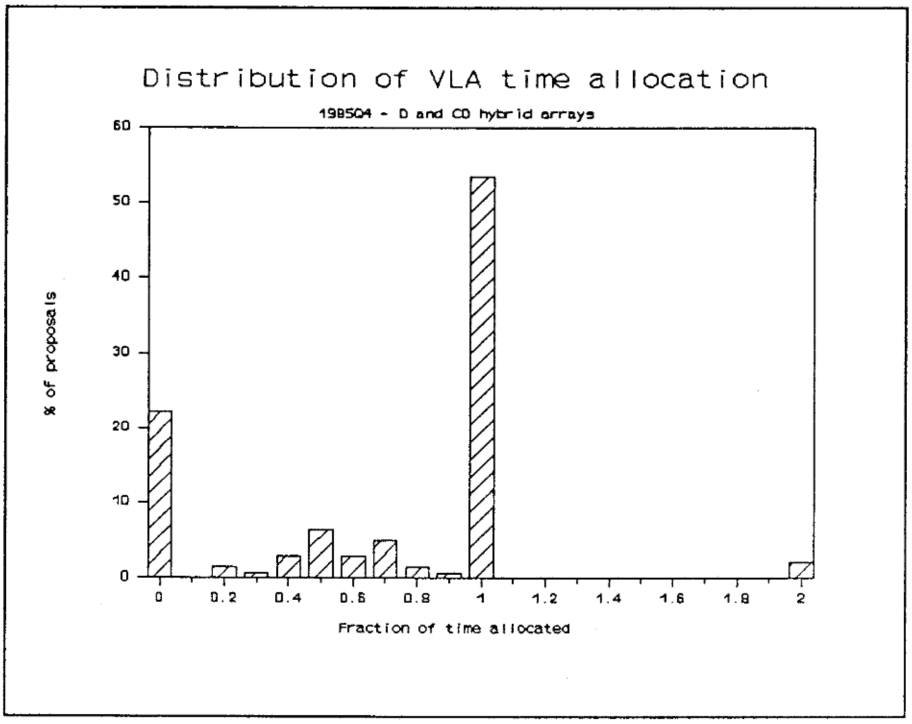

FIGURE 5.3 Distribution fraction of VLA Time Allocated Per Proposal

Figure 5.3 shows the distribution of the fraction of requested time which was allocated. Two conclusions of interest to proposers can be drawn. 1) in the majority of cases we allocate the actual time requested, 2) there is no significant tendency to allocate a smaller fraction of the time for larger requests. Consequently, there is no advantage to the proposer in breaking his proposal into smaller pieces, a practice which is also strongly discouraged because it increases the burden on both the referees and the time allocation committee. The total number of proposals reviewed for this particular quarter was 140. 83% of these have some time allocated and 55% percent of the total requested time was allocated NRAO Newsletter, (Jan 86)

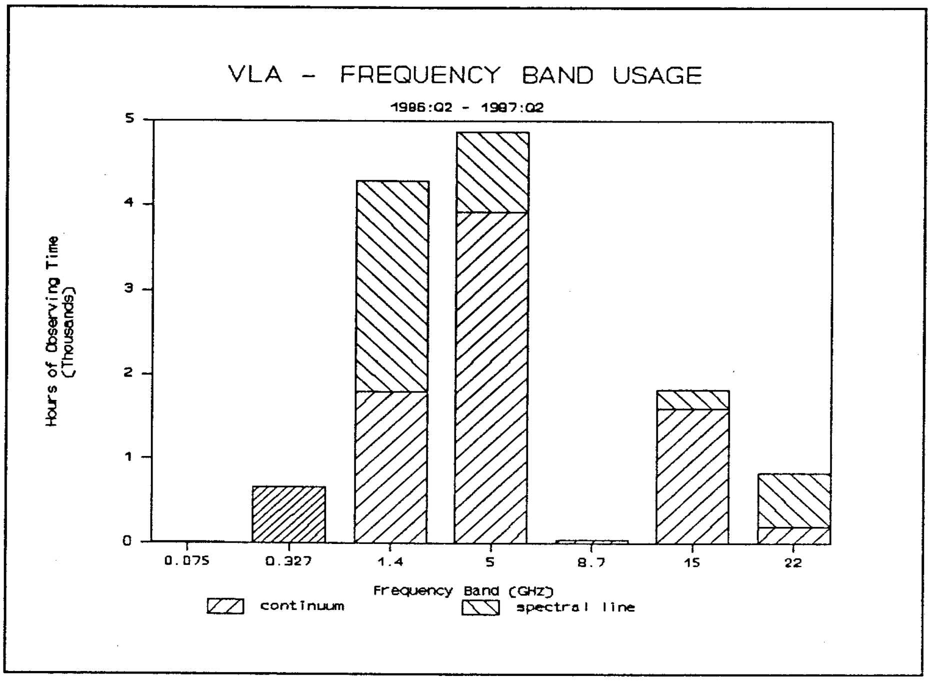

FIGURE 5.4 VLA-Frequency Band Usage

As a by-product of the preparation of our archive of VLA observations we have accumulated statistics of the observing time spent as a function of observing frequency at the VLA. Figure 5.4 shows the distribution of observing time in the period of 1986, second quarter to the end of 1987 second quarter. This period covers the full range of VLA configuration changes. The frequency bands apply to the different VLA receivers systems except for the split between 1.4 and 1.6 GHz. This split is such that 1.4 GHz includes all 21cm line and most 20cm continuum (about equally divided) while 1.6 GHz is mainly OH spectral line. Some obvious trends were also apparent during the year analyzed; as more antennas became available the use of 327 MHz increased rapidly and is probably double the rate indicated in this distribution by now. At the same time the use of 22-25 GHz decreased presumably due to the expectation to the new more sensitive system. The small amount of time spent at 75 MHz and 8.7 GHz results from earlier system tests in these bands and does not indicate potential use of these frequencies.

5.3. Scientific Results

The success or failure of the VLA should be judged by the scientific results produced. Already from the proposal statistics (sect. 5.2) it is clear that the VLA has had a major impact on both U.S. and international astronomy. The number of requests for observations has almost doubled in the first seven years of operation, the number of users has tripled and is now approaching 700, a significant fraction of the entire astronomical community. Figure 5.5 shows the trends in the use of VLA observing time in different astronomical fields. Most notable is the increase in the use of the VLA for stellar radio astronomy. This is a result of the increasing awareness of the potential of the VLA for this type of research combined with the large size of the stellar astronomical community.

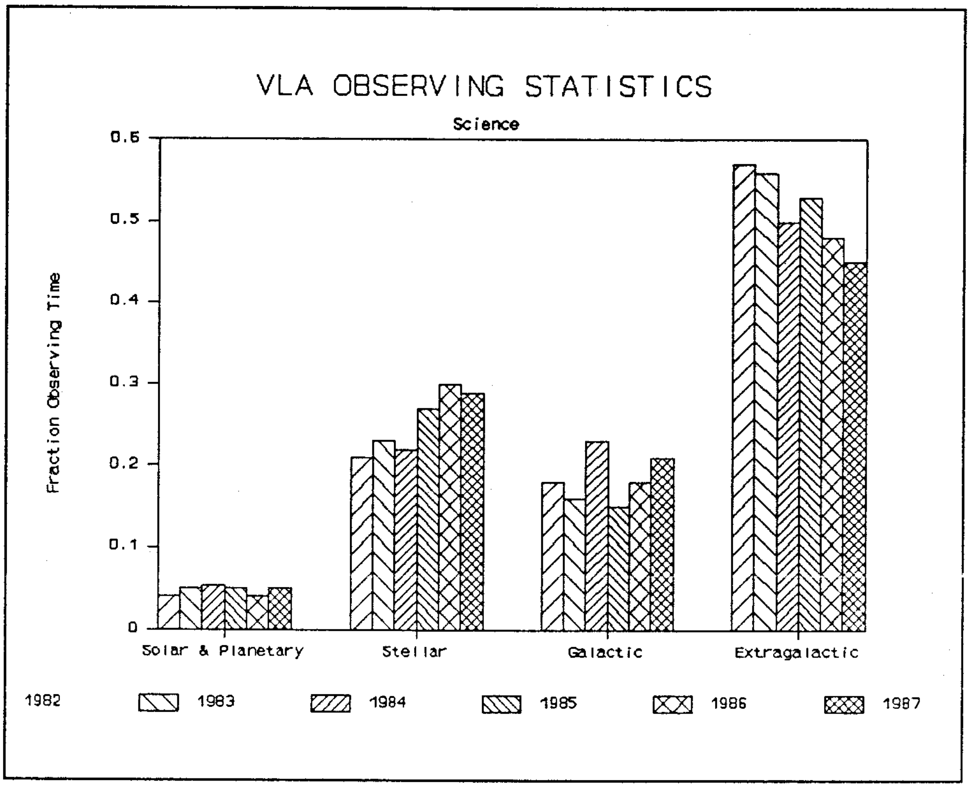

FIGURE 5.5 VIA Distribution of VLA Observing Time by Subject

During the last seven years I have kept a personal, and consequently somewhat biased, list of key scientific discoveries made with the VLA. This list with brief description and references is given in appendix IV in chronological order and in appendix V assorted by subject. Although this is only a tiny fraction of the total VLA output (more than 1000 publications up to 1987) it does give a good overview of the diversity of science being done and the number and quality of discoveries being made.

TABLE 5.3 VLA PUBLICATIONS

	1976-80	1981	1982	1983	1984	1985	1986	1987
Publications	(163)	84	78	101	106	180	188	200

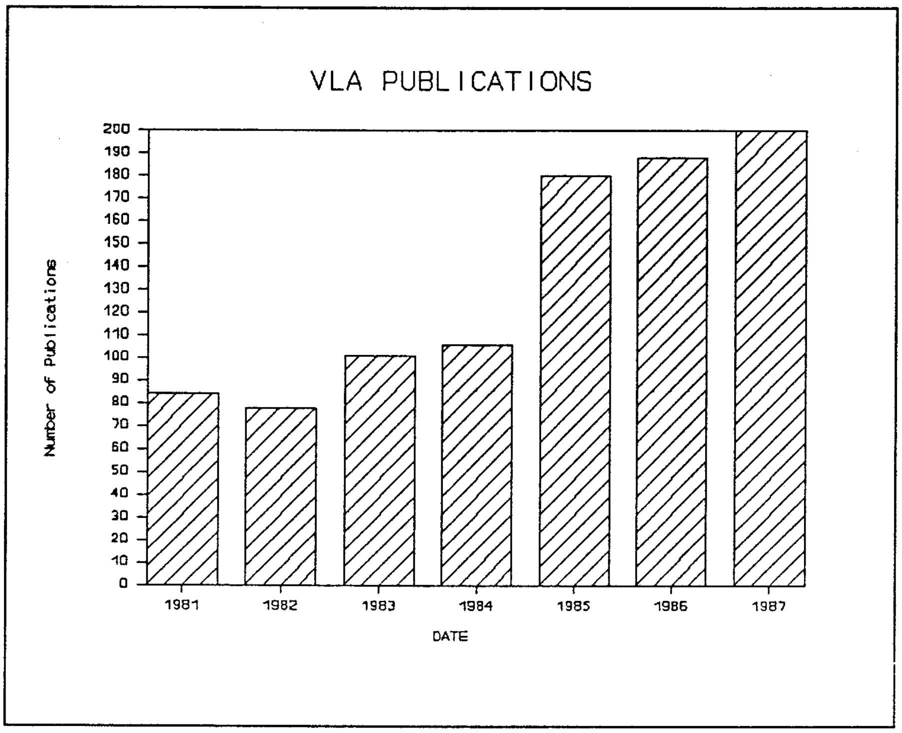

FIGURE 5.6 VLA Publications

5.4. Scientific Environment

By 1981 the base for almost all the scientific staff had moved to the site. In order to stimulate discussion and interaction one office in the SLOB was removed to provide an open area at the intersection of the 2 passageways. The scientific environment became clearly centered at the VLA and by taking advantage of continual stream of observers a lively, if sometimes narrowly focused, atmosphere developed. By 1985 we usually had 3 scientific lunch talks per week in a variety of formats and a regular series of colloquia.

6. THE USER COMMUNITY

6.1. Workshops

It soon became apparent that many users of the VLA were coming from institutions which did not have any strong background in radio astronomy, certainly not in radio astronomy using aperture synthesis. For this reason we decided to hold a workshop covering both the fundamental and new developments in the techniques of aperture synthesis radio astronomy. The workshop was primarily aimed at graduate students and was held for the first time in June 1982. As a result of the enthusiastic response to that workshop we decided to hold similar workshops every three years in order to catch each new generation of graduate students. Further workshops have been held in August 1985 and in June 1988.

The following is extracted from the Introduction to the first Synthesis Imaging Workshop.

Why have a workshop on synthesis mapping? Most of the major discoveries in radio astronomy have resulted from the development of new instrumentation. There is a long and impressive list of examples; the detection of radio emission from the sun, the detection of radio emission from the galaxy, the discovery of radio galaxies, the discovery of masers in the interstellar medium (you may recall that the first OH maser emission was known as mysterium), the discovery of quasars, the discovery of the black body radiation and the discovery of pulsars. The VLA is a major new instrumental development in radio astronomy. With an improvement in sensitivity and resolution of two orders of magnitude, a declination range from the north pole to -45˚ and sufficient speed to map sources of radio emission in a few minutes.

It is possibly the biggest step that has been taken in any single instrument. Given this new major instrument what do we have to do to make major discoveries with it? The problem is that if you find a new an unexpected effect in your observation it is most likely to be an instrumental error. Consequently you should be able to recognize these errors so that you do not waste too much time tracking down unimportant effects and save your effort for the occasion that is really important.

Most of the observational work done with the VLA is analytic in nature, that is, the observations will be investigating or following up in more detail the results of previous discoveries. In this kind of observation it is the observer who has to vouch for the integrity of his data. Although the VLA staff will do everything in their power to make the instrument as reliable and accurate as possible, it is, in the final analysis, the observer's responsibility that the data he derives is correct. The VLA is a very powerful and very flexible instrument, the better you understand how it works the better you will be able to exploit its flexibility in planning and reducing your observation.

Some of the new developments (image restoration, self-calibration, spectral-line mapping) do not appear in any of the text books on radio interferometry but they have revolutionized the art of synthesis mapping. We would like to take the opportunity of presenting information on some of these techniques during this workshop.

6.2. User Statistics

Table 6.1 and figure 6.1 show the phenomenal growth in the number of astronomers using the VLA since the end of construction. This has occurred because the instrument is fast, good science can sometimes be done with a five minute observation, and because its sensitivity and imaging capabilities have made it a valuable tool over a broad range of astronomical research areas. The increase in number of users has occurred in the outside community with a number of NRAO Research staff remaining almost constant.

TABLE 6.1 NUMBER OF USERS

	1980	1981	1982	1983	1984	1985	1986	1987
Visitors	181	292	349	445	445	451	472	545
Students	26	58	71	91	97	80	77	83
NRAO staff	32	37	32	35	45	41	38	38
TOTAL	239	387	452	571	587	572	587	666

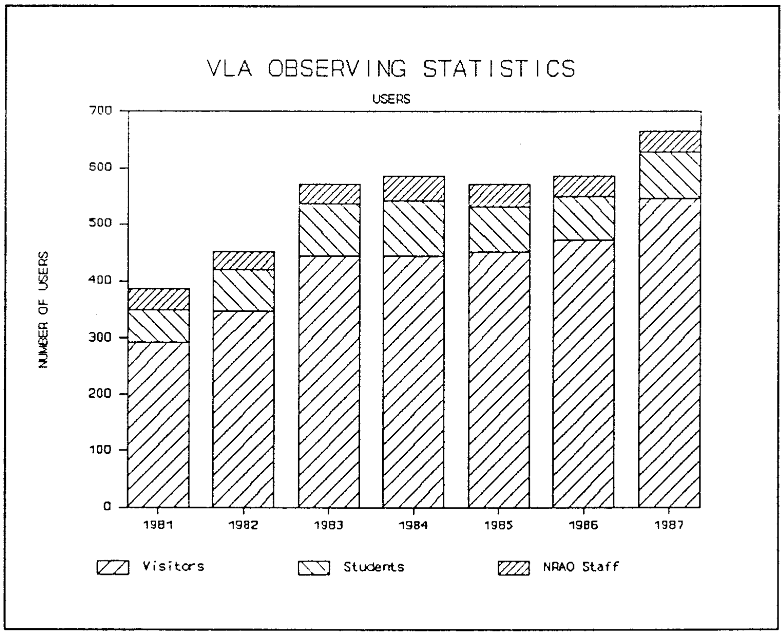

FIGURE 6.1 Number of Users

TABLE 6.2 OBSERVING TIME DISTRIBUTION

	1981	1982	1983	1984	1985	1986	1987
Visitors	38%	47%	52%	56%	58%	58%	56%
Students	8%	7%	8%	9%	8%	7%	7%
NRAO staff	14%	17%	14%	10%	11%	10%	11%
Test, cal & maint	40%	29%	26%	24%	22%	25%	27%

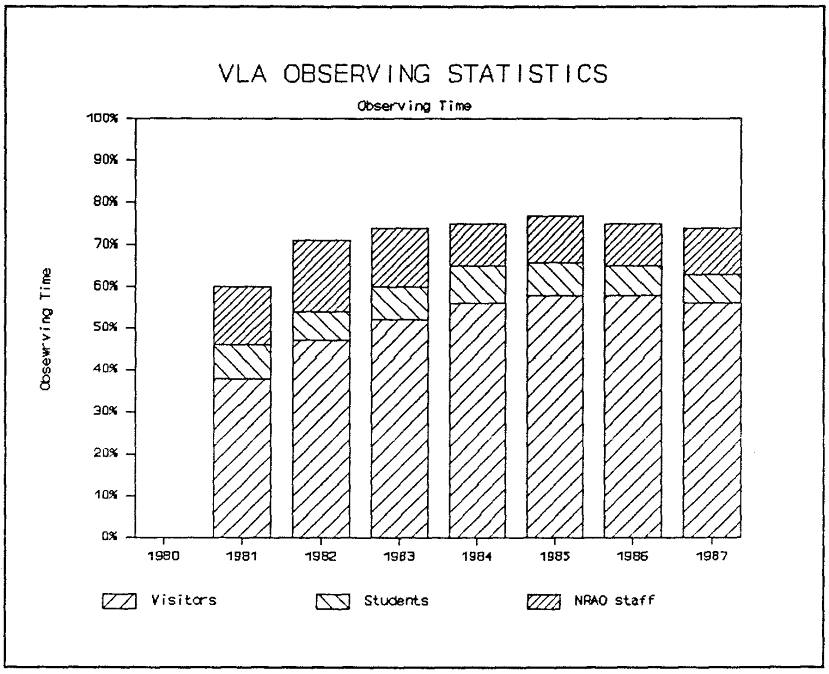

FIGURE 6.2 Observing Time Distribution

6.3. Geographical Distribution

The unique capabilities of the VLA combined with the policy of open access discussed in section 5.1 have resulted in a remarkably wide distribution of users, not only throughout the United States but internationally. It might well be asked whether any other facility has developed such a large and broad based user community. This open access policy has had a significant influence the policy of access to astronomical facilities in some other countries.

TABLE 6.3 INSTITUTIONS USING VLA

	1980	1981	1982	1983	1984	1985	1986	1987
USA				69	76	71	70	84
Foreign				58	87	64	70	81
TOTAL	76	95	111	127	133	135	140	165

Appendices V & VI lists the Institutes involved in observational programs with the VLA in 1986 and 1987.

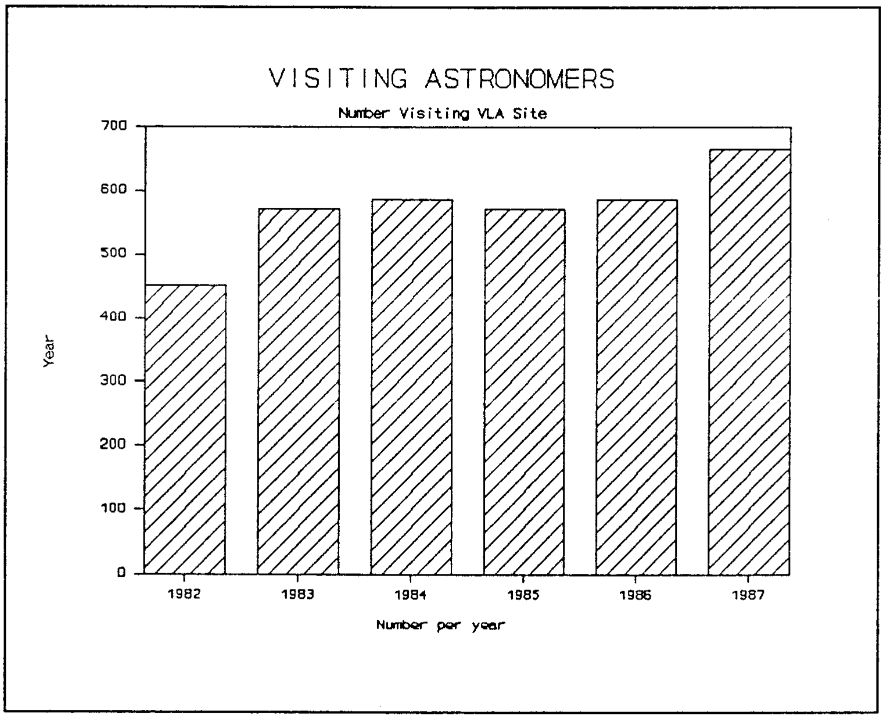

FIGURE 6.3 Visiting Astronomers at VLA

6.4 Remote Observing

At least some members of essentially every project travel to the plains of San Augustin to participate in their observations. This may include the actual observing process itself but in many cases the astronomers are more likely to be involved in data processing perhaps long after the observation was completed. The number of scientist visiting the VLA is shown in figure 6.3, it also considerably exceeds what was expected, generating a heavy load on the NRAO staff, the on-site facilities and the travel budgets. To alleviate the problem a program to make it easier to observe remotely was started in 1984. This included the addition of data analysts to the NRAO staff to provide some of the routine processing for outside observers and the possibility of remote dial-in for both the generation of observing files and the editing and calibration of data. Table 6.4 give some statistics on this program a year later. A very slight decrease is seen in the number of visiting astronomers for the following few years but then as the total number of observers still continued to increase the number actually visiting the site also stated to increase again. A more vigorous (and hence more expensive) program of remote observing and use of NRAO data analysts would certainly reduce the number of people coming to the site. However the many indirect advantages of the site visit, contact with the local staff, contact with the engineering staff, making real time decisions on observing strategy and sometimes taking advantage of better processing resources, will insure a continuing contact with the outside community.

TABLE 6.4 VLA REMOTE OBSERVING - (1985)

	Number	Fraction of Total
Total VLA Observations	675	
Data Analysts - Total Handled	182	27%
Edited & Calibrated - VLA	77	11%
VLBI	33	5%
Data Analysts hrs/Obs hrs	1.9	
Data Analysts Manpower	1.5 -2.5	
Backlog	160 days	
Dial in for remote calibration	18	3%

7. PUBLIC RELATIONS

7.1. Visitor Center

As a result of a vigorous campaign by Jack Lancaster, his last major effort as Construction Manager, the construction of a visitor center was funded by the State of New Mexico and opened in April 1983. A group of NRAO staff lead by Dick Sramek designed the static displays and walking tour, and Don Retallack produced the excellent audio visual show. At present 15,000 people visit the center each year.

7.2. Popularization

Such a dramatic and powerful scientific research facility has naturally generated many popular articles, see summary in Appendix VIII, and also because of its visual impact a large number of TV documentaries and a few screen films (Appendix IX). Most notable was the introductory sequence to MGM's film of Arthur C. Clark's "2010".

8. COMPUTER

8.1. Introduction

Without much doubt the least successful aspect of early VLA operations was the hopelessly inadequate computing resources needed given the increased array output and the changes in the nature of the processing task. The computer bottlenecks were initially so severe that the array started life with observing time restricted in order to reduce the pressure on the oversubscribed computers. The first step to alleviate this problem was relatively easy, it was possible to use some money still remaining in the construction budget to purchase the first of the VAX computers for the VLA and to upgrade the DEC10 KI general purpose computer to the, then top of the line, DEC 10 KL system. Efforts were also made to encourage the use of computers in the users' institutes, e.g. by exporting the Charlottesville IBM package to a number of sites and this allowed us to increase the array usage to full time by April 1981. Even so the full capacity of the correlator was not turned on and it is only with the new on-line system in 1988 that it will finally be possible to use all of the capability originally designed into the telescope!

In the early years, spectral line VLA observing was severely compromised by the lack of software. Barry Clark's innovative "pipeline" solution to VLA spectral line processing was progressing too slowly (for overview see "Whatever Happened to the Pipeline" by Bob Duquet, VLA Computer memo 172.) It also became apparent during these years that the effort needed to provide the basic service to the rapidly expanding user community consumed almost all software resources and significant software development at the VLA ground to a halt. An independent group was established in Charlottesville and was responsible for almost all post processing software development after the beginning of VLA operations. After some false starts, this finally culminated in the very successful AIPS software package.

At the VLA decisions were made to abandon some internal software efforts, such as CANDID (the astronomical environment package), and HARVEY, (the communication network package), and to replace them with commercial products such as DECNET. This reduced the software manpower load and improved reliability and maintainability.

8.2. Long Term Computing Plans

There was a reasonable budget for new computer equipment for the first few years of operation (Section 3.1) and continual enhancements to capability were occurring. However, by 1982 it was clear that this incremental expenditure was never going to provide the big increase in capacity needed to fully exploit the VLA's capability and a panel of high level outside computer experts was put together to discuss the future of computing for the VLA. The group met twice, once in 1982 and again in 1984. The 1982 Committee concluded "NRAO needs a long range plan based on astronomical requirements ... flexible and growable computer architecture ... should not depend on being at leading edge of computer technology ... requires a major new infusion of capital from NSF". A long range plan, involving use of a supercomputer, was developed and presented to the committee in 1984. They enthusiastically endorsed this proposal "The most attractive option currently available and absolutely essential for the prosecution of the science", and encouraged us to start using the NSF supercomputer access program. These discussions, especially the first meeting, were the most valuable sources of outside advice I received during my period as VLA Director. The success of this advisory committee was, I believe, due to the composition of the panel. We were extremely fortunate in getting a very talented and experienced group of individuals (none of whom were astronomers) who brought new ideas from outside of our natural community. Sadly, none of this input, nor the very significant efforts which NRAO has expended on the long term computer plan, received any support from NSF in terms of resource allocation.

Despite the lack of specific additional funding for VLA computing, the money available through the Research Equipment budget and the improvement in computing speed resulted in quite a significant enhancement in capacity since 1980 (Figure 8.1). Note also the increase in non NRAO capacity for both U.S. and especially for foreign users.

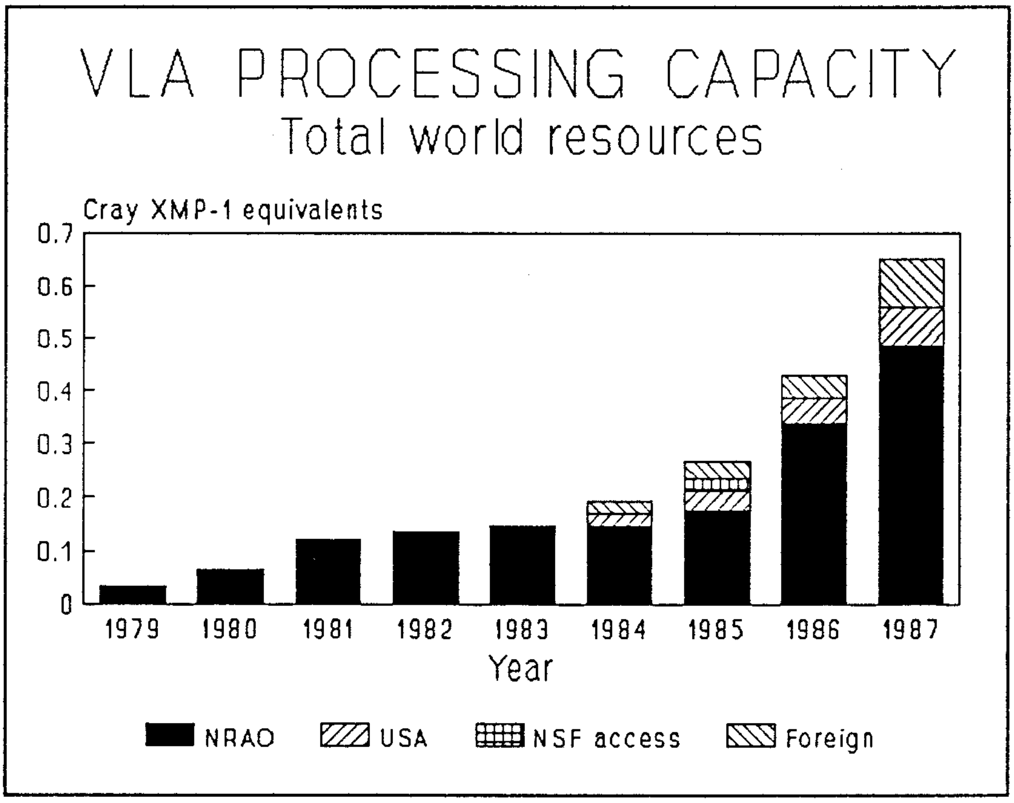

FIGURE 8.1 VLA Processing Capacity

8.3. Supercomputer Proposal

In 1984 some of the key VLA data processing algorithms were successfully tested on a CRAY I-S supercomputer at the Los Alamos National Laboratory and a plan to acquire a supercomputer for the VLA was discussed with the computer advisory committee. Based on their recommendations we requested and obtained access to the Digital Productions Cray XMP through the new NSF sponsored supercomputer access program. The Digital Production system was chosen because it was the only supercomputer at the time with adequate visualization capability. Despite the success of this program our proposal to the NSF for a VLA supercomputer floundered between the NSF astronomy and advanced scientific computing programs and was never funded. The followup proposal in 1987 for a small network of second generation mini supercomputers fared no better. By the end of 1987 the only increase in computing capacity achieved was 1 1/2 CONVEX C-1 mini supercomputers which had been squeezed out of NRAO's declining operating budget. These provided about 1/15 of the proposed capacity.

8.4. New Online System

In 1983 a major project to develop a new on-line computer system was started (Gareth Hunt and Ken Sowinski, Computer memo #166).

8.5. Chronological History of VLA Computing

A chronological history of VLA Computing with more detail than the general chronology and going back to the beginning of construction is given in Appendix II.

9. ELECTRONICS

9.1. Development

By the end of the construction of the VLA advances in technology had already made it possible to start upgrading the receivers and electronics at the VLA. For example by mid 1982 the Central Development in Charlottesville had developed an FET amplifier to replace the 15 GHz mixer and reduce the VLA system temperature from 250k to 110k. At the same time the 1.5 GHz upconverters were replaced with FET amplifiers to give better reliability and to reduce maintenance manpower. The new 15 GHz system was completed in November 1983 and then a new low frequency, 327 MHz, system was started. At this time there was strong scientific pressure to upgrade the 1.3 centimeter system now being heavily used for the very sensitivity limited NH_3 observations. However this upgrade had to be delayed waiting for the development of a suitable amplifier by the Central Development Lab. The 1.3 centimeter system upgrade finally commenced in August 1986. At this time the 5 GHz paramps were also replaced with FET amplifiers to increase reliability and decrease maintenance manpower. (Future front end development for the VLA - Paul Lilie, Electronics memo #213). During 1987 the 327 MHz installation was slowed down because of a lack of money and the interference shielding needed for compact arrays was deferred. A contract with NRL organized by Ken Johnston funded a partial 75 MHz system piggybacked on the 327 MHz system. This finally enabled the 327 MHz system to be completed and a start to be made at 75 MHz.

Throughout this period an additional major upgrade to the feed focus and rotation mount was underway. The unpredicted heavy demand on rapid frequency changing, which became an important observing style, was too demanding for the original system. It had been designed on the assumption that a few frequency changes would be made per day, not every few minutes!

The fact that significant improvements to the electronics were already possible by the end of construction, and the changes necessitated by unpredicted observing styles, shows the importance of a continuing investment budget for an instrument such as the VLA.

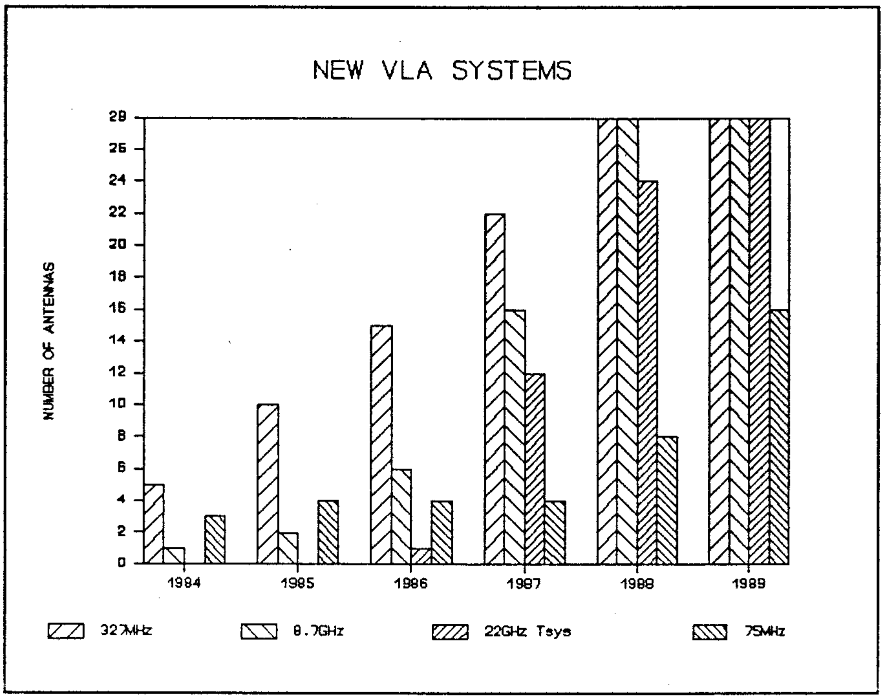

FIGURE 9.1 New VLA Systems

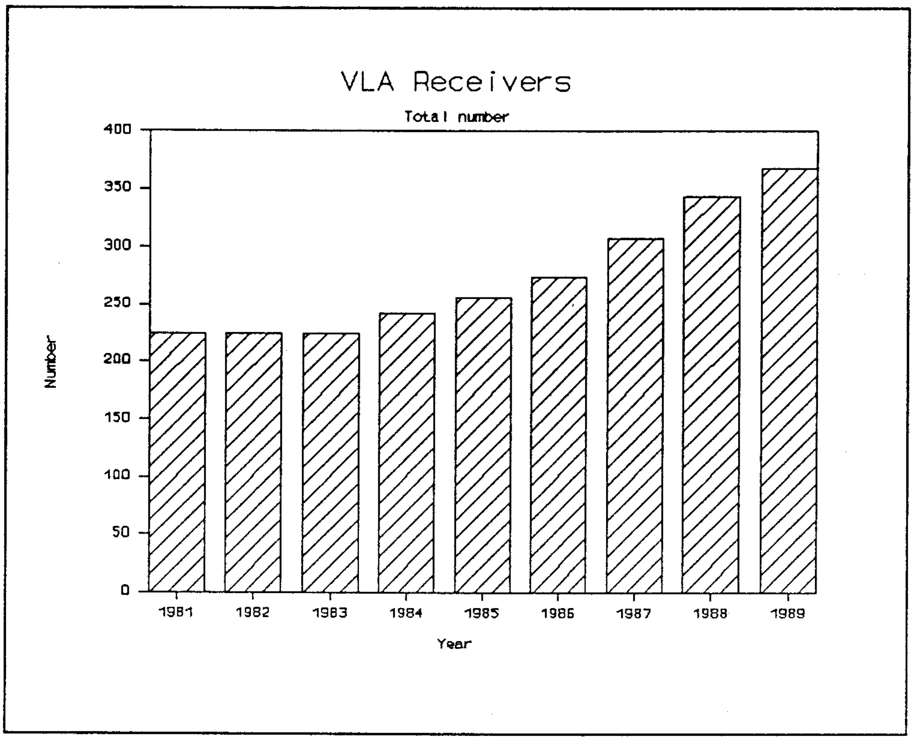

FIGURE 9.2 Evolution of a Number of VLA Receivers

9.2. Reliability

TABLE 9.1 DOWNTIME

	1980	1981	1982	1983	1984	1985	1986	1987
Quarter 1	20.0%	7.7%	6.4%	8.3%	4.9%	8.1%	11.6%	6.2%
Quarter 2	13.7%	4.8%	3.3%	5.7%	5.9%	6.9%	8.3%	9.5%
Quarter 3	11.3%	4.4%	5.3%	7.2%	4.5%	5.7%	5.0%	6.9%
Quarter 4	7.3%	4.6%	6.8%	8.3%	6.9%	6.3%	3.4%	7.0%
Ave.	13.1%	5.4%	5.5%	7.4%	5.6%	6.8%	7.1%	7.4%

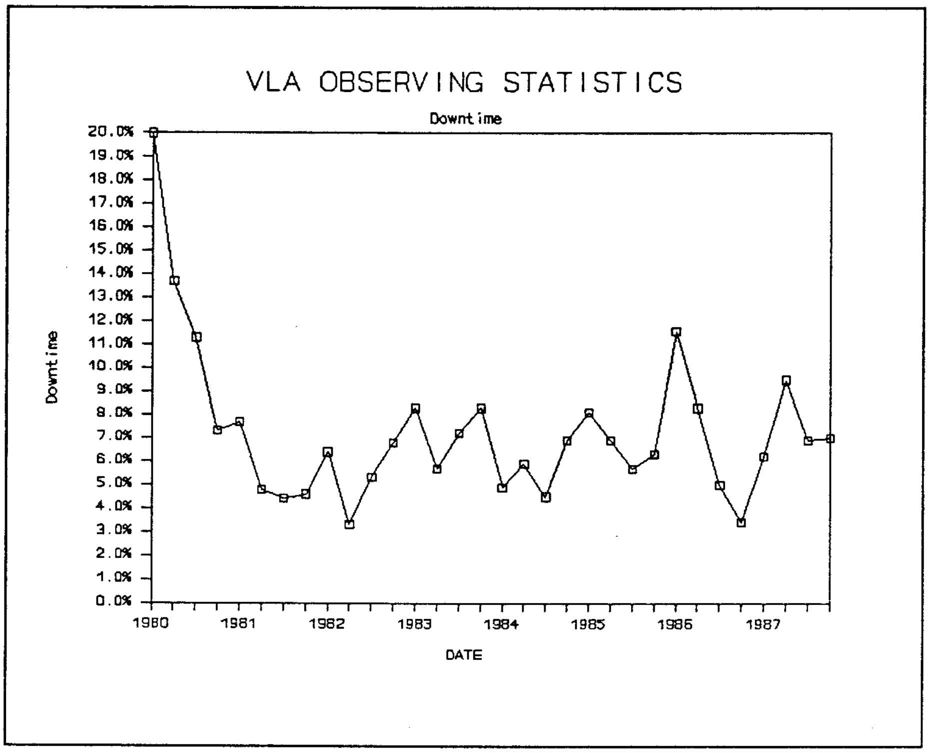

FIGURE 9.3 Downtime Statistics

10. ANTENNAS

10.1. Insulation

After long series of tests it was decided to insulate the telescope support tubes and yoke structure to provide a thermal constant approaching 24 hours to avoid pointing errors due to differential insolation heating of one side of the telescope. The trial insulating of one telescope was completed in June 1981 and the 28th telescope (including re-insulating of the first) was completed in April 1987.

10.2. Gearbox Modification

During construction the azimuth gear boxes were bolted to the pedestal structure with the pinion gear in proper contact with the azimuth gear. After several weeks of testing it was found that the bolts had loosened sufficiently so that the pinion was no longer in contact with the mating gear on one telescope. The design was therefore changed by welding the gear box directly to the telescope structure after it was adjusted to proper tolerance and bolted in place.

10.3. Cracks in Structure

During construction one telescope was discovered to have cracks in the welds joining the support tubes to the flanges in the pedestal structure. Investigation revealed poor quality control at the fabricators plant. The errors were pointed out to the vendor and no additional cracks were ever found. The existing cracks were relieved by re-welding.

10.4. Elevation Bearing Failure

In mid November, 1987 antenna 17 abruptly lost communication. The elevation bearing had failed allowing the structure above the elevation shaft to fall more than an inch damaging the waveguide and interrupting communications with the telescope. The instrument went into auto stow and remained parked until it could be repaired. The superstructure was jacked up on custom designed adapter brackets using 2 one hundred ton jacks and the damaged bearing removed. Special sleeves were fabricated and installed and a new bearing jacked into place. The telescope returned to service early February 1988.

10.5. Transporter

In September 1981 a crack developed in the fusion zone of a strength weld of the longitudinal to main transverse beam joint on transporter no. 2. The failure was probably due to unbalanced support of the on board telescope due to unplanned unloading of support cylinders in one truck. As a result three major changes were made. Lee King's stress analysis dictated lowering the loaded transporter travel speed from 5 to 4 MPH. The support cylinder fluid pressure is monitored constantly and an alarm sounds when any one truck takes less than its share of the load. Finally the load deck elevation is never more than two inches from direct support, thus deflection will not exceed design limits.

The transporter is a hydrostatic drive vehicle which required a surprisingly high level of maintenance, in excess of 10 hours of maintenance for each hour of operations. To reduce the labor budget a service building was completed in February 1985. Since the transporters have been serviced in a building away from the constantly blowing sand and dust breakdowns have been virtually eliminated and maintenance time is less than a third of early experience.

11. SITE

11.1. Reconfigurations

During the construction period the VLA antennas had been distributed over range of stations spanning many different configurations. In August 1980 the array was placed in a regular configuration, C array, for the first time. Re-configuration to A array then took place on October 25, 1980, initiating a sequence of reconfigurations approximately every 4 months so that a given configuration would cycle through all seasons over a four year period. For the first year all observing stopped while a "rapid" reconfiguration was performed working long hours partially at night. By 1981 the pattern was changed to a slower reconfiguration while continuing observing using those antennas which had not yet been moved or had already been moved and brought back up. During these periods astronomical projects not requiring a specific configuration (such as point source detection) were scheduled. Until January 1983 the sequence of configurations was A→B→D→C. At this time we recognized the advantage of the hybrid configurations with the north arm in the configuration one step larger to compensate for the projection when observing southern sources. In order to obtain all three hybrid configurations, A/B, B/C, C/D, the configuration sequence was changed to A→B→C→D.

By now array reconfigurations have become routine, the 500th antenna move took place on the 5 November 1984. And by mid 1988, 766 antenna moves had been successfully completed. Appendix X gives the VLA reconfiguration history.

11.2. Derailment

On 29 October 1982 transporter No. 2 was engaged in the task of relocating antenna 20 from BN3 to DN1. While on the east arm and in the horizontal turn approaching the "D-l Spur" the transporter derailed and substantial damage was done to the trackage. The transporter was unharmed.

From W. del Giudice, November 18, 1982

Further details of the derailment can be found in the following memos: "Investigation of the derailment of transporter #2 and antenna #20 on October 29, 1982", Les Temple, November 16, 1982; Memo 2, M. S. Roberts, from R. D. Ekers, "VLA Transporter Derailment" November 24, 1982; memo from R. Dorr to R. Ekers "Safety Aspects of Transporter Derailment" and memo from F. Wells to R. Ekers, January 6, 1983, "Derailment".

11.3. Cable Faults

The electrical power distribution system has presented major maintenance problems that could not have been anticipated at the time of construction and, has caught the entire power industry by surprise. The VLA power distribution system incorporates buried cable of the type that was highly recommended when installed but is now known to deteriorate on a time scale of about 10 years! A proposal to replace this cable was submitted to NSF in March in 1987 "Major Maintenance Program - Very Large Array Track and Power Systems" at a total cost of $1.35M. The seriousness of this situation for a time critical mission was recognized by a Voyager-Neptune review committee and as a result repair of that part of the cable used for the C and D encounter configurations was funded by NASA.

11.4. Rail Track

After nearly a decade of successful operation much of the VLA track system is 10 years old and at the point where maintenance needs are increasing. The maintenance needs are larger than anticipated due to the unexpected rapid deterioration of some rail ties. The VLA track system was constructed entirely of used material and ties that came from humid parts of the country are splitting and rotting in dry conditions of New Mexico. In March, 1987 a report was presented to NSF requesting funding for the cost and repair ($3M) and for the cost to maintain ($0.25M per year) the Very Large Array Track and Power Systems.

FIGURES

APPENDICES

APPENDIX I **CHRONOLOGICAL HISTORY OF VLA SINCE 1980**

1980	January	First application of adaptive calibration to VLA images.
1980	January	Reduce VLA observing to 50% because of computer bottleneck.
1980	February	Final increment of funds received by NSF to complete VLA construction.
1980	August	VLA first used as part of VLBI network.
1980	September	Last VLA antenna declared operational.
1980	October	VLA formally dedicated, attended by 600 guests and staff members.
1980	October	VLA open house, attended by 2,000 visitors.
1980	December	Final VLA computer construction budget increased to $6.5M.
1980	December	VAX 11/780 moved to VLA site.
1980	December	Completion of VLA construction project.
1981	January	VLBI/VLA VAX 11/780 delivered in Charlottesville.
1981	January	All 27 antennas working in the A configuration for the first time.
1981	February	VLA first used in VLBI MKII observations.
1981	March	DEC10/KI upgraded to DEClO/KL.
1981	April	Acquire second VAX 11/780 with AP at VLA.
1981	April	First Solar Observation.
1981	April	Transition to full time observing.
1981	June	Start 2nd Master L.O. System.
1981	August	VLA first used in VLBI MKIII observations.
1981	August	First image of a planet (Saturn).
1982	March	NRAO Computer Advisory Committee meets at VLA.
1982	June	First Synthesis Mapping Workshop - Socorro 85 participants.
1982	June	Begin Retrofitting New Feed Focus and Rotation Mount.
1982	June	327 MHz Prototype Feed and Receiver.
1982	July	Start 15 GHz FET receiver upgrade.
1982	July	Start replacement of 1.5 GHz upconverter with FET.
1982	August	Dial up lines available for remote observing.

1982	October	Derailment of Antenna #20 on Transporter #2 while on the turn approaching the D-1 spur from the east arm.
1982	November	First use of maximum entropy deconvolution algorithm for VLA data.
1982	December	Commence antenna insulation to improve pointing.
1982	December	Plant Maintenance division merged with Antenna division to form E&S division.
1983	April	VLA Visitor Center Dedication
1983	June	Second set of IF bands turned on (continuum output x 2).
1983	June	Contract to replace 2,000 ties on East arm.
1983	September	NRAO study of VLA computing finds class VI supercomputer capacity needed.
1983	November	Acquisition of new 32-bit VLA on-line computers begun.
1983	November	Complete 15 GHz FET receiver upgrade.
1983	November	Finish replacement of 1.5 GHz upconverter with FET.
1984	April	Funding for construction of VLBA approved.
1984	May	Start 327 MHz Project.
1984	May	MGM Filming "2010".
1984	September	NRAO Computer Advisory Committee meets at Green Bank.
1984	December	Commence project to install 327 MHz receivers.
1985	January	Decision to build a combined VLA/VLBA Operations Center in Socorro.
1985	March	4096 x 4096 Cassiopea A image deconvolved on Digital Productions Cray X-MP using NSF supercomputer access program.
1985	March	Conceptual proposal to NSF - A Supercomputer for Radio Astronomical Imaging.
1985	March	NASA/NSF agree on management plan for support of Voyager 2 - Neptune encounter.
1985	May	First fringes at 8.7 GHz.
1985	August	Start upgrade of on-line system to 32 bit architecture.
1985	August	Second Synthesis Imaging Workshop.
1985	December	CONVEX C-1 mini-supercomputer delivered in Charlottesvill1e.
1985	December	First use of mosaicing algorithm on VLA data.

1986	February	First Jansky Lecture in New Mexico.
1986	April	First 327 MHz images.
1986	May	Image Storage and Display System for 512 pixel cubes operational at VLA.
1986	May	State approves funding for joint VLA, VLBA Operations Center (AOC) in Socorro.
1986	June	"Pipeline" in routine use for batch processing data cubes.
1986	August	Start installation of 23 GHz FET upgrade.
1986	August	Start replacement of 4.8 GHz paramps with FET receivers.
1986	December	Convex C-1 mini-supercomputer delivered at VLA.
1986	December	Back-up on-line computer for VLA acquired with NASA funding.
1987	January	VLBA Project Office moves to Socorro.
1987	March	Proposal to NSF for repair and maintenance of the VLA track and power distribution system.
1987	April	Complete antenna insulation.
1987	May	First bi-static radar experiment (Saturn's rings with Goldstone-VLA).
1987	June	AOC Groundbreaking
1987	July	Complete 2nd Master L.O. system.
1987	August	NRL Contract for 75 MHz System.
1987	September	Proposal to NSF - Array Telescope Computing Plan
1987	October	Elevation bearing fails on antenna 17.
1988	January	Switch-over to new VLA on-line computer system.
1988	January	8.7 GHz becomes most sensitive VLA system.

<u>APPENDIX II</u> DETAILED CHRONOLOGICAL HISTORY OF VLA COMPUTING SINCE 1972

1969	January	VLA Proposal Vol. III specifies computing for 27-antenna VLA. $3.2M budgeted.
1972	August	$4.5M budgeted for computing.
1974	January	CLEAN deconvolution algorithm published.
1974	June	DEC awarded subcontract for initial continuum off-line computer, DEC 10/KI.
1974	July	Modular Computer Systems (Modcomp) awarded subcontract for on-line computer; initially a network of 4, later 7, ModComp II minicomputers
1974	October	SAIL language chosen for analysis & imaging software.
1975	October	Begin development of CANDID control language for VLA off-line data processing.
1975	December	First 2D maximum entropy deconvolution algorithm published.
1975	December	IMPS image display system. PDP 11/40 + COMTEL.
1976	January	Computer budget increased to $5.5M. Programming group increased from 6 to 14.
1976	February	Contract with ERIM to design optical processor for VLA image generation.
1976	June	Off-line computer group and DEC-10 move from Charlottesville to the VLA.
1977	January	Further development of CANDID stopped.
1977	May	First VLA image of an extended source.
1977	July	EXPORT facility at VLA allows first off-site processing.
1977	September	Charlottesville IBM 360 programmed in PL-1 for VLA data calibration.
1977	December	Optical processor development abandoned for a pipelined network of PDP11's array processors and transpose memory - the VLA "Pipeline".
1978	March	Independent post processing group established in Charlottesville.
1979	January	Acquire Pipeline hardware.
1979	February	AIPS post-processing project begun in Charlottesville; code developed in ModComp with FPS120B AP.
1979	July	Self-calibration algorithm available in Charlottesville ModComp.
1979	December	Acquire VAX 11/780 in Charlottesville.
1980	January	Reduce VLA observing to 50% because of computer bottleneck.
1980	January	First application of adaptive calibration to VLA images.

1980	May	FPS AP-120B array processor added to VAX.
1980	May	Fourier transform based CLEAN deconvolution algorithm for large images.
1980	December	VAX 11/780 moved to VLA site.
1980	December	Final VLA computer construction budget increased to $6.5M.
1981	January	VLBI/VLA VAX 11/780 delivered in Charlottesville.
1981	March	DEC10/KI upgraded to DEC10/KL.
1981	April	Acquire second VAX 11/780 with AP at VLA.
1981	June	Start 2nd Master L.O. System.
1982	March	First UNIX implementation of AIPS exported from U. Texas.
1982	March	NRAO Computer Advisory Committee meets at VLA. "Need a long range plan based on astronomical requirements ... flexible and growable computer architecture ... should not depend on being at leading edge of computer technology ... requires a major new infusion of capital from NSF"
1982	November	First use of maximum entropy deconvolution algorithm for VLA data.
1983	January	Decision to include primary calibration in AIPS.
1983	June	Second set of IF bands turned on (continuum output x 2).
1983	July	Curtis report to NSF recommends greater use of supercomputers for academic reasearch.
1983	September	First wide-field imaging algorithm, MX, available in AIPS.
1983	September	NRAO study of VLA computing finds class VI supercomputer capacity needed.
1983	October	DEC abandons its DEC10 line of computers.
1983	October	Scientific Panel assesses NRAO's computing plans, concludes: "We are convinced of the need for computing capacity at least in the small supercomputer range ... the VLBA will add to this need".
1983	November	Acquisition of new 32-bit VLA on-line computers begun.
1984	July	Tests of VLA deconvolution using CRAY 1-S at Los Alamos National Laboratory.
1984	September	NRAO Computer Advisory Committee meets at Green Bank; endorses plan to acquire a supercomputer. "The most attractive option currently available and absolutely essential for the prosecution of the science".
1984	December	Proposal to NSF for 40 hours of Class VI computer time.

1985	March	Conceptual proposal to NSF – A Supercomputer for Radio Astronomical Imaging.
1985	March	4096 x 4096 Cassiopea A image deconvolved on Digital Productions Cray X-MP using NSF supercomputer access program.
1985	March	NASA/NSF agree on management plan for support of Voyager 2 – Neptune encounter.
1985	April	Proposal to NSF for 160 hours of Class VI computer time.
1985	June	IMPS upgraded from PDP 11/44 to VAX 11/750.
1985	August	Start upgrades of online system to 32 bit architecture.
1985	August	Second Synthesis Imaging Workshop.
1985	December	CONVEX C-1 mini-supercomputer delivered in Charlottesville.
1985	December	First use of mosaicing algorithm on VLA data.
1986	January	AIPS fully operational in Convex C-1 in Charlottesville.
1986	March	180,000: 1 dynamic range reached.
1986	April	First 327 MHz images.
1986	May	Image Storage and Display System for 512 pixel cubes operational at VLA.
1986	June	"Pipeline" in routine use for batch processing data cubes.
1986	December	Convex C-1 mini-supercomputer delivered at VLA.
1986	December	Back-up on-line computer for VLA acquired with NASA funding.
1987	January	AIPS fully operational in Convex C-1 at VLA.
1987	January	NRAO hosts workshops on Graphics Displays and AIPS on supercomputers.
1987	September	Proposal to NSF - Array Telescope Computing Plan
1988	January	Switch-over to new VLA on-line computer system.

APPENDIX IV **VLA DISCOVERIES - CHRONOLOGICAL**

1979: *Large scale bends in radio jet in 3C449*, Perley, Willis & Scott, Nature 281, 437 (1979)

1979: *Similarity between optical and radio jet in M87,* Owen, Hardee & Bignell, Ap.J. 239, L11 (1980)

1980: *Bright radio jet in the quasar 4C32.69*, Potash & Wardle, Ap.J. 239, 42 (1980)

1980: *High resolution image of quite sun from solar eclipse,* Marsh, Hurford & Zirin, Ap.J. 236, 1017 (1980)

1980: *Observations of evolving helical structures in SS433 provided direct measurement of proper motion velocity and distance*., Hjellming & Johnston, Ap.J. 246, 1141 (1981), ibid IAU Highlights (1983)

1980: *Prompt radio emission from extragalactic supernovae*, Weiler, Sramek & Panagia, Science 231, 1251 (1986)

1981: *Central spherical non-thermal source in M31*, Hjellming & Smarr, Ap.J. 257, 113 (1982)

1981: *Detection of Saturn's rings in emission and absorption*, de Pater and Dickel, Icarus 50, 88 (1982)

1981: *Extragalactic OH masers in M82*, Weliachev, Fomalont & Greisen, A&A *137*, 335 (1984)

1981: *Resolution of thermal emission from P Cygn.i First observation of size scale of ionized stellar wind and determination of wind temperature*. White & Becker, Ap.J. 262, 657 (1982)

1981: *Shell structure in lobes of the radio galaxy 3C310*, van Breugel & Fomalont, Ap.J. 282, 155 (1984)

1981: *Ubiquitousness of one sided quasar jet*, eg Bridle & Perley, Ann. Rev. Astron. Astrophys. 22, 319 (1984)

1982: *Detailed observations of the radio jet in NGC6251*, Perley, Bridle & Willis, Ap.J. supp 54, 291 (1984)

1982: *Detection of asteroids and measurement of diameter of Ceres*, Wade & Johnston

1982: *Discovery of ionized cavity in wind from Antares (alpha Scorpii)*, Hjellming & Newell, Ap.J. 275, 704 (1983)

1982: *Large Faraday rotation gradient in M84*, Laing & Bridle MNRAS (1987)

1982: *Plumes emanating from the nuclei of edge-on galaxies NGC3079*, Duric et al., *Various galaxies*, Hummel et al.

1982: *Radio emission from the magnetic cataclysmic variable AM Herc*, Dulk, Bastian & Chanmugam, Ap.J. 273, 249 (1983)

1982: *Resolution of the "knots" in the M87 jet* ,Biretta, Owen & Hardee Ap.J. 274, 127 (1983)

1982: *Spiral shaped features in thermal emission from galactic center*, Ekers, van Gorkom, Schwarz & Goss, A&A 122, 143 (1983)

1983: *"Shadow disk" in the central HII region of the bipolar nebula S106*, Bally, Snell & Predmore Ap.J. 272, 154 (1983)

1983: *Discovery of compact, short lived radio emission in sunspots*, Lang, Wilson & Gaizauskas, Ap.J. 267, 455 (1983)

1983: *Electron cyclotron maser discovered in UV Ceti B*, Gary, Linsky & Dulk, Ap.J. Lett 263, L79 (1983)

1983: *Filamentary lobe structure and jet discovered in Cygnus A*, Perley, Dreher & Cowan Ap.J. 285, 135 (1984)

1983: *Interplanetary scintillation observations of solar wind velocity.* Scintillations in the radio emission from the quasar 3C279 have been used to measure the solar wind velocity within 3 solar radii of the solar limb. Unexpectedly rapid acceleration and extremely high, anisotropy was found. Coles et al., Conference proc, Kyoto (1984)

1983: *Population of variable radio sources in M82*, Kronberg & Sramek, Science 227, 28 (1985)

1983: *String of H2CO masers in Sgr B2*, Whiteoak & Gardner MNRAS 205, 27 (1983)

1984: *3C75 in Abell 400 is found to be a binary jet radio galaxy*. Owen, O'Dea, Inoue & Eilek, Ap.J. 294, 185 (1985)

1984: *Bubbles of non-thermal emission near the nucleus of M51*. Ford, Crane, Jacoby, Lawrie & van der Hulst, Ap.J. 293, 132 (1985)

1984: *HI distribution mapped in the elliptical galaxies NGC1052 & Cen A*, van Gorkom, Knapp, Raimond, Faber & Gallagher A.J., 91, 791 (1986); van Gorkom in IAU 127, ed de Zeeuw (1987)

1984: *Imaging of non-thermal shell surrounding the old nova GK Persei 1901 showed that nova shells can induce weaker equivalents of the emission common for supernova remnants*. Reynolds & Chevalier, Ap.J. 281, L33 (1984)

1984: *Large scale filamentary structure discovered in the Galactic center*, Yusef-Zadeh, Morris & Chance, Nature 310, 557 (1984)

1984*: New class of cone shaped non-thermal galactic radio sources*, Shaver et al Nature 313, 113 and Becker & Helfand, Nature 313, 115 (1985)

1984: *Radio continuum emission and central engine in Herbig-Haro 1 & 2*, Pravdo et a, Ap.J. 293, 135 (1985)

1984: *Resolution of gamma 2 Velorum ionized stellar wind confirms model*, Hogg in "Radio Stars", ed Hjellming & Gibson, p117 (1985)

1984: *Smoke rings in the radio galaxy Hercules A*, Dreher & Feigelson, Nature 308, 43 (1984)

1984: *Virgo cluster galaxies have small and deficient HI disks*, van Gorkom, Balkowski & Kotanyi, in "Clusters & Groups of Galaxies", ed Mardirossian, pp261 (1984)

1984: *FIR-radio correlation*, Dickey & Salpeter Astrophys. J 284, 461 (1984)

1985: *Angular expansion measured for Planetary Nebula NGC7027 When combined with radial velocity measurements this gives a direct determination of distance*. Masson, Ap.J. 302, 127 (1986)

1985: *Cas A Supernovae remnant 4k x4k image with 0.2" resolution*, produced on the Digital Productions Cray XMP supercomputer. Braun, Gull & Perley, Nature (1987)

1985: *Direct measurement of asymmetric expansion of radio flare in Cyg X-3 The strong outburst in Oct 85 was resolved by the VLA indicating expansion velocities of 0.1-0.3c*. Johnston

1985: *Evolution of the double radio lobes of Scorpius X-1*, Geldzahler & Fomalont, Ap.J. <u>311</u>, 85 (1986)

1985: *Expanding radio jet discovered in the symbiotic star CH Cygni Expansion velocity of 1100 km/s*. Seaquist & Taylor, Can.J.Phys. <u>64</u>, 520 (1986)

1985: *Faraday screen in front of Cygnus A*, Dreher, Carilli & Perley, Ap.J. <u>316</u>, 611 (1987)

1985: *Foreground objects depolarizing lobes of Fornax A*, Fomalont, Ebneter, van Breugel & Ekers, Astrophys. J. <u>346</u>, L17 (1989)

1985: *Large extension of HI arm in M51*, Rots, van der Hulst, Bosma, Crane, Athanasoula, Science <u>85</u> (Sep 1985)

1985: *Narrow band microwave emission from red dwarf star YZ Canis Minoris Narrow bandwidth and variability indicate a new class of coherent emission phenomena.* Lang & Wilson, Ap.J <u>302</u>, 117 (1986)

1985: *Second gravitational lens discovered (0023+171) VLA snap shot observations of 300' survey*. Hewett, Burke, Turner and Lawrence, BAAS <u>17</u>, 907 (1985).

1985: *Symmetric helical jet in 3C436*, Christiansen and Stocke, AC138

1986: *Detection of the intergalactic magnetic field in the Coma cluster*, Kim, Dewdney & Landecker in "Continuum Processes in Clusters of Galaxies" ed O'Dea & Uson (1987)

1986*: Discovery of a powerful (Type V?) radio supernova. in NGC891*, Rupen, Gunn, Knapp & van Gorkom, A.J. (1987)

1986: *Dynamic spectra of stellar microwave flares Indicates plasma emission process from regions that are rapidly changing their density environment as they move up through the atmosphere*. Bastian & Bookbinder, Nature <u>326</u>, 678 (1987)

1986: *Fast pulsar candidate found in the globular cluster M28*, Erickson, Mahoney, Becker & Helfand

1986: *HI shell around alpha Ori*, Bowers & Knapp BAAS, <u>18</u>, 954 (1986)

1986: *Hot spot in Pictor A coincident with polarized optical emission*, Perley & Roeser, BAAS <u>18</u>, 1005 (1987)

1986: *Large HI extent of Mark 348*, Simkin, van Gorkom & Su Hong Jun, Science <u>235</u>, 1367 (1987)

1986: *Linear polarization measured in the rings of Saturn*, Muhleman, Benge & Grossman

1986: *OH emission structure in the coma of Halley's Comet*, de Pater, Palmer & Snyder, Ap.J. <u>304</u>, 133 (1986)

1986: *Oscillation in the three arm spiral feature in Sgr A west*, Yusef-Zadeh & Morris, in Townes Symposium, Oct 1986.

1986: *Proper motion measurements on Galactic center point source*, Backer and Sramek, in Townes Symposium, Oct 1986.

1986: *Refractive interstellar scintillation in 1741-038*, Hjellming & Narayan, Ap.J. Lett

1986: *Rotation and collapse in core of the compact HII region G10.6-0.4. Velocity-spatial maps of the (1,1) NH3 inversion transition show redshifted absorption and rotation in the emission from the more extended envelope*. Ho & Haschick, Ap.J. 304, 50l (1986)

1986: *Second binary jet radio galaxy discovered. PKS2149-158*, Cameron, Parma & de Ruiter

1987: 3C326.1 identified with a protogalaxy at large distance. The high redshift VLA image of 3C326.1 lead to the identification of a possible protogalaxy at a redshift of 1.8. McCarthy, Spinrad, Djorgovski, Strauss, van Breugel & Lieber, Ap.J. Lett (1987)

1987: *Gigantic HI plume and expanding bubble connected to Arp 143*. Appleton, Ghigo, van Gorkom, & Schombert Struck-Marcell, Nature 330, 140 (1987)

1987: *Large He abundance gradients in HII regions*. Gardiner, Coss, Pankonin & Roelfsema, AA 175, 219 (1987)

1987: *Radar echo detected from Saturn's rings*. Muhleman, Grossman & Goldstein, BAAS 19, 882 (1987)

APPENDIX V **VLA DISCOVERIES BY SUBJECT**

Solar System

1980: *High resolution image of quite sun from solar eclipse*, Marsh, Hurford & Zirin, Ap.J. 236, 1017 (1980)

1981: *Detection of Saturn's rings in emission and absorption*, de Pater and Dickel, Icarus 50, 88 (1982)

1982: *Detection of asteroids and measurement of diameter of Ceres*, Wade & Johnston

1983: *Discovery of compact, short lived radio emission in sunspots*, Lang, Wilson & Gaizauskas, Ap.J. 267, 455 (1983)

1983: *Interplanetary scintillation observations of solar wind velocity Scintillations in the radio emission from the quasar 3C279 have been used to measure the solar wind velocity within 3 solar radii of the solar limb. Unexpectedly rapid acceleration and extremely high anisotropy was found*. Coles et al., Conference proc, Kyoto (1984)

1986: *Linear polarization measured in the rings of Saturn*, Muhleman, Benge & Grossman

1986: *OH emission structure in the coma of Halleys Comet*, Pater, Palmer & Snyder, Ap.J. 304, 133 (1986)

1987: *Radar echo detected from Saturns rings*. Muhleman, Grossman & Goldstein, BAAS 19, 882 (1987)

Stars

1980: *Observations of evolving helical structures in SS433 provided direct measurement of proper motion velocity and distance*. Hjellming & Johnston, Ap.J. 246, 1141 (1981), -ibid IAU Highlights (1983)

1981: *Resolution of thermal emission from P Cygni. First observation of size scale of ionized stellar wind and determination of wind temperature*. White & Becker, Ap.J. 262, 657 (1982)

1982: *Discovery of ionized cavity in wind from Antares (alpha Scorpii).* Hjellming & Newell, Ap.J. 275, 704 (1983)

1982: *Radio emission from the magnetic cataclysmic variable AM Herc*. Dulk, Bastian & Chanmugam, Ap.J. 273, 249 (1983)

1983: *"Shadow disk" in the central HII region of the bipolar nebula S106*. Bally, Snell & Predmore, Ap.J. 272, 154 (1983)

1983: *Electron cyclotron maser discovered in UV Ceti B*. Gary, Linsky & Dulk, Ap.J. Lett. 263, L79 (1983)

1984: *Resolution of gamma 2 Velorum ionized stellar wind confirms model,* Hogg in "Radio Stars", ed Hjellming & Gibson, 117 (1985)

1984: *Imaging of non-thermal shell surrounding the old nova GK Persei 1901 showed that nova shells can induce weaker equivalents of the emission common for supernova remnants*. Reynolds & Chevalier, Ap.J. 281, L33 (1984)

1984: *Radio continuum emission and central engine in Herbig-Haro 1 & 2*. Pravdo et al, Ap.J. 293, 135 (1985)

1985: *Evolution of the double radio lobes of Scorpius X-1*, Geldzahler & Fomalont, Ap.J. 311, 85 (1986)

1985: *Expanding radio jet discovered in the symbiotic star CH Cygni Expansion velocity of 1100 km/s*. Seaquist & Taylor, Can.J.Phys. 64, 520 (1986)

1985: *Narrow band microwave emission from red dwarf star YZ Canis Minoris Narrow bandwidth and variability indicate a new class of coherent emission phenomena*. Lang & Wilson, Ap.J. 302, 117 (1986)

1985: *Direct measurement of asymmetric expansion of radio flare in Cyg X-3. The strong outburst in Oct 85 was resolved by the VLA indicating expansion velocities of 0.1-0.3c*. Johnston

1986: *Dynamic spectra of stellar microwave flares Indicates plasma emission process from regions that are rapidly changing their density environment as they move up through the atmosphere*. Bastian & Bookbinder, Nature 326, 678 (1987)

1986: *Rotation and collapse in core of the compact HII region G10.6-0.4. Velocity-spatial maps of the (1,1) NH_3 inversion transition show redshifted absorption and rotation in the emission from the more extended envelope*, Ho & Haschick, Ap.J. 304, 50l (1986)

1986: *Fast pulsar candidate found in the globular cluster M28*. Erickson, Mahoney, Becker & Helfand

Interstellar Medium

1983: *String of H2CO masers in Sgr B2*, Whiteoak & Gardner, MNRAS 205, 27p (1983)

1984: *New class of cone shaped non-thermal galactic radio sources*, Shaver et al, Nature, 313, 113 and Becker & Helfand, Nature 313, ll5(1985)

1985: *Angular expansion measured for Planetary Nebula NGC7027 When combined with radial velocity measurements this gives a direct determination of distance*. Masson, Ap.J. 302, 127 (1986)

1986: *HI shell around alpha Ori*, Bowers & Knapp, BAAS 18, 954 (1986)

1986: *Refractive interstellar scintillation in 1741-038*, Hjellming & Narayan, Ap.J. Lett

1987: *Large He abundance gradients in HII regions.* Gardiner, Goss, Pankonin & Roelfsema, AA 175, 219 (1987)

Supernovae

1980: *Prompt radio emission from extragalactic supernovae*. Weiler, Sramek & Panagia, Science 231, 1251 (1986)

1985: *Cas A Supernovae remnant. 4k x 4k image with 0.2" resolution*, produced on the Digital Productions Cray XMP supercomputer. Braun, Gull & Perley, Nature (1987)

1986: *Discovery of a powerful (Type V?) radio supernova, in NGC891*. Rupen, Gunn, Knapp & van Gorkom, A.J. (1987)

Galactic center

1982: *Spiral shaped features in thermal emission from galactic center*. Ekers, van Gorkom, Schwarz & Goss, A&A 122, l43 (1983)

1984: *Large scale filamentary structure discovered in the Galactic center*. Yusef-Zadeh, Morris & Chance, Nature 310, 557 (1984)

1986: *Oscillation in the three arm spiral feature in Sgr A west*. Yusef-Zadeh & Morris, in Townes Symposium, Oct 1986.

1986: *Proper motion measurements on Galactic center point source.* Backer and Sramek, Townes Symposium, Oct 1986.

Normal Galaxies

1981: *Central spherical non-thermal source in M31*. Hjellming & Smarr, Ap.J. 257, 113 (1982)

1981: *Extragalactic OH masers in M82*. Weliachev, Fomalont & Greisen, A&A 137, 335 (1984)

1982: *Plumes emanating from the nuclei of edge-on galaxies NGC3079*. Duric et al., *Various galaxies,* Hummel et al.

1983: *Population of varaible radio sources in M82*. Kronberg & Sramek, Science 227, 28 (1985)

1984: *Bubbles of non-thermal emission near the nucleus of M51*. Ford, Crane, Jacoby, Lawrie & van der Hulst, Ap.J. 293, 132 (1985)

1984: *HI distribution mapped in the elliptical galaxies NGC1052 & CenA*, van Gorkom, Knapp, Raimond, Faber & Gallagher, A.J. 91, 791 (1986) and van Gorkom in IAU 127, ed de Zeeuw (1987)

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1984: *FIR-radio correlation,* Dickey & Salpeter Astrophys. J 284, 461 (1984)

1985: *Foreground objects depolarizing lobes of Fornax A,* Fomalont, Ebneter, van Breugel & Ekers, Astrophys. J. 346, L17 (1989)

1985: *Large extension of HI arm in M51*. Rots, van der Hulst, Bosma, Crane, Athanasoula, Science 85 (Sep 1985)

1986: *Large HI extent of Mark 348*. Simkin, van Gorkom & Su Hong Jun, Science 235, 1367 (1987)

1987: *Gigantic HI plume and expanding bubble connected to Arp 143*. Appleton, Ghigo, van Gorkom, & Schombert Struck-Marcell, Nature 330, 140 (1987)

Radio Galaxies and Quasars

1979: *Large scale bends in radio jet in 3C449*. Perley, Willis & Scott, Nature 281, 437 (1979)

1979: *Similarity between optical and radio jet in M87*. Owen, Hardee & Bignell, Ap.J. 239, L11 (1980)

1980: *Bright radio jet in the quasar 4C32.69*. Potash & Wardle, Ap.J. 239, 42 (1980)

1981: *Shell structure in lobes of the radio galaxy 3C310*. van Breugel & Fomalont, Ap.J. 282, 155 (1984)

1981: *Ubiquitousness of one sided quasar jets*. eg Bridle & Perley, Ann. Rev. Astron. Astrophys. 22, 319 (1984)

1982: *Detailed observations of the radio jet in NGC6251*. Perley, Bridle & Willis, Ap.J.supp 54, 291 (1984)

1982: *Large Faraday rotation gradient in M84*. Laing & Bridle, MNRAS (1987)

1982: *Resolution of the "knots" in the M87 jet*. Biretta, Owen & Hardee, Ap.J. 274, 127 (1983)

1983: *Filamentary lobe structure and jet discovered in Cygnus A*. Perley, Dreher & Cowan, Ap.J. 285, 135 (1984)

1984: *3C75 in Abell 400 is found to be a binary jet radio galaxy*. Owen, O'Dea, Inoue & Eilek, Ap.J. 294, 185 (1985)

1984: *Smoke rings in the radio galaxy Hercules A*. Dreher & Feigelson, Nature 308, 43 (1984)

1985: *Faraday screen in front of Cygnus A*. Dreher, Carilli & Perley, Ap.J. 316, 611 (1987)

1985: *Second gravitational lens discovered (0023+171).* VLA snap shot observations of 300' survey. Hewett, Burke, Turner and Lawrence, BAAS 17, 907 (1985).

1985: *Symmetric helical jet in 3C436*. Christiansen and Stock, AC138

1986: *Detection of the intergalactic magnetic field in the Coma cluster*. Kim, Dewdney & Landecker in "Continuum Processes in Clusters of Galaxies" ed O'Dea & Uson (1987)

1986: *Hot spot in Pictor A coincident with polarized optical emission*. Perley & Roeser, BAAS 18, l005 (1987)

1986: *Second binary jet radio galaxy discovered. PKS2149-158*. Cameron, Parma & de Ruiter (in preparation)

1987: *3C326.1 identified with a protogalaxy at large distance. The high redshift VLA image of 3C326.1 lead to the identification of a possible protogalaxy at a redshift of 1.8*. McCarthy, Spinrad, Djorgovski, Strauss, van Breugel & Liebert, Ap.J.Lett (1987); Ap.J. 319, L39 (1987)

APPENDIX VI OBSERVERS FROM INTERNATIONAL INSTITUTIONS DURING 1986 AND 1987

Institution	1986	1987
Anglo-Australian Observatory, AUSTRALIA	1	1
Arcetri Observatory, ITALY	12	1
Australian National University, AUSTRALIA	1	
Barcelona, SPAIN		1
Bologna, ITALY	30	52
Bureau des Longitudes, FRANCE	5	
Byurakan Obs, USSR		1
CEN - Saclay, FRANCE		10
CNES, FRANCE		2
CRPE, FRANCE		1
CSIRO, AUSTRALIA	24	5
CTIO, CHILE		1
Cambridge University, ENGLAND	8	4
Catania Univ, ITALY	2	3
Copernicus Univ., POLAND	1	
DAO, CANADA		2
DRAO, CANADA	3	4
David Dunlap Observatory, CANADA	1	1
Delft University, NETHERLANDS		3
ENS, Paris, FRANCE	2	1
ESA/ESTEC, NETHERLANDS	3	4
ESO - CHILE		3
ESO - FRG	19	4
ETH, NETHERLANDS		4
Hamburger Sternwarte, FRG	8	9
Hartebeesthock, S.AFRICA	1	2
Herzberg Institute of Astrophysics, CANADA	3	4
IAC, Tenerife, SPAIN	2	2
IAP, ARGENTINA	1	2
IAP, Paris, FRANCE	6	1
IAR, ARGENTINA	1	2
IAS, ITALY	2	3
IGN, Paris, FRANCE		2
IRAM, Granada, SPAIN	2	4
IRAM, Grenoble, SPAIN	6	
Imperial College, London, ENGLAND	4	
Institute of Astronomy Andalucia, SPAIN		3
Jagellonian Univ, POLAND	1	
Krakow Univ, POLAND		4
LSR - Utrecht, NETHERLANDS	2	1
Lancashire Polytechnic, ENGLAND	3	5
Leiden Univ, NETHERLANDS	11	12
Leige, BELGIUM		5
MPI, Heidelberg, FRG	5	11
MPI, Lindau, FRG	2	
MPIR, Bonn, FRG	58	62
MPIR, Garching bei Munchen, FRG		1
MRAO, ENGLAND	7	14
Macquarie Univ, AUSTRALIA	1	
Milano (IFC), ITALY	1	
Monash Univ, AUSTRALIA	1	
Mt Stromlo, AUSTRALIA	5	12

Mullard Space Science Lab, ENGLAND		2
NFRA, NETHERLANDS	31	41
NRAL, ENGLAND	76	41
NRC, CANADA	3	2
Nanjing Obs, CHINA		I
Nobeyama Radio Observatory, JAPAN	4	8
Observatoire de Marseille, FRANCE	5	5
Observatoire de Paris (Meudon), FRANCE	9	14
Onsala Space Observatory, SWEDEN	5	7
Peking Observatory (Beijing), CHINA		3
Queen Mary College, ENGLAND	8	8
Queen's University, CANADA	5	2
Raman Research Institute, INDIA	2	4
Rikkyo University, JAPAN		1
Royal Greenwich Observatory, ENGLAND	8	11
Royal Observatory, SCOTLAND	23	10
SAAO, S.AFRICA	1	1
Space Research Institute, USSR	3	8
Stockholm Observatory, SWEDEN	9	2
TIFR, INDIA	30	13
Turku University, FINLAND	1	1
Thessaloniki, GREECE	1	2
Tokyo Observatory, JAPAN	2	
Torino, ITALY		3
Trieste, ITALY		2
UNAM, MEXICO	24	22
University of Birmingham, ENGLAND	2	
University Bonn, FRG	5	1
University of British Columbia, CANADA	5	6
University of Calgary, CANADA	7	5
University College, London, ENGLAND	1	1
University of Durham, ENGLAND		1
University of Edinburg, SCOTLAND	2	
University of Glasgow, SCOTLAND	1	
University Gottingen, NETHERLANDS	3	
University Groningen (Kapteyn Lab), NETHERLANDS	34	15
University of Keele, ENGLAND	4	
University of Kent, ENGLAND	6	6
Universite Laval, CANADA	2	1
University of Leicester, ENGLAND	9	5
University of Manchester, ENGLAND	4	
University of Montreal, CANADA	2	
University of Nigeria, NIGERIA		1
University of Sydney, AUSTRALIA	1	1
University of Toronto, CANADA	41	35
University of Victoria, CANADA		4
Utsunomia University, JAPAN		4
Waterloo University, CANADA		5
Wise Observatory, ISRAEL	2	

APPENDIX VII **OBSERVERS FROM U.S. INSTITUTIONS DURING 1986 AND 1987**

Institution	1986	1987
Am. Institute of Physics		1
Arecibo Obs	3	1
Bell Labs	9	6
Bently College		3
Boston Univ.	3	6
Brandeis	14	8
Caltech	95	60
Carlton College		2
Columbia Univ.	22	5
Computer Science Corp.	1	
Computer Technology Assoc.		1
Cornell Univ.	14	22
Dartmouth College	3	2
DTM Corporation		1
George Mason University	1	4
Georgia State University	1	2
Goddard Institute of Space Studies	2	
Harvard University	4	26
CFA	59	56
SAO	3	7
Haverford College	2	2
Haystack Observatory	11	20
Institute for Advanced Studies		1
Interferometrics, Inc.		3
Iowa State University	2	2
Jet Propulsion Laboratory	19	41
Johns Hopkins University (separate from STScI)	3	5
La Plata Jr. High School		4
Lafayette College	1	
Lick Observatory		1
Lockheed - SMM/XRP		2
Los Alamos National Laboratories	5	6
Louisiana State University		2
Lowell Observatory		1
MIT	37	33
MIT - Lincoln Labs (Socorro)		3
Mt Wilson & Las Campanas Observatory	4	3
NASA/Goddard Space Flight Center (& SASC Tech.)	21	47
NSF		2
New Mexico Inst. of Mining & Technology	20	11
National Center for Atmospheric Research		2
National Optical Astronomy Observatories	8	3
National Solar Observatory		2
Naval Research Labs	72	61
New Mexico State University	1	1
North Carolina State University		1
Northeastern University	2	1
Ohio State University	I	
Oklahoma State University		2
Pennsylvania State University	13	15
Princeton University	22	22
Renssalaaer Polytechnic Institute	3	3
Rice University		1
Rutgers University	4	1

Space Telescope Science Institute	49	47
Stanford University		1
Steward Observatory	10	7
SUNY - Stony Brook	3	5
Tufts University	20	18
U S Naval Observatory	12	11
University of Alabama	1	
University of Arizona	3	
University of California, Berkeley	62	51
University of California, Davis	18	10
University of California, Los Angeles	9	16
University of California, San Diego	2	1
University of California, Santa Cruz		1
University of Chicago	5	7
University of Colorado	49	66
University of Florida	8	5
University of Hawaii	6	10
University of Illinois	12	19
University of Indiana		1
University of Iowa	22	22
University of Kentucky	1	4
University of Maryland	42	39
University of Massachusetts	6	12
University of Michigan	5	18
University of Minnesota	30	14
University of Missouri		4
University of New Mexico	22	23
University of North Carolina	7	2
University of Oklahoma	12	
University of Oregon	3	4
University of Pennsylvania		1
University of Pittsburg	4	4
University of Puerto Rico	3	1
University of Rochester		6
University of Texas	6	13
University of Toledo	3	
University of Virginia	7	8
University of Washington	2	
University of Wisconsin	8	3
Virginia Polytechnic Inst. & State Univ	6	2
Wellsley College		2
Williams College		1
Yale University		1

APPENDIX VIII **POPULAR ARTICLES**

Magazine	Date	Author	Article
OMNI		Judith Bell	Sun Dancing Earth
Science			A $76 Million Eye on the Sky
Rocky Mtn. Magazine			Cognoscenti Eye, a Monumental Desert Telescope. VLA Art
Community Profile		Jean Gruss	Only a Small Step from 21st Century
Eng. News Record	02/03/72		Radio Telescope Cluster will be World's Largest
ENR	12/21/72		Largest Rotating Telescope to have 375ft Dish
Reader's Digest	05/01/73	James R. Miller	The Speeded-up Search for Life in Space
NM Professional Eng.	02/01/74	Raymond R. Gibson	World's Largest RadioTelescope "The VLA"
Machine Design	05/01/74	Robert B. Aronson	New Windows to the Universe
New Mexico Progress	07/01/74		Very Large Array, World's Largest Telescope Project
Microwaves	07/01/74	Richard T. Davis	World's Largest Radio Telescope Being Developed
Science News	08/01/74	Kendrick Frazier	Future World Center of Radio Astronomy
Colorado Business	10/01/74	Anne Feeney	A $76 Million Eye on the Sky
Sky & Telescope	12/01/74 J	John W. Findlay, D. Milon	The National Radio Astronomy Observatory
ENR	01/09/75		Giant Antenna takes Shape in Desert
Sky & Telescope	06/01/75	David S. Heeschen	The Very Large Array
M Professional Eng.	01/01/76	Raymond R. Gibson	The Very Large Array Radio Telescope
Physics Today	02/01/76	Harold L. Davis	Progress Report on the VLA: Good, a New Nat Lab
Sky & Telescope	11/01/76		The VLA Takes Shape
Sandia Lab News	01/28/77		World's Largest Radio Telescope Under Construction near Socorro
Microwave Journal	03/01/77	S. Weinreb, et al.	Waveguide System for Very Large Antenna Array

Popular Science	03/01/77	Ray Nelson	27 Movable Dishes. World's Largest Radio Telescope
Der Spiegel	03/29/77		Kosmische Wanze
Ham Radio Horizons	05/01/77	John J. Ronan	An Oracle Comes of Age: The NRAO
New Mexico Magazine	05/01/77	Ray Nelson	Caution: Radio Telescope Crossing!
UMSCHAU	06-/01/77	Axel Wittmann	Neve FroBteleskope fur di Radioastronomie
The Observer	12/01/77	Tom Cole	VLA Golf
Smithsonian	07/01/78	John Neary	Huge New Radio Telescope Array Extends Celestial Vision
Sky & Telescope	09/01/78	Hjellming, Bignell, Balick	Mapping Planetary Nebulae with the VLA
Sky & Telescope	01/01/79	Henk Pander	An Artist's Astronomical Odyssey
Time	10/01/79		The Mysterious Celestial Twins
Astronomia	06/01/80	Giuseppe Gavazzi	L'Orecchio di Socorro
El Palacio	06/01/80	Robert M. Hjellming	The Very Large Array: Frontier of Radio Astronomy
New Mexico Magazine	02/01/81	Virginia Johnson	San Antonio's Owl Bar - Does it Serve World's Best Burger
New Mexico Magazine	04/01/81	Margaret Erhart	Passing Through Pie Town
iberica	06/01/81	Pascual Bolufer	Very Large Array y la Nueva etapaa de la radioastronomi
Empire	12/01/81	Howard M. Kaplin	Ear to the Heavens
Computer	01/01/82		Radio Telesc., Comp. Join in Space Signal Res.
Science Digest	03/01/82	Patrick Huyghe	The Mysterious Fountains of Space
Chicago Tribune	03/01/82	Casey Burko	The Music of the Stars
Discover	03/01/82	Dennis Overbye	Is Anyone Out There?
Science	06/01/82	R.M.Hjellming, R.C. Bignell	Radio Astronomy with the Very Large Array
Sky & Telescope	07/01/82	M. R. Kundu	Probing the Radio Sun
Continental Air-Extr	07/01/82	Casey Bukro	When the Universe Talks, America Listens

Report	07/01/82	Jack Lancaster	Very Large Array. Completion Report
Famiglia Cristiana	09/01/82	Ida Molinari	Quella Nota Che Vieiie Dall' infinito
Newton Graphic Science	12/01/82		VLA
Orion	02/01/83	A. Tarnutzer	Das Very Large Array (VLA)
Rainbow	04/01/83	Vera Foss Bradshaw	Lighthouse of the Sky
Model Railroad	04/01/83	Paul S. Riehle	The VLA CI RR Complex
National Geographic	06/01/83	Rick Gore	The Once and Future Universe
Astronomia	08/01/83	Marcello Felli	Osservando S106 Con il Very Large Array
Telegram	09/01/83	Godfrey Anderson	Sounds out of Space
Millimeter Waves	01/01/84	P. G. Mezger	Radio Astronomy Looks at Higher Frequencies
New Mexico Magazine	04/01/84	Mary Carroll Nelson	The Lightning Field
Digital Designs	05/01/84	Andrea M. Coville	Modular Architectures May be the Next Array. Proc.Design
Forskning och Framst	06/01/84	AAGE Sandquist	VARNYA Vintergata
Science	07/01/84	Marcia Bartusiak	Very Large Astronomy
New Mexico Magazine	08/01/84	Renee Rubin	The Eagle Guest Ranch - an Old Steakhouse in Cattle Country
New Mexico Magazine	10/01/84	Michael Zeilik	The VLA: Probing the Cosmos from Plains of San Augustin
OMNI	10/01/84	George Lake	Giants and Dwarfs Stars
Sky & Telescope	12/01/84	Jack 0. Burns	Dark Matter in the Universe
Invention & Technology	06/01/85	Richard Rhodes	Reflected Glory: How They Built Polomar
Sterne und Weltraum	03/01/85	K.Hummel, Roland, Ghave	Das Galakktische Zentrum: der uns nachste aktive galakt
Pipeliner	09/01/85		Eavesdropping on Distant Galaxies
l'Astronomie	11/01/85	Thierry Montmerle	Le Plus Grand Radio Telescope du Monde: le "VLA"
Ford Times	05/01/86	James Joseph	Tuning in on Space

Popular Communication	05/01/86	Christopher Bleeker	The New Magnavox D-2999/17 "World Receiver"
New Mexico Magazine	11/01/86	Nicole Plett	Alamo Navajos Rediscover Their Heritage
Hardcopy	12/01/86	Michael T. Peterson	VAX Systems Front End Cray, Supercomputers for Sci.App.
Science News	12/01/86	Kendrick Frazier	Off Beat Visit to the VLA: Rising from Ranchland
New Mexico Magazine	02/01/87	Bob Hogan	West Mesa Petroglyphs decisions must be made soon
Astronomy	08/01/87	Lys Ann Shore	The Telescope That Never Sleeps
NM Business Journal	10/01/87	Jean Gruss	Reaching for the Stars
National Geographic	11/01/87	Bart McDowell	New Mexico, Between Frontier and Future
Scientific Americati	01/01/88	K.Kellerman, A.R. Thompson	The Very-Long-Baseline-Array
Eastern Review	01/01/88	Shawna Vogel	E. T., Phone NASA
Astronomy	05/01/88	K. Weiler, et al.	Radio Astronomy Looks to Space
Time-Life			"Computers and the Cosmos"
Supernet	Spring, 1986	R.D. Ekers, P. Vanden Bout	"Supercomputers for Radio Astronomy"
Cray Channels			
Scientific American		Blanford	

<u>APPENDIX IX</u> **FILMING SUMMARY**

Ms. Susan Bartlett
Room 531
Audio-Visual Officer
Communications Resource Branch
National Science Foundation
1800 G Street. NW
Washington, D.C. 200550
Telephone 202-357-9776

Mr. Teruo Urabe
General Manager
Imex International
340 South Kenmore Avenue, #206
Los Angeles, California 90020
Telephone 213-384-8455

Mr. Richard J. Skaggs
President/Producer
Omstar Productions
1714 N. Ivar, gorth Wing
Hollywood, California 90028
Telephone 213-464-6699

Dick Young Productions, Ltd.
118 Riverside Drive
New York, New York 10024

KCET
4401 Sunset Boulevard
Los Angeles, California 90027
Telephone 213-666-6500
(worked on Dr. Sagan's Cosmos
Project)

Mr. Alec Nisbett
BBC-TV
Horizon
Kennington House
Richmond Way
London W14 OAX England
(In association with NOVA & WGBU
in Boston, MA)

KAET (PBS) 12-18-85
Phoenix, Arizona

NSF Movie
"The Observatories"
1. KPNO
2. Sac Peak
3. Green Bank
4. Arecibo, PR
5. VLA
6. CTIO CHILE (look into

KOB-TV4
4 Broadcast Plaza or
Box 1351
Albuquerque, NM 87125
Paula Maes
Public Affairs Dir.
(505)243-4411

KGGM-TV13
1414 Coal SW
Albuquerque, NM 87104
Jeanne Wayland
Public Affairs Dir.
(505)243-2285

KNME-TV5
Illustrated Daily
1130 University Blvd.
Albuquerque, NM 87106
Hal V. Rhodes
Public Affairs Dir.
(505)277-2121

KOOL-TV
511 West Adams
Phoenix, Arizona 85003
Karen Keene

KPIX-TV (20:00 min. Dub)
San Francisco, California

CNN News
Science Editor
News Story 4/18/85
Charles Crawford

KATSU Enterprises Inc.
842 So. Citrus Ave.
Los Angeles, Calif. 90036
(213)937-5702
Masahiko Wada

Belgian National TV
"The Magic of the Image"
Coordinator Lenore Malin
United States Information Agency
601D Street N.W.
Washington, D.C. 20547
(202)-376-7735
(Documentary including image
formation by synthesis
telescopes)

Newton's Apple
KTCA-TV (PBS)
1640 COMO Ave.
St. Paul, Minn 55108
(612)646-4611
Emily Goldberg

The Moving Picture Co.
"The Planets"
Channel 4 London,-
HENCOUP ENTERPRISES,
55 Colomb St.
Greenwich
London SE 10 9E2
Heather Couper

Australian Broadcasting
Commission
"Toward 2000"
145-149 Elizabeth St.
Sydney, G. P. 0. Box 487
Australia
Ian Finlay

"Beyond 2000"
P. 0. Box 505 Australia
Epping, 2121 NSW Australia
Ph. Natl. (02) 8697333
Intl. (612) 8697333
Telex:AA176611 Beyond
Contact: Cherry Manfield

MGM Productions
"2010"
Mr. Jonathan A. Zimbert
Associate Producer
10202 W. Washington Blv.
Culver City, CA 90230

WQED
"Infinite Voyage"
Metropolitan Pittsburgh Public
Broadcasting In.
3171 Los Feliz Boulevard
Los Angeles, CA 90039
Steve Eder/Producer
(213)667-1400
April 1987

APPENDIX X **VLA Configurations**

YEAR	MOVE DATES	ARRAY	FROM / TO
1980	2 Jul - 10 Jul	C	10 Jul / 13 Oct
1980/1981	13 Oct - 22 Oct	A	22 Nov / 27 Apr
1981	27 Apr - 6 May	B	06 May / 17 Aug
1981	17 Aug - 20 Aug	B/D	20 Aug / 31 Aug
1981	31 Aug - 01 Dec	D	01 Sep / 05 Oct
1981	05 Oct - 06 Oct	D/C	06 Oct / 13 Oct
1981/1982	13 Oct - 15 Oct	C	15 Oct / 15 Jan
1982	25 Jan - 10 Feb	A	10 Feb / 28 Jun
1982	28 Jun - 15 Jul	B	15 Jul / 25 Oct
1982/1983	25 Oct - 03 Nov	D	03 Nov / 05 Jan
1983	05 Jan - 06 Jan	D/C	06 Jan / 18 Jan
1983	18 Jan - 19 Jan	C	19 Jan / 16 May
1983	16 May - 19 May	C/D	19 May / 31 May
1983	31 May - 03 Jun	D	03 Jun / 25 Jul
1983	25 Jul - 05 Aug	A	05 Aug / 28 Nov
1983	28 Nov - 07 Dec	A/B	07 Dec / 19 Dec
1983/1984	19 Dec - 30 Dec	B	30 Dec / 27 Feb
1984	27 Feb - 29 Feb	B/C	29 Feb / 03 Apr
1984	03 Apr - 04 Apr	C	04 Apr / 25 Jun
1984	25 Jun - 27 Jun	C/D	27 Jun / 23 Jul
1984	23 Jul - 24 Jul	D	24 Jul / 29 Oct
1984/1985	29 Oct - 16 Nov	A	16 Nov / 11 Mar
1985	11 Mar - 15 Mar	A/B	15 Mar / 08 Apr
1985	08 Apr - 10 Apr	B	10 Apr / 10 Jun
1985	10 Jun - 11 Jun	B/C	11 Jun / 08 Jul
1985	08 Jul - 09 Jul	C	09 Jul / 30 Sep
1985	30 Sep - 02 Oct	C/D	02 Oct / 04 Nov
1985/1986	04 Nov - 05 Nov	D	05 Nov / 03 Feb
1986	03 Feb - 14 Feb	A	14 Feb / 09 Jun
1986	09 Jun - 12 Jun	A/B	12 Jun / 08 Jul
1986	08 Jul - 10 Jul	B	10 Jul / 15 Sep
1986	15 Sep - 17 Sep	B/C	17 Sep / 20 Oct
1986/1987	20 Oct - 21 Oct	C	21 Oct / 21 Jan
1987	21 Jan - 22 Jan	C/D	22 Jan / 23 Feb
1987	23 Feb - 27 Feb	D	27 Feb / 09 Jun
1987	09 Jun - 23 Jun	A	23 Jun / 12 Oct
1987	12 Oct - 15 Oct	A/B	15 Oct / 09 Nov
1987/1988	09 Nov - 12 Nov	B	12 Nov / 02 Feb
1988	02 Feb - 06 Feb	B/C	06 Feb / 06 Mar
1988	01 Mar - 02 Mar	B	02 Mar / 23 May
1988	23 May - 26 May	C/D	26 May / 27 June*
1988	27 Jun - 28 Jun	D	28 Jun / 30 Oct

Variable configuration geometry due to cable replacement (see 11.3).