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A Discussion of the WSRT Experience with Applications to the VLA

R.M. Hjellming and N.R. Vandenberg

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1. Introduction

During Oct.-Nov. 1976 we independently visited the Netherlands to talk with and learn from the Dwingeloo-Westerbork-Leiden-Gronigen people associated with the construction, operation, and use of the Westerbork Synthesis Radio Telescope (WSRT). Our objective was to ascertain as much as possible about the past and present experience with the WSRT, with specific interest in discussing how their experiences, both good and bad, could be applied to the VLA. Because of our interests the areas most heavily covered were the data reduction problems and the astronomical use of the instrument.

As most people in radio astronomy are aware, the WSRT has been and currently is the most successful aperture synthesis instrument in the world. Brought into existence largely due to the efforts of J. Oort, its purpose was originally conceived to be the mapping of extra-galactic radio sources. In discussions with those responsible for originally making the WSRT work, it is clear that a solid conservative approach was taken to virtually every aspect of the instrument. By building an East-West array the needs of an extra-galactic mapping instrument were satisfied while the basic equations of interferometry and aperture synthesis, and subsequent data reduction problems, were considerably simplified (for example, sorting in its usual sense is not necessary). The initial electronics was built for one wavelength (21cm) with relatively high noise temperature (260K) and narrow bandwidth (4MHz). The cabling used for data transmission to and from the control building was often redundantly but exactly duplicated to make individual antenna systems as identical as possible. Because of these things the initial system was very stable and many potential problems were minimized. They did not attempt to build antennas good at wavelengths shorter than 6cm and redundant antenna pairs were not correlated, partly to reduce the data handling problems. Ten 25-m antennas were located in fixed positions with spacings of 144m and two were made movable along a 300m range at one end of the array, with a maximum baseline length of 1600m. Only the moveable antennas are correlated with each fixed antenna, making 20 interferometers. No on-line correction or calibration of data was attempted and all subsequent data reduction was done at the Leiden University computing center. The initial software consisted of a batch-oriented set of a relatively few essential programs that determine correction and calibration constants, corrected and calibrated the data, made maps, and produced map displays. All of the above things were built into the WSRT system by a small group of people working for the

Netherlands Foundation for Radio Astronomy (SRZM, somewhat like NRAO in purpose and operation), with very little real help from non-SRZM staff, particularly in the years before 1970.

The basic philosophy of the WSRT system, including both hardware and software, has been to build a a good, dependable extra-galactic mapping instrument, and then to carry out step by step improvements. Some of the hardware improvements include an augmentation of the initial 21cm system with 6cm and 50cm systems, and the 21cm noise temperature has been reduced to 100K. An initial 80-channel line system is being replaced with a 5000-channel system in 1977 and two more movable telescopes are being added which will extend the baseline length to 3200m. Some of the software improvements soon to be introduced include more careful and sophisticated algorithms for calibration of data, faster FFT programs for the large amount of spectral line data, and extension of their current interactive systems.

Because of the conservative approach taken during the contruction phase of the project, one must be judicious in applying WSRT experience to the VLA. With the VLA, virtually everything from the telescope design to the software is being implemented as close to the state of the art as possible. The VLA will be an all-sky instrument with four wavelengths ranging from 21 cm to 13 mm, the lowest practicable system tempeartures are being built in, and bandwidths up to 50MHz are being used. Although this will have great advantages for the future, on a short term basis the problem of achieving a stable and usable aperture synthesis instrument is much more difficult than it was at Westerbork. In addition, the WSRT was not used for astronomical observations until the complete initial 21cm system was functioning on all telescopes with a complete initial software system, whereas the VLA has already begun partial operations.

Now that we have emphasized some essential differences between the two projects, let us now discuss a number of areas where the past experience of the WSRT staff and their advice to us seem relevant. In doing so we apologize to the many people who spent so much time with us in the Netherlands for any errors or distortions we may inadvertantly introduce. Also, during out visits there, many changes were being planned which should by now be implemented, and many of our comments are based on the status as of late 1976.

2. WSRT Organization and Operations

For those who may not be familiar with it, we will briefly discuss the organizational context in which the WSRT operates. The WSRT was buil and operated by the Netherlands Foundation for Radio Astronomy (SRZM) with financial support by the Netherlands Organization for the Advancement of Pure Research (ZWO). The SRZM headquarters is at Dwingeloo to support the WSRT at Westerbork (40km from Dwingeloo), the Dwingeloo telescope, the data reduction system in Leiden, and various other projects. Within the SRZM there is a Board consisting of non-SRZM staff that functions somewhat like the AUI board of trustees and there is a Working Group that manages and operates SRZM equipment and staff. As chairman of the working Group, W. Brouw functions as the equivalent of a director. The members of the working group are equivalents of division heads. They are J.F. van der Brugge for Central Technical Services, J.L. Casse for Electronics, H.C. Kahlman for telescope operations (WSRT and Dwingeloo), H.W. van Someren Greve for computers and data reduction (while W. Brouw is chairman), and A.H. Scholler for administration.

A group of radio astronomers working in the Netherlands are appointed to a Program Committee. This committee makes recommendations about which observing proposals are to be given how much observing time. There is another committee of foreign advisors which functions as an equivalent to some of NRAO'S various advisory committees.

Given the recommendations of the program committee, members of the telescope operations group working at Westerbork do detailed scheduling of observations and then carry out the observations. Astronomers are not assigned fixed blocks of time, but rather the equivalents of our VLA operators, more appropriately called "observers" for the WSRT, collect requested data according to schedules they arrange themselves. The telescope group, together with the reduction group, decides on appropriate calibration procedures for the instrument. For programs which have special requirements, an attempt is made to account for this in the scheduling. For example, observations which require high dynamic range will be held up until good weather occurs. Thus, except for special observing programs, the astronomer is not at all involved in the scheduling, calibration, or observing processes.

Our personal conclusions from the discussions in the Netherlands are that the VLA eventually should and will have to adopt a similar approach for a large fraction of its synthesis proposals. This conclusion is based on information and impressions gleaned from our discussions at the WSRT and our own knowledge of VLA complexities. The astronomer using an aperture synthesis instrument wants to obtain calibrated measurements of complex visibilities for specific sources, frequencies, bandwidths, and the distribution of u and v that he needs for his purposes. The vast majority do not really want to deal with the process of data collection and calibration except to make sure the right data is obtained, and that it is properly and adequately calibrated. As the instrument becomes more complex with the addition of more antennas, two more IFs, and the spectral line capability, only the exceptional astronomer can even begin to handle all the details that go into dealing with the electronics, telescope control, and the processing leading up to good calibrated visibility data. Because of its greater complexity, it was the concensus of those that we met, and our own subsequent conclusion, that the VLA will have to become even more of a "black box" than the WSRT.

The pre-1977 WSRT hardware system had no on-line corrections or calibrations applied to the data. In addition, except for a short experimental period, there was no noise tube calibration built into the hardware. WSRT people have found this system to be too limited and are in the process of shifting in the direction of obtaining as much on-line monitoring information as possible, and with the added computer at

Westerbork some on-line corrections can and will be applied. A noise tube calibration is being introduced with the new 5000 channnel line correlator. A large mini-computer (PDP 11/70) is being acquired at Dwingeloo to allow all determinations of correction and calibration constants there, and to give SRZM staff more capabilities to work with WSRT data. The Leiden computer will then use these correction and calibration constants in producing calibrated data tapes for subsequent mapping. We note that many of these changes to the WSRT hardware have been designed into the VLA from the beginning.

Though the new 5000 channel spectral line system will have many capabilities, the software will only support a "reasonable" fraction of them; later additions to the software support will be implemented as they are easy, possible, or necessary.

3. Standard Data Reduction in Leiden

Data collected at Westerbork for an entire week are accumulated on magnetic tape before being sent to Leiden for further processing. Then the data reduction group (2 people), using up to 1/3 of the total computer time on the Leiden University IBM 370/158, carry out the first part of a standard series of processing tasks without assistance or input from the astronomer. First of all, a program called MAKECAL is run to solve for correction and calibration parameters (a step that will soon be shifted to the new Dwingeloo computer). For most of the past eight years this has been done under the assumption that a single set of correlator gains and correlator phase centers are applicable to an entire week's data. With the initial, very stable system this worked well, but while we were in the Netherlands there was much discussion of the fact that the hardware system improvements had resulted in somewhat less stability; hence different, more careful calibration schemes are being evolved. One major aspect of the new schemes is the emphasis on faster reponse time from the calibration program output back to the telescope group. The reduced stability of the electronics system along with the use of the old standard calibration techniques has resulted in astronomers having to spend much time re-calibrating their data or evolving special procedures to adjust the calibration. Neither the reduction group nor the astronomers believe that this is an optimum use of their time.

The main lesson for the VLA which we learned from these discussions is that there must be two or more people dominantly concerned with calibration and its implementation. Functionally, one of these must be an equipment-knowledgeable astronomer who understands everything affecting the data and who sees to it that others carry out the proper routine procedures for implementing and evaluating calibration and the behavior of the instrument. From the Westerbork experience, problems arise and errors increase when the calibration process becomes routine and those who built and understand the instrument the best go on to do other things, leaving less experienced people with calibration responsibities.

For the VLA, it seems best if a top-notch astronomer be associated with the instrument who feels personally responsible for all corrections and calibrations, and who takes a skeptic's view of the normally functioning instrument - that is, seeing to it that many redundant checks and evaluations are carried out (mainly by others) and personally doing some of this on a spot-check basis. This astronomer should explore various aspects of the instrumental calibration, look for patterns in the data which signal abberations, and in general use his experience to handle specific cases of instrumental problems as well as to investigate and solve general instrumental questions by evolving new and better calibration schemes.

Once the correction and calibration parameters are determined and evaluated, a program called MAKEOBS produces calibrated versions of the week's data tapes and adds to a catalog of WSRT observations. Under the present system different frequencies are segregated on different tapes. A major concern of both SRZM staff and users is the long time needed to get to this stage. Largely due to factors outside their control, it typically takes as much as a week to get from the raw data tapes to the stage of calibrated data tapes. Thus it is often two weeks after a particular observation that word can be sent back to Westerbork about any problems found; and, because of distance and other communication problems, the process of getting information back to those running the WSRT and responsible for its equipment is often less efficient than desireable. Our conclusion from this particular problem is that the VLA will have a tremendous advantage (perhaps offset by having nastier problems to deal with) since everyone concerned works at the same site, and because calibration and data reduction can be oone essentially during observing or very soon afterwards. At the same time, the WSRT experience also emphasizes that those doing the data reduction and calibration need to communicate their findings and questions as soon as possible to those responsible for electronics, antennas, and operations.

4. Map Production and Analysis at Leiden and Groningen

Once there are WSRT calibrated data tapes, the data reduction group sends a short summary describing the available data to the concerned astronomers. No maps are made until the astronomer has sent instructions, frequently by mail, specifying mapping parameters, e.g. sources, frequency, polarization, source subtraction parameters, size, and grading (tapering). Astronomers may also come to Leiden to submit their jobs personally. Once the first instructions (in the form of input cards and IBM JCL statements) are received an iterative process begins whereby the data reduction staff examines the input cards and JCL for obvious errors, a program called MAKEMAP produces desired maps, the results are sent to the astronomer, the astronomer submits another request, and so on. Associated with specification of map parameters is the specification of map display parameters, usually for ruled surface plots (MAKEPLOT) or radiographs (gray scale pictures). The typical map is 512 by 512 in size covering 0.65 by 0.65 degrees of sky, with mapping out to the first null of the antenna beam. For those not exclusively using the Leiden computer, maps are distributed on magnetic tape in a standard format.

One basic complaint voiced by many we talked with is that the WSRT data reduction system is not oriented to first-time users, nor is it advertised as such. The program documentation consists of a set of Internal Technical Reports (ITR's) which are equivalent to the VLA Computer Memo series, and are generally aimed at experts. Other sources of help for users are members of the reduction group, and trial and error. Program default values can be used, but this often leads to trouble through lack of understanding. The lesson we gained for the VLA is that our documentation should be as useful and complete as possible since we will have many first-time and inexperienced users. The NRAO is philosophically much more user-oriented than the WSRT, so this need is a priori recognized.

From the first through the last map of an object, the data reduction group produces all the maps and standard map displays for the astronomer. Depending upon personality factors, some astronomers are content with a system of this type where a few to several months may elapse before a "final" map is obtain, whereas others feel frustrated. Thus, during this process a large fraction of the WSRT users make extensive use of interactive map display and analysis systems to investigate the contents of their maps. The best of these systems was developed by the Gronigen astronomers, and many WSRT users make use of this system to varying degrees. Based upon a PDP-9 mini-computer and two Tektronix storage tube display screens with hard copy capability, the Gronigen system provides capability to analyze maps, but has no capability for making maps (no FF available). Generally working with 64 by 64 sub-sections, they examine maps, display them in different ways, fit gaussians, subtract gaussians, subtract point sources by cleaning, and do various map combination operations. The same system is used for continuum and spectral line maps. Typically a session of this type results in further mapping and map display requests being sent to the Leiden data reduction group.

We were extremely impressed with the degreee of usefulness of the Gronigen map processing system, particularly at the role it plays in understanding the information contained in multi-channel spectral line maps. We conclude that systems of this type are very important to the astronomer who needs to work with spectral line maps.

The WSRT users emphasized to us that astronomers need to gain experience in analyzing maps since it is a very powerful but still very unique way of displaying information. For this process, interactive systems are very useful in that they speed up the learning process through relatively fast response times. Using solely a batch system the learning process is much slower and the astronomer tends to forget thing in between runs. Others we talked with emphasized the need to examine and display maps in many different ways: for example, various coordinate projections and map combinations. By having many alternate displays available, astronomers may be able to see and understand new things in their data.

For the VLA, it will be very useful to get quick looks at maps for an overview of the observing session. Then, extensive later computation can be done on a large computer. We were also cautioned that we must be careful against so extensive usage of interactive systems that astronomers do not take time to think about what they are doing.

5. Distance, Travel, and Communication

It was very striking, and sobering, to us that even in a country with relatively small travelling distances there was considerable concern about the problems arising from separation between the various centers. From Dwingeloo to Leiden it is 2 1/2 hours by train; Dwingeloo to Gronigen is 1/2 hours; and Gronigen to Leiden is 3 hours. Even with an excellent train system, staff and users strongly feel the effects of distances and travel time. This, and the associated communication problems, are some of the reasons for WSRT wanting to centralize the process of determining and evaluating correction and calibration parameters. Everything we heard about this problem reinforced the importance of having the entire process of observing through producing calibrated VLA data occur at the same place, i.e. the VLA site.

For the WSRT user-astronomer there are only up to three locations in the country he may have to visit to analyze data: the Leiden computer which gives him maps on tape and hard copy, his home site, and the Gronigen interactive system. We noted a high level of frustration due to the delays and travelling involved. The hopes and plans to improve this situation are: (1) an equivalent of the Leiden data reduction system with a maximum of 1-2 day turn-around time for output; the WSRT system could achieve this by buying and completely controlling their own large computing system (they could do it all with a used IBM 360/65); and (2) have a Gronigen-type interactive map processing system at every major center where there are astronomers.

Other improvements are also in the works. Gronigen plans to improve their system by adding an equivalent of a COMTAL-type display. A map display and analysis system is planned for SRZM staff at Dwingeloo; in fact, SRZM plans to use the display aspects of an optical processor as a component of their system. Finally, an inadeqaute interactive map processing system (in a separate mini-computer) at Leiden is being replaced by an improved system. There are hopes and plans to develop common software for these three systems that will all be PDP 11-based.

6. An Extrapolation to Users' Processing Needs for the VLA

The WSRT astronomer-user is involved with the instrument at only two phases: (1) when he initiates an observing request; and (2) when he initiates mapping requests and analyzes the maps in hard copy form or in an interactive map processing system. Essentially all the people that we discussed the problem with in the Netherlands felt that this will eventually be true of many VLA astronomer-users. We therefore conclude that VLA users data processing needs fall into only six logical categories which parallel the steps followed in the process of observing

Several of these have already been mentioned at least briefly.

1. A reasonable arrangement for processing observing requests so that appropriate selection of proposals is made, and standard observing procedures can be established.

2. A system which provides results in the form of calibrated visibility data tapes.

3. A plan for producing first-order maps with standard parameters at the time observations are taken or shortly thereafter.

4. Interactive map processing systems to assist the astronomer in the analysis of the first to the n-th maps.

5. A facility for batch production of second to n-th order maps and standard map displays.

6. Enough insight and flexibility on the part of the astronomer to be able to ask for the right information from the VLA and and to be able to do more than pass VLA maps untouched by the human mind into the literature.

We conclude that this implies three type of data reduction facilities which must be available to the VLA user:

1. NRAO facilities and staff provide calibrated data and standard (or requested) first order maps at the VLA site, This is essential to

minimize communication problems and make the hardware-software-results linkage as tight as possible.

2. One or more large computing facilities take calibrated data tapes a input and provide maps and standard map displays at the request of astronomers. It is not essential, and only a matter of personal style o speed in data analysis, that the astronomer ever visit such facilities himself. For this reason the location and number of these facilities can be based only upon financial or political considerations. The operation of these facilities should ensure that the astronomer can get requested maps and map displays with turn-around time of the order of a couple of days to a week. Based upon our impressions in the Netherlands, a delay of more than a week would be frustrating, but much less delay would make the astronomer more careless about what he asks for.

3. A number of interactive map processing systems are needed, such the Gronigen system as it is planned in the near future, the COMTAL-based system presently at the VLA site, and the system being proposed for Charlottesville. It seems to us that the most ideal situation would involve at least six systems located at major centers in the US to minimize the travel, access time, and cost. The system at the VLA site and the one in Charlottesville could be the beginning with the rest located in places like Boston, Chicago, Austin, Los Angeles, etc.

It may not be essential for the large computing center or the interactive map processing systems to be "owned" and maintained by NRAO.

Indeed, there would be advantages to having the mini-based map processing systems associated with major universities with the potential for independent innovation.

The above-mentioned three-facility data reduction system is basically what has evolved for the WSRT and we suspect it represents the most ideal future for VLA data reduction.

7. Spectral Line Aperture Synthesis

The 80-channel system at the WSRT has been used extensively by many astronomers, with excellent and interesting results. We observed some processing of line data on the Gronigen PDP-9 system and were much impressed by the ease with which spectral line data can be handled and understood with the proper programs and displays. It seems to us that fears regarding spectral line data processing are probably over-emphasized and possibly unfounded. Of course the VLA will have three times the number of channels as the WSRT, but it will also have much more map analysis power than is currently available in the extremely small PDP-9 system.

One interesting suggestion concerning many-channel line data is to use time as the velocity dimension, where color has been the "conventional" way of displaying velocity information. A movie could be made of the 256 channels, or special hardware such as a video disk and TV monitor with very rapid access and display could be used to scan (backwards and forwards) through the data.

8. Map Sizes, Field of View, and the Number of Points per Synthesized Beam-width

One of the major parameters determining the size of an aperture synthesis data reduction system is the size of the maps that need to be produced, processed, and displayed. In particular the disk (or other mass storage device) capacity of a system, and its thru-put limit is largely dependent on the largest size maps one expects to process in a routine fashion. As most people know, under ideal circumstances one would have 4-5 points per synthesized beam width, mapping out to at least the first null of the antenna beam, and a synthetic aperture coincident with the maximum antenna separation. This would mean 8192 by 8192 maps for the VLA A-array, and sizes scaled down by factors of 4 for the other arrays.

Because of the extensive aperture synthesis experience of the radio astronomers in the Netherlands, and because those responsible for regularly putting out 512 by 512 maps in large volumes best appreciate the practical problems, one of the major questions we discussed in the Netherlands was: what sizes do you envisage as both meeting minimum needs and being practicably supportable for the VLA? The recommendation of W. Brouw, who probably understands both needs and limitations in this area better than anyone else, was 4096 by 4096 for "good" A-array maps and 2048 by 2048 for equivalent "rough" maps. This translates, and scales for the other arrays, into the following for the critical parameters of the field of view and the number of points per synthesized beam width:

Config.	"Good" Maps Map Size	Pts.perSyn.Bw	FOV	"Rough" Maps Map Size	Pts.perSyn.BW	FOV
A	4096	2.7	1.5HPBW	2048	2	1.0HPBW
B	2048	4	1.6	1024	2	1.6
C	512	3.5	1.5	256	2	1.3
D	256	4.6	2 HPBW	128	4	1.5HPBW

A practical definition of a "good" map is one where a good display, source subtraction, or cleaning is desired. "Rough" maps might be those produced while observing to see what is developing, or for trial and error testing of map parameters.

9. Miscellaneous Topics

There are a number of points that were emphasized during our discussions in the Netherlands for which repetition for emphasis is worthwhile:

1. Essentially real time correction, calibration, and evaluation of the instrumental output is necessary both to evaluate the instrument and to keep up with the data. The VLA synchronous-asynchronous environment for achieving this purpose is ideal for this. WSRT staff would like to get as close to this as possible.

2. With rare exceptions, the VLA staff should not be dependent upon astronomer-user action to determine calibration procedures or provide the only source of information about aspects of results that involve instrumental behavior. As a minimum, regular samples of data, including all calibrators, must undergo parallel analysis and mapping by VLA staff. A dedicated data reduction staff is essential with one very knowledgeable person who personally deals with and examines results all the way through to the map and map analysis stage.

3. Three extreme forms of data handling seem necessary and inevitable:

(1) Batch processing for all massive computational tasks;

(2) Special processing of data for calibration and system evaluation purposes; and

(3) Map display and analysis tasks where a majority of astronomers find interactivity to be essential.

4. Documentation aimed at naive users should be produced and maintained so as to keep up with software development.

Other important points which have not yet been mentioned include the following:

5. The dynamic range of maps will become the dominant VLA problem because of the extra sensitivity of the VLA. Although an extensive evaluation of the factors limiting the dynamic range of WSRT maps has been carried out, WSRT staff has not yet gotten to the stage of improving the major limiting factors of their system. They very strongly recommend the VLA and NRAO staff should already be carrying out a thorough and systematic study of all the factors that will limit the dynamic range of VLA maps. They suggest that actual components of the system be assigned errors in this study so that their contribution to the overall dynamic range problem can be assessed. They believe this is essential in determining what portions of the system need to be worked on. They emphasize that everyone tends to be aware of the limiting factors involved in their own specialty, but they have very limited awareness of the importance of these factors relative to other parts of the "system" that are outside their specialty. In addition, those responsible for designing and building particular components of of hardware or software are unlikely to have an objective and thorough overview of the role of their piece of the system in limiting dynamic range.

6. There was a general impression that the 10-second sampling time would no be a problem as long as other effects like finite band-width, map curvature, etc. are not corrected for; however, with more sophisticated corrections shorter integration times may be essential.

7. At least one of us who previously thought map cleaning would not be routinely used for VLA maps underwent a major conversion during discussions with astronomers using the WSRT. In particular, aperture synthesis instruments with the sensitivity of the WSRT or the VLA will have many point sources in almost all fields being mapped. The only good way to verify the hypothesis that a particular bump is a point source is to fit it to a function like a gaussian and then subtract the source by cleaning; if bumps are removed and no spurious ones are introduced, the hypothesis is true. Only after all point sources are removed can one proceed to a detailed study of the extended sources of interest, or to examination of the map residuals whose distribution can indicate instrumental problems. We conclude that this type of processing will be important for VLA maps; however, there hopefully will be no need to "improve" maps of extended sources by cleaning.

8. The polarization capabilities are one of the most important areas where the VLA will extend the observational boundaries of radio astronomy. This results because of the increased sensitivity compared to the WSRT where sensistivity is a problem in polarization mapping.

9. A number of people associated with the WSRT seem to have concluded that an optical device could be very important as a component of a map display system, but that their capability to produce maps is limited to this particular purpose. This goes along with the opinion that digital accuracy is needed for computation and map analysis.

10. There was some concern that no one with what they considered to be aperture synthsis experience was involved with the VLA. They described the VLA experts as interferometeurs and felt that there are significant differences between this type of expertise and aperture synthesis expertise.

11. Because of the importance of polarization for the VLA, ionospheric data allowing post-facto polarization angle corrections should be obtained and incorporated in the VLA correction and calibration system.

12. There were very strong feelings that software exchange amongst the groups using the WSRT was rapidly developing and the the WSRT and the VLA should develop such exchanges. This included strong recommendations for tape format compatibilities and conventions for map pixel ordering.

13. There was considerable optimism about the future of the WSRT even when the VLA is fully operational. There seems to be three main reasons for this. In the area of line work the WSRT will always be competitive because it will be only a factor of 2 (their figure) less sensitive than the VLA. Secondly, planned improvements of the WSRT in selected areas will tend keep it abreast of the VLA. Finally, but not least important, they expect the competition for VLA observing time to be so severe that large numbers of excellent proposals will suffer long delays, thus leaving good aperture synthesis arrays with good competitive possibilities.

10. Are Visits Like This Worth-while?

As a closing comment, we would like to say that each of us felt that visits like this where a couple of weeks are devoted to concentrated exchange of information are very valuable. We learned a great deal and had some previously held convictions completely reversed. If we had spent much less time than this the level of study would have been much more spotty and superficial.

We particularly would like to thank the dozens of people who spent hours to days talking with us. Special thanks to Ernst Raimond who spent two weeks with each of us during our visits.