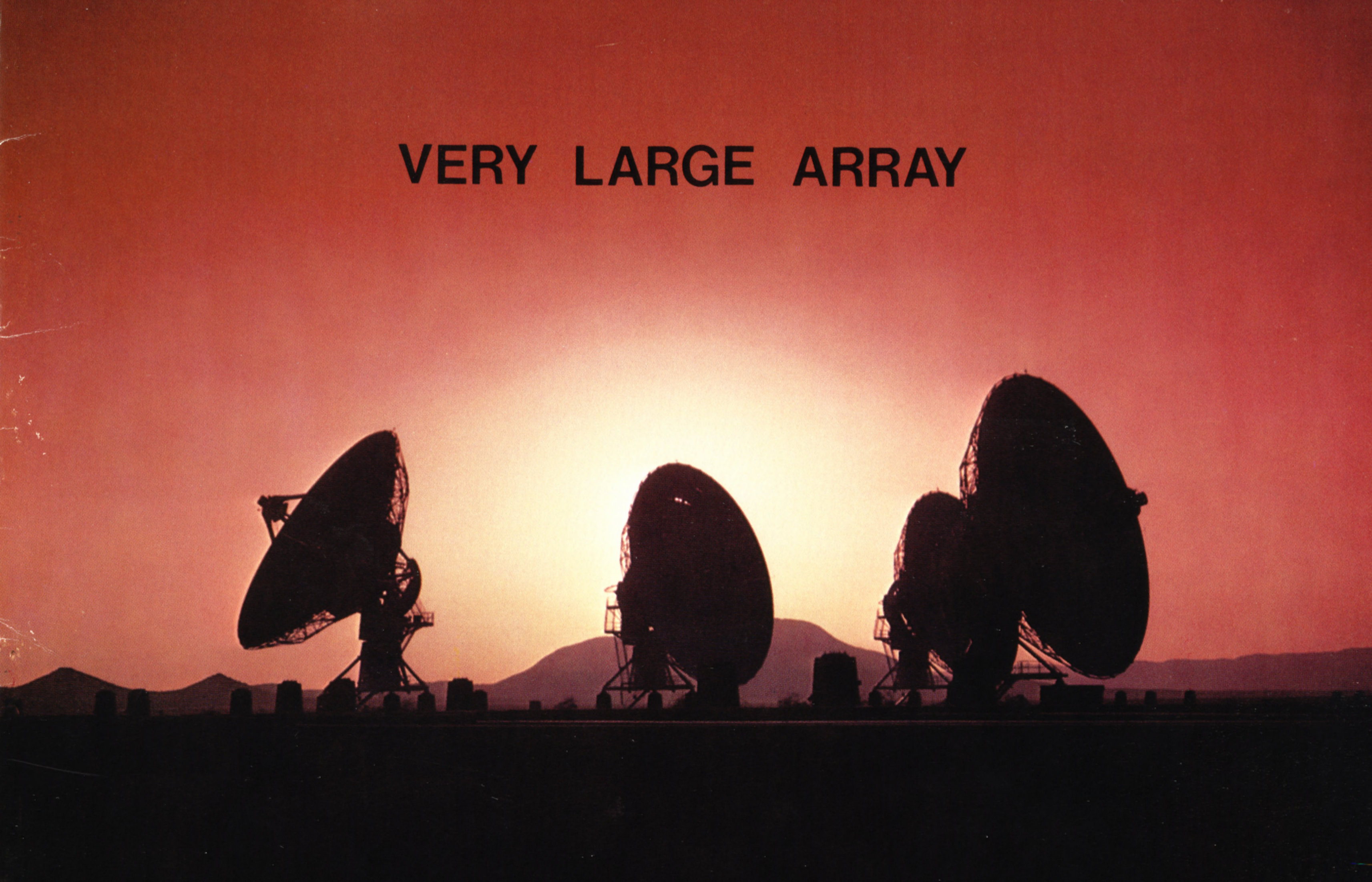
VERY LARGE ARRAY



NATIONAL RADIO ASTRONOMY OBSERVATORY
VERY LARGE ARRAY
SOCORRO, NEW MEXICO

NRAO

OPERATED BY ASSOCIATED UNIVERSITIES, INC.
UNDER CONTRACT WITH THE NATIONAL SCIENCE FOUNDATION

THE BEGINNING OF THE VLA

By 1960, radio astronomy was a well-established and highly productive science, a complementary counterpart to the ancient study of optical astronomy. Radio astronomy, in carrying astronomical research into previously unexplored parts of the electromagnetic spectrum, had revealed unexpected new objects and phenomena in space and had shed new light on others long known. Radio investigations had provided a vast amount of new information about the outer atmosphere of the sun; had begun the study of the gaseous, non-stellar component of our Galaxy, the Milky Way; and had demonstrated that many galaxies have large optically invisible regions containing high-energy particles. It was evident, however, that the possibilities for further progress in understanding the radio universe were severely limited by the poor detail with which it could be seen by the radio telescopes then in use.

The resolving power, or the ability of any single telescope to "see" objects or images in fine detail, is dependent upon the size of its aperture compared to the observed wavelength of the radiation. Radio wavelengths are much longer than optical wavelengths. Therefore, optical quality pictures at radio wavelengths could not be obtained unless very large telescopes or multiple antenna systems could be built.

Scientists in England and Australia were pioneers in this effort and demonstrated the capability of radio interferometers — radio telescopes comprising two or more widely separated antennas — to map radio sources on a scale much smaller than could be resolved by any single radio antenna. They were also formulating plans for "aperture-synthesis" radio telescopes. This type of instrument consists of many simultaneous interferometers whose numbers are, in effect, increased by the rotation of the earth and thus provide the mapping capability of a single antenna many thousands of feet in diameter. Instruments of this type were built and have been in use with great success for the past decade.

In 1961, the National Radio Astronomy Observatory began planning for an aperture-synthesis instrument, similar in concept to those in Europe, but far more ambitious. The Very Large Array (VLA), as envisioned, would be much larger, so that its resolving power could equal that of the largest optical telescopes; it would be usable over a wide range of radio wavelengths, since the radio emission of most astronomical objects varies with wavelength; and it would be usable as a mapping spectrometer to permit studies of the chemistry and dynamics of particular regions of space. The total area of its component antennas would be large enough to provide the sensitivity needed for detecting and mapping extremely faint sources, and the arrangement of its antennas would be adjustable over a wide range so that the instrument could be optimized for many different types of measurements.

Preliminary design studies were carried out during 1962-1963, and a two-antenna interferometer was built at the NRAO facility near Green Bank, West Virginia, to serve as a test-bed for technical design of the VLA. Intensive design work was conducted from 1964 to 1966, and in January 1967, a formal proposal for construction of the instrument was submitted to the National Science Foundation.

In 1972, when Congress authorized construction and appropriated initial funding, the high rate of inflation of the seventies was unforeseen. At that time, it was anticipated that the array would be completed by 1981 at a total cost of $76,000,000. Through stringent economies and some redesign of the system, the total cost at completion was held to $78,578,000.

The preliminary stages of the project — detailed design of the antennas and electronics, bidding and contracting for the antennas and components of the electronic and computing systems, surveying and initial preparation of the site — occupied most of 1973 and 1974. Major work was underway at the site by early 1975, and the assembled project staff was moved to New Mexico by mid-year.

The first antenna was accepted in September 1975 and the final antenna in November 1979. The first two antennas operated successfully as an interferometer in February 1976, and by mid-1977, enough antennas were operational so that useful astronomical observations could be made.

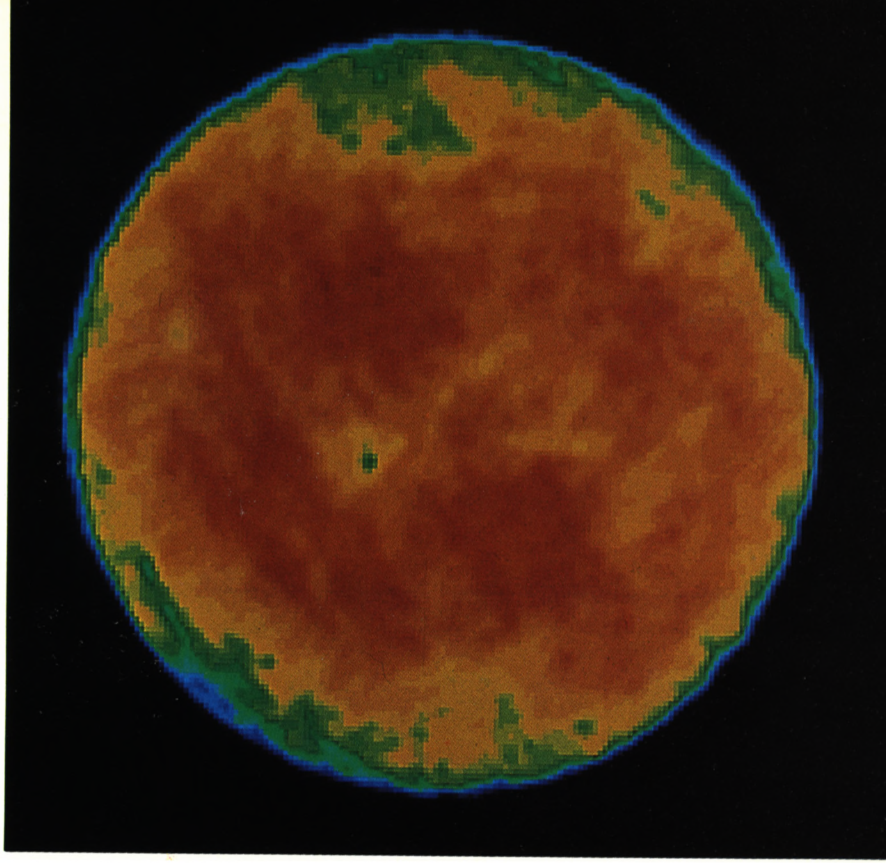
These early scientific observations were very important to the progress of the project since they provided severe performance tests of the antennas, the electronics, and the computer programs. Test results were relayed to project engineers and scientists, who were then able to correct faults and make improvements as construction progressed.

SOME EARLY RESULTS FROM THE VLA

From the astronomers' point of view, however, it is more exciting that these observations have led to a number of significant scientific results. A combination of high resolution and great sensitivity, along with a capability for rapidly changing the observing wavelength, made the VLA a unique and powerful first-line scientific instrument even in its partially completed state.

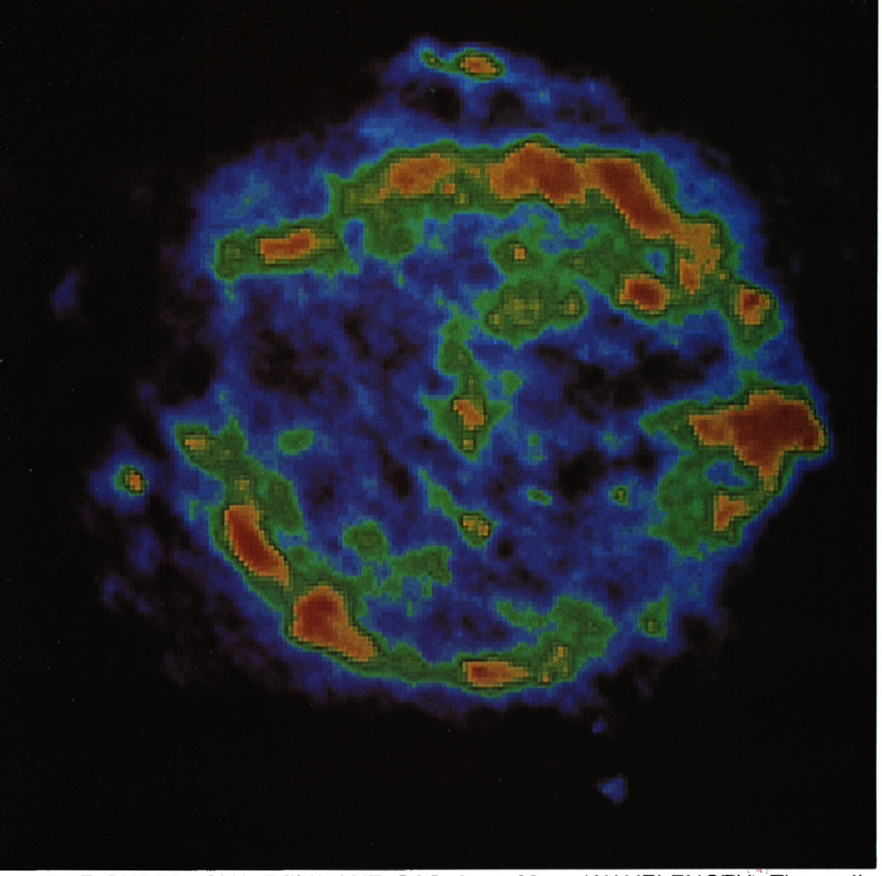
Observations ranged from the sun and planets of our solar system to the most distant extragalactic objects. The picture on this page shows a radio map of the planet Venus made at 6 centimeter (cm) wavelength. Red represents the most intense radio emission, and blue and green are the least intense. The atmosphere of Venus is partially opaque at this wavelength. At the rim of the planet, where our line of sight passes through absorbing gas, our view is limited to the cooler upper regions of the atmosphere. The temperature there is about 250°F, and the radio radiation is least intense. Away from the rim, we can see down to the hot surface of the planet where the temperature is about 800°F. An important feature of this picture is that the outer edge of the atmosphere is sharp and well-defined.

The VLA has been used to study such Milky Way objects as radio stars, gas clouds where new stars are being formed, and gas clouds which remain when a star ends its life in a violent explosion, called



THE PLANET VENUS at 6cm WAVELENGTH. Radio emission in the bluish regions arises high in the Venusian atmosphere, where the temperature is about 250°F, while the emission in the reddish regions arises much closer to the planet's surface, where the temperature is about 800°F.

Observations by D. Muhleman, G. Berge, and S. Deguchi - California Institute of Technology.



THE SUPERNOVA REMNANT CAS A at 20cm WAVELENGTH. The radio emission arises mainly in the shell formed where the debris thrown out by the stellar explosion meets the surrounding interstellar gas. The radio source is only about 350 years old, which is very young in comparison with most astronomical objects.

Observations by D. Milne - CSIRO, Australia; B. Balick - U. of Washington; R. Perley - NRAO; and P. Angerhofer - U. of Maryland.

a supernova. The accompanying picture shows the ring-like structure of the radio source Cas A, the remnant of a supernova which occurred about 350 years ago. Debris thrown out at the time of the explosion penetrated into the surrounding gas, forming a shell from which most of the radio emission originates. Because the object is so young, the stellar debris is still moving outward at a high velocity. Detailed maps made with the VLA over the next several years are expected to enable astronomers to see the motion of the shell and other changes in the source as the energy of the stellar debris dissipates.

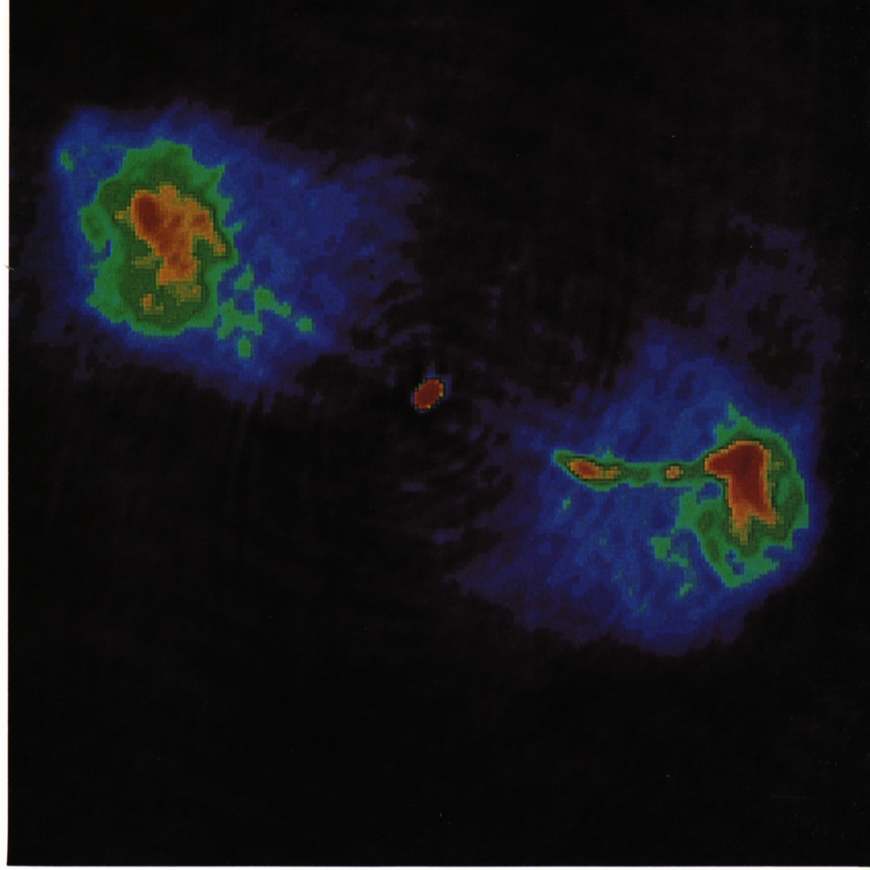
Since giant radio galaxies were discovered some 25 years ago, scientists have been trying to understand the source of their great energy and the means by which this energy is transferred from the parent galaxy to the two large regions of radio emission which are generally located at distances several hundred thousand light years away from the parent galaxy. Some of the more striking work at the VLA has involved the mapping of these "double" radio galaxies.

In the map of the source 3C 388, the very bright radio spot at the center of the figure lies in the same direction as the optical galaxy. On either side of the galaxy are large regions of radio emission, six hundred thousand light years in extent, which are presumably being supplied with energy from the active nucleus of the galaxy. The ridge of radio emission seen in the right-hand component is called a radio "jet" and may mark the location of a channel through which energy is supplied by the nucleus to the extended radio component.

One of the most remarkable astronomical objects observed with the VLA is a double quasar associated with the radio source 0957 + 561. This double quasar consists of two objects nearly identical in brightness and spectrum at radio, light, and X-ray wavelengths. In the radio map of the double quasar the quasar images appear as bright spots at the center and lower center of the picture.

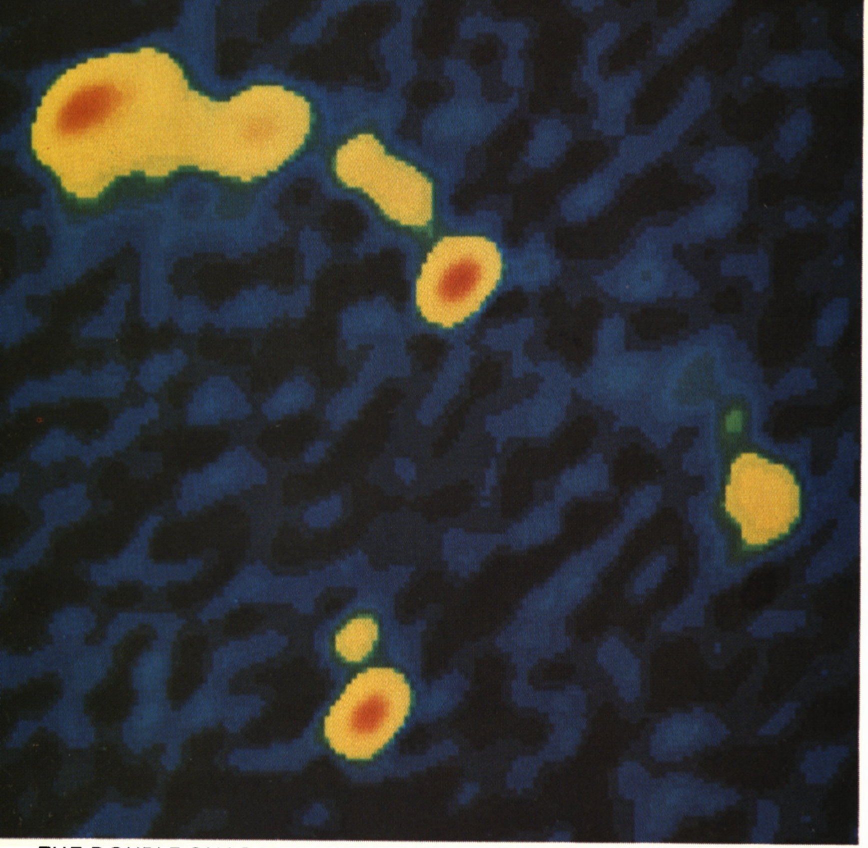
A possible interpretation of this source is that the bright spots are two images of the same quasar, the double-image having been formed by the bending of both light and radio waves in the gravitational field of an intervening massive galaxy. The upper image has a radio tail, which is part of the real quasar, but this tail is not repeated in the lower image, possibly because of the asymmetrical shape of the gravitational lens.

This interpretation was recently given a boost when optical astronomers found a faint, but massive, galaxy near the quasar shown at the lower center of the picture. This galaxy, which lies in a distant cluster of galaxies, is also a radio source and is seen as the faint extension of radio emission to the north of the lower image.



THE RADIO GALAXY 3C 388 at 6cm WAVELENGTH. The galaxy coincides with the small, very bright radio souce in the center of the picture. The two large, extended regions where radio emission is seen lie outside the optical image of the galaxy, a general characteristic of radio galaxies. The ridge of radio emission, or "jet", which stretches from the outer edge of the right-hand component back towards the central galaxy may show the location of a channel within which energy is transported from the active nucleus to the extended radio region.

Observations by J. Burns - NRAO and W. Christiansen - U. of North Carolina.



THE DOUBLE-QUASAR SOURCE 0957 + 561 at 6cm WAVELENGTH. The two intense radio sources close to the center of the picture coincide with optical objects having identical redshifts (velocities away from the earth), suggesting that they are two images of the same object, created by the bending of the light rays and radio waves by an intervening galaxy. In this theory the intervening galaxy is acting as a gravitational lens.

Observations by P. Greenfield, B. Burke, and D. Roberts - Massachusetts Institute of Technology.

THE SITE, RAIL SYSTEM, AND ANTENNAS

The selection of an appropriate site for the VLA was dictated by a number of requirements. The ground had to be flat so that antennas could be readily shifted from one arrangement, or configuration, to another. This flat area had to be large enough to accommodate three arms, each approximately 13 miles long, and had to permit an optimum orientation of the arms — one arm nearly, but not exactly, north-south and the other two arms differing from the first by about 120 degrees. To minimize the distorting effects of weather and earth atmosphere, it was desirable that the site be in an arid climate, one mile or more above sea level. Finally, in order to observe the southern sky,it was necessary to have the instrument south of latitude 40 degrees. After an extensive study of possible sites, the immense Plains of San Augustin near Socorro, New Mexico, proved to be by far the best choice.

The site lies in an ancient lake bed 7000 feet above sea level. During the Ice Age, it was a small inland sea; now it is a vast grassy plain. Human habitation has always been sparse but possesses a very long history. Traces of campsites and artifacts characteristic of the earliest Indians have been found along the former lake shore. One such campsite near the outer end of the southwestern arm, probably six to eight thousand years old, was excavated by archeologists from New Mexico State University before array construction began.

The VLA consists of 27 individual antennas arranged along three equally spaced radial arms, forming a Y-shaped array. Two of the arms are 13 miles long, and the third, the northern branch, is 11.8 miles. A double set of standard gauge railroad tracks, spaced 18 feet apart, are used by a specially designed transporter to move antennas to and from the 72 observing stations.

Each arm has 24 stations, strategically located so as to maximize the astronomical information obtained. These observing stations are used in one of four different configurations during an observing run. The "A" configuration is the most extended and will spread the 27 antennas along the full length of the arms. In this arrangement the VLA can map small, intense radio sources with the highest resolution.

Configuration "D", the most compact, brings the antennas together on very short 0.4 mile arms where maps of larger sources can be made, at lower resolution, but with much greater sensitivity to faint, extended fields of radio emission. Intermediate configurations, "B" and "C", have arm lengths of 4.0 and 1.2 miles respectively.

The antennas, each weighing 210 tons, are ruggedly built precision instruments designed to operate in winds up to 40 mph and can survive gusts up to 130 mph. A very accurate 82-foot diameter aluminum parabolic reflector surface captures and focuses radio waves arriving from space. A 6-foot

THE TRANSPORTER NEARS AN ANTENNA IN THE ASSEMBLY BUILDING.

THE ARRAY HAS BEGUN AN OBSERVING PROGRAM

diameter asymmetrical subreflector, supported by four massive legs, is mounted at the apex of the 82-foot reflector. At the vertex of the reflector, beneath the subreflector, are the feeds and receivers for four operating frequency bands.

Signals from the radio source under observation are reflected from the main reflector up to the subreflector, which then focuses them back down into the feed and receiver. An ingenious arrangement of the feed system places the feed horns for all four frequency bands in position ready for use on the main reflector surface. The computer controls the feed in use, shutting off those not selected by the astronomer.

Each antenna can rotate horizontally full circle and can sweep vertically over the range from 8 degrees above the horizon to zenith and 35 degrees beyond. The antennas, under computer control, track radio sources as they move across the sky.

THE ELECTRONICS AND COMPUTER SYSTEMS

Radio waves received from outer space are very weak and must be greatly amplified by a highly sophisticated electronic receiving system. The receiver on each antenna is located in the antenna vertex room immediately below the feeds, where the amplifying elements in the receiver are cooled to

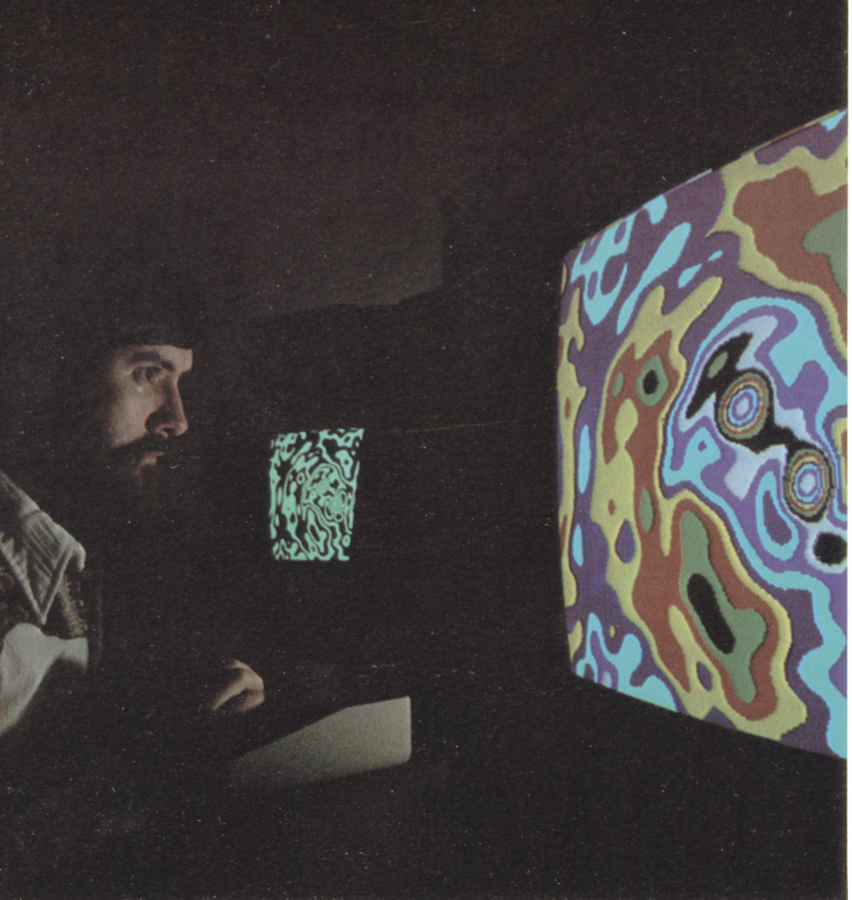
-430°F to minimize unwanted signals generated by the receiver system.

To make high resolution radio maps of astronomical objects, the VLA combines the signals from all 27 antennas. This combining process is carried out in the Control Building. A crucial part of the electronics is the waveguide communication system which links the vertex room of each antenna with the Control Building. The waveguide, a hollow steel tube 60 millimeters (2.35 inches) in diameter with an inner conducting surface of finely wound copper wire, is laid parallel to the railroad bed at a depth of three to ten feet.

Two functionally distinct computing systems form an integral part of the VLA. The astronomer stores instructions for his observing program in the "synchronous" computer, which then conducts the observations under the watchful guidance of an array operator. The synchronous computer controls the antennas and the electronic system during each observation, continuously monitors the performance of the entire array, and prepares data from the receiving system for transmission to the "asynchronous" computer for further processing.

Data from the synchronous system are transmitted directly to the asynchronous computer, which is a large, powerful machine capable of performing the numerous complicated mathematical manipulations necessary to produce a map suitable for scientific analysis and interpretation.

THE DUTY OPERATOR IN THE CONTROL BUILDING GUIDES THE ARRAY THROUGH THE PROGRAM.



THE RESULTS ARE STUDIED USING A COMPUTER DISPLAY.

EPILOGUE

The partially completed array has proven its ability to define radio sources in unprecedented detail, and the finished instrument will perform even better. The original goals have been met. However, our increasing knowledge of the universe will cause the needs of science to change, and the VLA has the versatility to adapt to those changing needs. In this sense, the Very Large Array will never be completed, and will remain at the forefront of radio astronomy for a very long time.