אוסף עזרא אוריון
ארכיון אמנות במרחב הציבורי
Ezra Orion Collection
Public Art Archive

כותרת: בין גלאקטי, ביקור בVLA בניו מקסיקו
טקסטים, חוברות, התכתבויות, גזרי עיתון, פתקים, כרטיסי ביקור

<u>מיקום בארכיון</u>
ארגז: 22
תיק: 2
תת תיק: 2

Title: Intergalactic, Visit to VLA, New Mexico
Text, booklets, correspondence, news clips, notes, business cards

<u>Location in Archive</u>
Box: 22
Folder: 2
Sub folder: 2

המכון לנוכחות ציבורית
המרכז הישראלי לאמנות דיגיטלית, חולון
לחומרי המקור צרו קשר דרך archive@digitalartlab.org.il

The Institute for Public Presence
The Israeli Center for Digital Art, Holon
For original materials please contact us at archive@digitalartlab.org.il

TELAVIV UNIVERSITY אוניברסיטת תל-אביב

RAYMOND & BEVERLY SACKLER
FACULTY OF EXACT SCIENCES
THE FLORENCE & GEORGE WISE
OBSERVATORY

הפקולטה למדעים מדוייקים
ע"ש ריימונד ובברלי סאקלר
מצפה הכוכבים
ע"ש פלורנס וג'ורג' וייז

August 21st 1990

To: Ezra Orion, Midreshet Sde Boker
From: Sylvia Navon, Wise Observatory

The attached message arrived from Hagai Netzer in the electronic mail today.

As I have been unsuccesful in contacting you by telephone, I am mailing the message to you.

In case you would like to write to the director, as suggested by Hagai in his message, the following are the Headquarters and New Mexico addresses.

National Radio Astronomy Observatory

Headquarters: Edgemont Road
Charlottesville, VA 22903

New Mexico P.O. Box O
Socorro, NM 87801

I hope that this will help you in your endeavour.

Sylvia Navon

413788 — 420729 .טל ,תל-אביב 69 978, ,רמת-אביב, האוניברסיטה קרית
RAMAT AVIV, 69 978, TEL AVIV ISRAEL. CABLE : VERSITY T-A TELEX : 342171 VERSY IL. TEL. TEL. 420729 — 413788

Date: Mon, 20 Aug 90 12:20 EDT
From: NETZER%ASTUVB@OHSTPY
Subject: for Sylvia,
To: b10@TAUNOS.BITNET
Message-id: <4860CA1420FF201C49@MPS.OHIO-STATE.EDU>
X-Envelope-to: b10@TAUNOS.BITNET
X-VMS-To: OHSTPY::IN%"b10@taunos.bitnet"

Dear Sylvia,
Could you please help me to transfer this information to Ezra Orion,
from "Midreshet Sdeh Boker" telephone 057-565720.

1. There is NO ranging (i.e. active radar) facility on any of the VLA (very large array) dishes in New Mexico.
2. The only ranging facility on big radio telescopes in the USA is in Arecibo (largest radio telescope in the world) and the Haystack observaory near Boston (a large single dish).
3. The VLA is operated by the National Radio Astronomy Observatory (see address in the AAS book, in case he needs it) and I would recommend getting in touch with the director regarding any experiment he wants to perform with them. I did not find out more detailes about the VLA dishes and a good place to check will be Sky and Telescope.

Thanks
Hagai

The Israel Museum
Jerusalem, ISRAEL
September,...1990

To:
Director
The Very Large Array
National Radio Astronomy Observatory
Socorro, New Mexico
U.S.A.

Dear Sir,

Intergallactic Sculpture

Following the energy beem launch from Bar-Giora Observatory ranger, near Jerusalem, on June 22th 1989 - a 1 Billion km. tall "Super obelisk" - vertically to the plane of the Milky Way - we propose for the 1992 universary, a launch of multi-beem "super Cathedral".

The idea was proposed by the Israeli sculptor Ezra Orion, at the International Sculpture Center Conference IS90, June 5-9th 1990, in Washington D.C..

As the Vary Large Array is very well known around the world, some astronomers in Israel advised us to contact you.

We would like to enquire preliminary about the feasibility of two alternatives:

1. Arranging 30 radio-telescope antenna dishes in an rectangular display of about 500 X 100 meters; Aiming all of them vertically to the horison, and to the gravity plane of the Milky Way, at an apropriate date and hour.

   Broadcasting from each antenna a powerful energy beem for 55 minutes, 33 seconds - one billion km. tall multi-beemed roofless "Super Cathedral", which will cruise light-speed the intergallactic infinity.

2. In case there is no ranging facility on any of the VLA dishes - to arrange the 30 dishes at day time for about an hour in the same display, in order to film them from the air and from the ground.

The idea is to organize it all as an Hi-tec Intergallactic Act - a happening with the attendence of Art personalities, the Media etc. - connected to the 1992 500 years universary.

Can you kindly inform us what are the regularities; on what channel can we apply, in order to negotiate the feasibility of the realization of this proposal.

Sincerely yours,

.....

.....

CC:

- David Furchgott, Director, International Sculpture Center, Washington D.C.
-
-
-

מוזיאון ישראל, ירושלים
the israel museum, jerusalem
متحف اسرائيل، اورشليم القدس

10.10.90

Director
The Very Large Array
National Radio Astronomy Observatory
Socorro, NM
USA

Dear Sir:

Re: INTERGALLACTIC SCULPTURE

Following the energy beam launch from Bar-Giora Observatory's ranger near Jerusalem on June 22, 1989, (a 1 billion km. tall "super obelisk," vertically to the plane of the Milky Way), we propose a launch of multi-beam "super catherdral," for the 1992 "universary."

As the Vary Large Array is very well known around the world, some astronomers in Israel advised us to contact you. We would like to enquire about the feasibility of two alternatives:

1. Arranging 30 radio-telescope antenna dishes in a rectangular display of about 500 x 100 meters, aiming all of them vertically at the horizon, and the gravity plane of the Milky Way, on an appropriate date and hour.

   Broadcasting from each antenna a powerful energy beam for 55 minutes, 33 seconds, a one billion km. tall multi-beamed roofless "super cathedral," which will cruise the intergallactic infinity at light-speed.

2. In case there is no ranging facility on any of the VLA dishes, to arrange the 30 dishes during the day for about an hour in the same display, in order to film them from the air and from the ground.

The idea is to organize it all as a Hi-tec Intergallactic Act; a happening to be attended by art personalities, the media, etc, in conjunction with the 1992, 500 year "universary."

Would you kindly supply us with the regulations; to what channel can we apply in order to negotiate the feasibility of realizing this proposal.

Sincerely yours,

Yigal Zalmona
Chief Curator of the Arts
Curator
The David Orgler
Department of Israel Art

YZ/dm

cc: David Furchgott, Director
International Sculpture Center

91710 jerusalem, p.o.b 71117, tel. 02-708811, fax. 02-631833

17/6/98

נועם רבינוביץ
ומרק גוטין (מנכ"ל מילניום)

נגד : המוזיאון ומהדר
הנסיונות - קטלוגים
הולכת להציג מוזיאון האור עם
מנומהדר
← הכנס. פתוח △ שלנו
עם ה-2000 : אובליסק אור ועק
אני
מתוך רקע טבעיות ומתני חללית
היא הוא
+ טל אני

19/7

National Radio Astronomy Observatory
P. O. Box O, Socorro, New Mexico 87801-0387
Telephone (505) 835-7000 TWX 910 9881710 FAX (505) 835-7027

February 19, 1991

Mr. Yigal Zalmona
Chief Curator of the Arts
The David Orgler
Department of Israel Art
The Israel Museum
Jerusalem

Dear Mr. Zalmona,

The "Intergalactic Sculpture" that you propose for 1992 should be an interesting and exciting event. Participation of the Very Large Array telescope, however, will be impossible since we are only a receiving facility. The VLA has no broadcasting capability, since that has never been required in the type of astronomical research that is carried out with the instrument.

Photography of the VLA from the ground and from the air during the event could be arranged without difficulty as a backup activity if you wish. We cannot, however, interrupt the normal scientific routine of the instrument to make a special "pose" for the cameras. Nevertheless, I am sure that the nature and scope of your event will not be compromised by the orientation of the antennas at the designated time.

Please keep us informed of the progress of your planned event.

Sincerely,

R. J. Havlen
Head/VLA Observatory Services

RJH/tr

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

National Radio Astronomy Observatory
P. O. Box O, Socorro, New Mexico 87801-0387
Telephone (505) 835-7000 TWX 910 9881710 FAX (505) 835-7027

June 25, 1991

Mr. Ezra Orion
Midreshet Sde-Boker
Negev, Israel

Dear Mr. Orion:

As I explained in my letter of February 19, 1991 to Mr. Zalmona, you are welcome to film the antennas of the VLA during your proposed "Intergalactic Sculpture" although we cannot compromise the scientific research of the instrument at any time.

You are also welcome to visit the VLA this year, if you desire, in order to make further arrangements. Your arrangements for a helicopter, however, should be made independently of the NRAO. The closest available helicopters are in Albuquerque, New Mexico.

Sincerely,

R. J. Havlen
Head/Observatory Services

RJH/tr

V.L.A.

National Radio Astronomy Observatory
P. O. Box O, Socorro, New Mexico 87801-0387
Telephone (505) 835-7000 TWX 910 9881710 FAX (505) 835-7027

February 19, 1991

Mr. Yigal Zalmona
Chief Curator of the Arts
The David Orgler
Department of Israel Art
The Israel Museum
Jerusalem

Dear Mr. Zalmona,

The "Intergalactic Sculpture" that you propose for 1992 should be an interesting and exciting event. Participation of the Very Large Array telescope, however, will be impossible since we are only a receiving facility. The VLA has no broadcasting capability, since that has never been required in the type of astronomical research that is carried out with the instrument.

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Please keep us informed of the progress of your planned event.

Sincerely,

R. J. Havlen
Head/VLA Observatory Services

RJH/tr

National Radio Astronomy Observatory
P.O. Box O, 1003 Lopezville Road, Socorro, New Mexico 87801-0387
Telephone: (505) 835-7000 Fax: (505) 835-7027

April 2, 1996

Prof. Hagai Netzer
Tel Aviv University
Wise Observatory
Tel Aviv University
Ramat Aviv, Tel Aviv 69978
Israel

Dear Prof. Netzer:

Thank you for your letter about the proposed project by artist Ezra Orion.

Before committing this observatory to any level of participation or support of the project, we must have a full description of the project, including its goals and complete details of how it will be carried out.

We would appreciate receiving such a description by e-mail or to our postal address:

NRAO
P. O. Box O
Socorro, NM 87801
USA

Thank you for your assistance.

Sincerely,

W. Miller Goss
Director
VLA/VLBA Operations

National Radio Astronomy Observatory
P.O. Box O, 1003 Lopezville Road, Socorro, New Mexico 87801-0387
Telephone: (505) 835-7000 Fax: (505) 835-7027

April 2, 1996

Prof. Hagai Netzer
Tel Aviv University
Wise Observatory
Tel Aviv University
Ramat Aviv, Tel Aviv 69978
Israel

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We would appreciate receiving such a description by e-mail or to our postal address:

NRAO
P. O. Box O
Socorro, NM 87801
USA

Thank you for your assistance.

Sincerely,

W. Miller Goss
Director
VLA/VLBA Operations

1

Midrashat Sde-Boker
International Center for Desert Sculpture
ISRAEL
June 14, 1996

Mr. W. Miller Goss
Director
V.L.A.
U.S.A.

Dear Sir,

Super-Cathedral II

2000

Prof. Hagai Netzer gave me a coppy of your letter of April 2.
I am planning to visit U.S. between August 18 to September 10.
Can we meet in Washington, together with Hagai? After that preliminary step,
I would like to visit the V.L.A. and discuss with you various possible participations in the
'Super-Cathedral II' launch.

Thank you beforehand -

Sincerely,

Ezra Orion
Desert Sculptor

CC: Prof. H. Netzer

National Radio Astronomy Observatory
P.O. Box O, Socorro, New Mexico 87801-0387
Telephone (505) 835-7000 TWX 910 9881710 FAX (505) 835-7027

3 July 1996

Ezra Orion
Midrashat Sde-Boker
International Center for Desert Sculpture
ISRAEL
FAX: 07-558352

Dear Mr. Orion:

Unfortunately, no one from this observatory will be able to meet you in Washington during your visit to the U.S.

We still need, as stated in our letter of 2 April (copy enclosed), a full description of your project, including its goals and complete details of how it will be carried out. Such a description, in writing, will be necessary before we can begin discussions about any participation or support of the project.

You may send the description to me at the postal address above, or by electronic mail to dfinley@nrao.edu.

Sincerely,

David G. Finley
Public Information Officer

Enclosure

cc: Prof. H. Netzer

Midrashat Sde-Boker
International Center for Desert Sculpture
ISRAEL
July 4, 1996

Mr. W. Miller Goss
Director
V.L.A.
U.S.A.

Dear Sir,

Super-Cathedral II

- A slightly delay -

Following my letter of June 14 - I will land in U.S. around August 28 -
Can we meet in Washington, together with Hagai? After that preliminary step,
I would like to visit the V.L.A. and discuss with you various possible participations in the 'Super-Cathedral II' launch.

Thank you beforehand -

Sincerely,

Ezra Orion
Desert Sculptor

CC: Prof. H. Netzer

Midrashat Sde-Boker
International Center for Desert Sculpture
July 22, 1996

Mr. W. Miller Goss
Director
V.L.A.
U.S.A.
FAX: (505)8357027

Dear Sir,

Super-Cathedral II
- A visit in the V.L.A. -

Thank you and David Finley for your letter of July 3.
As I wrote you in my letter of July 4, I planned **to visit** yours after the proposed preliminary talk in Washington - between September 4th - 10th.
So comming there - can we meet for a preliminary dialogue?
"A full description of the project" will hopefully be a result of a **meaningful dialogue** between us, toward the year 2000.
I send you today by post the 'Intergalactic Sculpture' booklet - as a background.
I know the V.L.A. only from photoes. It is realy impressive - -
The preliminary idea about the 'Super-Cathedral II' is to launch the huge energy shafts - by two groups of the 'Wegener Laser Ranging Netwerk' - the first on early morning. 16 April 2000 - from Urope; and the second on early evening of the same day - from North-America - vertically to the gravity plain of the Milky Way - one billion km. tall each - light speed - -
For the nearly 10 hours gap between them we aim to combine several complimentary evants - and one of them is an helicopter screening internationally the V.L.A. - long shadowed before sunset.

- Let us develope it together -

Waiting for your FAX answer -

Ezra Orion
Desert Sculptor
FAX: (972)07-558352

CC: Prof. H. Netzer

National Radio Astronomy Observatory
P.O. Box O, Socorro, New Mexico 87801-0387
Telephone (505) 835-7000 TWX 910 9881710 FAX (505) 835-7027

2 August 1996

Mr. Ezra Orion
Midrashat Sde-Boker
International Center for Desert Sculpture
ISRAEL
FAX: 972-7--558352

Dear Mr. Orion:

We have reviewed your letters of July 22 and July 30, as well as the material you sent describing your "Super-Cathedral II" project. Your project is outside the scope of this Observatory's activities. Accordingly, we have no interest in participating in or endorsing this project. I see no reason to discuss this matter in the future.

While the VLA is a radio observatory, and might not be affected, it appears that your project possibly could raise concerns among optical astronomers using ground-based or orbiting observatories. You might wish to consult with the optical astronomy community on this matter.

Sincerely yours,

Mike Goss

W.M. Goss
Director, VLA/VLBA Operations

Midrashat Sde-Boker
International Center for Desert Sculpture
ISRAEL 84990
August 4,1996

Mr. W. Miller Goss
Director
V.L.A.
U.S.A.
FAX: 001-505-835-7027

Dear Sir,

A Visit in the V.L.A.

Received your FAX of 2 August.

As I explained in my letter of July 30 - there is going to be a gap of about 10 hours between the laser luanch of early morning from Urope to the second one in the late evening from North-America.

The idea was to **enrich** it by several events that will be screened and reported in real-time synchronically by T.V. .

Your 27 passive Radio-Telescopes are **monomental** and the primary idea is to film them from an helicopter, half an hour before sunset - by global T.V. - about 2 hours before the American laser launch.

Prof. Hagai Netzer discussed it with Mr. Havlen on August 1991. It was preliminary approved, for some non-service, maintenence Wednesday.

I plan to visit your site earlier - on 1-2 September - as a regular visitor.
Can we meet then for 20 minutes - hopefully to renew the dialogue.

Waiting for your FAX answer -

E. Orion

Ezra Orion
Desert Sculptor
FAX: (972)7-558352

C.C.: Prof, Hagai Netzer - Astro Physics,
Tel-Aviv University, ISRAEL

3 X

National Radio Astronomy Observatory
P.O. Box O, 1003 Lopezville Road, Socorro, New Mexico 87801-0387
Telephone: (505) 835-7000 Fax: (505) 835-7027

August 5, 1996

Mr. Ezra Orion
Midrashat Sde-Boker
International Center for Desert Sculpture
ISRAEL 84990

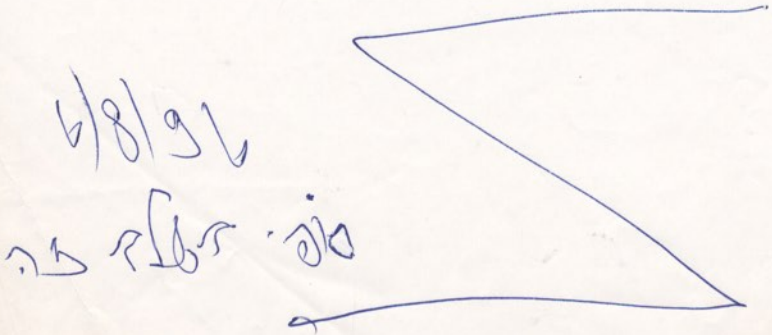
Dear Mr. Orion:

I thought my previous letter was clear. We are not interested in your project. Bob Havlen left NRAO a number of years ago and has no influence to commit NRAO to participation.

The weekend of 31 August is a long weekend in the United States (Labor Day) and I will not be available.

Sincerely,

Director
NRAO-VLA/VLBA Operations



June

Sharon Hayes

001-213-660-8752 L.A.

for Andi

Midrashat Sde-Boker
International Center for Desert Sculpture
ISRAEL 84990
August 7,1996
FAX: 972-7-558352

Sharon Hare
Los Angelos
001-213-660-8752

Shalom,

Visit the 'Very Large Array'

- New-Mexico -

On Friday, 30 August, I am going to meet Mr. Peter Ulrich, Sub-Director of N.A.S.A. in Washington D.C. .

After it, I want very much to visit the V.L.A. near Albuquerke, New-Mexico - sometime arround 1-2 of September.

I don't have an International driving lisence.

Do you know anybody there who could take me there and back?

Many thanks,

Ezra Orion

Roni
Do you think Chris would be interested? Does he have a fax? Perhaps Ezra can contact him. P.S.
Rachamimov knows him & saw his work with Ezra's faith
Love June

NATIONAL RADIO ASTRONOMY OBSERVATORY

ASSOCIATED UNIVERSITIES, INC.

DAVID G. FINLEY

Public Information Officer

Array Operations Center
P.O. Box O
Socorro, NM 87801-0387

(505) 835-7302
Fax: (505) 835-7027
Internet: dfinley@nrao.edu

Sep. 17, 1996

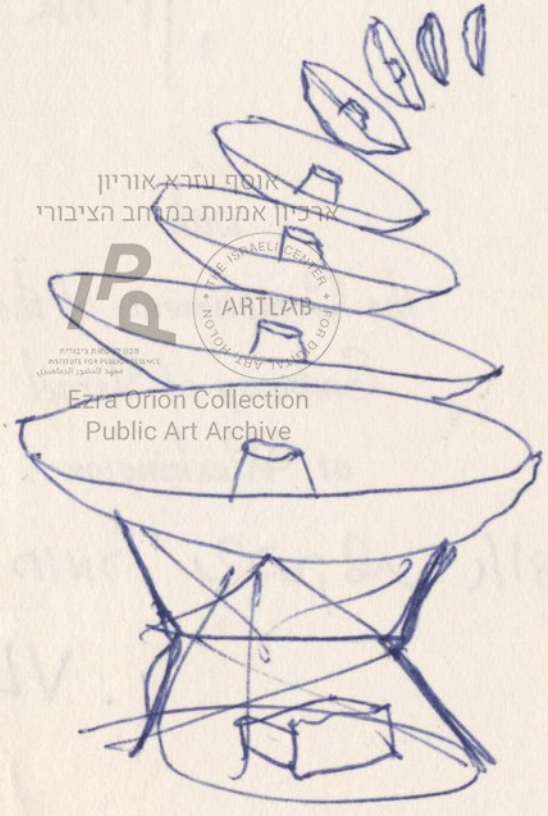
לעזרא אורין,

with
the Compliments of the
Embassy of Israel
at Washington

מצבת התומר שהקים אודות
ה- VLA.

בברכת מאיר חתימה,
טובה,

אפרים



Sep. 17, 1996

לעזרא אורין,

with
the Compliments of the
Embassy of Israel
at Washington

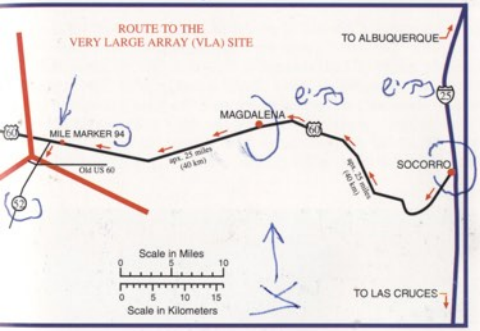
מצבה התואר שביקשת אודות
ה- VLA.

בברכת לאור חתימה,
טובה,

אלישבע

HISTORY OF THE VLA

In the early 1960s it was recognized that astronomical observations at radio frequencies gave physical insight about celestial objects that was complementary to the information one gained from observations with optical telescopes. Design work began on a radio telescope capable of making radio images equal to the best optical images--that radio telescope was the VLA. With $78.6M in funding from the National Science Foundation, VLA construction began in 1974 and was completed in 1981.



VISITING THE VLA

Visitors are welcome at the VLA. The VLA is located on the Plains of San Agustin 50 miles west of Socorro on US 60. From US 60, the site is reached by going 2 miles south along state highway 52 and then turning west on the VLA access road which is well marked. Park at the Visitor Center.

The Visitor Center contains displays which describe radio astronomy and the remarkable VLA telescope. You may see the antennas and the site on a self-guided walking tour. The Visitor Center is open throughout the year from 8:30 a.m. to sunset.

THE NATIONAL RADIO ASTRONOMY OBSERVATORY

Charlottesville, Virginia
Socorro, New Mexico Tucson, Arizona
Green Bank, West Virginia
and from St. Croix, Virgin Islands
to Mauna Kea, Hawaii

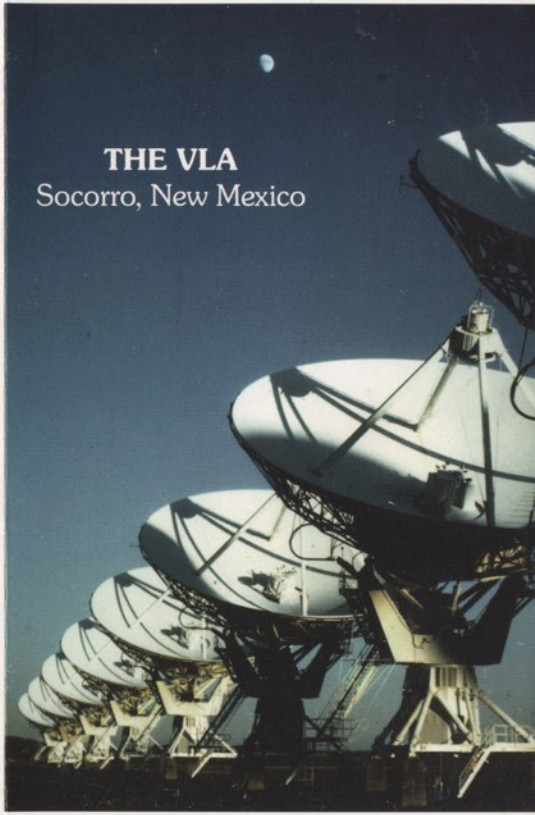
The National Radio Astronomy Observatory operates the foremost radio telescopes for research in the science of radio astronomy. The NRAO was established in 1956 to provide scientists with large radio telescopes necessary for the continued advancement of radio astronomy. The parent site was located in Green Bank, WV, because of its unique shielding from radio interference provided by the surrounding mountains. The establishment of a "radio-quiet zone" further strengthened this asset. The Green Bank Telescope (GBT), to be completed there in 1997, will be the largest fully steerable radio telescope in the world. Headquarters for the NRAO is located in Charlottesville, VA. From Socorro, NM, the NRAO operates both the Very Large Array (VLA) and the Very Long Baseline Array (VLBA). The VLBA consists of ten identical radio telescopes throughout the U.S. from St. Croix, VI, to Mauna Kea, HI. These two aperture synthesis telescopes are used to make detailed radio images of the sky. The NRAO 12 meter millimeter-wave telescope is located on Kitt Peak near Tucson, AZ.

The NRAO facilities are a center for astrophysical research for astronomers from all over the world. Each year more than 850 scientists use the telescopes to detect the weak radio waves coming from space in order to understand the nature of objects such as quasars, pulsars, and black holes. Working with the Observatory staff, they also help design more accurate telescopes, more sensitive electronics, and more powerful computer systems needed for the advancement of the science.

The NRAO is a facility of the National Science Foundation. It is operated under cooperative agreement by Associated Universities, Inc. Observing time on the NRAO telescopes is granted to qualified scientists whose research proposals are the most highly rated in peer-reviewed competition. Astronomers from U.S. Institutions using the VLA are eligible for research support from the NRAO.

THE NATIONAL RADIO ASTRONOMY OBSERVATORY

VERY LARGE ARRAY RADIO TELESCOPE

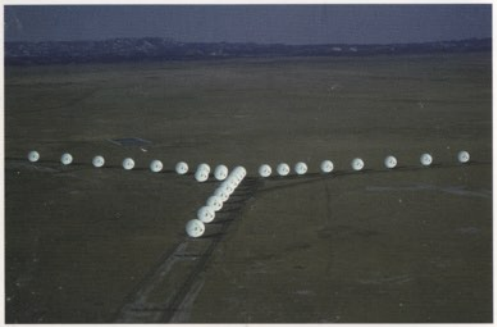


The National Radio Astronomy Observatory is a facility of the National Science Foundation operated under cooperative agreement by Associated Universities, Inc.

THE VERY LARGE ARRAY RADIO TELESCOPE

WHAT IS THE VLA?

The Very Large Array (VLA) is a radio telescope that is used to make images of astronomical objects with a level of detail comparable with photographs made by the world's largest optical telescopes. The VLA receives the naturally-occurring radio waves from planets, stars and galaxies throughout the universe.



HOW DOES THE VLA WORK?

The 27 dish-shaped antennas of the VLA work together to make a radio "picture" or image. The radio waves from the astronomical object being studied are collected, focused and amplified at the antennas. The signals are then transmitted to the control building where the signal from each antenna is combined with the signals from all the other antennas. A computer is used to process the signals and make the radio image.

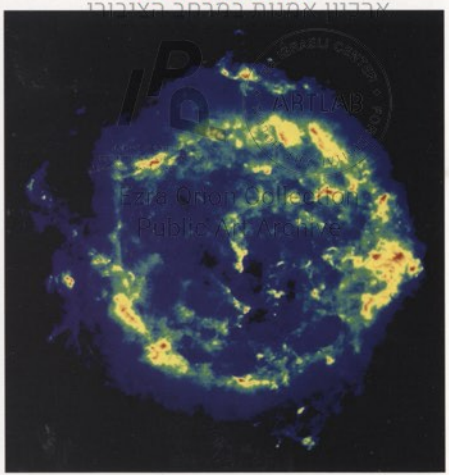
The VLA antennas are movable along rail tracks. When all the antennas are close together the VLA makes images of a large region of the sky; when the antennas are spread out across more than 20 miles of the site the VLA makes very detailed images of a small part of the sky. Moving the antennas from close together to very far apart gives the VLA a "zoom lens" capability.

WHAT IS THE VLA USED FOR?

Astronomers use the VLA images to study the physical processes by which the sun, planets, comets, stars, galaxies and gas clouds throughout the universe produce radio waves. From these studies scientists hope to learn about the nature of celestial objects; how many, how distant and how diverse they are, what their chemical composition might be, and what the relationship is between them.

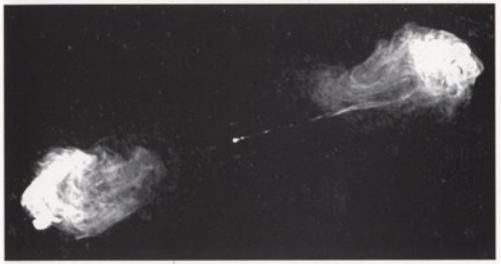
The following VLA images are examples of a few of the objects being studied.

CASSIOPEIA A



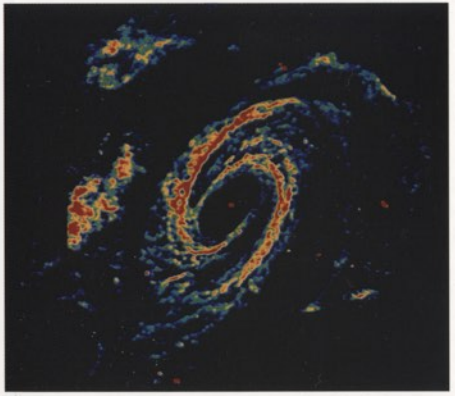
The supernova remnant Cassiopeia A is produced by the ejected material of a star which exploded in 1680. As this material moves outward in an expanding shell with a speed of 10 million miles per hour, it produces radio waves as it collides with the tenuous hydrogen gas in space. The supernova remnant is in our Milky Way galaxy and is 9000 light years away.

CYGNUS A



The radio source Cygnus A is produced in a galaxy 600 million light years away. The radio waves are coming from electrons propelled at nearly the speed of light through a long thin "jet" at the core of the galaxy, and deposited in giant "radio lobes". It is here where the speeding electrons are trapped by the magnetic field around the galaxy to produce radio waves much like the Van Allen belts around the earth. Where did all the electrons come from? From the bright, small radio component in the center of the galaxy - the location of a black hole.

M 81



This is the most detailed radio image ever made of the hydrogen gas in the galaxy M81, located in the constellation Ursa Major. This image shows the relative brightness of radio emission from neutral hydrogen - red represents high brightness and blue low brightness. Both the spiral arms and interarm regions show numerous knots and holes. These knots and holes indicate that the small-scale structure of the galaxy is likely produced by local processes occurring within the galaxy such as star formation and supernova explosions.

A Resource for All of Science

The VLBA is a national research facility, funded by the National Science Foundation. It is open for use by all scientists. Scientists who wish to use the VLBA send proposals to the National Radio Astronomy Observatory, describing what they want to observe and the scientific benefits they expect to gain from the observation. These proposals are sent out to non-NRAO scientists for review and comment. Finally, a time-allocation committee awards observing time based on the relative scientific merit of the proposals, as indicated by the reviewers. This process is typical of national astronomical observatories.

What is Radio Astronomy?

You can read this page because your eyes detect the light reflected from it. Light consists of *electromagnetic waves*. The different colors of light are electromagnetic waves of different lengths.

Visible light, however, covers only a small part of the range of wavelengths in which electromagnetic waves can be produced. Radio waves are electromagnetic waves of much greater wavelength than those of light.

For centuries, astronomers learned about the sky by studying the light coming from astronomical objects, first by simply looking at the objects, and later by making photographs. Many astronomical objects emit radio waves, but that fact wasn't discovered until 1932. Since then, astronomers have developed sophisticated systems that allow them to make pictures from the radio waves emitted by astronomical objects. The VLBA is the latest in a line of increasingly complex radio telescopes.

A number of celestial objects emit more strongly at radio wavelengths than at those of light, so radio astronomy has produced many surprises in the last half-century. By studying the sky with *both* radio and optical telescopes, astronomers can gain much more complete understanding of the processes at work in the Universe.

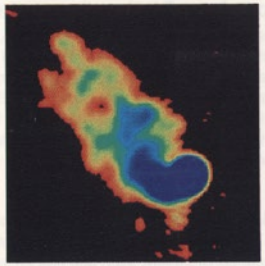
Science with the VLBA

The VLBA's sharp vision, or resolution, is an ideal tool for learning new things about a wide variety of astronomical objects and processes. The VLBA brings the capability for extremely high-resolution radio astronomy to more scientists than ever before.

The VLBA can show new details of the powerful cores of distant quasars, which spew out tremendous amounts of energy. It can make precise measurements of the speed of debris from exploded stars, known as supernovae. It can reduce the large uncertainty that still remains about something as fundamental as the size of our Universe. Closer to home, the precise knowledge of each station's position allows the VLBA to be used by geologists to study the motion of Earth's continental plates and thus the processes that produce earthquakes and volcanoes.

Many of the VLBA's discoveries will be entirely unexpected. Even before becoming operational, the VLBA produced unexpected results, including the discovery of unusual areas of silicon monoxide gas around old stars and a strangely-twisted jet of fast-moving particles coming from the nucleus of a galaxy 300 million light-years distant (below).

The Universe is a laboratory unlike any we can build, with tremendous temperatures, pressures, densities, and powerful electric and magnetic fields. The VLBA is one of our most powerful tools for gaining new scientific knowledge from this natural laboratory.



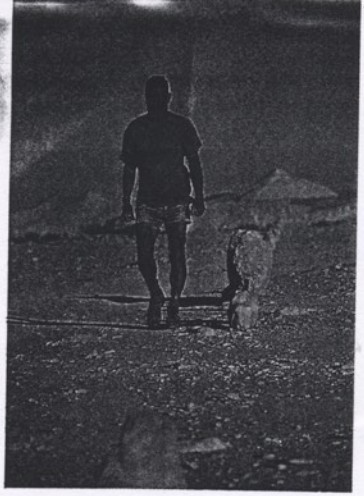
The National Radio Astronomy Observatory is operated by Associated Universities, Inc., under cooperative agreement with the National Science Foundation.

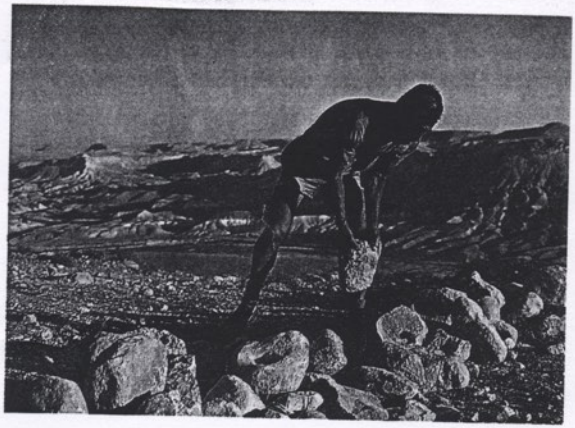
The Very Long Baseline Array (VLBA)

A Continent-Wide Radio Telescope Array

National Radio Astronomy Observatory

Array Operations Center
P.O. Box O
Socorro, New Mexico 87801





AFFACCIANDOSI sull'enorme cratere Ramon, l'impressionante erosione della crosta terrestre che taglia in due il deserto del Negev, in Israele, Ezra Orion immagina di trovarsi di fronte all'immensa valle Marineris che il satellite americano Viking 1 ha fotografato su Marte nel 1976. Immobile sul dirupo che scende a picco nel cratere, Orion fissa lo sguardo verso un punto infinito. La forza di quel deserto sterminato è la stessa che gli permette di proiettare i suoi progetti futuri verso lo spazio, e, dallo spazio, sul pianeta Marte. E Marte appare, in questo luogo sperduto e straordinario, la meta naturale di quasi cinquant'anni di lavoro, pensieri, filosofia, arte e scultura.

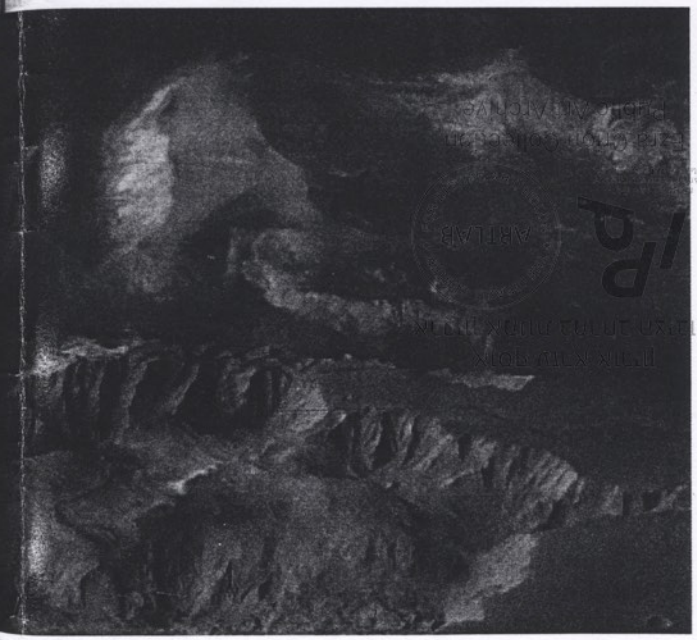
In fondo è così, in un modo assolutamente semplice, che questo scultore definitosi per anni "desertico" ha lanciato una sfida "spaziale" e "intergalattica" assai più grande di se stesso e dell'uomo. Ezra Orion ha infatti proposto alla Nasa di portare la prima scultura umana su Marte. Dal deserto del Negev, dove vive dal 1967, l'artista è partito in questi mesi alla volta dei Jet Propulsion Laboratories di Pasadena, California, per sottoporre agli scienziati il sogno che coltiva dal 1982: impiegare il *Mars-rover*, un robot telecomandato allo studio per future missioni spaziali, come strumento

per disporre una fila di pietre perpendicolarmente all'orlo dello strapiombo della valle Marineris che taglia per 4.000 chilometri l'equatore di Marte, seguendo le indicazioni che lo stesso Orion dovrebbe impartire dalla base a Terra.

"Sono sculture gli altopiani tettonici, le spaccature tra continenti, la collisione e il sollevamento di crinali montuosi, il piegarsi della crosta terrestre", spiega lo scultore israeliano mostrando le antichissime forme geologiche che ci circondano. "Plasmando masse infinitamente piccole con un'abilità minuta, l'uomo si unisce per una frazione di secondo a questi processi cosmici".

Dalla "geo-estasi" quale esperienza esistenziale alle stesse, il passo pare, a sentire Orion, ancora più ovvio. "La ricerca astronomica ha allargato il nostro sguardo sull'universo a galassie infinitamente lontane, a miliardi di 'sistemi solari'. I miei progetti, legati allo spostamento delle rocce e allo sfruttamento della luce del Sole, sono una sintesi tra il rispetto della natura e la stima per l'uomo, che ne fa parte".

Rocce e un robot per scolpire nelle valli marziane



Sopra: l'immagine di Marte ripresa dalla sonda spaziale Viking ed elaborata al computer mostra l'imponente sistema di canyon della valle Marineris nei suoi colori naturali. *A sinistra:* Ezra Orion davanti alla foto della simulazione dell'intervento che dovrà realizzare, sul suolo di Marte, una "linea di pietra". Il *Mars rover* comandato da Terra dall'artista disporrà le pietre sul bordo del precipizio della valle Marineris. Un'opera che Orion sta simulando oggi con altre rocce, quelle di Sde Zin, nel deserto israeliano del Negev, tra le quali Orion vive e lavora ogni giorno *(in alto).*

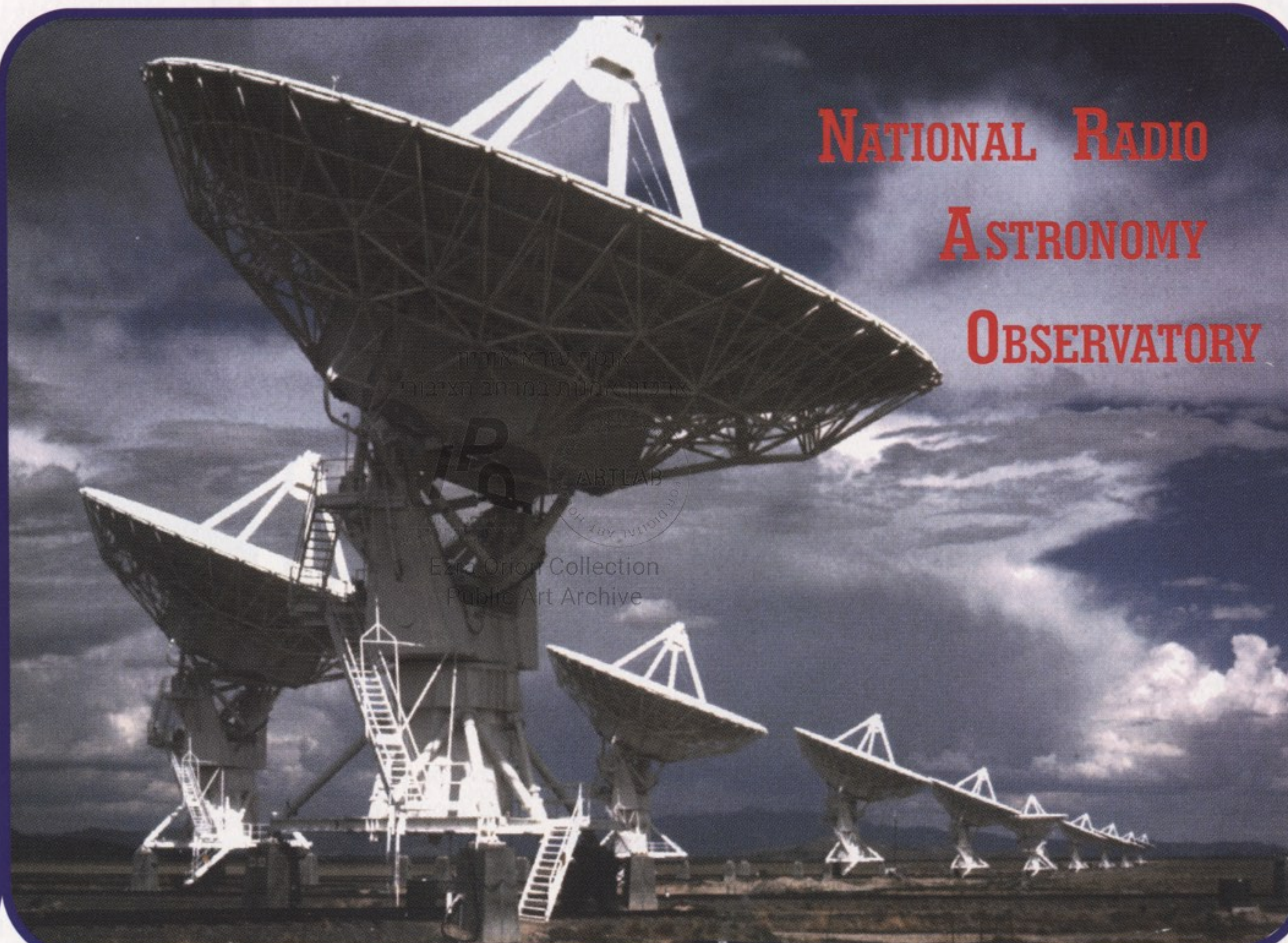
Nato in un kibbuz della Galilea 62 anni fa, fisico da atleta, roccia tra le rocce, Ezra Orion sembra l'Icaro del 2000. Le sue sculture, seminate tra i deserti di Israele e sulle pendici dell'Annapurna, in Nepal, sono forme piene di forza fatte di pietre o metalli abbandonati – come le vecchie rotaie della ferrovia ottomana che passava nelle vicinanze della città di Haifa, dove Ezra visse da giovane – di sabbia o roccia chiara. Assomigliano a tanti decolli, simbolizzano un lancio verso l'alto, verso la luce.

Sulla luce Ezra ha concentrato il suo impegno creativo in attesa di concludere l'accordo con la Nasa e realizzare il suo sogno marziano. "La luce, che noi vediamo come lampo effimero è un mezzo di comunicazione intergalattica che permette di immaginare fantastici viaggi nel tempo e raggiungere distanze remote nello spazio", spiega Orion.

La notte del 22 giugno 1989 l'artista ha fatto partire dalla base spaziale israeliana di Bar Giora un "super obelisco" di luce lungo un miliardo di chilometri, tenendo acceso un raggio laser diretto verticalmente rispetto al piano della Galassia per 55 minuti e 33 secondi. Nell'aprile del 1992 ha organizzato la "super cattedrale" nello spazio: fasci di luce laser sono stati lanciati simultaneamente in verticale dalle basi europee e americane del Wegener Laser Ranging Network (una rete mondiale di proiettori laser utilizzati per verificare la "deriva dei continenti"). Oggi lo scultore prepara un'altra scultura laser, "i cui fasci di luce collegheranno entro il 2020 la Terra alla Luna, a Marte e al Sole".

Tra i tanti apprezzamenti ricevuti, a Orion piace ricordare le parole che nel 1995, davanti all'assemblea plenaria delle Nazioni Unite, gli ha dedicato l'ex-ministro degli Esteri israeliano Shimon Peres. "L'idea di estendere la scultura al sistema solare", ha detto Peres, "è prodotto di una grande audacia artistica, simile alla nostra audacia nell'aver aperto una via di pace". Da allora la pace sembra un po' arenata. Non così i progetti di Orion.

VERY LARGE ARRAY
VISITOR BROCHURE



The VLBA

Background and Details

The Very Long Baseline Array

National Radio Astronomy Observatory

NRAO Array Operations Center
Socorro, New Mexico

A System of Superlatives

The VLBA *-- It's the world's largest dedicated astronomical instrument, spanning 5,000 miles from Hawaii to the Virgin Islands. Its radio "vision" is sharp enough to read a newspaper in New York from the distance of Los Angeles. Its atomic clocks are accurate within one second in a million years. Its state-of-the-art radio receivers are cooled to within a few degrees of absolute zero to detect radio signals billions of times weaker than those of ordinary communication systems. Its superfast tape recorders pack as much information in just 2/5 of an inch of tape as your PC does on an entire floppy disk. Its central computer can perform 750 billion multiplications every second.*

These elements combine to provide scientists with the best resolution -- the sharpest images -- of any telescope on earth or in space. The VLBA is providing valuable new insights into such questions as: how stars are born and die; how galaxies evolve; what the early Universe was like; and just how old and how big is our Universe? Astronomy, however, is not the only beneficiary of the VLBA's tremendous capability. The VLBA can provide greatly improved information that will contribute to research on global climate changes, earthquake prediction, and improved spacecraft navigation.

Radio Astronomy: A Science of Revolutionary Revelations

Though radio astronomy is little more than 50 years old, it has revolutionized our understanding and concepts of the universe. Almost everything we know about the universe beyond our solar system was learned by studying and analyzing *electromagnetic radiation* arriving at the Earth from distant astronomical bodies. Electromagnetic radiation comes in many forms, including the light our eyes see, the radio waves that bring us music and pictures from broadcast stations, the ultraviolet that tans (and damages) our skin, the infrared that we feel as heat, the X-rays that doctors use to look inside our bodies, and the gamma rays that can be deadly. All these forms of electromagnetic radiation differ by the lengths of their waves and make up what scientists call the *electromagnetic spectrum.*

The visible light that we see constitutes only a small percentage of the electromagnetic spectrum, but, until the advent of radio astronomy in the 1930s, it was the only part of the spectrum that astronomers were able to use in their studies of the cosmos. Radio astronomy provided scientists with a whole new window on the universe. Observing the universe with radio telescopes reveals evidence of processes that had been unknown through the entire history of optical astronomy. Because of radio astronomy, we now have a much more complete understanding of our universe, its past history, the possibilities for its future, and the fascinating objects that make it up, than would ever have been possible with optical astronomy alone. Radio telescopes have shown that our universe is filled with phenomena of power and violence that were unimagined a half-century ago.

Today, astronomers have viewed the universe using telescopes able to "see" nearly all parts of the electromagnetic spectrum. Electromagnetic waves in the visible and radio parts of the spectrum (and some infrared waves) are the only ones able to pass through Earth's atmosphere well enough to be observed on

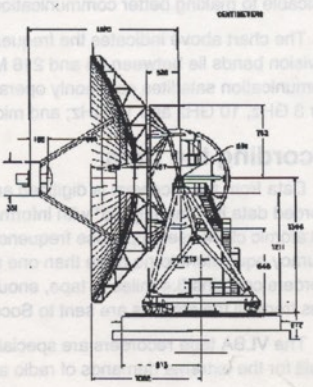
Because of the important, exciting work that requires VLBI, the National Radio Astronomy Observatory has built the Very Long Baseline Array (VLBA), a set of ten identical radio telescopes distributed across United States territory from Hawaii to the Virgin Islands. The VLBA was designed from the start to operate as a single instrument, providing a dedicated facility for VLBI observations and making VLBI much more easily accessible to astronomers from a wide variety of subspecialities. With a maximum baseline of 5,000 miles, the VLBA is the largest dedicated astronomical instrument in the world. It offers astronomers the ability to observe celestial objects with a resolution of less than a thousandth of a second of arc -- sufficient to read a newspaper in New York from the distance of Los Angeles. The VLBA provides unparalleled versatility for high-resolution observations and is a national instrument open to all scientists in the U.S. and abroad.

From the Mountaintops to the Seashore -- The Ten VLBA Stations

The drawing at left shows the locations of the ten VLBA stations -- from St. Croix in the Caribbean to the lofty height of Mauna Kea on Hawaii. These locations were carefully chosen to make the VLBA an effective scientific instrument while minimizing the costs of construction and operation. All the sites are on U.S. territory. Each site is important to the whole system's performance. The configuration of the ten sites provides both long and intermediate-length east-west and north-south baselines. In addition, the sites in the Southwest offer shorter baselines when combined with the existing VLA and also provide high, dry locations needed for some of the shorter-wavelength observations. Careful surveys of many potential sites were made and the ten selected were chosen because they met the scientific objectives of the VLBA while providing relatively easy access, acceptable climate, and, in some cases, proximity to existing astronomical facilities and their support organizations. The sites also were chosen to minimize radio interference from broadcast stations, industrial and other two-way radio systems, and power lines.

Each installation is identical to all the others -- all the control buildings were built from the same blueprints. Each has identical computers to control the antenna and receivers and identical-format tape drives. Since the stations are operated remotely from Socorro, New Mexico, each has a weather station to alert the operators to high winds, snow, and other conditions that could hamper observations or endanger the antenna. If such conditions occur, the antenna is "stowed" in a safe, straight-up position.

In addition to the VLBA, there is a world-wide distribution of radio telescopes that can be used for VLBI observations. The VLBA will work in conjunction with many of these for special observations. This is particularly important to obtain more and longer baselines and when an astronomical object must be observed on a 24-hour basis -- other observatories can observe it when it is below the horizon for VLBA telescopes. The VLBA routinely operates in conjunction with telescopes in Europe, Australia, and other locations worldwide. In addition, the VLBA will be an important part of space VLBI observations using orbiting radio telescopes planned for the mid 1990s.

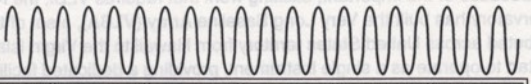


The VLBA's Antennas

The VLBA antennas collect the radio waves from the astronomical objects. The path a signal follows through its processing by the VLBA is illustrated in the diagram on the back page. The VLBA antennas were designed to provide the maximum in efficiency, accuracy and reliability. Each antenna is fully steerable, can point anywhere in the sky, and can move rapidly between different observing targets. The VLBA antennas, parabolic dishes 25 meters (82 feet) in diameter, were designed with an advanced support structure that allows operation at

VLBA Radio Receivers

Wavelengths and Frequencies



90 cm	50 cm	20 cm	13 cm	6 cm	4 cm	2 cm	1 cm	7 mm
330 MHz	610 MHz	1.5 GHz	2.3 GHz	4.8 GHz	8.4 GHz	15 GHz	23 GHz	43 GHz

higher frequencies (shorter wavelengths). This is important for two reasons. First, shorter wavelengths mean better resolution, always an important goal. Second, some important molecules found in space emit radio waves of these shorter wavelengths, and the ability to receive those shorter waves thus allows astronomers to discover new information about a variety of cosmic objects. In order to effectively receive shorter waves, the antenna structure must be constructed to closer tolerances and also must retain its shape under the stresses of gravity and wind. The VLBA antennas were designed with all this in mind.

Receiving the Radio Waves

Radio astronomy receivers must be extremely sensitive -- the signals received from astronomical sources are typically millions or billions of times weaker than those received from ordinary communication systems. In order to achieve this type of sensitivity, the noise -- like the "hiss" you hear in your radio when tuning between stations -- must be reduced. Most of this noise comes from within the receiver itself, caused by the motions of the atoms in the transistors. This motion, and thus the noise, can be reduced by cooling the receiver. (Remember that at absolute zero, -273 C or -459 F, atomic motion ceases.) The VLBA receivers are cooled to a temperature of 15 Kelvin or -432 F. To do this, we use refrigerators that work on the same principle as your home refrigerator -- a gas is compressed, and when the pressure is released, the gas expands and cools. You often experience this effect when holding a can of spray paint. As the pressure is released in the can, the gas expands and the can feels cool to you. The VLBA cryogenic refrigerators use Helium as the expanding gas instead of the Freon your home refrigerator uses.

The VLBA radio receivers were constructed by NRAO and represent the state of the art in microwave radio receiving systems. Radio astronomy has a long history of driving technical developments in receiving systems. Much of the technology in the widely-used satellite communication systems of today has its roots in radio astronomy laboratories. Tomorrow's satellite systems will likewise be more efficient and useful to millions of people because radio astronomers' need for ever-better equipment is producing technology applicable to making better communication systems.

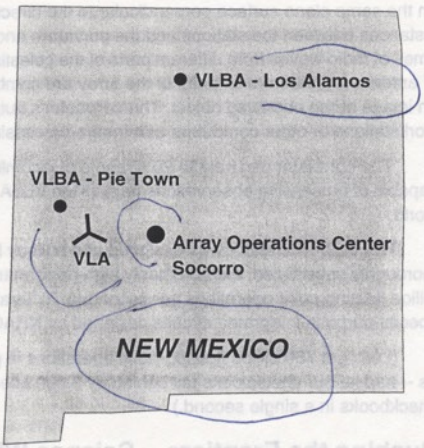
The chart above indicates the frequency bands of the VLBA stations. For comparison, the VHF television bands lie between 54 and 216 MHz; the UHF television bands are between 470 and 806 MHz; communication satellites commonly operate near 4 GHz, 7.5 GHz, and 11 GHz; radar uses frequencies near 3 GHz, 10 GHz and 16 GHz; and microwave ovens operate at about 2.5 GHz.

Recording the Data

Data from the receivers is digitized and recorded on magnetic tapes at each VLBA station. The recorded data is "time-tagged" with information from an extremely accurate hydrogen maser atomic clock. This atomic clock uses a precise frequency of radio emission from the hydrogen atom to produce an accuracy equivalent to no more than one second's error in a million years. Each reel used by the VLBA recorders contains 3.4 miles of tape, enough to record the data from nearly 12 hours of observations. The tapes from all the stations are sent to Socorro where the processing and analysis of the data are done.

The VLBA tape recorders are special-purpose machines, based on commercial units but essentially rebuilt for the extreme demands of radio astronomy. They represent the cutting edge of magnetic-tape

recording technology. Some of their advanced features include ultra-narrow recording heads and advanced control electronics. These recorders write 504 tracks across the width of a one-inch tape. They pack more than 3.5 MegaBytes of information on an inch of tape. (Compare this to 1.44 MegaBytes on a high-density 3.5-inch floppy disk.) Each VLBA station has two of these recorders.



Array Operations Center, Socorro

The Array Operations Center (AOC) in Socorro, New Mexico is headquarters for the VLBA as well as for the Very Large Array (VLA) radio telescope, which is 52 miles west of Socorro. Completed in 1988, the AOC is located on the campus of the New Mexico Institute of Mining and Technology (New Mexico Tech), a 104-year-old institution offering undergraduate and graduate degrees, primarily in the physical sciences. The AOC was constructed with financial assistance from the State of New Mexico.

About 180 staff members work at the AOC, which includes the VLBA control room, offices for management and administrative personnel, electronics laboratories, and offices for nearly 40 staff astronomers who manage the facilities, develop long-range upgrade programs for the VLBA and VLA, assist and train visiting astronomers in using the radio telescopes, and pursue research programs in radio astronomy.

From the VLBA control room at the AOC, operators can control each of the VLBA stations, performing such operations as pointing the antenna, changing from one wavelength band to another, and starting and stopping the tape recorders. The control room in Socorro and each VLBA station are connected by computer network links. Computers at each station relay information on the station's status to the control room.

Though normal operations are controlled from the AOC, any facility as complex as a VLBA station does, however, require people on-site. There is a large amount of equipment, both electronic and mechanical, that requires regular attention and maintenance. In addition, tapes must be mounted and removed from the tape recorders, and completed tapes sent to Socorro. Each VLBA station has two full-time employees, highly-qualified technicians who are responsible for the smooth operation of their state-of-the-art facility. The VLBA is a 24-hour, seven-day-a-week operation, and the site technicians are on call to respond whenever equipment difficulties may require their presence.

Assembling the Data -- The VLBA Correlator

The VLBA *correlator* is a special-purpose high-performance computer where data from all ten VLBA stations are combined to yield the information from which astronomers produce images of celestial objects as if from a single giant antenna 5,000 miles wide. It receives data from all stations through a bank of VLBA tape recorders. Tapes from all stations are played back simultaneously, and, through the precise "time tags" placed on the tapes by the hydrogen maser atomic clocks at each station, the observation is essentially re-created for the correlator.

Signals from different stations are manipulated mathematically to make it appear that all stations are

on the same plane surface perpendicular to the direction toward the object observed, despite the great distances between the stations and the curvature and rotation of the earth. Tiny differences in the arrival times of radio waves from different parts of the celestial body modify the combined signal detected by pairs of antennas. Data from all pairs of the array are combined to produce the information necessary to make an image of the observed object. The correlator's output can then be used by astronomers with workstations or other computers with image-processing software.

The correlator can handle 20 streams of incoming recorded station information at a time, so it is capable of processing observations from all ten VLBA stations plus 10 other VLBI stations elsewhere in the world.

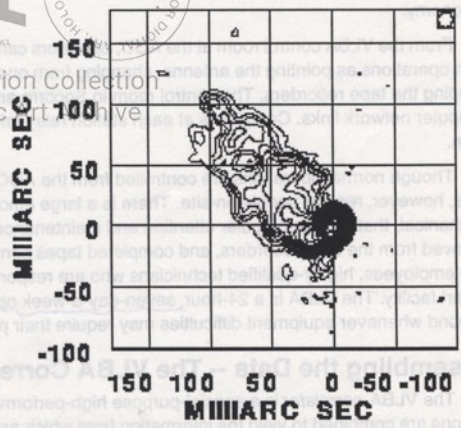
The VLBA correlator was designed and built by NRAO scientists and engineers. It is in effect a thoroughly specialized, extraordinarily high-performance computer, operating routinely at a speed of 750 billion floating point operations per second (0.75 TeraFLOP). A one-of-a-kind machine, it incorporates special-purpose integrated circuits designed by NRAO and manufactured under contract.

(Let's put 750 billion floating-point operations in perspective. If everyone in the U.S. -- 250 million of us -- had let our checkbooks fall behind by 3,000 checks, 0.75-TeraFLOPS would balance all those checkbooks in a single second.)

Pushing the Frontiers -- Science With the VLBA

Over its lifetime, the VLBA will dramatically improve our knowledge of a wide variety of astronomical phenomena, and also will make valuable contributions to research areas important to understanding the Earth we live on.

As a dedicated instrument, the VLBA is able to monitor astronomical radio sources that are variable on timescales of days to weeks to months. Such monitoring is a routine part of operations, performed without the need for special arrangements among several observatories. This capability has yielded detailed day-to-day information about outbursts of an X-Ray nova, for example. Similarly, the VLBA can respond quickly when events such as supernova explosions require immediate observation to avoid missing valuable scientific data. The VLBA was used to obtain valuable data about the early stages of Supernovas 1993J and 1994I. In addition, because the entire VLBA system is designed to operate 24 hours a day, 7 days a week, astronomers are able to obtain images of large numbers of celestial objects that cannot be resolved without VLBI, providing a wealth of new information about these objects.



The galaxy Markarian 501's twisted jet, nearly 400 million light-years distant. VLBA image by J.M. Wrobel and J.E. Conway.

The VLBA has brought astronomers new capabilities to observe regions with extreme differences in the radio "brightness" -- high dynamic range observations. In fact, some of the first images produced by the complete VLBA system were the highest-dynamic-range VLBI images ever made. Because all of the VLBA stations are identical, and because of the technical capabilities of the stations, it has become much easier for astronomers to make highly-detailed maps of the polarization of radio sources.

All these capabilities are being turned to work on some of the greatest challenges facing astronomers -- including attempts to understand the nature of quasars and the powerful nuclei of galaxies; studies of pulsars, supernova remnants, and other phenomena within our own Galaxy; studies of the life cycles of stars; and direct trigonometric measurements of greater distances than possible before, thus refining our understanding of the scale of the universe. In addition, the history of astronomy shows that new instruments with improved capabilities nearly always yield surprising information that was unexpected by their builders. The VLBA will undoubtedly be no exception.

The applications of Very Long Baseline Interferometry are not limited to astronomy; indeed, VLBI is a major contributor to some very down-to-Earth research with potential benefit to millions of people. The Earth's solid surface is composed of giant *plates* of rocky crust that "float" atop the semi-fluid and slowly-moving *mantle*. Where these plates meet each other is where most of the Earth's violence -- in the form of earthquakes and volcanoes -- occurs. In order to better understand the processes that bring about these violent events, geophysicists need to have better measurements of the actual movements of the crustal plates. This is where VLBI can help.

Just as VLBI techniques provide greater resolution to astronomers looking for fine detail in celestial bodies, these techniques can be "turned around" to provide extremely fine measurements of the baselines between VLBI stations. By using extremely distant quasars as an ultra-stable reference system, the distance between VLBI (and VLBA) stations can be measured to an accuracy of about one centimeter. By making measurements among multiple stations over several years, the changing positions of those stations with respect to each other can be tracked -- thus indicating the motion of the continental plates on which they sit. This gives geophysicists the detailed information that they use to test theories in a number of fields, including the still-infant field of earthquake prediction.

Building the VLBA

Long a dream of radio astronomers, the VLBA began its road to reality with the formal submission of a proposal for the instrument in May of 1982. Design of the VLBA was authorized in 1984 and construction was authorized in 1985. Construction began on the first station, at Pie Town, in February of 1986, and the last station, at Mauna Kea, was completed in April of 1993. The first scientific observations were made with the partially-completed VLBA in October of 1987. On 29 May 1993, the VLBA made its first astronomical observation with all ten stations recording scientific data. The VLBA was officially opened on 20 August 1993.

Further Reading:

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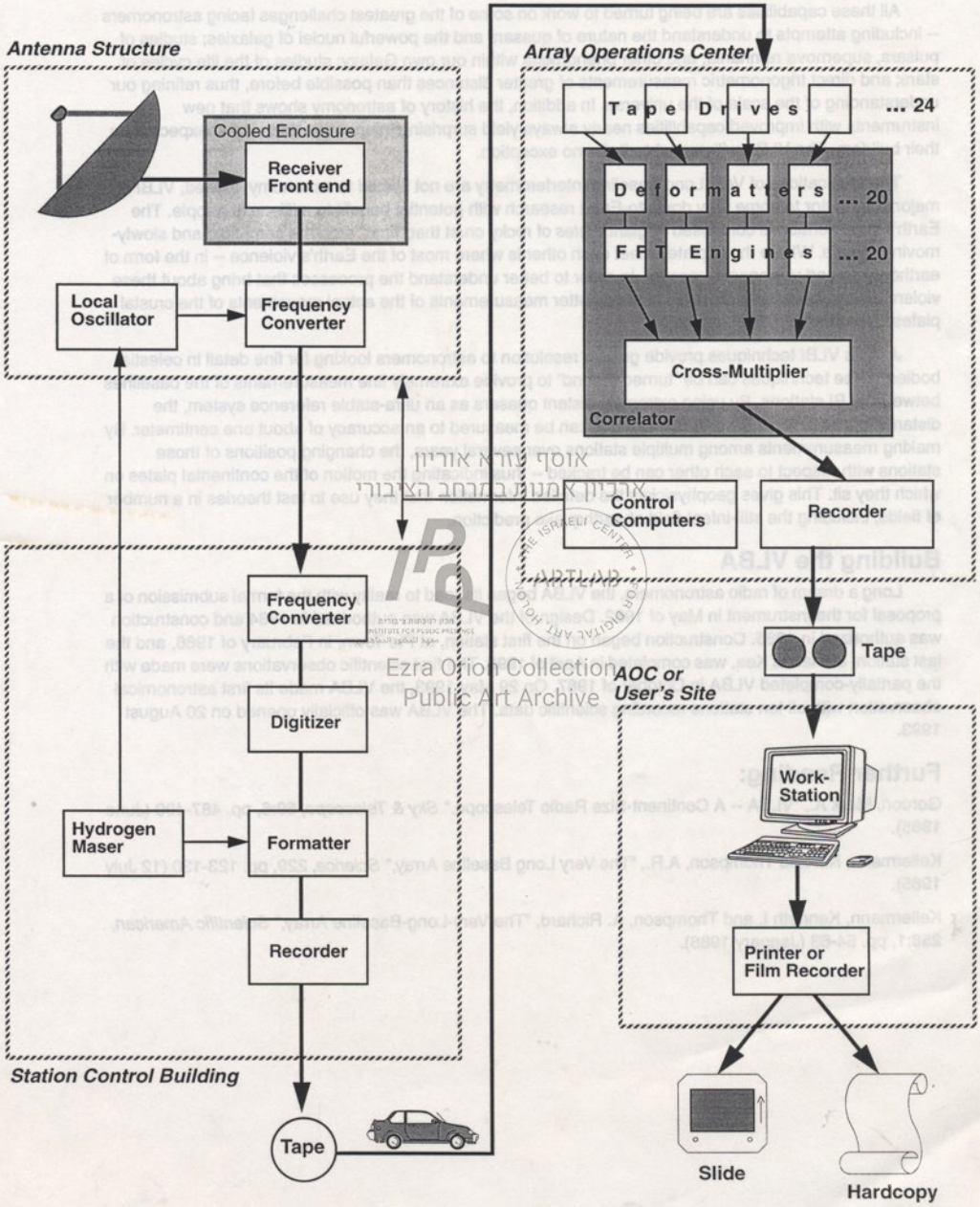
From Sky to Slide -- The Parts of the VLBA



Services for Educators

National Radio Astronomy Observatory
Socorro, New Mexico

The National Radio Astronomy Observatory

The National Radio Astronomy Observatory (NRAO) is a nonprofit research organization operated by Associated Universities, Inc., and funded by the National Science Foundation. With headquarters in Charlottesville, Virginia, NRAO operates radio telescope facilities at Green Bank, West Virginia; Tucson, Arizona; and Socorro, New Mexico.

What We Do

NRAO provides state-of-the-art radio telescope facilities for use by the scientific community. We conceive, design, build, operate and maintain radio telescopes used by scientists from around the world. Scientists use our facilities to study virtually all types of astronomical objects known, from planets and comets in our own Solar System to quasars at the edge of the known universe.

NRAO in New Mexico

NRAO operates two radio telescopes in New Mexico -- the Very Large Array (VLA) and the Very Long Baseline Array (VLBA). The administrative and scientific headquarters for both these instruments is the Array Operations Center, which is located on the campus of New Mexico Tech in Socorro. The VLA, with 27 large dish antennas, is located 52 miles west of Socorro on U.S. 60. The VLBA is a continent-wide system of ten antennas ranging from Hawaii to the Virgin Islands. Two of the VLBA antennas are in New Mexico, at Pie Town, west of the VLA, and at Los Alamos. The entire VLBA is controlled from facilities at the Array Operations Center in Socorro.

NRAO -- A Resource for Education

With world-class research facilities and a staff of more than 200, including scientists, engineers, computer specialists and technicians, NRAO-New Mexico represents an important resource for educators seeking assistance and supplementation for scientific and technical curricula. Among the educational services we offer are:

VLA Visitor Center and Tours -- The Visitor Center at the VLA site is open from 8:30 a.m. to sunset every day, and includes an automated slide show and self-guided tour. Though there is no staff at the Visitor Center, we can often arrange a guided tour for educational groups, with at least two weeks' notice.

Speakers -- Our staff includes scientific, engineering and technical professionals from a wide range of backgrounds. We can provide speakers for classrooms or school groups on topics including astronomy, electronics, careers in science, and others. Please ask about speakers a month before your need.

Literature -- NRAO can provide literature about radio astronomy and our instruments to assist educators in preparing lectures and lesson plans.

Information About Science -- Planning an instructional unit on space, astronomy or electronics? Have questions about science or technology? Don't know where to find information? Call NRAO -- we don't have all the answers, but we usually will be able to point you in the right direction!

There is no charge for these services. For more information, or to arrange a tour or speaker, call the **NRAO Public Information Office** at (505) 835-7000.

National Radio Astronomy Observatory (NRAO), P.O. Box O, Socorro, NM 87801

The National Radio Astronomy Observatory is Operated by Associated Universities, Inc., under cooperative agreement with the National Science Foundation.

Some Facts About the... Very Large Array

General

The National Science Foundation's Very Large Array is a radio telescope using 27 antennas arranged in a "Y" shape on the Plains of San Augustin 50 miles west of Socorro, NM. All 27 antennas usually work together as a single instrument. Each antenna uses a parabolic dish 25 meters (82 feet) in diameter, and weighs 230 tons. The antennas are placed in four standard configurations, with the maximum antenna separation ranging from 1 km to 36 km. The configuration is changed approximately every four months by using special transporter vehicles to move the antennas along dual sets of railroad tracks and place them on concrete pads distributed along the arms of the "Y." The VLA is used to produce images of the sky as seen at radio wavelengths. Both the pointing and the data collection of the antennas are controlled by computers in real time. Initial processing of the collected data is done in real time on-site, with calibration, post-processing and image production done later, either at VLA facilities or at the astronomer's home institution. The VLA is one instrument of the National Radio Astronomy Observatory (NRAO). The NRAO is a facility of the National Science Foundation, operated under cooperative agreement by Associated Universities, Inc.

Frequency Bands and Wavelengths

P Band	L Band	C Band	X Band	U Band	K Band	Q Band
70-75 MHz	300-340 MHz	1.34-1.73 GHz	4.5 - 5.0 GHz	8.0-8.8 GHz	13.3-15.4 GHz	22-24 GHz	40-50 GHz
400 cm	90 cm	20 cm	6 cm	3.6 cm	2 cm	1.3 cm	7 mm

Sensitivity

Radio astronomy depends upon receiving extremely weak signals from celestial objects. The signals detected by the VLA and other radio telescopes are millions or even billions of times weaker than those used for communication systems. For example, a tiny, 100-milliwatt transmitter using an omnidirectional antenna (similar to those used to control toy cars) placed on the moon would produce a signal on Earth that would be considered quite strong by radio astronomers.

Resolution

The VLA's resolution varies with the array's configuration and with the wavelength being observed. The larger configurations provide greater resolution than the smaller ones and the shorter wavelengths (higher frequencies) provide greater resolution than the longer wavelengths. Depending on frequency, each antenna's beam size ranges from 10 degrees of arc to 2 minutes of arc. The width of the synthesized beam using the entire array ranges from 25 seconds of arc to 0.08 second of arc.

Users and Their Research

The VLA is used by scientists from around the world whose research spans an extremely wide range of areas. *The Economist* magazine described the VLA as "one of the most productive observatories of the past decade." Though the VLA operates 24 hours a day, seven days a week, there are more requests for its use than can be filled. Astronomers who wish to use the VLA submit proposals outlining their research projects. Observing time on the VLA is awarded to proposers based on scientific merit of the projects and their ability to effectively use the VLA's capabilities.

Research projects pursued using the VLA cover the range of objects found in the Universe. VLA observations can yield valuable information about our own Earth as a planet and about quasars, the most distant bodies in the Universe, billions of light-years distant. Between these extremes, the VLA is used by solar physicists to study the sun, by planetary scientists to study other planets in our solar system, and by astronomers studying "neighbor" stars in our Milky Way galaxy. Astronomers also use the VLA to study the mysterious inner portion of the Milky Way, giant gas clouds where new stars are forming, and galaxies from a few million light-years to several billion light-years away.

The VLA was used to receive faint radio signals from the Voyager spacecraft as it passed Neptune in 1989. In 1995, the VLA received signals from the Galileo probe as it plunged into Jupiter's atmosphere. Though the VLA is purely a passive receiving system with no transmitters of its own, it is regularly used as a receiver for experiments in planetary radar astronomy. These experiments use powerful transmitters in California to send signals to planets, moons, comets and asteroids, then receive the reflected radio waves at the VLA to provide new information about these bodies. Radar astronomy projects using the VLA have revealed new details of objects including Mercury, the closest planet to the sun, and Saturn's moon, Titan, nearly a billion miles from Earth.

NRAO

Radio Astronomy in New Mexico: The VLA and VLBA

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Radio Astronomy in New Mexico: The VLA and VLBA

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Abstract

New Mexico is host to two of the world's premier radio astronomy facilities, the Very Large Array (VLA) and the Very Long Baseline Array (VLBA), operated by the National Radio Astronomy Observatory for the National Science Foundation. These instruments, open to the scientific community on a peer-review basis, are extremely versatile resources, capable of supporting a wide range of research programs within astronomy, planetary science and geophysics. The technical capabilities and research applications of these instruments are reviewed. Future plans include use of the VLBA in conjunction with orbiting radio observatories and a major upgrade for the older VLA.

Introduction

The Very Large Array (VLA) and the Very Long Baseline Array (VLBA) are two of the most important instruments available to the world's radio astronomers. The VLA, dedicated in 1980, has compiled an enviable record of scientific achievement and demonstrated tremendous versatility as a research tool. The VLBA, dedicated in 1993, already has begun to make landmark contributions to our understanding of the universe.

Both these instruments of the National Radio Astronomy Observatory are facilities of the National Science Foundation, provided at no cost to the scientific community. Observing time is allocated on the basis of peer review. The instruments serve researchers in a wide variety of scientific specialties and from hundreds of institutions around the world. A significant percentage of observing time is provided to graduate students for thesis work, thus making these instruments important resources for training future generations of astronomers.

* The National Radio Astronomy Observatory is operated by Associated Universities, Inc., under cooperative agreement with the National Science Foundation.

The administrative and scientific headquarters for both instruments is the Array Operations Center (AOC), a building located on the campus of the New Mexico Institute of Mining and Technology in Socorro. The AOC houses electronics laboratories where equipment for both the VLA and the VLBA is constructed and maintained. In addition, the AOC contains the control room from which the ten stations of the continent-wide VLBA are remotely operated.

The VLA is located 52 miles west of Socorro, on U.S. Highway 60. It is operated from a control room on the site. A number of maintenance facilities also reside on the site. There is a Visitor Center at the VLA, open every day from 8:30 a.m. to sunset, and more than 15,000 tourists take advantage of its free displays and self-guided walking tour every year.

Of the 600 to 800 scientists who are part of research teams using the VLA and VLBA each year, approximately 400 will come to the AOC. These visiting scientists come to New Mexico to prepare for and monitor their observing runs and to use the AOC's computing facilities for data reduction and image processing.

The Very Large Array

The VLA was conceived in the 1960s and built in the 1970s with the aim of producing a very versatile and sensitive radio telescope with angular resolution comparable to that of the best ground-based optical telescopes (1). The VLA was dedicated in 1980. The VLA (and the VLBA also) is an "aperture synthesis" interferometric instrument, designed to gain the resolving power of a very large antenna by utilizing a number of smaller antennas (2). In the case of the VLA, the information from all of its antennas is combined mathematically to produce resolving power equal to that of a single antenna as much as 36 km in diameter.

The VLA is arranged in a "Y" pattern, with nine antennas on each of the three arms, for a total of 27 antennas. The maximum antenna separation ranges from 1 km to 36 km. The antennas are fully-steerable parabolic dishes 25 meters (82 feet) in diameter, weighing approximately 230 tons. A communications system utilizing buried microwave waveguide carries control and monitor information to and from the antennas and the astronomical data from the antennas to the central control building (3).

Along the three arms of the VLA, there are 72 stations where the movable antennas can be mounted. A railroad system allows transporter vehicles to carry an antenna to any of the 72 stations. The entire array of 27 antennas is reconfigured approximately every four months. There are four standard configurations for the VLA, each offering a different range of resolving power, so completing the configuration cycle requires a total of 16 months. Changing from one configuration to another requires an average of two weeks.

The VLA currently is capable of observing at wavelengths from 90 cm to 7 mm, in seven separate segments, or bands. The resolution obtainable depends on the wavelength being observed and the configuration of the array. The greatest resolution ranges from 200 to 1.5 seconds of arc (arcseconds) in the smallest configuration to 6 to 0.05

arcseconds in the largest configuration. Typical sensitivity figures for the VLA range from 1.4 to 0.06 milliJanskys.** Observing projects at the VLA generally take from a half-hour to several days (4).

The astronomical data from all the VLA's antennas are assembled in real time in a process called *correlation* and the result is recorded on magnetic tape. The observer then takes the data in this form and performs post-processing and image processing on a workstation-class computer. Observers without sufficient computing resources at their home institutions can use NRAO computing facilities at the AOC.

Though a product of designs from the 1970s, the VLA has benefitted from technological advances throughout its service lifetime. The result has been a tremendous increase in capability and versatility over the original designs. Some of the major improvements have resulted from increased receiver sensitivity and the exponential growth in computing capability over the past 20 years. One example of the impact of these advances is that, while the original designers contemplated an instrument that would produce two or three images per day, the VLA now can produce images of strong, isolated radio sources in as little as a few minutes.

To take full advantage of newer technology, the NRAO has begun preparing for a large-scale upgrade of the VLA. This process began with a 1995 scientific workshop in which researchers from various specialties outlined their desires for improved capability of the instrument. Major parts of a proposed VLA upgrade program will include replacing the microwave waveguide system with an optical fiber system, building a new special-purpose correlation computer, and adding receivers to expand the wavelength coverage.

The Very Long Baseline Array

The desire for ever-increasing resolving power led radio astronomers to develop the technique of Very Long Baseline Interferometry (VLBI), in which the antennas of a synthesis array are so widely separated that a real-time communication system among them is no longer practicable. Instead, the signals from each antenna are recorded on magnetic tape and the tapes brought to a single location for the correlation process. This technique was first demonstrated in 1967 (5). VLBI systems currently offer the best resolving power available to astronomy.

Since the 1960s, VLBI observing has been conducted using existing radio observatories, which schedule coordinated observations at intervals of a few months. Such observations yielded valuable scientific results, but the VLBI "instruments" so assembled nonetheless had drawbacks. These included the difficulty of arranging and scheduling coordinated observations operated by multiple organizations, less than optimum siting of the antennas to produce a good synthesis image, and variations in sensitivity, pointing accuracy and frequency coverage of the individual antennas (6).

** A Jansky is the standard unit of flux used in radio astronomy. It represents 10^{-26} Watts per square meter per Hertz. A milliJansky is one-thousandth of a Jansky.

then be used by astronomers with workstations to perform post-processing and image processing.

Since its official opening in 1993, the VLBA has been used for scientific observing for a steadily-increasing percentage of the time, aiming toward a full, 24-hour, 7-day schedule. At the same time, system improvements and software development for the correlator have been ongoing. The wavelength coverage is being expanded by addition of receivers for a band at 3.5 mm.

Scientific Programs

Versatility is a hallmark of both the VLA and the VLBA. Both instruments, when brought on-line, offered new capabilities to the scientific community. Members of the community have proven highly resourceful in using the capabilities of these instruments for a wide variety of investigations. The VLA, for example, has been used to observe objects as near as the Moon and near-earth asteroids, as far as quasars at the edge of the observable universe, and nearly everything in between. Radio observations are often scheduled in conjunction with observation of the same objects at other wavelengths by ground-based and orbiting instruments.

Closer to home, the VLBA is an important tool for geophysics. The technique of VLBI can produce not only extremely high resolution for observing astronomical bodies, but also, using distant quasars as an inertial reference system, extremely precise three-dimensional positional information on the observing stations themselves. This information is used by geophysicists to learn about continental drift and the rotation and orientation of the earth in space. This can shed new light on such phenomena as: the earth's mantle convection, plate motion and earthquakes; atmospheric and ocean loading on the crust; and the gravitational effect of the Moon, Sun and planets.

Within the Solar System, the VLA routinely observes the Sun, planets, asteroids, and comets. The NRAO scientific staff includes both a full-time solar astronomer and a planetary scientist. Planetary observing at the VLA employs both passive observations and radar observations in conjunction with NASA's solar-system radar transmitter at Goldstone, California. Observations of Jupiter during the impacts of fragments of Comet Shoemaker-Levy 9 in 1994 revealed that the impacts significantly disrupted the pattern of microwave emission from the planet's radiation belts (8). The wide variety of other planetary studies ranges from monitoring atmospheric water vapor on Mars to detailed studies of Saturn's ring system.

Stellar astronomers use the VLA and VLBA to study the whole life cycle from protostars to supernova remnants. The recent addition of 7 mm receivers to the VLA, funded by the government of Mexico, has provided a powerful tool for probing young stellar objects and their environments. This includes studies of protoplanetary disks. Both the VLA and VLBA observe newly-discovered supernovae as targets of opportunity, and then monitor these objects to obtain radio light curves and, in the case of the VLBA, to measure the expansion of the shell of explosion debris in nearby galaxies.

The study of galaxies in all their variety and complexity is a mainstay of research with both instruments. This starts with studies of our own Milky Way galaxy, and both instruments are used to probe the region near its center, which contains a black-hole candidate. Studies of other galaxies probe the composition, dynamics and evolution of those galaxies. Galactic mergers are an expanding area of research.

The VLA and VLBA are frequently used to study the variety of active galactic nuclei, from different types of radio galaxies to extremely energetic quasars. Such studies seek to resolve the many outstanding questions about the environments and inner workings of these powerful "engines." Many observers hope to use detailed radio images to test theoretical models of these active galactic nuclei.

A large amount of VLA observing time currently is devoted to a project of long-term importance to the astronomical community -- the conduct of two large-scale surveys of the sky at radio wavelengths. These surveys are aimed at providing a reference resource to serve scientists for many years to come. The first of these, the NRAO VLA Sky Survey (NVSS), is designed to observe the 82 percent of the sky visible from New Mexico by the end of 1996. This survey is expected to produce a catalog of two million cosmic radio sources, most of which never have been seen before (9). The other survey, called Faint Images of the Radio Sky at Twenty-centimeters (FIRST), is producing more-detailed images of a region of the North Galactic Cap which also is being surveyed at optical wavelengths by the Sloan Digital Sky Survey (10).

Both these surveys are being made as a service to the astronomical community, and the data are being released as soon as they are reduced and verified. The products of these surveys are available freely through the Internet.

Finally, some recent results from both instruments indicate the significance of research done at NRAO's facilities in New Mexico.

The power of the VLBA was illustrated by that instrument's observations of the galaxy NGC 4258, some 21 million light-years distant, which produced the most elegant and conclusive evidence so far for the existence of an extragalactic black hole. An international team of astronomers used the VLBA to observe emissions from water molecules in a disk of material circling the core of this galaxy. From information on the velocity of the water molecules, the astronomers concluded that the disk is circling a central object of 40 million solar masses. This mass lies within a radius of less than half a light-year, making its minimum density nearly 100 million solar masses per cubic light-year, far greater than that of any known star cluster (11).

Both the VLA and the VLBA have been involved in the discovery and study of a new class of objects within our own Milky Way galaxy. In March and April of 1994, VLA observers made a series of images of an energetic object that had been discovered by an orbiting X-ray observatory. They discovered that the object was emitting "jets" of subatomic particles and were able to track condensations in those jets that were moving at apparent speeds greater than that of light. This illusion, called "superluminal motion," has been observed frequently in the much more massive and distant active galactic nuclei

and quasars, but never before had been seen in our own Galaxy. The researchers believe the new object is a binary-star system some 40,000 light-years distant, with one of the pair a neutron star or black hole, which is accelerating particles to an actual speed of 92 percent of light speed (12). Another X-ray emitting object, discovered in July of 1994, also was observed with both the VLA and VLBA. The high-resolution VLBA images of this object, at a distance of 10,000 light-years, have revealed similar particle speeds and complex motions. (13) Optical studies of this binary system show that it contains a black hole. (14). These unexpected, nearby Galactic objects will be the target of intense study to decipher the physics of such "jet" phenomena, which are seen at greater distances in large numbers.

For additional information about the National Radio Astronomy Observatory, its instruments, or the scientific programs, see the NRAO World Wide Web Home Page, at URL:

http://info.aoc.nrao.edu/

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Figure Captions:

Antennas of the VLA: The Very Large Array, on the Plains of San Augustin, west of Socorro, uses 27 dish antennas, each weighing 230 tons, to make detailed images of the sky. Photo Courtesy NRAO/AUI.

Cygnus A: The radio galaxy Cygnus A, imaged with the Very Large Array in all four of its antenna configurations. The galaxy's nucleus is the small point in the center of the image. The nucleus is emitting jets of material in opposite directions. These jets impact material surrounding the galaxy, giving rise to the giant "lobes" of radio emission seen in this image. The energy required to produce these jets is believed to come from a black hole millions of times more massive than the Sun. Photo courtesy R.A. Perley, J.J. Cowan, J.W. Dreher, and NRAO/AUI.