NATIONAL RADIO ASTRONOMY OBSERVATORY

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Newsletter

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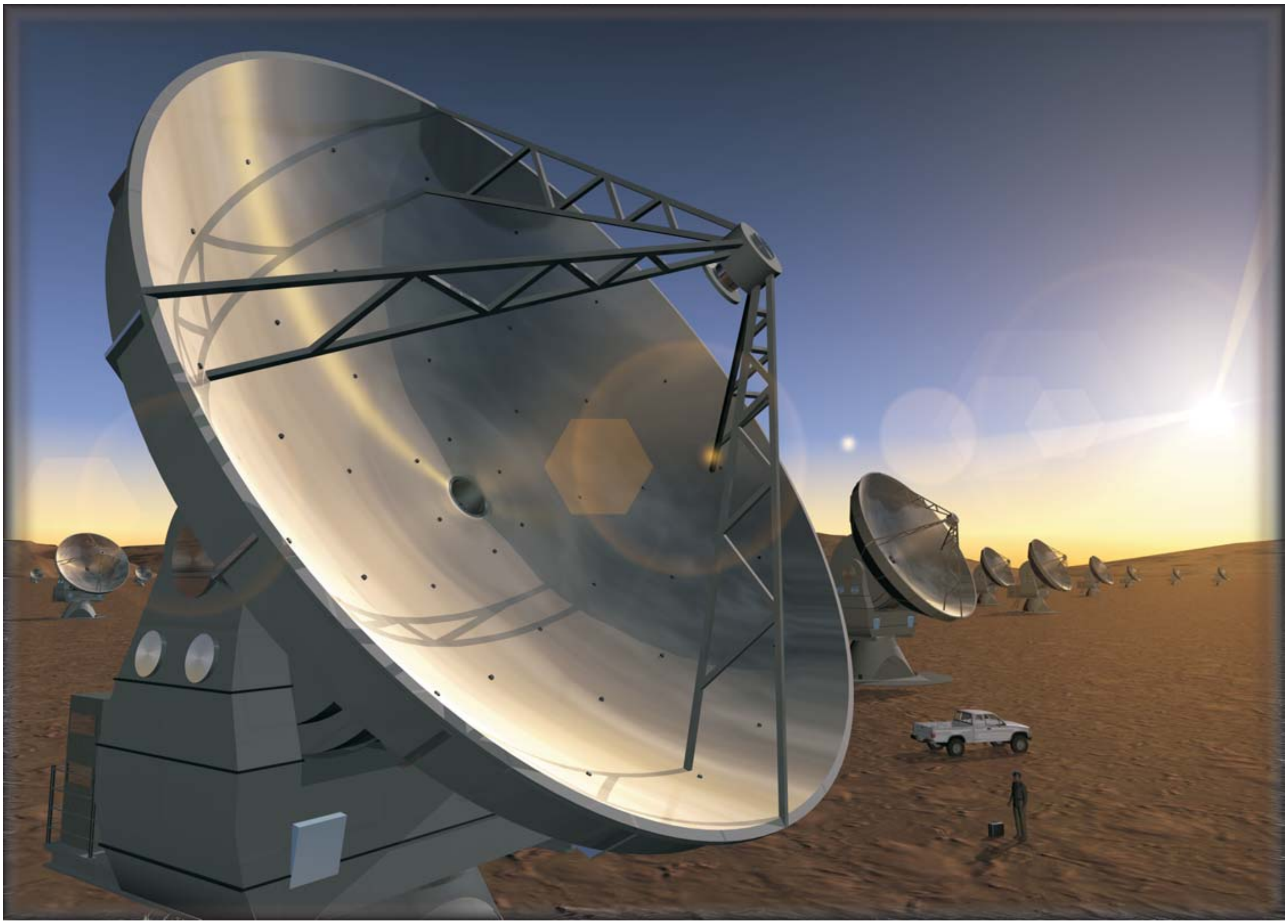
Groundbreaking for the ALMA Project

Green Bank Telescope Enhancements



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The NRAO Graphics Department will be happy to assist you in the production of images for your article as well as for your research papers. Contact Patricia Smiley (psmiley@nrao.edu) with your request.

If you have an interesting new result obtained using NRAO telescopes that could be featured in this section of the NRAO Newsletter, please contact Juan Uson at juson@nrao.edu. We particularly encourage Ph.D. students to describe their thesis work.

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Cover Image: European Southern Observatory (ESO) computer image of the Atacama Large Millimeter Array (ALMA) at sunset. The Atacama Large Millimeter Array (ALMA) is an international astronomy facility. ALMA is an equal partnership between Europe and North America, in cooperation with the Republic of Chile, and is funded in North America by the U.S. National Science Foundation (NSF) in cooperation with the National Research Council of Canada (NRC), and in Europe by the European Southern Observatory (ESO) and Spain. ALMA construction and operations are led on behalf of North America by the National Radio Astronomy Observatory (NRAO), which is managed by Associated Universities, Inc. (AUI), and on behalf of Europe by ESO.

Atacama Large Millimeter Array (ALMA)

Groundbreaking for the ALMA Project

On November 6, 2003, at the site of the future Operations Support Facility (OSF) for ALMA at an altitude of 9600 feet, ground was broken by ALMA Director Massimo Tarenghi, NSF Division of Astronomical Sciences Director Wayne van Citters, and ESO Council President Piet van der Kruit at a ceremony attended by dozens of distinguished guests. Only a little more than 30 years after the first detection of interstellar CO by the NRAO 12 Meter Telescope, construction of ALMA, a telescope capable of detecting the first CO molecules in the Universe, had begun.

Flags of the ALMA participant countries fly beside the new road to the array site, which lies beyond Cerro Negro (background).

Some 50 special guests in a convoy of 17 vehicles participated in a site visit on the previous day, the largest crowd of visitors so far. All remained well during the trip indicating that the site is quite accessible to the uninitiated when adequate precautions, such as the use of the provided bottled oxygen, are taken.

From around the world and from across Chile, guests began to arrive just before noon on the newly constructed ALMA road from Chilean highway 23 between San Pedro de Atacama and Toconao through the OSF site to the 16,500 foot Llano de Chajnantor, the site of the ALMA telescopes. At the OSF, the original concept which was developed by Mark Gordon and Robert Brown, guests mingled in the stunning weather, meeting newcomers near a display of the flags of the ALMA participant nations. As people approached the splendid white tent, the center of festivities, members of the press interviewed the various ALMA principals. Far below, the vista extended for dozens of miles, dominated by the great Salar de Atacama stretched along the horizon to the village of San Pedro. In the foreground, the temporary camps for construction workers and ALMA personnel were already in place. Peering over the northern horizon, the upper reaches of Licancabur dominated the skyline. Up the mountain, the new ALMA road wound through the rocky landscape beside Cerro Negro toward the high site. Slowly guests made their way toward the tent, sampling refreshments along the way. Cries of 'Hola!' rang out as arriving old friends greeted one another to the sounds of Atacameñan music.

Massimo Tarenghi and Fred Lo with ALMA workers.

By a quarter past twelve, most had arrived at the tent to seek their assigned tables. Each table had been given the name of a Chilean wildflower; a photo marked

Dr. Lo addresses the participants in the Groundbreaking ceremony.

each. Thus familiarized with the local flora, guests met their tablemates and took their seats. At each place lay a mysterious dark felt bag. Projected high above the speakers was the new ALMA logo—a Southern Cross above an array of radio telescopes. Event organizers and Masters of Ceremonies Daniel Hofstadt and Eduardo Hardy (ESO and AUI/NRAO representatives in Chile, respectively) introduced an array of speakers.

Leading off, ESO Council President Piet Vander Kruit outlined the scientific promise of ALMA. "We are children of the Universe. Actually, we are children of the Universe in a very strict sense. Look at our bodies. By weight we are made up of about a quarter or so of hydrogen. The rest is in other chemical elements, of which carbon, nitrogen and oxygen are the major contributors. In contrast, the Universe, when it was about three minutes old and sufficiently cool that atomic nuclei could exist, consisted of three-quarters of hydrogen and one quarter of helium. There was no carbon, no nitrogen, no oxygen or any other chemical element except a trace of lithium and boron. We now know that the chemical elements that make up most of our bodies were formed by nuclear reactions in heavy stars that live for a very short while and blew themselves up as supernovae and release the heavy elements into the interstellar gas so that new planets and possibly life can be formed. We are stardust. In spite of progress in the twentieth century, such as understanding nucleosynthesis, there are still fundamental questions left. Some important ones among these are the following. When and how did galaxies form and in what way did early star formation and chemical enrichment take place? How do planets form around young stars? To completely solve all aspects of these and other problems we absolutely need to be able to observe at millimeter and sub-millimeter wavelengths."

Building on the theme of international cooperation, the Director of the Division of Astronomical Sciences of the U. S. National Science Foundation Wayne van Citters delivered a message from Rita Colwell, the Director of NSF. In her message, Dr. Colwell said: "The plateau where ALMA's antennae will rise is one of the most starkly beautiful places on Earth. It's not enough for the scientific community to identify an outstanding site for astronomy; we rely also on the generosity and cooperation of a willing host. Chile has a long history of opening regions of exceptional scientific merit to the world community. The Atacama Large Millimeter Array will expand our vision of the universe with 'eyes' that pierce the shrouded mantles of space through which light cannot penetrate. ALMA's 64 radio telescopes will serve as windows through which scientists and the curious public will 'see' back in time and far away, to where the earliest and most distant galaxies were forming." van Citters noted "how far we have come in our understanding, our ambition, our sheer scientific audacity in less than one professional lifetime." From debating whether sufficiently bright detail would support baselines as long as 100 m on fledgling arrays, or whether extragalactic molecules could possibly be bright enough, to the present, he continued, where we "await ALMA's ability to map molecular gas in the first generation of galaxies; this gas already contains elements heavier than hydrogen that were forged in the first generations of stars to form, less than a billion years after the origin of time itself."

Arthur Carty, President of the National Research Council of Canada, noted that as a chemist by training, he had "come to appreciate the value of astronomy not only as a fundamental and important scientific discipline, but also as a unique vehicle for encouraging national and international cooperation and for turning our young people on to science and technology."

Riccardo Giacconi, President of AUI, noted the great scientific promise of ALMA.

Noting that the date was exactly the fortieth anniversary of the signing of ESO's first agreement with Chile, ESO Director-General Catherine Cesarsky noted "here, on Chilean soil, in the great emptiness of the Atacama desert and closer to the sky than ground-based astronomers have ever been, we are now embarking upon an ambitious exploration of new and unknown celestial territories. We do so in the service of science and society, ultimately for the benefit of humanity."

NRAO Director Fred K. Y. Lo recalled the long road leading to the ALMA groundbreaking in his remarks. "We are here celebrating the realization of the aspirations of many astronomers for more than twenty years to build a powerful array that can let us peer into the beginnings of the Universe, galaxies, stars and planets and perhaps life itself," he noted. "There are many people on the NA side to recognize for bringing ALMA into reality, but I would like to mention three names. The first is Bob Dickman at the NSF. He has been the champion of ALMA within NSF for many years and continues to play an important role by serving on the ALMA Board. Second is my predecessor, Paul Vanden Bout. Without his persistence for more than 15 years to get the MMA, and later ALMA, funded, his genius of forming international alliances, and many other efforts including the selection of Chajnantor as a site, we would not have ALMA today. Last but not least, AUI President Riccardo Giaconni. As ESO Director General, he signed the key international agreement with Paul Vanden Bout that led eventually to the Bilateral ALMA that we are celebrating today. Now that he has joined the NA side, he is making sure that we do not deviate from getting ALMA built on time and on budget."

Intendente Jorge Molina welcomed ALMA to the Second Region of Chile and made reference to the interest of the Region in becoming the "astronomy world capital" now that both the VLT and ALMA are located there. He also referred to the impact ALMA will have on the local community, in particular after the signature on 28 October of the agreement between ALMA and the Intendencia that benefits the San Pedro Commune.

Mayor of San Pedro de Atacama Sandra Berna echoed Intendente Molina's remarks, noting that San Pedro was the capital of Chilean archaeology and that now it may become a capital of science as well. Finally, the Bishop of Calama, Obispo Guillermo Vera Soto, blessing the beginning of the ALMA construction work, used biblical imagery in referring to the astronomical aims of the project.

A reflection on ALMA science was given by the President of AUI, Riccardo Giacconi, winner of the 2002 Nobel Prize in Physics. Dr. Giacconi shared his vision of the scientific significance of ALMA, elaborating on themes of particular interest. "ALMA will have

NSF's Robert Dickman christens a block with Chilean wine as Eduardo Hardy, Fred Lo, Massimo Tarenghi, Catherine Cesarsky and Daniel Hofstadt (l-r) look on.

unsurpassed sensitivity and imaging capabilities for molecular spectroscopic study of external galaxies and will be able to detect the first galaxies formed through their dust emission at $z > 20$. It will be able to study star formation cores in nearby galaxies and assess the role of morphology and environment in their dynamic and chemical evolution. The setting of ALMA in the southern hemisphere will permit detailed studies of the large and small magellanic clouds. The study of organic molecules in interstellar space will provide indispensable clues to the origin of life in the universe".

Project Director Massimo Tarenghi expressed the ALMA team's feelings about reaching this milestone. "We may have a lot of hard work in front of us," he said, "but all of us in the team are excited about this unique project. We are ready to work for the international astronomical community and to provide them in due time with an outstanding instrument allowing trailblazing research projects in many different fields of modern astrophysics."

After a punctual and successful ceremony many guests returned to the task of finishing the construction in a similarly timely fashion.

H. A. Wootten

Detailed Remarks of Speakers

Rita R. Colwell
Director, National Science Foundation

The U.S. National Science Foundation joins today with our North American partner Canada, and with the European Southern Observatory, Spain, and Chile to prepare for a spectacular new instrument. The Atacama Large Millimeter Array will expand our vision of the universe with "eyes" that pierce the shrouded mantles of space through which light cannot penetrate.

I extend both my congratulations and my regret for not being able to join you. As you break ground for a new observatory, I will join the President at a ceremony to recognize scientists and engineers who have broken ground with far-reaching observations throughout their careers. They will be receiving the distinguished National Medal of Science.

The plateau where ALMA's antennae will rise is one of the most starkly beautiful places on Earth. It's not enough for the scientific community to identify an outstanding site for astronomy; we rely also on the generosity and cooperation of a willing host. Chile has a long history of opening regions of exceptional scientific merit to the world community.

Last year, I participated in the official opening of Gemini South near La Serena. Gemini is but one in a long line of facilities that have taken advantage of the observing conditions in Chile and paved the way for one more.

Today marks the official start of construction. But the ALMA partnership also breaks ground with a novel collaboration that ensures equal access by astronomers on at least three continents. International partnerships are quickly becoming the norm of the millennium, enabling organizations and nations to combine funds to achieve greater scientific capability. NSF is proud to participate in the creation of an instrument that will provide unprecedented power for science and immeasurable knowledge for all.

ALMA's 64 radio telescopes will serve as windows through which scientists and the curious public will "see" back in time and far away, to where the earliest and most distant galaxies were forming.

Our investments in ALMA's educational programs will be as important as our outlays for construction, operations, and scientific research. With our ALMA partners, we will engage a younger generation of scientists and engineers in bonds that leap national borders and integrate education with research.

We at NSF extend our best wishes for the speedy completion of ALMA and for a lifetime of spectacular achievements.

Wayne Van Citters
Director, NSF Division of Astronomical Sciences

It is a great personal pleasure for me to be here with friends from Chile, Europe, North America, and Japan at this historic occasion. As I was thinking about this ceremony on the plane flight down to Chile, it reminded me of the first site visit I held on coming to NSF almost 25 years ago. We were reviewing the fledgling millimeter interferometer built by Caltech in the Owens Valley of California. One of the major points of discussion at the time was whether it was scientifically cost effective to expand the baseline (the distance between the two antennas) from 50 meters to 100 meters. There was a substantial body of thought that this would not be worthwhile, for after all, surely there would not be any source that would be bright enough on such small scales to be detected. Today we break ground for a millimeter interferometer that will have baselines measured in thousands of meters.

Very soon the question turned to one of whether it was worthwhile to use millimeter telescopes, and millimeter interferometers in particular, to observe molecular gas in external galaxies. Surely there would not be any detail visible at the necessary brightness. Today we eagerly await ALMA's ability to map molecular gas in the first generation of galaxies; this gas already contains elements heavier than hydrogen that were forged in the first generations of stars to form, less than a billion years after the origin of time itself.

How far we have come in our understanding, our ambition, our sheer scientific audacity in less than one professional lifetime.

The scientific promise of ALMA is compelling and its contributions to our comprehension of the Universe and our place in it will be profound. As Rita noted in her remarks, the questions to which we seek answers transcend national boundaries and cultural divides. So in addition to breaking ground for a powerful scientific instrument today, let us also pledge to respond to a powerful challenge put to the American Astronomical Society by Arthur Carty last year in Nashville. Let the ALMA partnership use the universal appeal of astronomy to bind us together across oceans and between continents.

I believe that a world pursuing a global strategy to discover how the beauty that surrounds us today came to be, including we who are enjoying it, that world must ultimately put aside suspicion, hatred, racism and greed. Let us dedicate ALMA as an instrument of understanding, not only of scientific fact but also of ourselves. Through ALMA let us leave a legacy of mutual respect, of free and open inquiry, and of love of the truth to our children - indeed to the children of the world community.

K. Y. Lo
Director, NRAO

Distinguished guests, ladies and gentlemen,

On behalf of the National Radio Astronomy Observatory, the North American (NA) Executive of the ALMA Project, I welcome you to this ground breaking ceremony. Today, we are celebrating the realization of the aspirations of many astronomers for more than twenty years to build a powerful array that can let us peer into the beginning of the Universe, galaxies, stars and planets, and perhaps even life. ALMA is truly one of the cornerstones of major ground-based telescopes in the many decades to come.

In the US, the beginning of ALMA went back to 1982 when the NSF Committee on the Future of Millimeter-wave Astronomy headed by Professor Alan Barrett of MIT recommended the building of a national millimeter-wave array, called the MMA. Over the years, I remember participating in many workshops on the development of the MMA.

As a member of the NRAO Visiting Committee, I visited the Plano de Chajnantor, Pampa la Bola and Rio Frio in 1996. They were at that time potential sites for the MMA, the Large Millimeter and Sub-millimeter Array of Japan, and the Large Southern Array of Europe. I remember distinctly thinking at that time: the rational thing was for the three very similar projects to become one, but for practical and political reasons, it would never happen. Here we are today, commemorating basically the merging of the US and European projects, and we are fully expecting the final step of merging with the Japanese project in 2004. How wrong I was, but what a triumph for astronomy and international relations!

For making the North American participation in ALMA possible, I must thank the US National Science Foundation for supporting the ALMA and the Canadian National Research Council for contributing to the project. In addition, we are very honored to have both the US Ambassador Brownfield and Canadian Ambassador Giroux joining us in this ceremony.

There are many people on the NA side to recognize for bringing ALMA into reality, but I would like to mention three names. The first is Bob Dickman at the NSF. He has been the champion of ALMA within NSF for many years and continues to play an important role by serving on the ALMA Board. Second is my predecessor, Paul Vanden Bout. Without his persistence for more than 15 years to get the MMA, and later ALMA, funded, his genius of forming international alliances, and many other efforts including the selection of Chajnantor as a site, we would not have ALMA today. Last but not least, AUI President Riccardo Giaconni. As ESO Director General, he signed the key international agreement with Paul Vanden Bout that led eventually to the Bilateral ALMA that we are celebrating today. Now that he has joined the NA side, he is making sure that we do not deviate from getting ALMA built on time and on budget.

As NRAO Director, I have the heavy responsibility to ensure our Observatory will do its part to get this very complex telescope array built by 2012. Of course, much of the work is borne by the NRAO ALMA Team. There are too many to name, but I would like to recognize a few key members who are here today: our ALMA Division Head, Darrel Emerson, Project Manager Marc Rafal, Project Scientist Al Wootten, AUI Vice President Pat Donahoe, Eduardo Hardy our representative in Chile, and Simon Radford who has worked on preparing the site here for almost ten years.

Finally, I would like to thank the Chilean government at all levels, our Chilean astronomy colleagues, and the citizens of Region II, all of whom so graciously allow ALMA to be built in their beautiful country.

I look forward next to the ALMA dedication ceremony in 2012 and to making my first image with the array.

Thank you very much for joining us in this celebration.

Riccardo Giacconi
AUI President

I have been asked to make a brief statement about the scientific significance of the event we celebrate here today. The exciting discoveries in astronomy and astrophysics of the last decade and the great technological advances in astronomical instrumentation hold the promise that in the beginning of this new millennium we will take a giant step forward in our understanding of the cosmos. In the last decade we have, for the first time, discovered the existence of numerous planets around stars other than the sun; we have peered at the very edge of the visible universe only a few hundred thousand years after the big bang to study the seeds of galaxy formation; we have found evidence of a new form of energy that might be the largest constituent of the universe. We have found that galaxies and clusters of galaxies were formed much earlier than we had thought and that most galaxies (including our own) harbor massive black holes. The study of black hole physics and of the phenomena occurring in γ ray burst sources has made great advances and holds the promise to test theories of gravity, including general relativity, under strong field conditions. For the first time we have detected neutrinos from a supernova explosion and extended astrophysical observations of specific phenomena to particle detection.

An ambitious plan of study has emerged for the next twenty or thirty years which combines the study of the extremely large with that of the extremely small. To understand the Universe we need to further advance our knowledge of the fundamental laws of physics and of the elementary constituents of matter. The Universe itself is becoming the laboratory where the very high energies, high densities, and strong fields provide the testing ground for these new laws. This plan anticipates the development of new and more powerful observational facilities in all the wavelengths of the electromagnetic spectrum, as well as particle detectors, through international collaborations on a scale never seen before. ALMA will be at the forefront of these facilities and hopefully will provide a model for such collaborative efforts. ALMA observations will serve to elucidate many of the most important questions in astrophysics today.

ALMA will permit us to study the distant Universe and observe the first seeds of galaxy formation and the subsequent galaxy evolution. It will have the required sensitivity, resolution, and bandwidth to observe the small scale anisotropies in the cosmic microwave background imprinted by the initial fluctuations at $Z \sim 100$ and the distortions due to the Sunyaev-Zeldovich effect in clusters of galaxies. Together with X-ray observation this will permit direct measurement of the size and curvature of the universe.

ALMA will have unsurpassed sensitivity and imaging capabilities for molecular spectroscopic study of external galaxies and will be able to detect the first galaxies formed through their dust emission at $Z > 20$. It will be able to study star formation cores in nearby galaxies and assess the role of morphology and environment in their dynamic and chemical evolution. The setting of ALMA in the southern hemisphere will permit detailed studies of the large and small Magellanic clouds. The study of organic molecules in interstellar space will provide indispensable clues to the origin of life in the universe.

ALMA will offer unique capabilities to study super massive black holes in all galaxies including our own. With the same angular resolution of the Hubble Space Telescope, ALMA can resolve the disks fueling the central black holes in galaxies as far as Virgo and yield geometry, physical conditions and kinematics of the gas. Finally if used as the prime component in a world wide millimeter wave VLBT network, ALMA would allow us to map the structure of active galactic nuclei with a resolution of 10 micro arc seconds, the highest resolution achievable in astronomy. Thus ALMA will contribute to the all wavelength attack on the fundamental problems of the origin of the universe, of development of structures and possibly of organic life.

I would like to conclude with a very brief personal remark. I consider myself extremely fortunate in having lived in this epoch of advances in astronomy not equaled since the time of Copernicus, Galileo, Kepler, Tycho, and Newton. I was privileged in being associate with some of the great enterprises in our field: the start of X-ray astronomy and the development of Chandra, the operation of the Hubble Space Telescope, the development of the Very Large Telescope on Paranal, and now the start of the ALMA Project. In some of my recent papers I found myself using data from Chandra, HST and VLT to clarify, after forty years of work, the mystery of the X-ray background. Still some of the X-ray sources we observe in the deepest survey are so faint that neither HST nor VLT can identify them, and they may well be new types of celestial objects. I hope ALMA will be able to solve this new mystery in my lifetime. I would like to end by thanking our host, Chile, for joining us in this noble voyage of discovery and making this enchanted land the home for some of the most important of these great enterprises.

Me gustaría concluir agradeciendo a nuestro anfitrión, Chile, el haberse unido a nosotros en este noble viaje de descubrimiento, haciendo esta tierra encantada el hogar de algunas de las mas importantes de estas grandes aventuras. Muchas gracias!

ALMA Science Meeting

University of Maryland Conference Center
May 14-15, 2004

In October 1999, a meeting was held in Washington, D. C. to bring together scientists working on the development of what would become ALMA to review the scientific program planned for the array and how that program interacted with the science goals of other astronomical facilities contemporaneous with it. The results of that meeting were published in Science with ALMA, ASP Conference Series Volume 235. Much of the research planned for ALMA at that meeting has appeared in the ALMA Design Reference Science Plan, a collection of experiments planned for ALMA recently presented by the ALMA Project and available at *www.alma.nrao.edu*.

As a story elsewhere in this Newsletter relates, ALMA construction is now well under way. Planning for its operation has also progressed, and a new building which will house the North American ALMA Resource Center is under construction in Charlottesville. Early Science is expected from a subset of ALMA telescopes by the end of 2007.

An ALMA Town Hall meeting will be held at the AAS meeting in Atlanta on January 8 at 1:00-2:00 p.m., in the Regency VI room. The session will focus on ALMA science and on the interaction between ALMA and the American user through the ALMA Resource Center in Charlottesville.

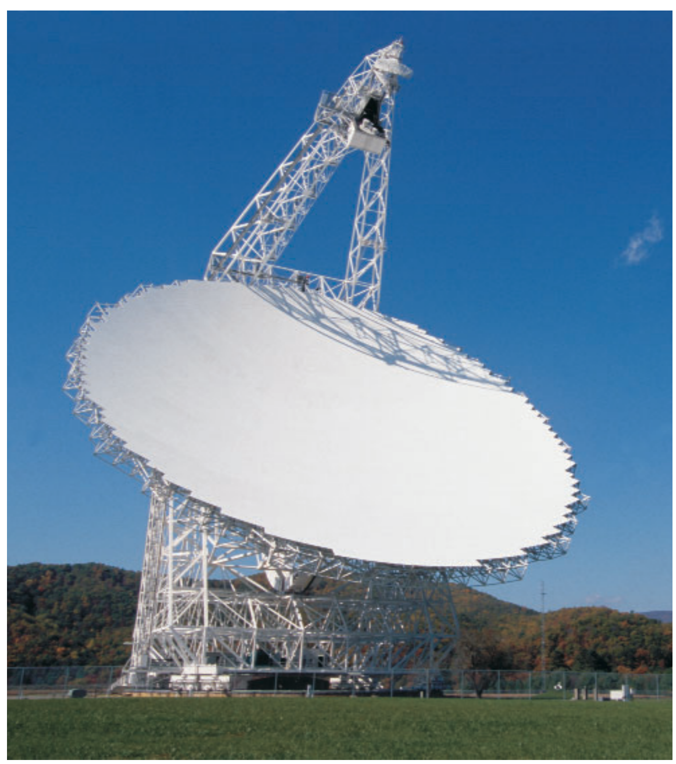
In a meeting to be held at the University of Maryland Conference Center May 14-15, 2004, astronomers are invited to discuss the present state of plans for ALMA, ALMA's scientific goals and how best to enable them, and the face ALMA presents to its scientists users. Further details will be available soon.

H. A. Wootten

Green Bank

The Green Bank Telescope

The autumn months have brought a number of enhancements to GBT operational capabilities and continued progress on development projects. In operational areas, the 18-26.5 GHz and 40-50 GHz receivers have now been installed, the Spectrometer is performing robustly, observations are now easier to configure—with more improvements on the way—and there are now convenient methods to export data to a number of analysis packages. As a consequence of these enhancements, most classes of observing projects can now be scheduled routinely. The azimuth track issues described in past *NRAO Newsletters* have been relatively stable over the past few months and progress continues toward a long-term resolution. The staff and university collaborators are making progress on a number of development projects, including the Precision Telescope Control System, the Penn Array Camera, the 26-40 GHz (Ka-band) receiver, and the Pulsar Spigot Mode of the spectrometer.



The Green Bank Telescope (GBT)

The 18-26.5 GHz (K-band) receiver was reinstalled in October and is in routine use for science projects.

Spectral baseline quality and calibration accuracy are much improved from last spring, and nearly all of the observing requests for this receiver can now be supported. Engineering modifications of the 40-50 GHz (Q-band) receiver were completed over the summer and early fall and the receiver was installed in late November. Final commissioning of this receiver will be completed in December and January, and initial science projects are planned for February. The 12-15 GHz (Ku-band) receiver has also been upgraded with new low noise amplifiers from the Central Development Lab.

The GBT Spectrometer is now in routine use in nearly all of its priority autocorrelation modes. Improvements in hardware, firmware, and software have largely eliminated system crashes, and the device runs robustly for long periods. Additional improvements including a re-design of the Long Term Accumulator (LTA) card, which mostly affects maintainability, are underway.

A new tool for expediting observing configurations is under development. A beta version of this tool was released in November and has already been in use by staff astronomers and several observers. Initial response to the tool has been very positive. Further enhancements to the tool are underway and are planned for release in the first quarter of 2004.

A straightforward method to export GBT data to external data analysis packages is also under development. In November, the beta release of a Single Dish FITS (SDFITS) writer was released. Using as input the GBT device FITS files produced by each observation, the SDFITS application writes a consolidated FITS file suitable for export to other packages. This format can already be read by IDL and AIPS++. Extensions to the keywords and additions to the information content of the SDFITS files are underway, with final version release expected in early 2004.

Studies of the GBT azimuth track continue. The field trial of the test modification of one splice joint performed last June is proceeding. A detailed, quasi-dynamical finite element analysis of the existing track and some modification alternatives is underway at the firm of Simpson, Gumpertz, and Heger. Measurements of track deflections and motions to be used to test the finite element model were made in November. We expect to assimilate the information necessary to make a decision about the best course of action for the track by early 2004. The track itself has been relatively stable over the past few months. In October, a small crack in one wear plate that had been initially detected last winter propagated to the extent that replacement of the plate was warranted. We have several spare plates on hand, and the replacement was accomplished quickly.

Good progress continues on the major GBT development projects. The Precision Telescope Control System project that will enable operation to 115 GHz has had a number of successes this autumn. An in-progress review of the project was held on 3-4 December. The PTCS Project team has been using antenna structural temperature sensors to predict radial focus and both azimuth and elevation pointing errors. A prototype version of this was demonstrated in November with great success, and development of the production equivalent should quickly follow. At the same time, our ability to disentangle gravitational and thermal effects has allowed us to significantly improve both the traditional pointing and focus-tracking models. Latest results are posted on the PTCS web pages at *www.gb.nrao.edu/ptcs*.

A critical design review of the Penn Array Receiver, a 64-pixel bolometer camera for the 3 mm band was held on 17-18 October. The panel members were Drs. William Duncan (chair), Dale Fixsen, and Chris Carilli. The panel was enthusiastic about the project and made a number of valuable comments and recommendations that should prove very helpful to the project. The camera is slated for delivery in 2005.

Work on the 26-40 GHz (Ka-band) receiver continues. First cool-down of the cryostat is expected by January, with completion of the receiver by the end of March. We expect to perform initial engineering tests in Spring 2004, with first scientific use beginning in the fall.

The Pulsar Spigot Mode of the GBT Spectrometer has seen first scientific use and is almost ready for use by knowledgeable experts. The Spigot Mode allows very fast data dumps at wide bandwidths (up to 800 MHz). The project is a collaboration of David Kaplan (Caltech) and the NRAO staff.

P. R. Jewell

Socorro

VLA Configuration Schedule; VLA / VLBA Proposals

Configuration	Starting Date	Ending Date	Proposal Deadline
B	17 Oct 2003	19 Jan 2004	2 Jun 2003
CnB	30 Jan 2004	16 Feb 2004	1 Oct 2003
C	20 Feb 2004	17 May 2004	1 Oct 2003
DnC	28 May 2004	14 Jun 2004	2 Feb 2004
D	18 Jun 2004	13 Sep 2004	2 Feb 2004
A(+PT)	01 Oct 2004	10 Jan 2005	1 Jun 2004
BnA	21 Jan 2005	07 Feb 2005	1 Oct 2004
B	11 Feb 2005	09 May 2005	1 Oct 2004
CnB	20 May 2005	06 Jun 2005	1 Feb 2005
C	10 Jun 2005	05 Sep 2005	1 Feb 2005

GENERAL: Please use the most recent proposal coversheets, which can be retrieved at *http://www.nrao.edu/administration/directors_office/tel-vla.shtml* for the VLA and at *http://www.nrao.edu/administration/directors_office/vlba-gvlbi.shtml* for the VLBA. Proposals in Adobe Postscript format may be sent to *propsoc@nrao.edu*. Please ensure that the Postscript files request US standard letter paper. Proposals may also be sent by paper mail, as described at the web addresses given above. FAX submissions will not be accepted. Only black-and-white reproductions of proposal figures will be forwarded to VLA/VLBA referees. Finally, VLA/VLBA referee reports are now distributed to proposers by email only, so please provide current email addresses for all proposal authors via the most recent LaTeX proposal coversheets.

VLA: The maximum antenna separations for the four VLA configurations are A-36 km, B-11 km, C-3 km, and D-1 km. The BnA, CnB, and DnC configurations are the hybrid configurations with the long north arm, which produce a circular beam for sources south of about -15 degree declination and for sources north of about 80 degree declination. Some types of VLA observations are significantly more difficult in daytime than at night. These include observations at 90 cm (solar and other interference; disturbed ionosphere, especially at dawn), deep 20 cm observations (solar interference), line observations at 18 and 21 cm (solar interference), polarization measurements at L band (uncertainty in ionospheric rotation measure), and observations at 2 cm and shorter wavelengths in B and A configurations (tropospheric phase variations, especially in summer). Proposers should defer such observations for a configuration cycle to avoid such problems. In 2004, the D configuration daytime will involve RAs between 05^h and 11^h. Current and past VLA schedules may be found at *http://www.vla.nrao.edu/astro/prop/schedules/old/*. EVLA construction will continue to impact VLA observers; please see the web page at *http://www.aoc.nrao.edu/evla/archive/transittion/im*.

Approximate VLA Configuration Schedule

	Q1	Q2	Q3	Q4
2003	D	D,A	A,B	B
2004	C	D	D,A	A
2005	B	B,C	C	D
2006	D,A	A	B	C

VLBA: Time will be allocated for the VLBA on intervals approximately corresponding to the VLA configurations, from those proposals in hand at the corresponding VLA proposal deadline. VLBA proposals requesting antennas beyond the 10-element VLBA must justify, quantitatively, the benefits of the additional antennas. Any proposal requesting a non-VLBA antenna is ineligible for dynamic scheduling, and fixed date scheduling of the VLBA currently amounts to only about one quarter of observing time. Adverse weather increases the scheduling prospects for dynamics requesting frequencies below about 10 GHz. When the

VLA-Pie Town link is in use during the VLA's A configuration, we will try to substitute a single VLA antenna for Pie Town in a concurrent VLBA dynamic program. Therefore, scheduling prospects will be enhanced for VLBA dynamic programs that can accommodate such a swap. See *http://www.aoc.nrao.edu/vlba/schedules/this_dir.html* for a list of dynamic programs which are currently in the queue or were recently observed. VLBA proposals requesting the GBT, the VLA, and/or Arecibo need to be sent only to the NRAO. Any proposal requesting NRAO antennas and antennas from two or more institutions affiliated with the European VLBI Network (EVN) is a Global proposal, and must reach BOTH the EVN scheduler and the NRAO on or before the proposal deadline. VLBA proposals requesting only one EVN antenna, or requesting unaffiliated antennas, are handled on a bilateral basis; the proposal should be sent both to the NRAO and to the operating institution of the other antenna requested. Coordination of observations with non-NRAO antennas, other than members of the EVN and the DSN, is the responsibility of the proposer.

B.G. Clark, J. M. Wrobel
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VLBI Global Network Call for Proposals

Proposals for VLBI Global Network observing are handled by the NRAO. There are three Global Network sessions per year, with up to three weeks allowed per session. The Global Network sessions currently planned are:

Date	Proposals Due
05 Feb to 26 Feb 2004	01 Oct 2003
20 May to 10 Jun 2004	01 Feb 2004
21 Oct to 11 Nov 2004	01 Jun 2004

Any proposal requesting NRAO antennas and antennas from two or more institutions affiliated with the European VLBI Network (EVN) is a Global proposal, and must reach BOTH the EVN scheduler and the NRAO on or before the proposal deadline. FAX submissions of Global proposals will not be accepted. A few EVN-only observations may be processed by the Socorro correlator if they require features of the EVN correlator at JIVE which are not yet implemented. Other proposals (not in EVN sessions) that request the use of the Socorro correlator must be sent to NRAO, even if they do not request the use of NRAO antennas. Similarly, proposals that request the use of the EVN correlator at JIVE must be sent to the EVN, even if they do not request the use of any EVN antennas. All requests for use of the Bonn correlator must be sent to the MPIfR.

Please use the most recent proposal coversheet, which can be retrieved at *http://www.nrao.edu/administration/directors_office/vlba-gvlbi.shtml*. Proposals may be submitted electronically in Adobe Postscript format. For Global proposals, those to the EVN alone, or those requiring the Bonn correlator, send proposals to *proposevn@hp.mpifr-bonn.mpg.de*. For Global proposals that include requests for NRAO resources, send proposals to *propsoc@nrao.edu*. Please ensure that the Postscript files sent to the latter address request U. S. standard letter paper. Proposals may also be sent by paper mail, as described at the web address given. Only black-and-white reproductions of proposal figures will be forwarded to VLA/VLBA referees. Finally, VLA/VLBA referee reports are now distributed to proposers by email only, so please provide current email addresses for all proposal authors via the most recent LaTeX proposal coversheet.

B.G. Clark, J. M. Wrobel
schedsoc@nrao.edu

VLBA Spacecraft Navigation Pilot Project

A VLBA Spacecraft Navigation Pilot Project has been initiated. The project, funded by NASA, will study several aspects of VLBA phase-referencing measurements as a vital adjunct to conventional spacecraft navigation.

The central task will be carried out in collaboration with several groups at the Jet Propulsion Laboratory to assess the feasibility of this approach. This study will include an evaluation of the precision achievable via phase-referenced VLBA observations of spacecraft downlink transmitters and the enhancement of navigation results produced by the inclusion of such measurements in the overall solution.

In addition, NRAO will develop designs and cost estimates for upgrading VLBA hardware, software, and operational procedures in several areas. These would all be required to support routine spacecraft navigation observations, with adequate sensitivity, at NASA's new space communication frequency band:

- Upgrades to the VLBA correlator to incorporate the spacecraft ephemeris into the wavefront delay model, and to add new tables to the output files to maintain complete model accountability.
- Upgrades to the VLBA correlator's playback interface, and to the station and correlator control software, to exploit the full 1-Gbps bandwidth of the disk-based Mark 5B recording system.
- New Ka-band (33 GHz) receiver systems.
- Upgrades to VLBA operational procedures to optimize our ability to perform spacecraft navigation observations with minimal impact on the VLBA's ongoing astronomy progra

We anticipate that the project will show a mutually beneficial arrangement to be possible, with NRAO providing a significant quantity of spacecraft navigation results to NASA, while NASA provides the substantial upgrades, outlined above, to the VLBA's observational capabilities. With these upgrades, we expect that the number of hours available for astronomical observing will be at least as high as the average over the last few years.

NASA's support for the Pilot Project has made possible the participation, at fractional work-year levels, of NRAO personnel from almost all divisions at the AOC, and from the Central Development Laboratory in Charlottesville.

J. D. Romney

VLBI Using Arecibo

Potential proposers of VLBI observations requiring high sensitivity are reminded that they may propose to use the 305-m Arecibo telescope along with the VLBA for sources in the declination range visible by Arecibo, between -1 degrees and +38 degrees declination, and in standard VLBA frequency bands below 10 GHz. These proposals should be submitted as usual to NRAO, where they will be refereed by the normal process; they need not be submitted to Arecibo. Proposals should include a specific justification of why the addition of the Arecibo telescope is important for the proposed science.

The Arecibo slew rates of 24 deg/min in azimuth and 2.4 deg/min in zenith angle will often permit useful phase referencing with both the VLBA and Arecibo. Proposers should remember that Arecibo always operates within 19.7 deg of the zenith, and that azimuth drives are multiplied over real angle by cosec(zenith angle). The typical improvements in fringe-detection and image sensitivity by including Arecibo with the VLBA are a factor of 5 or better, depending on the frequency and zenith angle. Recent VLBI programs that have been carried out using Arecibo include imaging of luminous infrared galaxies (e.g., Momjian et al. 2003, ApJ, 597, 809), supernova detection in Arp 220, imaging of the gamma-ray burst GRB 030329, and various VLBI observations of pulsars and OH megamasers.

Please see *http://www.naic.edu/aomenu.htm* for more information about the observing properties of the Arecibo telescope. By following the appropriate links, one can find details about the sensitivity at various bands, complete lists of VLBI observations carried out at Arecibo, and other useful information. Over the next few months, we will be working on achieving smoother VLBI operations with Arecibo, including the routine provision of calibration data for the VLBI observers.

J. S. Ulvestad,
C. Salter (NAIC)

VLA Calibration Transfer in VLBI Experiments

The VLA can now be treated much more like a VLBA antenna for purposes of calibrating VLBI experiments that include either the phased VLA or a single VLA antenna. This is possible since we recently started to distribute the VLA gain curve, VLA system temperature, and VLA weather information harvested during VLBI experiments in the form of tables attached to the correlated data. The AIPS calibration of the VLA single dish antenna in a VLBI experiment can be processed along with the VLBA antennas using the VLBAUTIL procedures described in Appendix C of the AIPS cookbook. Using the VLA phased array in the observation still requires the user to insert the source flux density in the "SU-table" before calibration. In rare cases in which multiple setups in the same frequency band are used, the new, default calibration procedure may not fully work and observers are required to use the previous "ANTAB" method to obtain proper calibration. For most users there will be no extra calibration burden when using the VLA in a VLBA observations. Currently we are looking into similar improvements to streamline the calibration for VLBI experiments correlated in Socorro that involve the GBT and Arecibo.

L. O. Sjouwerman

Large VLA Proposals

We remind potential proposers that the February 2, 2004 proposal deadline is a deadline for VLA large proposals for the next VLA configuration cycle. This deadline will be for observations during the time period beginning with the A configuration during the last trimester of 2004, and extending through the D configuration at the end of 2005. For more details, see *NRAO Newsletter No. 97* or *http://www.vla.nrao.edu/astro/prop/largeprop/*.

J. S. Ulvestad

Interferometry Computing

We have reorganized a number of areas of interferometry computing in order to focus more clearly on the operating and planned interferometers in NRAO. This reorganization is aimed at creating a tighter link between the ALMA and EVLA project requirements, and those who are responsible for delivering software products to meet those requirements.

During the summer, we formed a matrix-managed Interferometry Software Division, which is co-managed by Brian Glendenning (representing ALMA) and Jim Ulvestad (representing EVLA, VLA, and VLBA). This Division includes Integrated Product Teams responsible for post-processing software, data pipelines, data archives, and proposal handling. To ensure coordination within the NRAO of the long-term developments that are necessary for all NRAO's telescopes, Doug Tody has been appointed chief architect for the Interferometry Software Division. Doug's duties will include guiding the efforts of Integrated Product Teams in data flow and data management areas as part of his continuing efforts in the development of the Virtual Observatory.

Within VLA/VLBA Operations, the previous Computing Division has been split into two new divisions. One division is the Computing Infrastructure Division, responsible for all local computing infrastructure, including systems administration, software/hardware upgrades and maintenance, and communications. James Robnett, who formerly led the systems administration effort in the previous Computing Division, has been appointed Head of the Computing Infrastructure Division. The other new division is the EVLA Computing Division, responsible for all aspects of EVLA software development, including those EVLA-specific activities formerly housed in the end-to-end project within Data Management. Gustaaf van Moorsel, who headed the previous Computer Division, has been appointed head of the EVLA Computing Division.

Of course, we will continue our important efforts to maintain and upgrade the current operational telescopes, the VLA and VLBA. Support activities from personnel in the Computing Infrastructure Division continue to be supervised within that Division. In addition, several members of the new EVLA Computing Division have responsibilities for the operating telescopes. These responsibilities will be coordinated by Peggy Perley, the Head of the Array Operations Division.

J. S. Ulvestad, B. E. Glendenning

Antenna Bearing Replacements

An elevation bearing on the VLBA antenna in St. Croix was replaced in July 2003, and the azimuth bearing on VLA antenna 15 was replaced in August 2003. The bearings were replaced because metal flakes were found in grease samples collected from them. A high metal content in the grease indicates a failed bearing or excessive bearing wear.

The installation of the new elevation bearing and its pillow black mount at the VLBA antenna in St. Croix. Photograph by Pete Allen.

The elevation bearing on the VLBA antenna in St. Croix failed because of an excessive axial load on the bearing, which is designed to support radial loads only. The axial load arises from a subtlety in the design of the bearing support structure and was most likely induced when the bearing was first installed. An elevation bearing at the VLBA antenna in Los Alamos failed in a similar manner in 2001. Since all VLBA antennas are essentially identical, we can expect similar bearing failures at other VLBA antennas in the future.

Our strategy for replacing VLBA elevation bearings is to continue monitoring bearing grease samples and to replace those bearings that show excessive metal content in the samples. Replacements for the bearings will be of a new design that can support both axial and radial loads. This strategy extracts maximum use of the existing bearings and minimizes bearing replacement costs.

A very aggressive program to replace all VLBA elevation bearings is not warranted at this time because bearing wear can be detected prior to a severe failure. For example, the grease samples taken at St. Croix suggested that the bearing was damaged, but the antenna showed no degradation in its pointing performance.

The replacement of the 10-foot diameter azimuth bearing on antenna 15 is the seventh azimuth bearing replacement undertaken by the Engineering Services Division. As with the other azimuth bearings that have been replaced, an inspection of the replaced bearing on antenna 15 showed that the metal flakes in the grease were caused by excessive bearing wear. The wear is attributed to normal operations over the 20-plus year service life of the bearings and, possibly, inadequate lubrication of the bearings when they were originally installed. More bearing replacements will be required to maintain antenna infrastructure over the lifetime of the EVLA.

If azimuth bearing wear can be detected soon enough, the used bearing can be reconditioned by a bearing manufacturer and reinstalled on another antenna at a cost that is $20K less than the cost of a new bearing. Of course, a small number of new bearings must be purchased to return antennas to operation while the used bearings are reconditioned. We recently arranged for the purchase of four new azimuth bearings and the reconditioning of a used bearing. These bearings will be used to replace two azimuth bearings in each calendar year of 2004 and 2005.

M. M. McKinnon

X-Ray and Radio Connections

"Almost by definition, high energy sources are non-thermal and emit throughout the electromagnetic and other spectra and spectrally chauvinist interpretations of their behavior are incomplete" (Blandford 2003).

NRAO and AUI are sponsoring the meeting "X-Ray and Radio Connections" with the Chandra X-Ray Center and Los Alamos National Laboratories to take place in Santa Fe Tuesday, February 3, through Friday, February 6, 2004. The purpose of the meeting is to encourage increased scientific return from multi-wavelength astronomy involving X-ray and radio instrumentation. Currently, observations of high-energy phenomena sometimes are split among several communities that independently investigate objects in their own waveband. This can lead to reduced scientific results compared to those possible from multiwavelength programs.

This meeting will provide an opportunity for researchers to review underlying physical models, compare x-ray and radio observations, start new collaborations and develop a list of areas where new observations and theoretical development could significantly advance our understanding in the next few years.

The topics of the meeting were chosen to focus on scientific areas where cross fertilization between theory and observations in both x-ray and radio wavebands provides a key to the underlying physical processes. We knew from the outset that there were numerous fields that would benefit from an "x-ray and radio connections" session. However, it was also clear that a small meeting would best facilitate discussion and that focusing on a few topics would be better than a shotgun approach. The chosen topics include: massive star cluster outflows, colliding stellar winds, supernova remnants, pulsar wind nebulae, dissipation of jets and lobes, and cluster mergers. If this meeting is a success we would consider planning "X-ray and Radio Connections II" (no sooner than January 2006) which would cover topics that we were unable to cover in this meeting. The website is *http://www/aoc/nrao.edu/events/xraydio/*.

Confirmed speakers include:

Robert Berrington (NRL)
Henrik Beuther (Harvard-Smithsonian CfA)
Michael Corcoran (USRA & NASA-GSFC)
Anne Decourchelle (Saclay)
Tracey DeLaney (U Minnesota)
Dave DeYoung (NOAO Tucson)
Jean Eilek (New Mexico Tech)
Luigina Feretti (CNR Bologna)
Martin Hardcastle (U Bristol)
John Kirk (MPI-K Heidelberg)
Robert Laing (U Oxford)
Andrew Melatos (U Melbourne)
Julian Pittard (U Leeds)
Steve Reynolds (NC State)
Craig Sarazin (U Virginia)

Meeting Chairs:

Kristy Dyer (NSF Astronomy & Astrophysics Postdoctoral Fellow, NRAO-Socorro)
Lorant Sjouwerman (Scientific Services, NRAO-Socorro)

K. K. Dyer, L. O. Sjouwerman

Education and Public Outreach at NRAO-Socorro

NRAO Socorro's Education and Public Outreach efforts reached a milestone this summer with the opening of the gift shop at the Very Large Array Visitor Center. Ground was broken in early March, and the shop opened its doors for business on June 18. The purpose of opening a gift shop was to provide our tourists a friendly face to greet them and to answer their questions. In the past, our visitor center was not staffed and tourists were left to figure out their own answers about radio astronomy, the VLA, or the nearest gas station. Our clerks enhance the visitors' experiences with answers and information resources. The revenue raised in gift shop proceeds will pay the clerks' salaries.

From a commercial standpoint, the gift shop provides our guests, many of whom have "wanted to come to the VLA for a long time," with souvenirs of their visit. We sell primarily NRAO logo merchandise, books, "Contact" DVDs, and jewelry produced by artisans

VLA Visitor Center Gift Shop

Danielle Lucero (NMT grad student) and Jim Muehlberg (NRAO) working on the NRAO/New Mexico Tech Instructional Interferometer.

from the local Alamo Navajo Reservation. For guests who visit the VLA outside normal gift shop hours, we do sell some of our merchandise mail-order over the web at *www.vla.nrao.edu/genpub/shop/*.

A second milestone was reached with the completion of the first two elements of the N^2I^2 (NRAO/New Mexico Tech Instructional Interferometer). Work on the instrument began in 2000 with a planning meeting between Robyn Harrison and Dave Westpfahl, culminating this spring in "first light" from two 10-foot dishes located at Etscorn Observatory on the New Mexico Tech campus. The cooperative effort between NRAO and New Mexico Tech (NMT) involved funding and volunteer labor from both entities.

NMT grad student Danielle Lucero, with after-hours and weekend volunteer assistance from NRAO employees Jim Muehlberg and Mike Revnell, built the adding interferometer with a 24-meter east/west baseline. A simple combiner sends a single signal to the 21cm receiver, donated by Gareth Harris. The Sun, Cassiopeia A, Cygnus A, Taurus A, Virgo A, and Sagittarius A have been successfully detected thus far. The setup can be used for single dish drift scans, interferometer drift scans at meridian, and fringe detection.

The purpose of the N^2I^2 is to provide a "hands-on" instrument for teachers and students. It will be used as a tool for learning about radio astronomy and interferometry, and to afford opportunities for research experiences. A two-week class for teachers is planned through NMT's Master of Science Teaching program, as well as shorter weekend workshops sponsored by NRAO. More information on the construction and testing of N^2I^2 can be found at *www.nrao.edu/epo/amateur*.

R. J. Harrison

In General

NRAO Archives

The NRAO Archives is pleased to announce the availability of a Web resource describing Nannielou Hepburn Dieter Conklin's career as the first US woman working in radio astronomy: *http://www.nrao.edu/archives/Conklin/conklin.shtml*. "Nan Dieter Conklin: A Life in Science" was written by Dr. Conklin in 2001, and covers her work from 1946-1977, beginning at the Maria Mitchell Observatory and ending at University of California Berkeley.

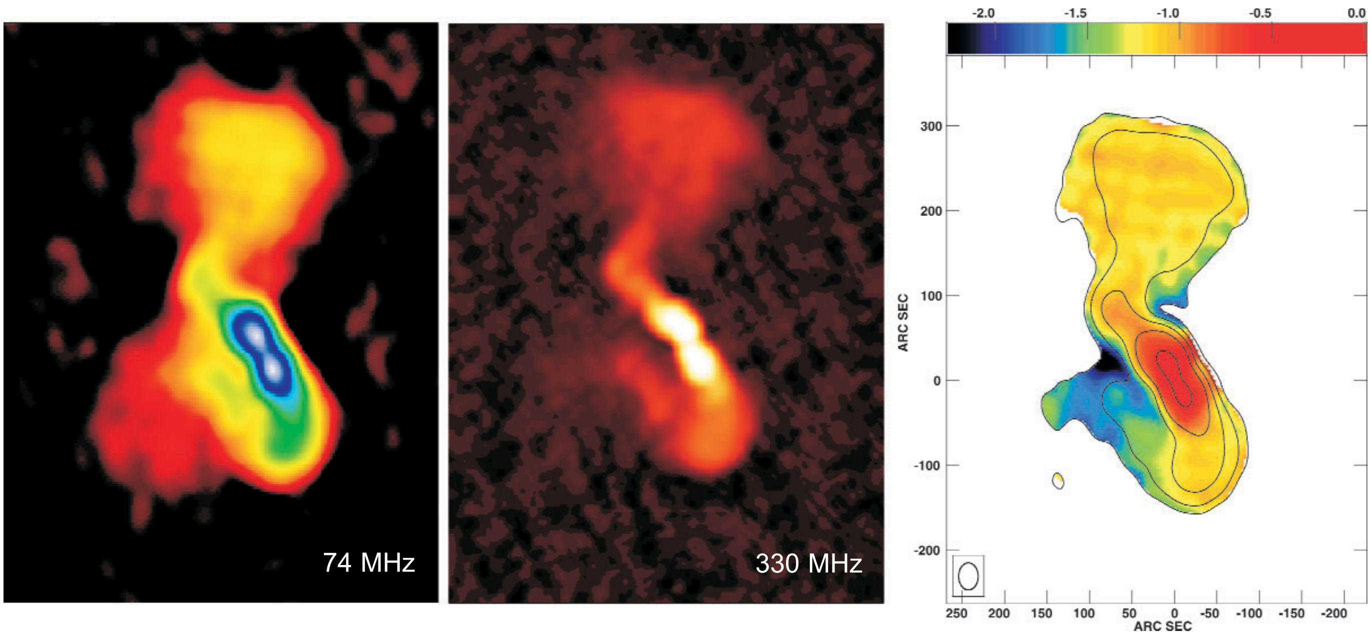
The NRAO Archives has been established to seek out, collect, organize, and preserve institutional records and personal papers of enduring value which document NRAO's historical development, institutional history, instrument construction, and ongoing activities. As the national facility for radio astronomy, the NRAO archives will also include materials on the history and development of radio astronomy in the U.S., particularly if such materials are in danger of being lost or discarded by other institutions or individuals.

For further information, please contact NRAO Archivist Ellen Bouton, *ebouton@nrao.edu*.

E. N. Bouton

New Results

The Many Faces of Hydra A: Low Frequency Observations Reveal the Big Picture



VLA images of Hydra A; 3C218. (left) 74 MHz, A-configuration image with ~25" resolution. (middle) 330 MHz, combined A-, B-, and C- configuration image, displayed at ~15" resolution. (right) The spectral index map of Hydra A between 330 MHz and 74 MHz is shown in color, with overlaid contours from the 330 MHz image at (1, 4, 16, 64, 512) × 54 mJy/beam (the 5σ noise level). The two frequencies were mapped with a matching resolution of ~25" before being combined in this image.

Although it is the seventh brightest source in the 3C catalog, images of Hydra A (3C218) at low radio frequencies with good angular resolution have never been available. Hydra A is a well known, powerful FR I radio galaxy located in the core of a poor galaxy cluster at z = 0.0542. Observations of this source at frequencies above 5 GHz reveal bright inner jets which trace an "S" shape (Taylor et al. 1990) and combined cover roughly 1.5′ in a north-south direction.

A new analysis of VLA observations at 330 and 74 MHz shows that the well-known bright inner jets of Hydra A are longer than previously seen, and extend for roughly 2′ on both sides of the source. They then bend dramatically and end in diffuse lobes. The entire source covers nearly 8′, or roughly 375 h_{71}^{-1} kpc (Lane et al. 2004). The synchrotron spectrum of Hydra A has a relatively flat slope in the radio core, which steepens in the jets and lobes. It is not yet known what fraction of FR I galaxies have similar diffuse extended structures visible at low frequencies, but they have been seen in a few other sources such as M87 in the core of the Virgo cluster (Owen, Eilek, & Kassim 2000).

Recent X-ray observations of the thermal gas in this system show that Hydra A is surrounded by dense, cool gas which extends well beyond the bright radio jets (Nulsen et al. 2002) and is roughly aligned with the low frequency outer emission. This may be entrained cluster core gas which has been dragged out by buoyantly rising outer lobes. Through a comparison of the new radio data with recent X-ray observations, we will be able to investigate what dominates the energy budget in the center of this system.

Tracy Clarke (Univ. of Virginia),
Wendy Lane (Naval Research Laboratory)

References:

Lane, W. M., Clarke, T. E., Taylor, G. B., Perley, R. A., & Kassim, N. E. 2004, AJ (in press)

Nulsen, P. E. J., David, L .P., McNamara, B. R., Jones, C., Forman, W. R., & Wise, M. 2002, ApJ, 568, 163

Owen, F. N., Eilek, J. A., & Kassim, N. E. 2000, ApJ, 543, 611

Taylor, G. B., Perley, R. A., Inoue, M., Kato, T., Tabara, H., & Aizu, K. 1990, ApJ, 360, 41

Hydrogen Cyanide Emission from a Distant (z=2.6) Quasar — the Essential Signature of a Starburst

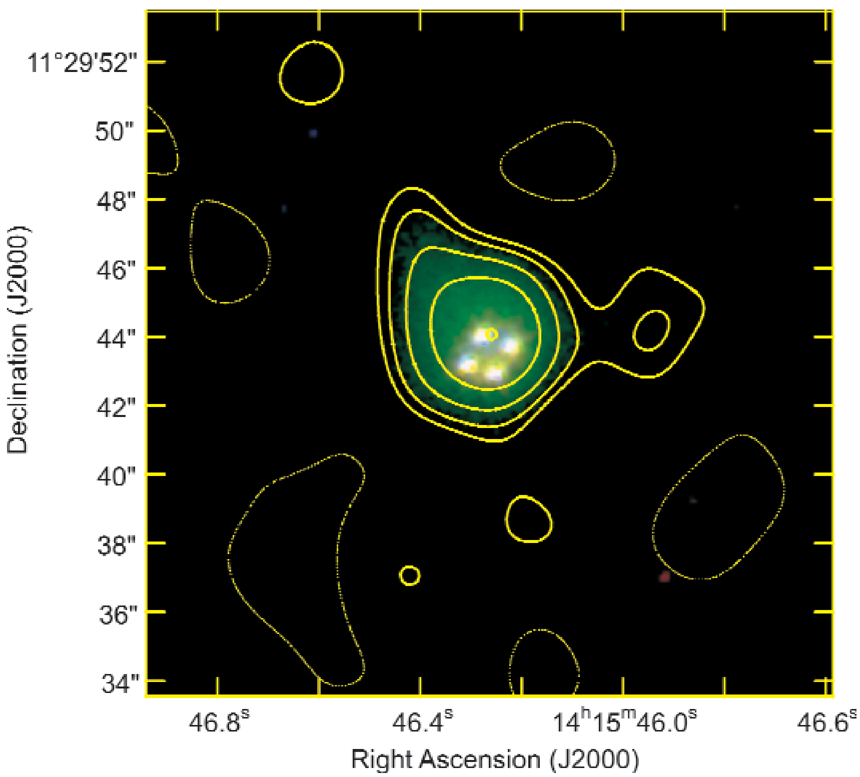


Figure 1. The Cloverleaf in HCN(J=1-0) emission (green) at a resolution of 4". The contours are "square-root of 2" in units of 0.015 Jy km s^{-1}, which is 1.7 times the rms noise, superimposed on an optical image made from HST archival data. A continuum has been subtracted.

The detection of carbon monoxide (CO) emission from 24 high redshift (z > 1) galaxies suggests that their observed high infrared luminosities ($L_{IR} > 10^{11}\ L_{\odot}$) result from high rates of star formation. Alternatively, as a substantial fraction (possibly all) of these galaxies harbor active galactic nuclei (AGN), the infrared luminosities could also have an AGN origin. The detection of CO emission is sufficient to establish the presence of a reservoir of molecular gas required for star formation, but not to establish that this gas is present in densities sufficient for star formation to occur.

Detection of emission from molecules with larger electric dipole moments than CO can provide a reliable signature of star formation. Carbon monosulfide (CS) and hydrogen cyanide (HCN) are examples, each requiring gas densities of ~10^5 cm^{-3} for excitation of its energy levels, compared with ~300 cm^{-3} for CO. CS and HCN emission have been identified with the high density gas in the cores of molecular clouds that are forming high-mass stars in the Galaxy. Previous detections of HCN emission in ultra- luminous infrared galaxies encouraged us to search for HCN emission in the Cloverleaf, a galaxy at z=2.5579 known to have large IR luminosity, that had been detected in several CO transitions.

The Cloverleaf is imaged by a gravitational lens into four components separated by ~ 1". A lens model based on radiation from the molecular gas makes it possible to infer intrinsic source properties.

The VLA was used in D-configuration at the red-shifted frequency of 24.9149 GHz to image the Cloverleaf from data obtained in 12 hours of integration (Figure 1).

The HCN(J=1-0) line was detected at the 6σ level with a peak flux density of 0.24 mJy and profile/width similar to that of CO(7-6). The HCN line luminosity is comparable to that seen in ultra-luminous IR galaxies. Comparison with Arp 220 leads to a star formation rate in the Cloverleaf of $10^3 M_\odot yr^{-1}$, 300 times that of the Milky Way. The Cloverleaf's reservoir of $10^{10} M_\odot$ of dense, molecular gas will be depleted in a starburst lifetime of only 10^7 years, assuming 100 percent efficiency. The starburst accounts for about 20 percent of the infrared emission, the balance is presumably due to the AGN.

P. A. Vanden Bout, C. L. Carilli (NRAO)
P. M. Solomon (SUNY-Stony Brook)
M. Guelin (IRAM)

References:

Kneib, J.-P., Alloin, D., Mellier, Y., Guilloteau, S., Barvainis, R., & Antonucci, R. 1998, A&A, 329, 827

Solomon, P. M., Vanden Bout, P. A., Carilli, C. L., & Guelin, M. 2003, Nature (December 11).

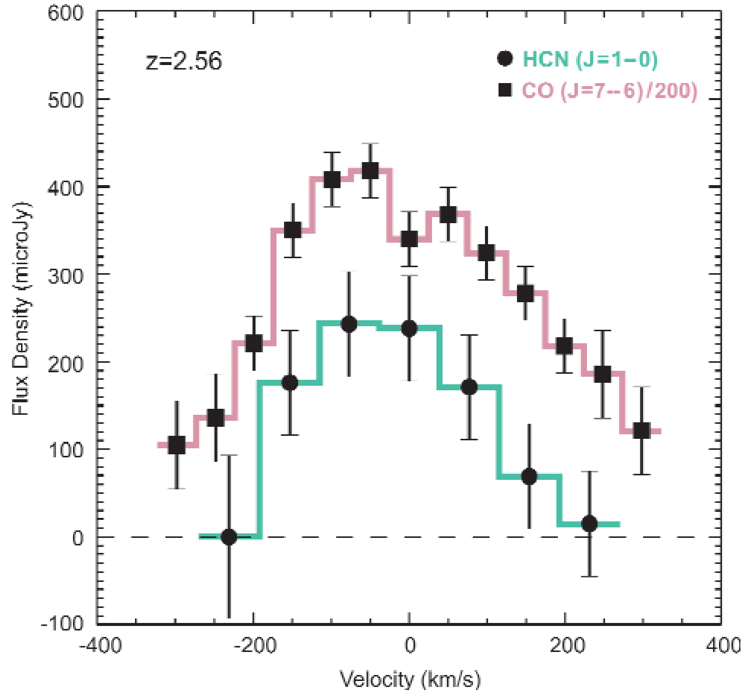


Figure 2. Spectrum of HCN(J=1-0) emission observed in the Cloverleaf together with the spectrum of CO(J=7-6) from Kneib et al. (1998), scaled down by a factor of 200.

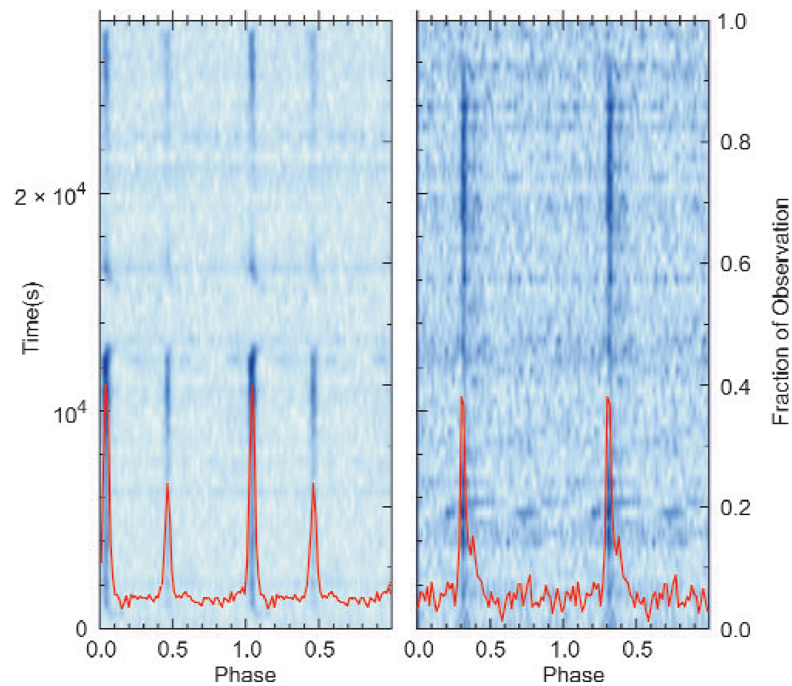
GBT Discovery of Two Binary Millisecond Pulsars in the Globular Cluster M30

Globular clusters produce millisecond pulsars (MSPs) at a rate per unit mass that is up to an order-of-magnitude greater than the Galaxy itself. Stellar interactions in the high-density cores of clusters can result in compact binary systems where old neutron stars are "recycled" and spun-up to millisecond spin periods via accretion. The rotational stability of MSPs can be used to test gravitational theories in compact binaries; plasma physics can be constrained with measurements of eclipsing binary MSPs; stellar evolutionary models are tested by multi-wavelength observations of binary pulsar companion stars; and properties of the clusters themselves, such as the mass-to-light ratio and the dynamics of the cluster core, can be determined through timing observations of several pulsars in each cluster.

Using 7.8 hours of "First Science" data with the GBT taken at 1370 MHz with the Berkeley-Caltech Pulsar Machine (BCPM) on September 9, 2001 as part of a major search for pulsars in globular clusters, we found two binary MSPs after performing extensive computer analysis in order to remove interference, correct for the dispersive effects of the interstellar medium, and account for the binary motion of the pulsars (Ransom et al. 2003).

Pulsar J2140-2310A (M30A) is an eclipsing 11-ms pulsar in a 4-hr circular orbit around a low-mass ($\sim 0.1-0.2 M_\odot$) companion star. Timing observations over the past two years have shown that the pulsar is located only 4″ from the core of the cluster and appears to be spinning faster over time — an effect caused by the pulsar's motion in the gravitational potential of the cluster itself. Using this information, we show that the cluster core has a mass-to-light ratio > 0.5 (which is consistent with cluster dynamical and evolutionary theory) and that the pulsar itself has a low magnetic field strength ($< 4.2 \times 10^8$ G) and high age ($> 10^8$ yrs), which are typical values for MSPs. Using the precise timing position, we have also identified plausible counterparts to the system in both Chandra X-ray data (most likely from thermal emission from the neutron star surface) and HST optical data (presumably from the companion star).

M30A also exhibits regular eclipses of its pulsed emission by the ionized wind from the companion star. Measurements of the pulse arrival times during eclipse ingress and egress show delays of up to 2-3 ms due to the plasma in the eclipse region. In addition, the duration of the radio eclipses seems to be dependent on the observing frequency. Additional measurements should allow the team to constrain the likely eclipse mechanisms for this interesting system.



Pulse profiles from the 7.8-hr discovery observation of the 11-ms binary pulsar M30A (left) and the 13-ms eccentric binary pulsar M30B (right). The Doppler effects of each orbit have been removed, and two complete profiles are plotted for clarity. The underlying data show the consistency of the pulsed emission as well as some effects due to interference as a function of time. Strong scintillation and portions of at least two eclipses of M30A are evident, including dispersive delays to the pulse arrival times at eclipse ingress and egress.

Pulsar J2140-23B (M30B) is a 13-ms pulsar in an as yet undetermined, yet clearly very interesting, orbit. The pulsar was detected for ~7 hours in the original discovery observation but has not been seen since, due presumably to the same intensive diffractive scintillation that plagues the observations of M30A. However, the discovery data showed very significant accelerations of the pulsar which constrain the orbit to be highly eccentric ($e > 0.5$), of 1-10 days in duration, and around a companion of 0.2-1.0 solar masses. Future detections of this system, which is almost certainly highly-relativistic, may allow the accurate measurement of the masses of both the pulsar and the companion-numbers which are important for pulsar "recycling" theory and the determination of neutron star equations of state.

Timing observations of M30 with the GBT are continuing and the potential for both new science and additional pulsars is strong.

Scott Ransom (Mc Gill University/MIT)

References:

Ransom, S. M., Stairs, I. H., Backer, D. C., Greenhill, L. J., Bassa, C. G., Hessels, J. W. T., & Kaspi, V. M. 2003, ApJ (in press, astro-ph/0310347).

TXCam: The Movie (Part I)

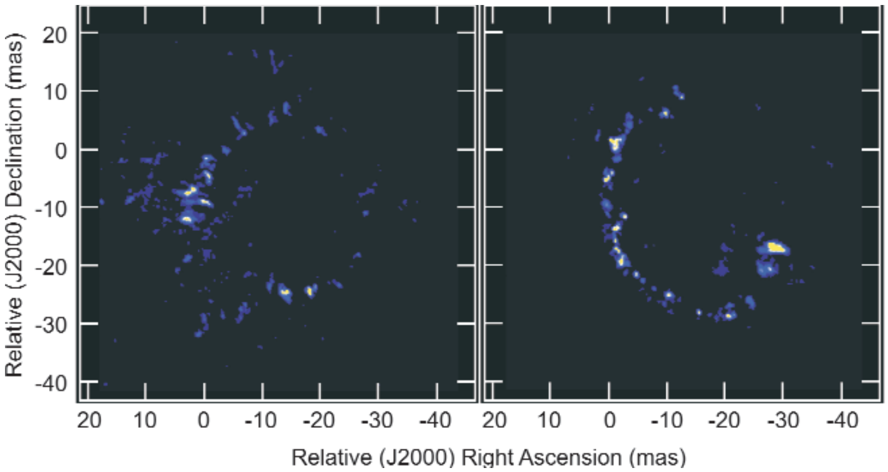


Figure 1. Two frames from the TX Cam movie.

The astronomical SiO masers located in the extended atmospheres of asymptotic giant branch (AGB) stars act as unique tracers of the physical processes at work in the near-circumstellar environments of cool, evolved stars. The extended atmosphere is defined as the region between the photosphere and the inner dust formation radius, usually lying at a distance of a few stellar radii. In AGB stars this is a complex region, dominated by the mass-loss process and permeated by shocks, magnetic fields and local temperature and density gradients. The study of these regions is not easy since dust often prohibits optical observations and the necessary spatial resolution is not yet available in other wavebands. However, the individual SiO maser components have sufficiently high brightness temperatures to allow VLBI imaging of this region at sub-milliarcsecond (mas) resolution.

We have used the unique high-frequency capabilities of the VLBA to monitor the 43 GHz, v=1, J=1-0 SiO masers in the atmosphere of TX Cam. TX Cam is a rather ordinary, if somewhat evolved, Mira star with a spectral classification that varies between M8 and M10 over a pulsation period of 557.4 days. It lies at a distance of 390 pc. Although there are numerous lines from C- and S-rich molecular species, no OH or H_2O masers have been detected.

We originally selected TX Cam for the monitoring program from a sample of 25 other stars. It had a clearly circular structure in SiO, which looked relatively simple; its flux density was usually high and it lay at a declination of 56°. Over a period of 3 years, from 1997—2000, we obtained 76 epochs of data from the VLBA. In the first half of this period the epochs were separated by two weeks, later this interval became a month. The data analysis followed a pipeline procedure and the resultant integrated velocity maps of each epoch were combined to form a movie (*http://www.jb.man.ac.uk/~pdiamond/txcam_movie.mpg*) with the first 44 epochs (Figure 1, Diamond & Kemball 2003).

The paper discusses the global proper motion of the SiO maser emission as a function of pulsation phase. We measure a dominant expansion mode between optical phases ~0.7-1.5, confirming ballistic deceleration,

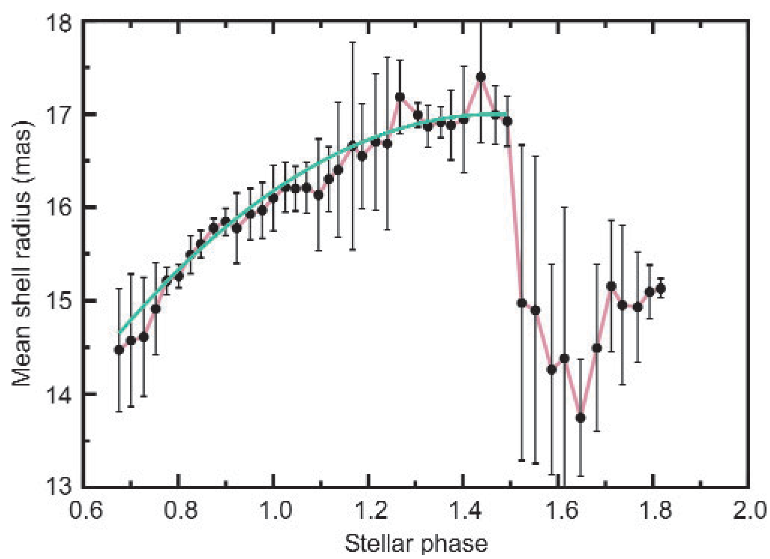


Figure 2. Inner radius plotted as a function of time showing how the SiO breathes with the stellar pulsation period.

and compare this to predictions from existing pulsation models for late-type, evolved stars. A challenge was figuring out how to measure the average radius of the emission, when clearly the ring of masers is never circular and is often asymmetric. We developed a technique that estimated the inner radius at regular points around the ring and thus determined the average size for each epoch. Plotting the inner radius as a function of time shows, in a dramatic fashion, how the SiO breathes with the stellar pulsation period (Figure 2).

In the movie, local infall and outflow motions are clearly superimposed on the dominant expansion mode, and non-radial local gas motions are also evident for individual SiO maser components. The overall morphology and evolution of the SiO emission deviates significantly from spherical symmetry. This has important implications for models of pulsation kinematics and mass-loss in the near-circumstellar environments of Mira variables.

As in Hollywood, we are perfectionists when it comes to our art. The production of the TX Cam movie has been a project long in the making and is clearly far from complete. A movie of all epochs is under construction and will be followed by further analysis of this rich and complex VLBA data set.

Philip Diamond (Jodrell Bank Observatory)
Athol Kemball (NCSA/Univ. of Illinois at Urbana-Champaign)

Reference:

Diamond, P. J. & Kemball, A. J. 2003, ApJ (in press).

The Most Detailed Picture Yet of an Embedded High-mass YSO

High-mass stars are important actors in the ecology of the interstellar medium (ISM) and the evolution of galaxies, yet there is no general theory of their formation. Small sample size, large distances, clustering and crowding, and high extinction conspire to make the process of high-mass star formation very difficult to study. Relatively few massive accreting young stellar objects (YSOs) are known.

The Orion KL region is the archetypal and closest region forming high-mass stars (~450 pc). It contains a compact centimeter and millimeter-wave continuum source, designated “I” in the discovery survey, that marks the location of a deeply embedded YSO. Mass flows at distances between 20 and 70 AU from source “I” are peppered with regions of SiO maser emission, which signifies temperatures of 1000-2000 K and H_2 densities of $\sim 10^{10}$ cm^{-3}. Because this is very high intensity emission, the VLBA can be used to map it with resolutions of <1 AU and <1 km s^{-1} (both Dopper velocity and proper motion).

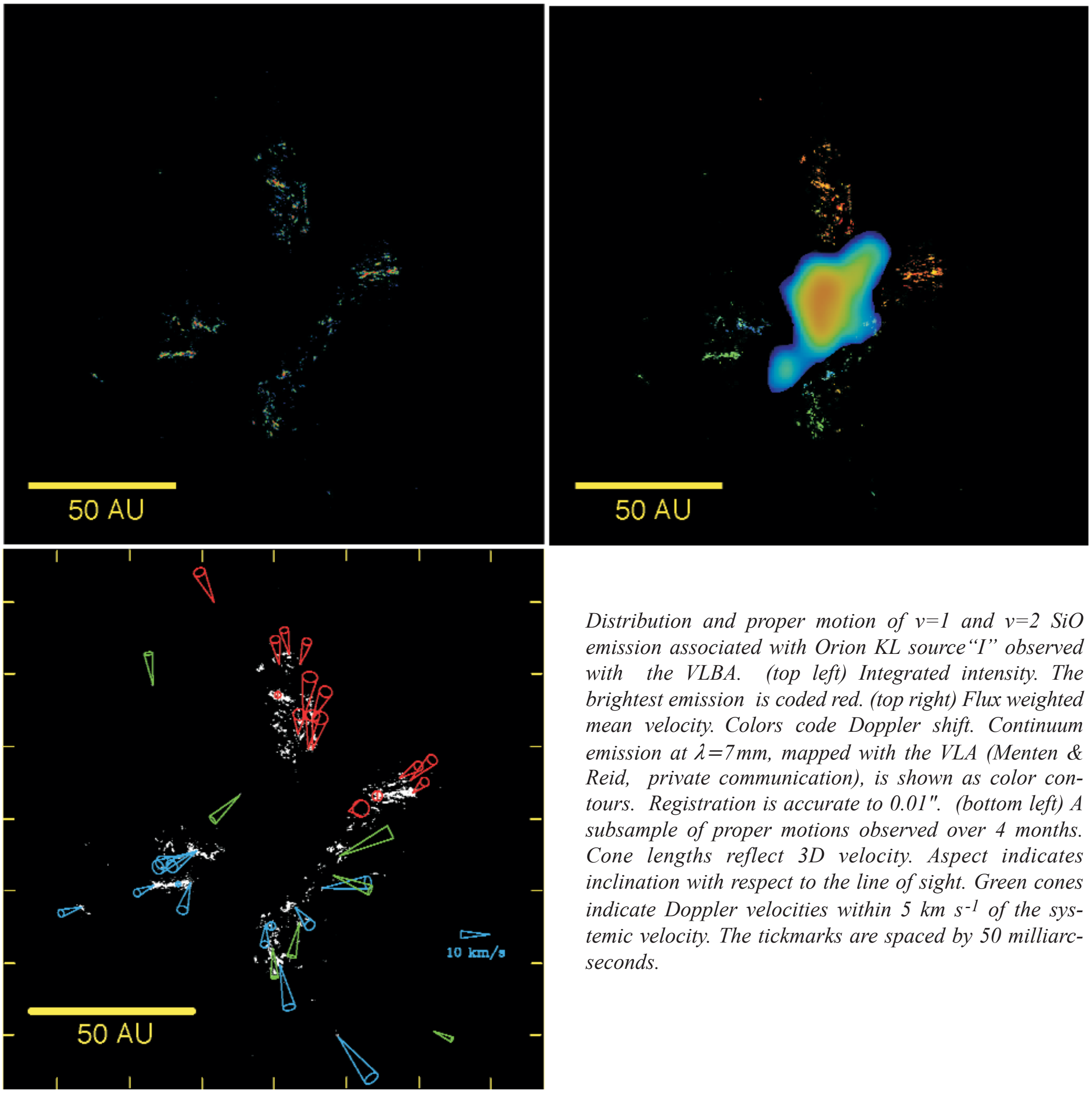
A three-year time series of monthly VLBA observations is now being reduced. In the end, 2.5 TByte of images (64 GByte per epoch) will be compiled and proper motions estimated. A combination of proper motion and Doppler velocity information will yield maps of 3D velocity and acceleration vectors.

Source “I” is important to study because it is possibly the *only* YSO for which gas structure and 3D dynamics can be fully resolved at radii < 10^2 AU, where outflows are launched and collimated. Analysis of just a few epochs suggests that the YSO, with a dynamical mass of $\sim 9\,M_\odot$, drives a rotating, bipolar, funnel-like wind from the surface of an accretion disk that is seen nearly edge-on. The limbs and bases of the funnels are traced by SiO maser emission. By the end of the study, it will be possible to determine whether the outflow motions are ballistic or helical, thus answering the long-standing questions: where are outflows collimated and are magnetic fields important in the formation of massive stars?

Lincoln Greenhill (SAO) & Claire Chandler (NRAO)

Reference:

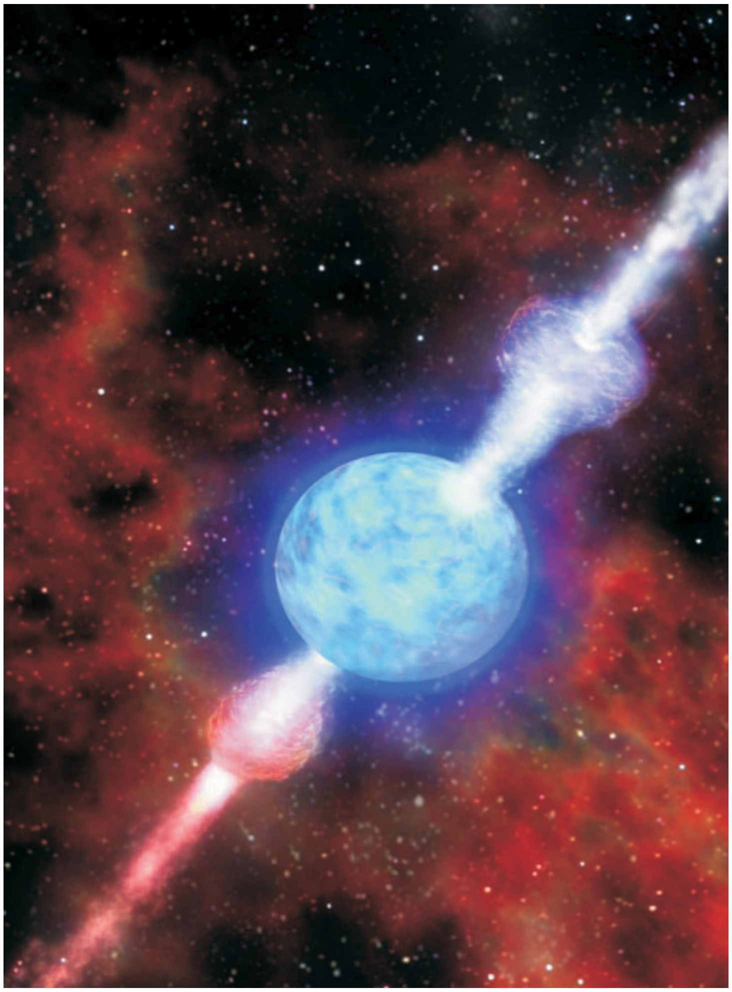
Greenhill, L. J., Chandler, C. J., Reid, M. J., Diamond, P. J., & Moran, J. M. 2004, Proc. IAU Symp. 221, ASP Conf. Series (in press).



Distribution and proper motion of v=1 and v=2 SiO emission associated with Orion KL source "I" observed with the VLBA. (top left) Integrated intensity. The brightest emission is coded red. (top right) Flux weighted mean velocity. Colors code Doppler shift. Continuum emission at λ=7mm, mapped with the VLA (Menten & Reid, private communication), is shown as color contours. Registration is accurate to 0.01". (bottom left) A subsample of proper motions observed over 4 months. Cone lengths reflect 3D velocity. Aspect indicates inclination with respect to the line of sight. Green cones indicate Doppler velocities within 5 km s^{-1} of the systemic velocity. The tickmarks are spaced by 50 milliarcseconds.

Press Release: November 12, 2003

Despite Appearances, Cosmic Explosions Have Common Origin, Astronomers Discover



Artist's Conception of Twin Jets in Energetic Cosmic Explosion Credit: Dana Berry, SkyWorks Digital

A Fourth of July fireworks display features bright explosions that light the sky with different colors, yet all have the same cause. They just put their explosive energy into different colors of light. Similarly, astronomers have discovered, a variety of bright cosmic explosions all have the same origin and the same amount of total energy.

This is the conclusion of an international team of astronomers that used the National Science Foundation's Very Large Array (VLA) radio telescope to study the closest known gamma-ray burst earlier this year.

"For some reason we don't yet understand, these explosions put greatly varying percentages of their explosive energy into the gamma-ray portion of their output," said Dale Frail, of the National Radio Astronomy Observatory (NRAO) in Socorro, NM. That means, he said, that both strong and weak gamma-ray bursts, along with X-ray flashes, which emit almost no gamma rays, are just different forms of the same cosmic beast. The research team reported their results in the November 13 issue of the scientific journal Nature.

The scientists trained the VLA on a gamma-ray burst discovered using NASA's HETE-2 satellite last March 29. This burst, dubbed GRB 030329, was the closest such burst yet seen, about 2.6 billion light-years from Earth. Because of this relative proximity, the burst was bright, with visible light from its explosion reaching a level that could be seen in amateur telescopes. As the burst faded, astronomers noted an underlying distinctive signature of a supernova explosion, confirming that the event was associated with the death of a massive star.

An excerpt from the press release by Dave Finley.
For the complete article go to
http://www.nrao.edu/pr/2003/grbtwinjet/