NRAO IN THE NEWS

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Representative Samples From 2001

NRAO Press Releases

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January 3, 2001

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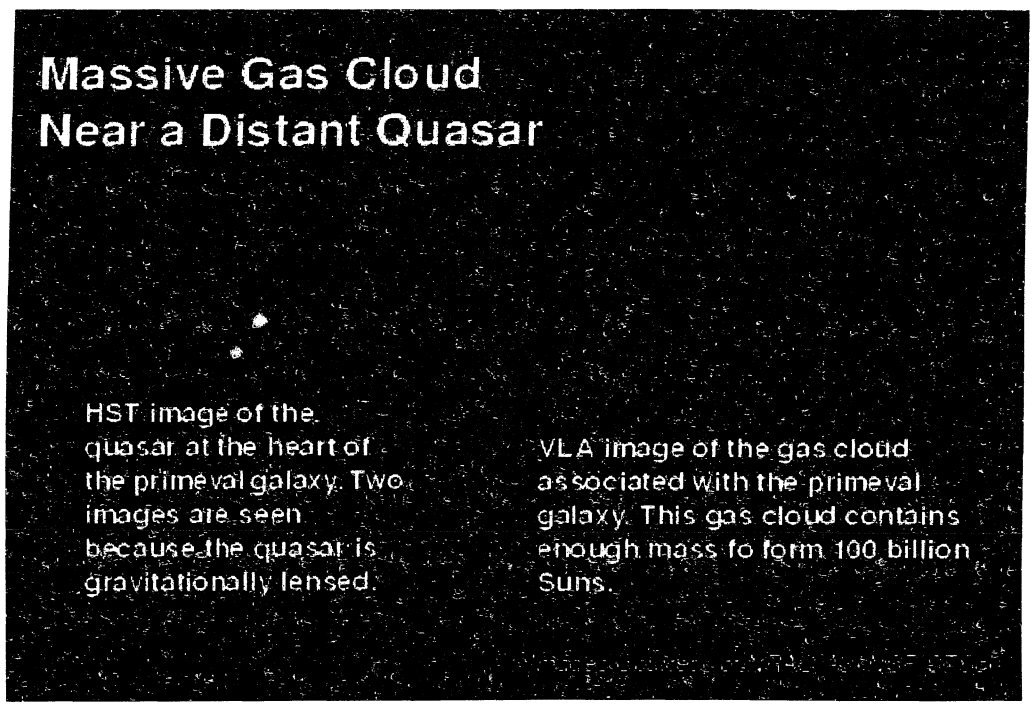
Young Galaxy Surrounded by Material Needed to Make Stars, VLA Reveals

Astronomers using the National Science Foundation's Very Large Array (VLA) radio telescope have discovered a massive reservoir of cold gas from which a primeval galaxy formed its first stars. Looking more than 12 billion years into the past, the scientists found that the young galaxy experiencing a "burst" of star formation was surrounded by enough cold molecular gas to make 100 billion suns.



"This is the first time anyone has seen the massive reservoir of cold gas required for these incredible 'starbursts' to produce a galaxy," said Chris Carilli, an astronomer at the NSF's National Radio Astronomy Observatory (NRAO) in Socorro, NM. "There is much more gas here than we anticipated," Carilli added.

The research team was led by Padeli Papadoupoulos of Leiden Observatory in the Netherlands and also included Rob Ivison of University College London and Geraint Lewis of the Anglo-Australian Observatory in Australia. The scientists reported their findings in the January 4 edition of the journal *Nature*.

The astronomers found the gas when studying a quasar called APM 08279+5255, discovered in 1998. Observations with optical and infrared telescopes revealed that the quasar, a young galaxy with a

voracious black hole at its center, was forming new stars rapidly in a starburst. At a distance of more than 12 billion light-years, the quasar is seen as it was more than 12 billion years ago, just a billion or so years after the Big Bang.

"This thing is at the edge of the dark ages," before the first stars in the universe were born, said Carilli.

The year after its discovery, APM 08279+5255 was found to have warm carbon monoxide (CO) gas near its center, heated by the energy released as the galaxy's black hole devours material. The VLA observations revealed cold CO gas much more widely distributed than its warmer counterpart. Based on observations of closer objects, the astronomers presume the CO gas is accompanied by large amounts of molecular hydrogen gas (H2). Cold CO gas never has been detected before in such a distant object.

Though APM 08279+5255 is a young galaxy undergoing its first massive burst of star formation, the CO gas indicates that very massive stars formed quickly, lived through their short lifetimes, and exploded as supernovae. Carbon and Oxygen, the component elements of CO, are formed in the cores of stars, so their presence in the cold gas tells the astronomers that massive, short-lived stars had to have exploded already, spreading these elements throughout the galaxy's interstellar gas.

"The original discovery of this quasar was quite a surprise, as observations revealed it is among the most luminous objects known in the universe. The discovery of this massive reservoir of cold gas is equally surprising. It provides vital clues to the birth of galaxies, such as our own Milky Way," Lewis said.

Discovery of the gas was made possible by the galaxy's great distance. The expansion of the universe "stretches" light and radio waves to longer wavelengths -- the more distant the object, the more stretching is seen. Radio waves emitted by the cold CO gas originally had wavelengths of about 1.3 and 2.6 millimeters, but were "redshifted" to wavelengths of 7 and 13 millimeters -- wavelengths the VLA can receive.

"It took eight years to refine this technique, but the effort has been worthwhile. This is the golden age of cosmology. We are learning more and more about our universe, from the smallest planets to the largest galaxy clusters. This new result is a crucial piece in the jigsaw and may help resolve many misconceptions about how galaxies form and evolve" Ivison said.

"Because of its sensitivity and its ability to make detailed images, the VLA is the only telescope able to unveil these large reservoirs of cold molecular gas in the distant universe," Carilli said. "In addition, as we expand the technical capabilities of the VLA in the coming years, making it even more sensitive and able to show more detail, it will become the world's premier tool for studying this vital aspect of the young universe."

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

Information from the Anglo-Australian Observatory

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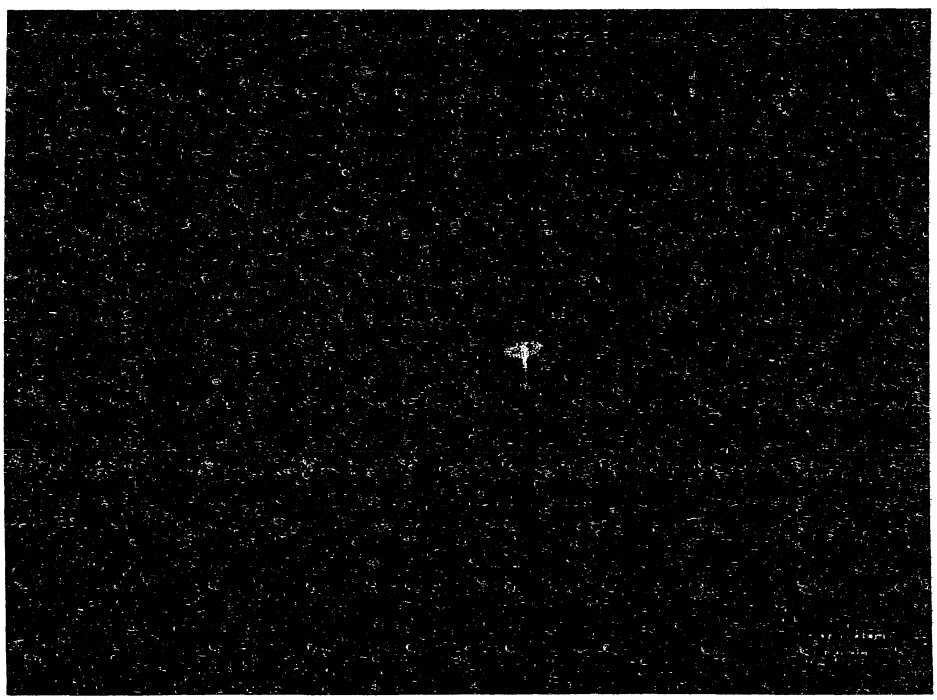
VLA's Sharpened Vision Shows Details of Still-Forming Star

Using a new observing capability of the National Science Foundation's Very Large Array (VLA) radio telescope, astronomers have discovered a solar-system-sized disk of gas and dust feeding material onto a young star with 8 to 10 times the mass of the Sun. This is the first time an inner "accretion disk" has been seen around such a massive star. The VLA images also revealed the inner portion of an energetic outflow of material powered by the accretion disk.

"Disks and outflows in young stars increase dramatically in mass and energy as the mass of the young star increases. We don't know if the same process is at work in all young stars or how the disks can both power an outflow that extends more than 15 light-years and also start the process of forming planets," said Debra Shepherd, of the National Radio Astronomy Observatory (NRAO) in Socorro, New Mexico. "By studying the birth of massive young stars, we're pushing the limits of our understanding and trying to learn if there are critical differences between the outflows from high and low mass young stars," she added



ARTIST'S CONCEPTION of the G192.16-3.82 system observed with the Very Large Array radio telescope. The massive protostar is shown with its accretion disk and outflow. The accretion disk is about the size of our Solar System. The larger gas torus surrounds the protostar and its nearby companion. A "neighbor," lower-mass protostar is at left.
CREDIT: Boris Starosta, NRAO/AUI/NSF.

Shepherd and Mark Claussen, also from the

NRAO in Socorro, and Stan Kurtz of the National Autonomous University in Mexico, presented their findings today at the American Astronomical Society's meeting in San Diego, CA.

The scientists made the discovery using the VLA connected by a newly- operational fiber-optic link to one of the radio-telescope antennas of the NSF's Very Long Baseline Array (VLBA), located at Pie Town, NM, 32 miles away from the VLA. Linking the VLA to the Pie Town antenna almost doubled the resolving power, or ability to see fine detail, available to the astronomers.

"We could not have seen these structures without using the Pie Town antenna connected to the VLA," said Claussen. Work on the VLA-Pie Town fiber-optic link, financed by the NSF and Associated Universities, Inc., which operates NRAO for the NSF, began in late 1997. The linked facilities first were available for routine astronomical observations last autumn.

In late November, the scientists pointed the sharpened vision of the combined telescopes at an object called G192.16-3.82, more than 6,000 light-years distant in the constellation Orion. First observed in 1990, G192.16-3.82 was found to be a massive young star powering one of the largest stellar outflows -- extending more than 30 light years from end to end -- in the entire Milky Way Galaxy. Earlier observations showed the young star is surrounded by a large, rotating disk with a diameter greater than 1,000 times the Sun-Earth distance. Astronomers, however, believed that the outflow had to originate from a structure much smaller than this disk.

The VLA-Pie Town system gave them their first glimpse of the suspected smaller structure, another disk slightly larger than our own Solar System containing enough gas and dust to make 20 Suns. In addition, they saw the inner portion of the outflow of material powered by that disk. The new observations also showed that the smaller disk probably is truncated by the gravitational pull of another, previously-unseen young star less massive than the first.

Close to the larger protostar, the outflow is wide, covering an angle of about 40 degrees. "With smaller protostars, the outflow begins wide but then is narrowed down to a thin jet relatively close to its origin. However, when the protostar is more massive, the outflow tends to remain wide," Shepherd said. "We think that magnetic fields narrow down the flow from the smaller protostars. It's possible that when the flow contains much more mass, such as in this system, the magnetic fields may be just too weak in most cases to get this done," she said.

"Our new observations now make it possible to test this idea by comparing computer simulations to what we see in the real universe," Shepherd said.

The VLA is a system of 27 radio-telescope antennas distributed over the high desert west of Socorro, NM, in the shape of a giant "Y." Made famous in movies, commercials, magazine articles and numerous published photos, the VLA has been one of the world's most versatile and productive astronomical observatories since its dedication in 1980.

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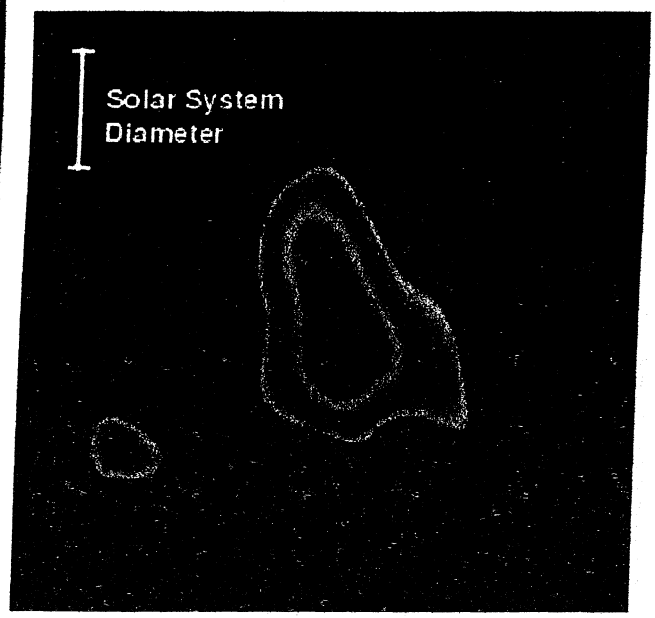


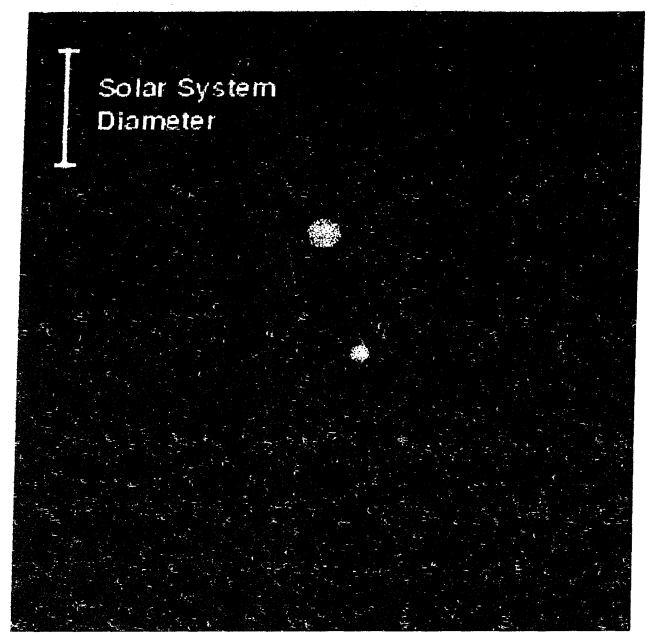
At right, the VLA image is shown as white contours laid over a model of the system which produces the observed radio-emission pattern. This model includes a disk of material being drawn into the young star, an outflow of material powered by the disk, and a previously unsuspected companion protostar.

CREDIT: D. Shepherd, M. Claussen, S. Kurtz, NRAO, AUI and NSF.

Available at: http://www.nrao.edu/pr/bigysodisk.html

VLA's Sharpened Vision Reveals Details of Still-Forming Massive Sta

Using the Very Large Array radio telescope connected b a new fiber-optic link to an antenna of the Very Long Baseline Array (VLBA) at Pie Town, NM, astronomers made the image at **left** of a young star 6,000 light-years distant in the constellation Orion. The size of the young sta and its surroundings is compared to our own Solar Systen



made important contributions to the understanding of stars in the Milky Way, the workings of distant galaxies, and to calibrating the distance scale of the universe.

Both the VLA and the VLBA use multiple radio-telescope antennas to produce greater resolving power than is possible with an individual antenna. Because of the different sizes of these two arrays of antennas, they produce images showing different levels of detail. NRAO scientists and engineers have developed plans to combine the VLA with the VLBA antennas closest to it, in New Mexico, Texas and Arizona, along with a number of new antennas, to fill in a gap in resolving power that exists between the VLA and VLBA.

If this plan is funded, the closer VLBA antennas and the new antennas will be connected to the VLA by fiber-optic links to produce the Expanded VLA (EVLA).

"The successful linking of the Pie Town VLBA antenna to the VLA shows that we can connect these radio-telescope antennas with fiber-optic cable over long distances and make them work as a single instrument," said Claussen, who worked extensively on the project. "This has produced a valuable new capability for astronomers to use now -- as shown by our study of this young stellar system -- but it also proves that our concept for expanding the VLA is technically sound," he added.

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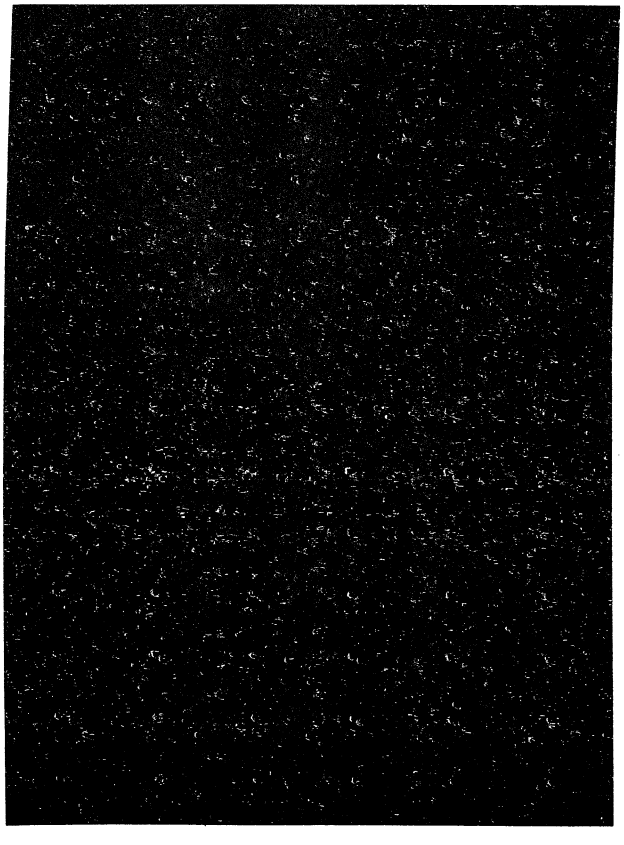
New Images Show Unprecedented Detail of Neighbor Galaxy's Gas

Using radio telescopes in the United States and Europe, astronomers have made the most detailed images ever of Hydrogen gas in a spiral galaxy other than the Milky Way. The scientists used the National Science Foundation's Very Large Array (VLA) radio telescope in New Mexico and the Westerbork Synthesis Radio Telescope (WSRT) in the Netherlands to produce an image of the galaxy M33, known to amateur astronomers as the Pinwheel Galaxy.



"An image with the level of detail we have achieved opens the door to learning fundamental new facts about the relationship between massive stars and the galaxy's complicated gaseous environment. This, in turn, will help us better understand how galaxies age," said David Thilker, of the National Radio Astronomy Observatory (NRAO) in Socorro, NM. Thilker worked with Robert Braun of the Netherlands Foundation for Research in Astronomy and Rene Walterbos of New Mexico State University in Las Cruces. The scientists reported their findings today at the American Astronomical Society's meeting in San Diego, CA.

The VLA and WSRT received radio waves at a wavelength of 21 centimeters that are naturally emitted by Hydrogen atoms. Using this data, the astronomers produced images showing the distribution of neutral atomic Hydrogen in M33. In addition, because the atoms emit at a very specific wavelength, the scientists could detect the galaxy's rotation by tuning the telescopes' radio receivers to receive radio waves whose length has been changed by Doppler shifting.

The new images show details of the galaxy smaller than 130 light-years. "With more computer processing, we will be able to see features as small as 65 light-years," Thilker said. "This, we believe, will allow us to see

'bubbles' in the galaxy's gas that have been inflated as the result of one or more supernova explosions," Thilker added.

At a distance from Earth of about 2.7 million light-years, M33 is a member of the Local Group of galaxies, which also includes our own Milky Way and the Andromeda Galaxy. With a diameter of about 60,000 light-years, it is roughly half the size of the Milky Way. Under vary dark skies, people with excellent vision can see M33 with the unaided eye. With common amateur telescopes, its spiral arms can be seen.

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

Graphics for This Story

Radio Image of M33's Gas

Doppler Image Showing Galaxy's Rotation

Radio/Optical Combination Image of M33

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U.S.-Canadian Partnership in Radio Astronomy Valuable for Science, NRAO Director Says

The United States and Canada intend to collaborate on two of the most important radio astronomy projects of the new century -- the Atacama Large Millimeter Array (ALMA) and the Expanded Very Large Array (EVLA), astronomers from both countries announced today.

"This cooperative program -- the North American Partnership in Radio Astronomy -- involves the key projects that will dominate radio astronomy world-wide," said Paul Vanden Bout, director of the National Radio Astronomy Observatory (NRAO). "This partnership will multiply the efforts of both nations' astronomers for the benefit of science. It builds on a long tradition of cooperative efforts in radio astronomy, and will ensure that we continue that tradition into the new millennium," Vanden Bout said.

The U.S.-Canada radio astronomy partnership is outlined in two letters of intent signed recently. The first, between the U.S. National Science Foundation (NSF) and Canada's National Research Council (NRC), states that both agencies will use their best efforts to obtain the necessary funding for construction and operation of ALMA. The second, between the National Radio Astronomy Observatory, funded by the NSF, and the Herzberg Institute of Astrophysics, funded by the NRC, forms a partnership in the EVLA.

The VLA Expansion Project is a two-phase program designed to improve the scientific capabilities of the VLA tenfold by replacing 1970s-vintage equipment with modern technologies and adding new radio-telescope antennas to the existing 27-antenna array. Dedicated in 1980, the VLA has been used for more than 10,000 observing projects covering nearly every area of astrophysics. It is the most powerful, flexible and widely-used radio telescope in the world. The Expanded VLA will provide the improved observational capabilities needed to meet the research challenges of the coming years. In addition to the participation by Canada, funds have been pledged by Mexico. Both Mexico and Germany have funded VLA improvements in the past. A proposal to the NSF requesting U.S. funds for the EVLA is currently under review by the National Science Foundation.

The agreement between the NRAO and the Herzberg Institute of Astrophysics (HIA) calls for HIA to build a new correlator -- the digital "heart" that combines the received signals from multiple antennas to make those antennas work as a single, powerful telescope -- for the EVLA. The new correlator will represent a contribution of $10 million (US$). The full EVLA project will cost about $150 million, to be done in two phases, the first costing $75 million.

"Canada has a strong program of radio astronomy, and in particular a skilled team of specialists in designing correlators, and we are pleased to have their talents directed toward building a new machine for the VLA," Vanden Bout said.

ALMA will consist of 64 12-meter-diameter dish antennas comprising a single imaging telescope to study the universe at millimeter and submillimeter wavelengths -- the region between radio waves and infrared waves. An international project being designed and developed by the U.S. and European nations, ALMA will be located on a high-altitude site in the Atacama desert of Chile.

"ALMA will give scientists an unprecedented look at the structure of the early universe and revolutionary insights on how stars and planets form, among many other contributions," Vanden Bout said. "The EVLA will bring unmatched power and versatility to the study of objects as close as the Sun and planets and as far as primeval galaxies at the edge of the observable universe. Together, these two instruments will be at the forefront of 21st Century astrophysics," he added.

"ALMA has been a bilateral project involving the United States and Europe. These new agreements with Canada turn ALMA into a partnership between Europe and North America," Vanden Bout said.

Design and development work on ALMA has been ongoing since 1998, funded by the NSF and European organizations. Canadians already have participated in this work. ALMA is planned for completion this decade. The new partnership calls for Canada to seek funding for a $20 million (US$) contribution toward construction of ALMA. The total construction cost of ALMA is $552 million (2000 US$), to be shared equally between Europe and North America.

Under both letters of intent, applications for observing time on ALMA and NRAO radio telescopes, including the VLA, the Very Long Baseline Array (VLBA), and the Green Bank Telescope (GBT), from Canadian scientists will be treated the same as applications from U.S. scientists. Also, Canadian scientists will be appointed to NRAO advisory and oversight committees, and U.S. scientists will be appointed to similar Canadian committees.

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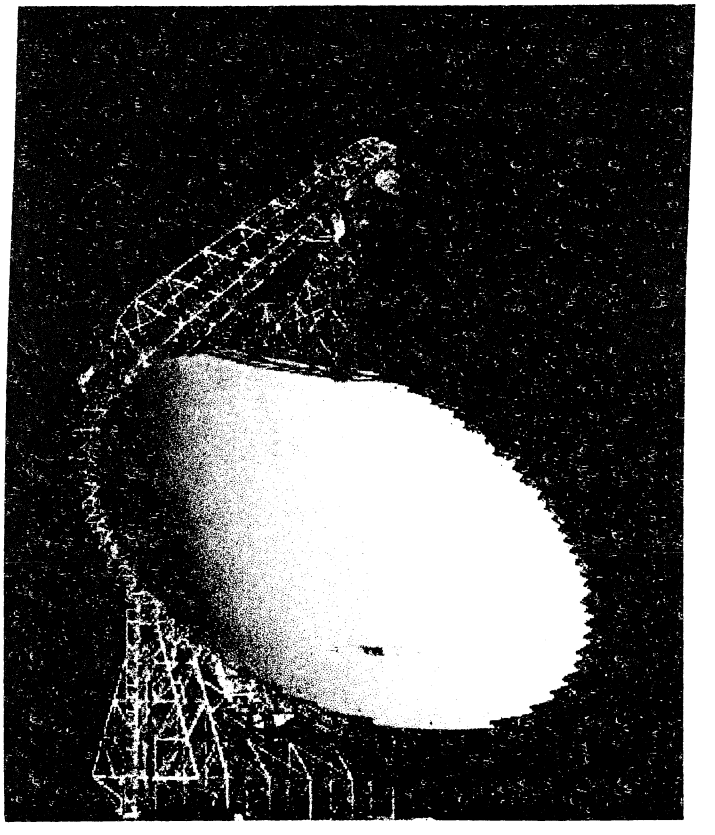
Decision Announced in Green Bank Telescope Arbitration Case

A decision has been reached by the arbitrator in the dispute between COMSAT Corporation, now part of Lockheed-Martin Global Telecommunications, and Associated Universities, Inc. (AUI) regarding additional costs on the contract to design and construct the Robert C. Byrd Green Bank Telescope (GBT). The GBT, in West Virginia, is the world's largest fully steerable radio telescope, the newest facility in the National Radio Astronomy Observatory's (NRAO) suite of astronomical instruments. The decision, released by the American Arbitration Association (AAA), calls for AUI, which operates the NRAO, to pay COMSAT $4.07 million over the fixed-price contract amount. The contract had standard provisions for disputes, which specify binding arbitration through the AAA for matters that could not be resolved in negotiation.

The contract to design and construct the GBT had an agreed fixed price of $55 million, with work to begin on December 19, 1990 and to be completed by the end of 1994. The contract terms required the telescope to be designed and built to performance specifications, placing most of the performance risks associated with the project on the contractor. The telescope was accepted from the contractor on October 13, 2000, nearly six years later than the original contract delivery date. During the entire period of contract work the only agreed change in scope was a single change order for $150,000 executed in August of 1993.



In 1998, COMSAT sought an additional payment of approximately $29 million above the contracted amount, alleging that AUI/NRAO had forced it to conduct unnecessary work on the telescope design and to build the telescope to an unreasonable life cycle (fatigue) specification. COMSAT also claimed that AUI/NRAO was obligated to pay the costs of accommodating what it claimed to be additional wind loads. COMSAT blamed these circumstances for its delay in completing the project on time and within the contract price.

AUI/NRAO maintained that the COMSAT claims were without merit, noting that COMSAT was responsible for both designing and constructing the telescope to performance specifications. Furthermore,

it was AUI/NRAO's position that any costs incurred by COMSAT beyond those anticipated at the signing of the contract were the result of COMSAT's own decisions and management of the project. AUI/NRAO filed its own claims against COMSAT for the costs to AUI/NRAO resulting from the delayed delivery and loss of use of the telescope. The AUI/NRAO claims totaled approximately $13 million.

After negotiations between the parties failed, COMSAT called for an arbitration by the AAA, as the contract specified. After a lengthy period of discovery, a formal hearing, and study of the record, the arbitrator issued his decision.

The arbitrator ruled that AUI is to pay COMSAT $1.05 million for the costs of the additional wind loads, $3.17 million for the fatigue costs, and $2.40 million for delay costs associated with these items. He dismissed the COMSAT claim for design optimization costs. He ruled that COMSAT is to pay AUI $2.55 million for costs of delay, and dismissed the AUI claim for loss of use. The net result is that AUI is to pay COMSAT $4.07 million within 30 days.

"While we do not agree with every aspect of the decision, the limited amount of the award versus the amount originally sought by COMSAT clearly indicates the essential merit of AUI/NRAO's position. What is more important, however, is that this matter is finally resolved and we now can focus our efforts on making this world-class instrument available to the scientific community," said Paul Vanden Bout, NRAO Director. "We understand that after the arbitrator's award COMSAT still will have spent many millions more than the contract amount on this job. The fact that they finished the job is testimony to the integrity, honor, and good faith of the company," he added.

The telescope, named the Robert C. Byrd Green Bank Telescope in honor of U.S. Senator Robert C. Byrd of West Virginia at a dedication ceremony on August 25, 2000, now has been outfitted with scientific instrumentation. Its commissioning period, during which tests of performance and calibration of instrumentation are conducted, is well underway. A limited call for First Science observing programs yielded 80 proposals from more than 200 scientists around the world. Eighteen of these have been selected to be scheduled for observing time on the telescope.

"The GBT is a powerful new tool for discovery that astronomers look forward to using," said Prof. Joe Taylor of Princeton University, a member of the AUI Board of Trustees whose work on pulsars received the Nobel Prize in 1993.

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Students Use VLA to Make Startling Brown-Dwarf Discovery

A group of summer students making a long-shot astronomical gamble with the National Science Foundation's (NSF) Very Large Array (VLA) have found the first radio emission ever detected from a brown dwarf, an enigmatic object that is neither a star nor a planet, but something in between. Their surprising discovery is forcing experts to re-think their theories about how brown dwarfs work.

"Many astronomers are surprised at this discovery, because they didn't expect such strong radio emission from this object," said Shri Kulkarni, a Caltech professor who was on the team that first discovered a brown dwarf in 1995, and advisor to one of the students.

"What is so cool is that this is research that probably nobody else would have tried to do because of its low chance of success. That made it ideal for summer students -- we had almost nothing to lose," said Kate Becker, a student at Oberlin College in Ohio.

"The radio emission these students discovered coming from this brown dwarf is 10,000 times stronger than anyone expected," said Dale Frail, an astronomer at the National Radio Astronomy Observatory (NRAO) in Socorro, NM. "This student project is going to open up a whole new area of research for the VLA," Frail added.

The students, in addition to Becker, are: Edo Berger from Caltech; Steven Ball from New Mexico Tech in Socorro, NM; Melanie Clarke from Carleton College in Northfield, MN; Therese Fukuda from the University of Denver; Ian Hoffman from the University of New Mexico in Albuquerque; Richard Mellon from The Pennsylvania State University; Emmanuel Momjian from the University of Kentucky; Nathanial Murphy from Amherst College in Amherst, MA; Stacey Teng from the University of Maryland; Timothy Woodruff from Southwestern University in Georgetown, TX; Ashley Zauderer from Agnes Scott College in Decatur, GA; and Robert Zavala from New Mexico State University in Las Cruces, NM. Frail also is an author of the research paper, published in the March 15 edition of the scientific journal *Nature.*

Berger, Hoffman, Momjian and Murphy are graduate students, and the rest were participants in the NSF-funded Research Experiences for Undergraduates program.

The 14 students spent last summer working with NRAO scientists in Socorro. While each student had their own scientist-mentor, the VLA summer students also traditionally receive some VLA observing time for a collaborative project of their own. They sought ideas for their project from the NRAO staff, and, when they asked Frail, he suggested that they look at the latest research result from the recently-launched Chandra X-ray satellite.

The students went to the Chandra World Wide Web site, and found that the satellite had detected an X-ray flare from the brown dwarf LP944-20. "We did some background reading, and realized that, based on predictions, the brown dwarf would be unobservable with the VLA, but we decided to try it anyway," said Berger.

"Everybody we talked to said there was almost no chance that we'd see anything at all," said Becker. "They added, though, that it would be really exciting if we did," she said.

The students had been given three hours of VLA observing time for their project. They used an hour and a half of it on the brown dwarf.

The day after their observation, the students gathered at the NRAO Array Operations Center in Socorro to process their data and make their images. Berger, who had experience processing VLA data, worked alone in the same room as the other students, who were working together on another computer. Berger finished first and was shocked at his image.

"I saw a bright object at the exact position of the brown dwarf, and was pretty sure I had made a mistake," Berger said. He waited for the others, who were working under the guidance of another NRAO astronomer. Ten minutes later, their image appeared on the screen, also showing the bright object at the brown dwarf's location.

"We all got excited," said Berger, who then began breaking the hour and a half's worth of data up into smaller slices of time. This showed that the brown dwarf's radio emission had risen to a strong peak, then weakened. That meant that the star had undergone a flare. "Then we got real excited," Berger said. They immediately sought and received more observing time, ultimately capturing two more flares.

"They got very lucky," Frail said. "The thing flared during their observation. Other astronomers had looked for radio emission from brown dwarfs and not found any. This one flared at just the right time," Frail added.

"It was just an incredible fluke that we found it," said Becker.

Brown dwarfs are too big to be planets but too small to be true stars, as they have too little mass to trigger hydrogen fusion reactions at their cores, the source of the energy output in larger stars. With roughly 15 to 80 times the mass of Jupiter, the largest planet in our Solar System, brown dwarfs had long been thought to exist. Actually finding them, however, proved difficult. After decades of searching, astronomers found the first brown dwarf in 1995, and a few dozen now are known.

The strong radio emission was unexpected because brown dwarfs, according to conventional theories, are not supposed to have magnetic fields strong enough to generate the radio emission. "The presumed internal structure of a brown dwarf will not permit a strong enough magnetic field," said Frail. "It looks

like we're going to have to re-examine how we believe brown dwarfs work," he said.

"The mere fact that they detected radio emission is remarkable," said Tim Bastian, an astronomer at the NRAO in Charlottesville, Virginia, who added that this object "will likely have something to teach us."

"We're going to have to study this and other brown dwarfs more extensively with the VLA to answer the questions raised by our summer students' discovery," Frail said.

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

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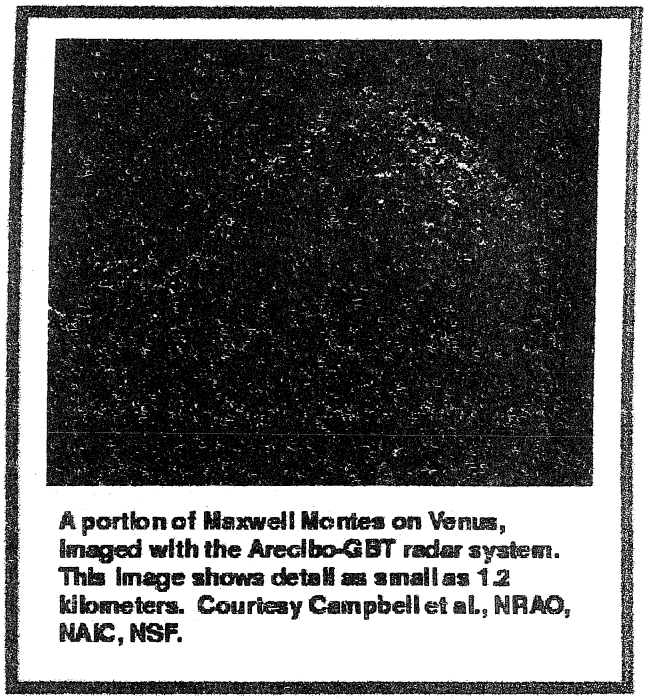
New Radio Telescope Makes First Scientific Observations

The world's two largest radio telescopes have combined to make detailed radar images of the cloud-shrouded surface of Venus and of a tiny asteroid that passed near the Earth. The images mark the first scientific contributions from the National Science Foundation's (NSF) new Robert C. Byrd Green Bank Telescope in West Virginia, which worked with the NSF's recently-upgraded Arecibo telescope in Puerto Rico. The project used the radar transmitter on the Arecibo telescope and the huge collecting areas of both telescopes to receive the echoes.

"These images are the first of many scientific contributions to come from the Robert C. Byrd Green Bank Telescope, and a great way for it to begin its scientific career," said Paul Vanden Bout, director of the National Radio Astronomy Observatory (NRAO). "Our congratulations go to the scientists involved in this project as well as to the hard-working staffs at Green Bank and Arecibo who made this accomplishment possible," Vanden Bout added.



A portion of Maxwell Montes on Venus, imaged with the Arecibo-GBT radar system. This image shows detail as small as 1.2 kilometers. Courtesy Campbell et al., NRAO, NAIC, NSF.

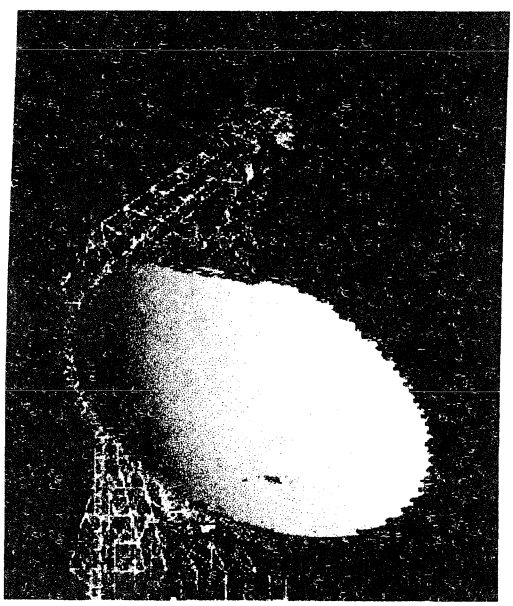
To the eye, Venus hides behind a veil of brilliant white clouds, but these clouds can be penetrated by radar waves, revealing the planet's surface. The combination of the Green Bank Telescope (GBT), the world's largest fully-steerable radio telescope, and the Arecibo telescope, the world's most powerful radar, makes an unmatched tool for studying Venus and other solar-system bodies.

"Having a really big telescope like the new Green Bank Telescope to receive the radar echoes from small asteroids that are really close to the Earth and from very distant objects like Titan, the large moon of Saturn, will be a real boon to radar studies of the solar system." said Cornell University professor Donald Campbell, leader of the research team.

Ten years ago, the radar system on NASA's Magellan spacecraft probed though the clouds of Venus to reveal in amazing detail the surface of the Earth's twin planet. These new studies using the GBT and Arecibo, the first since Magellan to cover large areas of the planet's surface, will provide images showing surface features as small as about 1 km (3,000 ft), only three times the size of the Arecibo telescope itself.

Venus may be a geologically active planet similar to the Earth, and the new images will be used to look for changes on Venus due to volcanic activity, landslides and other processes that may have modified the surface since the Magellan mission. The radar echoes received by both telescopes also can be combined to form a radar interferometer capable of measuring altitudes over some of the planet's mountainous regions with considerably better detail than was achieved by Magellan.

These were the first scheduled observations with the new Robert C. Byrd Green Bank Telescope, demonstrating its capabilities for solar-system studies. In addition to the observations of Venus, a tiny 150m (500 ft) asteroid, 2001 EC16, was imaged with the two telescopes working as a combined radar system on March 26 when the asteroid was only 8 times the distance of the Moon from the Earth. The image could show details on the asteroid's surface only 15 meters (50 ft) in size and shows EC16 to be an irregularly shaped object rotating about once every 200 hrs, one of the slowest rotation rates so far measured for these objects. It took about 20 seconds for the radar signal to go to EC16 and back, compared with the almost 5 minutes needed to go to Venus and back. EC16 was discovered by the NEAT asteroid survey on March 15, 11 days prior to the radar observations. Very large numbers of these near-Earth asteroids are being discovered and the combined Arecibo-GBT radar system will be needed to properly study a significant number of them.



The observing team led by Campbell also included Jean-Luc Margot of Caltech, Lynn Carter of Cornell, and Bruce Campbell of the Smithsonian Institution.

The 100-meter (330 feet) Robert C. Byrd Green Bank Telescope was dedicated in August 2000 and now is being prepared for routine scientific operation. It is operated by the National Radio Astronomy Observatory, headquartered in Charlottesville, Virginia. It is the largest fully-steerable telescope in the world. It is a highly advanced telescope with a mechanized reflecting surface and a laser measurement system for continuous adjustments to its structure.

The 305-meter (1,000 feet) Arecibo telescope recently has completed a major upgrade funded by the NSF and NASA to improve its observing capabilities, including a more powerful radar transmitter for planetary studies. It is operated by the National Astronomy and Ionosphere Center (NAIC) headquartered at Cornell University. Its reflector is fixed to the ground, and is the largest telescope of any type in the world. The radar capability of Arecibo, combined with the large reflectors of Arecibo and Green Bank, make for a uniquely powerful radar imaging capability. Both observatories are facilities of the National Science Foundation. The NRAO is operated for the NSF by Associated Universities, Inc., under a cooperative agreement. NAIC is operated by Cornell University, also under a cooperative agreement with the NSF.

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May 16, 2001

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Young Star May Be Belching Spheres of Gas, Astronomers Say

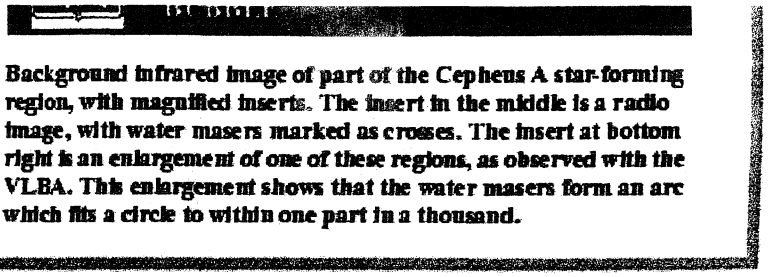
A young star more than 2,000 light-years away in the constellation Cepheus may be belching out spheres of gas, say astronomers who observed it with the National Science Foundation's Very Long Baseline Array (VLBA) radio telescope. Not only is the star ejecting spheres of gas, the researchers say, but it also may be ejecting them repeatedly, phenomena not predicted by current theories of how young stars shed matter.

In order to remain stable while accumulating matter, young stars have to throw off some of the infalling material to avoid "spinning up" so fast they would break apart, according to current theories. Infalling matter forms a thin spinning disk around the core of the new star, and material is ejected in twin "jets" perpendicular to the plane of the disk.

"Twin jets have been seen emerging from many young stars, so we are quite surprised to see evidence that this object may be ejecting not jets, but spheres of gas," said Paul T.P. Ho, an astronomer at the Harvard-Smithsonian Center for Astrophysics. The research is reported in the May 17 edition of the scientific journal *Nature*.

The astronomers observed a complex star-forming region in Cepheus and found an arc of water molecules that act like giant celestial amplifiers to boost the strength of

amplifiers to boost the strength of radio signals at a frequency of 22 GHz. Such radio-wave amplifiers, called masers, show up as bright spots readily observed with radio telescopes.



Background infrared image of part of the Cepheus A star-forming region, with magnified inserts. The insert in the middle is a radio image, with water masers marked as crosses. The insert at bottom right is an enlargement of one of these regions, as observed with the VLBA. This enlargement shows that the water masers form an arc which fits a circle to within one part in a thousand.

"With the great ability of the VLBA to show fine detail, we could track the motions of these maser spots over a period of weeks, and saw that this arc of water molecules is expanding at nearly 20,000 miles per hour," said Ho. "This was possible because we could detect detail equivalent to seeing Lincoln's nose on a penny in Los Angeles from the distance of New York," Ho added.

"These observations pushed the tremendous capabilities of the VLBA and of modern computing power to their limits. This is an extremely complex observational project," said Luis F. Rodriguez, of Mexico's National Autonomous University.

The arc of water masers can be fit to a nearly-perfect circle to within one part in a thousand. That, the researchers say, means that the water vapor in the arc most likely is part of a complete sphere. "The arc we see fits a circle so well that it is unlikely that any geometry other than that of a sphere would produce it," Ho said. The sphere would be about 1.5 times the size of the Solar System.

Because the arc, and presumably the sphere of which it is part, is so thin and so uniform, the researchers say that it came from a single, short-lived ejection. In addition, other evidence suggests that the sphere from an earlier ejection now is being overtaken by a newer spherical bubble that took only about 33 years after being ejected to reach its observed size.

"We now have at least one case, we believe, in which a young star has repeatedly ejected mass spherically in short bursts," Guillem Anglada, of the Institute of Astrophysics of Andalucia (CSIC), in Granada, Spain, said. "In light of our current understanding of star formation, we don't yet understand how this can happen, so we have an exciting new scientific challenge. It is surprising that nature can maintain such perfect symmetry, especially since the environment around the young star must be so varied. This appears to be a triumph of order over chaos," he added.

The researchers, in addition to Rodriguez, Ho and Anglada, are: Jose M. Torrelles, Institute for Space Studies of Catalonia (IEEC)-Spanish Research Council (CSIC), Spain; Nimesh A. Patel and Lincoln Greenhill, of the Harvard-Smithsonian Center for Astrophysics; Jose F. Gomez, Laboratory for Space Astrophysics and Theoretical Physics of the National Institute for Aerospace Technology, Madrid, Spain; Salvador Curiel and Jorge Canto, of Mexico's National Autonomous University; and Guido Garay, Department of Astronomy of the University of Chile.

The VLBA is part of the National Radio Astronomy Observatory. It consists of ten radio-telescope antennas, each 82 feet (25 meters) in diameter, spread across the U.S. from Hawaii to the U.S. Virgin Islands. Operated from Socorro, New Mexico, the VLBA provides astronomers with the greatest angular resolution, or ability to see fine detail, of any telescope on Earth or in space.

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

The Center for Astrophysics combines the resources and research facilities of the Harvard College Observatory and the Smithsonian Astrophysical Observatory under a single director to pursue studies of

those basic physical processes that determine the nature and evolution of the universe. Some 300 Smithsonian and Harvard scientists cooperate in broad programs of astrophysical research supported by Federal appropriations and University funds as well as contracts and grants from government agencies.

Images to Accompany This Story

Full-Sized Version of Image Above, With Logos

Full-Sized Version of Image Above, Without Logos

Image Above With No Annotation

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May 24, 2001

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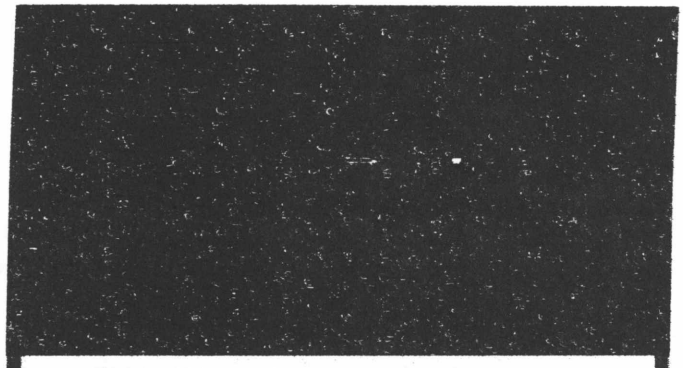
World-Wide Effort Produces Dramatic "Movie" of Cosmic Jet

Astronomers using a world-wide collection of radio telescopes, including the National Science Foundation's Very Long Baseline Array (VLBA) of the National Radio Astronomy Observatory (NRAO), have made a dramatic "movie" of a voracious, superdense neutron star repeatedly spitting out subatomic particles at nearly the speed of light into two narrow jets as it pulls material from a companion star. The movie shows these jets ejecting clouds of hot plasma that are then "zapped" by pulses of energy in the jets as they move away from the neutron star.

"We have directly measured the speed of energy flow in a cosmic jet for the first time," said Ed Fomalont, an astronomer at the NRAO in Charlottesville, Virginia. Fomalont worked with Barry Geldzahler and Charles Bradshaw of George Mason University in Fairfax, Virginia. The astronomers used the VLBA, the NSF's Very Large Array (VLA) and the Green Bank 140-foot telescope, along with radio telescopes from the European VLBI Network, Australia, Japan and South Africa to record the double-star system's eruptions continuously for 56 hours.



Frame from the radio-telescope "movie" of Scorpius X-1, showing a flare of the object's core.

"This study is going to be extremely valuable in helping us understand a phenomenon that we see throughout the universe," Fomalont said. Cosmic jets of superfast particles are ejected from the cores of numerous galaxies. On a smaller scale, similar jets are ejected from binary-star systems closer to home, in our own Milky Way Galaxy. While the jets from galaxy cores are thought to be powered by supermassive black holes millions of times more massive than the Sun, the closer "microquasars" are powered by much smaller black holes or by neutron stars only a few times more massive than the sun.

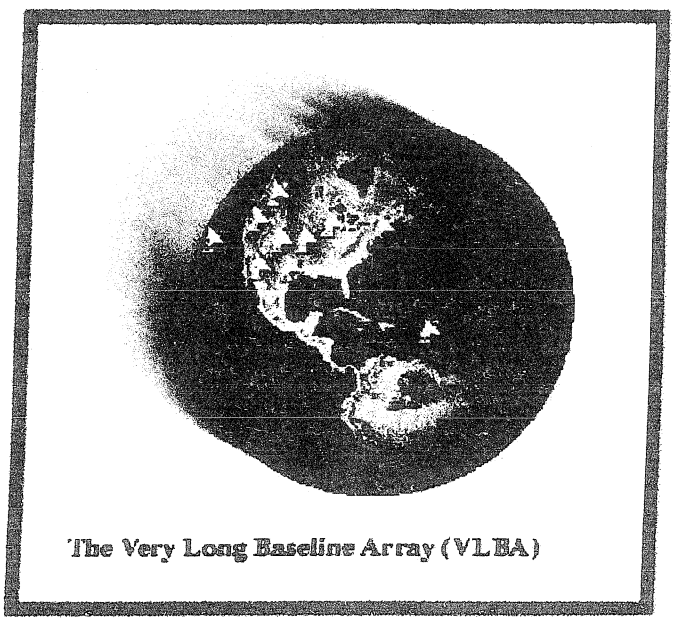
"Studying one of the closer, smaller examples will help us understand how they all work, including the bigger ones," Geldzahler said. "The jets coming from distant galaxies are harder to study because of their much greater distance and the slowness of their evolution. The changes we saw in an hour take thousands

of years in the distant galaxies," he added.

The astronomers observed Scorpius X-1, a system consisting of a neutron star roughly 1.5 times the mass of the sun and a "normal" star about the same mass as the sun. The two, more than 9,000 light-years from Earth in the constellation Scorpius, orbit each other every 18 hours and 53 minutes. Scientific instruments aboard a brief rocket flight over New Mexico in 1962 revealed that X-rays are coming from the system, and the pair of stars has been observed extensively since then.

For the latest study, whose results are published in the May 20 issue of the *Astrophysical Journal Letters*, Fomalont, Geldzahler and Bradshaw used telescopes around the world to make highly-detailed radio images of the ejections. As the object went below the horizon for one set of radio telescopes, it was rising for the next set, allowing continuous imaging for the 56-hour period.

In the U.S., the astronomers used the VLBA, a network of 10 radio telescopes spread across U.S. territory from Hawaii to the Virgin Islands. They also used the European VLBI Network, including telescopes in the United Kingdom, Italy, Poland, Spain, Sweden and the Netherlands, plus a telescope in South Africa and one at the NRAO in Green Bank, WV. In addition, they used the Asia-Pacific Telescope Array which included five telescopes in Australia, plus telescopes in China, Japan and South Africa.



The Very Long Baseline Array (VLBA)

"To keep watching this thing as the Earth turned, we had to use most of the major radio telescopes in the world, and the necessary coordination took months to organize," Fomalont said.

At the same time, two optical observatories, Braeside Observatory and the Steward Observatory 90-inch telescope on Kitt Peak, and the orbiting Rossi X-ray Timing Explorer observed the object. "These observations tell us what is happening near the neutron star and the accretion disk" said Bradshaw. "All of the energy in the jet and the radio source is produced from this small region."

The individual radio telescopes were combined into larger "virtual telescopes" capable of producing extremely detailed images. The "movie" of Scorpius X-1 consists of images showing detail roughly equivalent to being able to read a newspaper in Los Angeles from the distance of New York.

Cosmic jets, most astronomers believe, arise when a massive object, such as a neutron star or a black hole, draws in material. Instead of being sucked directly into the massive object, the material first forms a whirling "accretion disk" that closely orbits the central object. Friction within the accretion disk can heat it to temperatures so hot that it radiates X-rays. Excess energy also is vented by ejecting subatomic particles from the poles of the disk at speeds nearly that of light.

"These things are tremendous particle accelerators, propelling huge amounts of matter at fantastic speeds. Unfortunately, we don't understand the physics of how they work very well at all. That's why we're so excited to have this 'movie' of extremely detailed images to help us figure out what is really going on in this system," Geldzahler said. "Ed and I have been studying Scorpius X-1 for nearly 20 years and we

finally got the resources to probe deeply into its evolution."

During the 56 hours in June of 1999 when the astronomers were observing, Scorpius X-1 cooperated by being very active. The object's core, near the orbiting pair of stars, showed changes in the brightness of its radio emission. In addition, "lobes" of bright radio emission were pushed outward by the jets at about half the speed of light. These lobes, the scientists think, are produced when the fast moving particles in the jet, created from the accretion disk, collide with the surrounding interstellar material caught in the flow. Near the beginning of the movie, one moving set of lobes disappeared, but new lobes were ejected from the core a few hours later and proceeded outward.

The movie also shows Einstein's relativity in action. Although two clouds are pushed by the jets in opposite directions away from the core, the cloud moving toward the Earth appears to be 15 times brighter and moving two times as fast as the cloud moving away from us. "We believe that both clouds are similar and the difference that we see is just a relativistic illusion caused by their fast motions," said Fomalont.

Twice, the core flared in brightness as it shot a burst of electrons outward at more than 95 percent of light speed. As this burst reached the lobes, the collision of the fast electrons with the lobe material caused the lobes to brighten. The exquisite detail and continuous formation of the radio images allowed the scientists to directly measure the speed of the fast electrons in the beam, marking the first time ever that the speed of energy flow in such a cosmic jet has been measured.

"Scorpius X-1 put on a great show for us. Now it's up to us to figure out how it performs its act," said Fomalont.

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

Images to Accompany This Story

NOTE: Your browser window should be at least as wide as the above line to view the movie.

Continuously-Running Animated GIF of the Scorpius X-1 Radio-Telescope Movie (1.3 MB)

An Annotated "Guided Tour" of the Movie (HTML)

Quicktime Version of the Scorpius X-1 Radio-Telescope Movie (7.2 MB)

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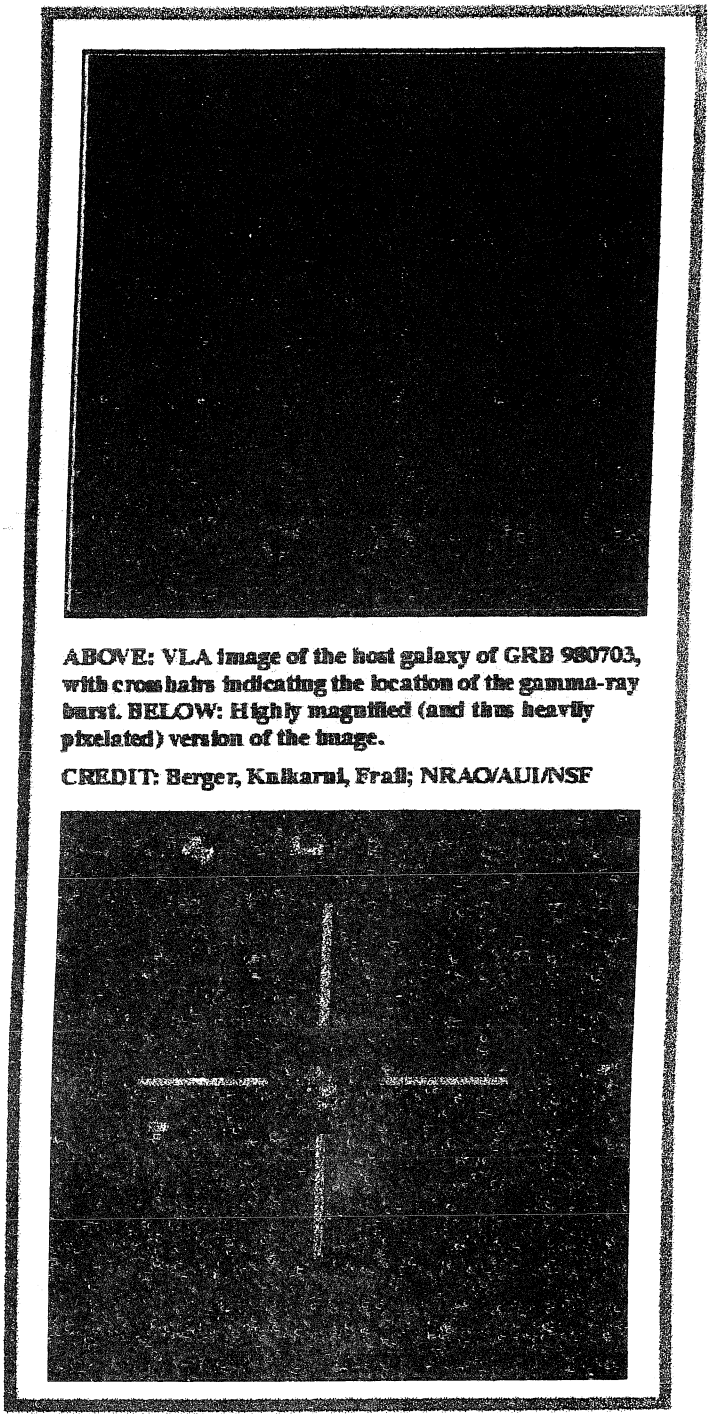
From Enigma to Tool: Gamma-Ray Burst Reveals Secrets of Host Galaxy

Five years ago, astronomers knew almost nothing about Gamma Ray Bursts. Now, a team of observers using the National Science Foundation's Very Large Array (VLA) radio telescope has used a gamma-ray burst as a powerful tool to unveil the nature of the galaxy in which it occurred, more than 7 billion light-years away.

"We believe that gamma-ray bursts may become one of the best available tools for studying the history of star formation in the universe," said Edo Berger, a graduate student at Caltech. Berger worked with Caltech astronomy professor Shri Kulkarni and Dale Frail, an astronomer at the National Radio Astronomy Observatory (NRAO) in Socorro, New Mexico, to study a gamma-ray burst first seen on July 3, 1998. The astronomers presented their results at the American Astronomical Society's meeting in Pasadena, CA.

"For the first time, we've seen the host galaxy of a gamma-ray burst with a radio telescope," Berger said. "Previously, gamma-ray-burst host galaxies have been seen with optical telescopes, but detecting this galaxy with a radio telescope has given us new clues about the nature of the galaxy itself -- clues we couldn't have gotten any other way," he added.



ABOVE: VLA image of the host galaxy of GRB 980703, with crosshairs indicating the location of the gamma-ray burst. BELOW: Highly magnified (and thus heavily pixelated) version of the image.

CREDIT: Berger, Kulkarni, Frail; NRAO/AUI/NSF

For example, based on optical-telescope studies, astronomers estimated that new stars are forming in the host galaxy at the rate of about the mass equivalent of 20 suns per year. However, data from the radio observations show that the actual star-formation rate is 25 times greater -- the mass equivalent of 500 suns per year.

"With the VLA, we are seeing the entire region of star formation in this galaxy, including the areas so dusty that visible light can't get out," said Frail.

Gamma-ray bursts are the most powerful explosions since the Big Bang. First discovered in 1967 by a satellite launched to monitor compliance with the atmospheric nuclear test ban treaty, gamma-ray bursts remained one of astronomy's premier mysteries for 30 years. For three decades, astronomers debated whether the explosions were close, in our own Milky Way Galaxy, or far, in distant galaxies. In addition, a plethora of theories attempted to explain the bursts, but a lack of observational data prevented scientists from choosing among the theories.

Optical and radio telescopes first spotted the "afterglows" from gamma- ray bursts in 1997. It was quickly determined that the explosions are occurring in very distant galaxies. Subsequent observations, most astronomers believe, have narrowed the theories down to two: either the explosions are the result of pairs of old, superdense neutron stars colliding with each other or are the death throes of young, very massive

stars.

"This burst in 1998 came from a region near the center of its host galaxy, where star birth is occuring at a rapid rate. This supports the theory that gamma-ray bursts come from the death explosions of very young, massive stars," said Kulkarni.

The burst, known as GRB 980703, was detected by a satellite on July 3, 1998, and the VLA first observed it a day later. The astronomers continued to observe the object with the VLA at intervals over the next 1,000 days. This is the longest period over which a gamma-ray-burst afterglow ever has been observed; the previous record-holder was a burst in 1997 that was followed with the VLA for a period of 445 days.

"The afterglow of the burst kept getting fainter with time, but we then noticed that the intensity of radio emission was leveling off. We realized that the burst afterglow was still fading, but what was remaining steady was radio emission from the galaxy itself," Berger said.

This allowed the scientists to study the characteristics of the galaxy, and of the region within the galaxy where the burst occurred. They concluded that the gamma-ray burst occurred near the center of the galaxy in a region where the galaxy is experiencing its maximum amount of star formation.

"If, as we believe, gamma-ray bursts come from the super-explosions of massive stars, they can help us trace the star-formation history of the universe," Berger said. "The gamma rays from these bursts can penetrate the dust in star-forming regions and allow us to study galaxies and the tenuous material between galaxies at great distances," Berger said. "This means that gamma-ray bursts may provide a unique tool for studying star formation at a wide range of distances, and thus for understanding how star formation rates may have changed through the history of the universe," he added.

By studying "starburst" regions of intense star formation in distant galaxies where gamma-ray bursts have occurred, astronomers can compare their properties to starburst regions in more-nearby galaxies. The distant galaxies are seen as they were when much younger than today, so these comparisons will help astronomers understand how the process of stellar birth in galaxies may have been affected by the passage of billions of years.

"Gamma-ray bursts can serve as beacons, pointing us to regions of intense star formation in very distant galaxies," Kulkarni said.

"With the planned expansion of the VLA, which will improve dramatically its ability to detect the host galaxies of these bursts, we will be able to make even more detailed studies of galaxies even more distant," said Frail.

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

Images to Accompany This Story

VLA Image of Host Galaxy

Magnified Image With Crosshairs

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June 6, 2001

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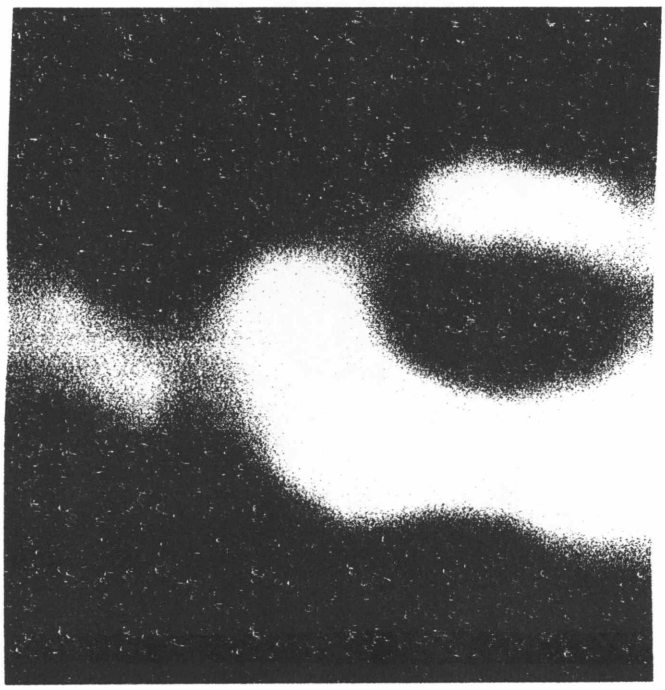
Adolescent Interstellar Cloud Poised to Make Star-forming Debut

Astronomers using the National Science Foundation's (NSF) 140-foot radio telescope at the National Radio Astronomy Observatory (NRAO) in Green Bank, W.Va., have discovered a highly unusual, massive interstellar cloud that appears poised to begin a burst of star formation. The cloud may be the first ever to be detected in the transition between atomic and molecular states.

NRAO scientists Felix J. Lockman and Anthony H. Minter presented their findings at the American Astronomical Society meeting in Pasadena, Calif.

The scientists discovered the cloud, identified as G28.17+0.05, lying along the inner plane of the Milky Way Galaxy, approximately 16,300 light-years from Earth. Observations of the cloud indicate that it is near one of the Galaxy's sweeping spiral arms, which are outlined by young stars and the massive clouds that form them. Lockman and Minter speculate that as the interstellar cloud slams into the Galactic arm, the resulting shock wave may be precipitating the conversion of the neutral hydrogen atoms into heavier molecules, which could herald the onset of star formation.



"These may be the first observations of a cloud that is in the transition between the neutral atomic hydrogen and molecular phases," said Lockman. "This provides astronomers a unique opportunity to study the chemistry of very young interstellar clouds, which could give us significant insights into the early stages of star formation and the structure of the Galaxy."

Interstellar clouds that contain neutral atomic hydrogen, called HI (H-one) clouds, are thought of as giant, cold blobs of gas. Researchers study these objects because they offer intriguing glimpses of the

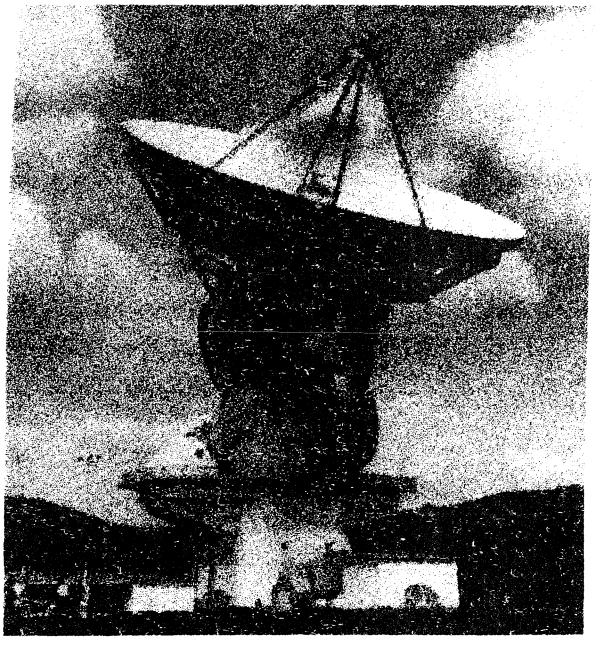
composition of our Galaxy and the cosmos, and reveal much about how stars and planets are born. Hydrogen atoms in these clouds give off natural signals (at the 21-cm wavelength), which can be detected only by radio telescopes.

The scientists discovered that this HI cloud was unusual in many respects. First, it was uncharacteristically massive, about 500 light- years across and containing nearly 100,000 times the mass of the sun in atomic hydrogen. The gas in clouds this large and massive has typically undergone the transition to the molecular phase, and has begun making stars. The size and mass of this cloud indicate that it is gravitationally bound, which means that it should be collapsing and forming new stars.

"When you find a cloud that is as massive as the one we detected, and one that is gravitationally bound as this structure indicates, then you would expect to see areas of star formation," said Lockman. The scientists were able to identify a few indicators of star formation, but not at the rate that one would expect. "We think we have caught something in a special state." Lockman said, "It could be one of the missing links in the cycle of star formation."

The core of the cloud also gives off radio signals at 1720 MHz from the molecule OH in an unusual state of excitation. Since other astronomers have detected similar signals throughout the Galactic plane, the researchers believe that these emissions may be an indication that this previously undetected type of cloud may turn out to be fairly common.

"We suspect that this cloud may be the first example of an object that may be fairly common in the inner Galactic plane," said Lockman, "but has not been recognized. That is, a cloud that is observed while entering a spiral shock and is in the transition between atomic to molecular hydrogen."



The scientists caution, however, that additional research is needed to confirm their speculations. "The presence of anomalous OH through the Galactic plane does suggest that other clouds of this nature can be detected," said Lockman, "and it would be particularly valuable if a similar cloud could be detected entering the 'spiral shock' on the opposite side of the Galactic center." The patterns of velocities of atomic and molecular gas should be reversed there, due to the difference in galactic rotation. Such a discovery could help to validate the possible interaction among the spiral shock, atomic hydrogen, and star formation.

The NSF's 140-foot radio telescope now is decommissioned after a long and highly productive career. Research will continue on the newly commissioned Robert C. Byrd Green Bank Telescope, which is the world's largest fully steerable radio telescope. "Though the 140-foot telescope enabled us to make remarkable observations," commented Minter, "we anticipate that the new Green Bank Telescope, with its increased sensitivity and better resolution, will enable us to see more clearly the nature of this peculiar object."

In addition to Minter and Lockman, other astronomers involved in this research include Glen I. Langston, NRAO; and Jennifer A. Lockman who was a student from the College of Charleston, S.C., at the time the research was conducted.

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VLBA Provides Best Detail Yet of Star-Forming Cloud's Magnetic Field

Astronomers have used the National Science Foundation's Very Long Baseline Array (VLBA) radio telescope to do a very detailed map of the magnetic field within a star-forming cloud, an achievement that will help scientists unravel the mysterious first steps of the stellar birth process.

"This study provides new and important data needed by theorists to understand how magnetic fields affect the early stages of star formation," said Anuj Sarma, an astronomer at the University of Illinois at Urbana-Champaign. Sarma worked with Thomas Troland of the University of Kentucky and Jonathan Romney of the National Radio Astronomy Observatory (NRAO) in Socorro, New Mexico. Their research results were published in the Astrophysical Journal Letters.

Stars are formed when gas in giant interstellar clouds collapses gravitationally. Magnetic fields are believed to support such gas clouds, helping them resist gravitational collapse, so the beginning stages of star formation arise from a complex interplay of the magnetic fields and gravity that is not yet well understood.

"In order to understand how star formation gets started, we need to know in detail the structure of the magnetic fields in a star-forming cloud," Sarma said. "Our observations with the VLBA have provided one more big step in this direction," he added.

The astronomers studied a cloud of molecular gas more than 5,000 light- years from Earth in a spiral arm of our own Milky Way Galaxy. The cloud, known as W3 IRS5, contains seven newly-formed stars. In addition, it contains a number of regions, somewhat smaller than the diameter of Earth's orbit, in which water vapor molecules act to amplify, or strengthen, radio emission. Such regions, called masers, are a radio- wave parallel to lasers, which amplify light.

The scientists used the VLBA to make a detailed study of the radio waves coming from these maser regions in the gas cloud. They detected a phenomenon called the Zeeman effect, in which a very precise frequency emitted by atoms or molecules, called a spectral line, is split into two by a magnetic field. Analyzing this effect allowed the astronomers to measure the strength of the magnetic field at the locations of the maser regions.

"The bright, amplified radio emission coming from these water masers allowed us to measure the

magnetic-field strength," Troland said.

The Expanded Very Large Array (EVLA) and the Atacama Large Millimeter Array (ALMA), two instruments under development by the NRAO, will provide improved sensitivity to faint radio emissions, and allow even more detailed studies of the magnetic fields in star-forming regions.

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

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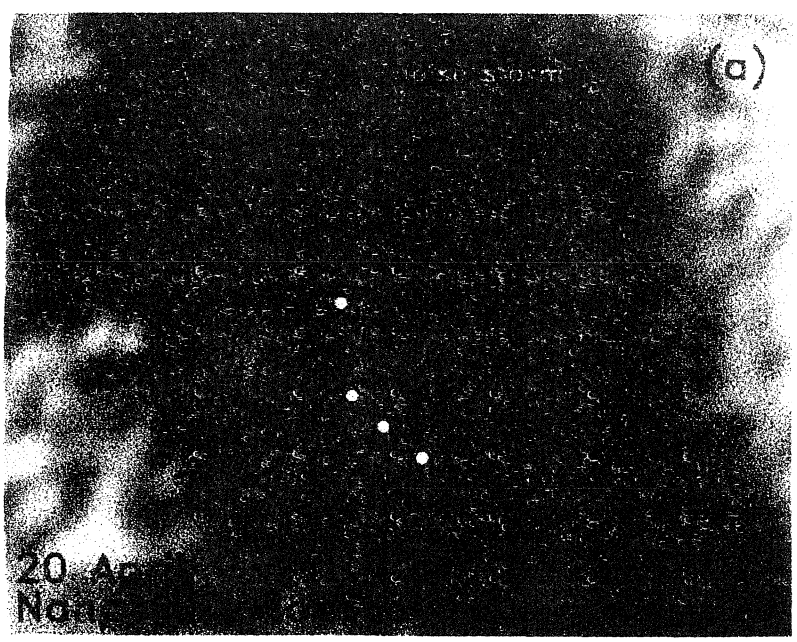
Radio Astronomers Get Their First Glimpse of Powerful Solar Storm

Astronomers have made the first radio-telescope images of a powerful coronal mass ejection on the Sun, giving them a long-sought glimpse of hitherto unseen aspects of these potentially dangerous events.

"These observations are going to provide us with a new and unique tool for deciphering the mechanisms of coronal mass ejections and how they are related to other solar events," said Tim Bastian, an astronomer at the National Science Foundation's National Radio Astronomy Observatory (NRAO) in Charlottesville, Virginia.



Bastian, along with Monique Pick, Alain Kerdraon and Dalmiro Maia of the Paris Observatory, and Angelos Vourlidas of the Naval Research Laboratory in Washington, D.C., used a solar radio telescope in Nancay, France, to study a coronal mass ejection that occurred on April 20, 1998. Their results will be published in the September 1 edition of the *Astrophysical Journal Letters*.

Coronal mass ejections are powerful magnetic explosions in the Sun's corona, or outer atmosphere, that can blast billions of tons of charged particles into interplanetary space at tremendous speeds. If the ejection is aimed in the direction of Earth, the speeding particles interact with our planet's magnetic field to cause auroral displays, radio-communication blackouts, and potentially damage satellites and

electric-power systems.

"Coronal mass ejections have been observed for many years, but only with visible-light telescopes, usually in space. While previous radio observations have provided us with powerful diagnostics of mass ejections and associated phenomena in the corona, this is the first time that one has been directly imaged in wavelengths other than visible light," Bastian said. "These new data from the radio observations give us important clues about how these very energetic events work," he added.

The radio images show an expanding set of loops similar to the loops seen at visible wavelengths. The radio loops, astronomers believe, indicate regions where electrons are being accelerated to nearly the speed of light at about the time the ejection process is getting started. The same ejection observed by the radio telescope also was observed by orbiting solar telescopes.

Depending on what later radio observations show, the solar studies may reveal new insights into the physics of other astronomical phenomena. For example, shocks in the corona and the interplanetary medium accelerate electrons and ions, a process believed to occur in supernova remnants - the expanding debris from stellar explosions. The electrons also may be accelerated by processes associated with magnetic reconnection, a process that occurs in the Earth's magnetosphere. "The Sun is an excellent physics laboratory, and what it teaches us can then help us understand other astrophysical phenomena in the universe," Bastian said.

The radio detection of a coronal mass ejection also means that warning of the potentially dangerous effects of these events could come from ground-based radio telescopes, rather than more-expensive orbiting observatories. "With solar radio telescopes strategically placed at three or four locations around the world, coronal mass ejections could be detected 24 hours a day to provide advance warning," Bastian said.

The Nancay station for radio astronomy is a facility of the Paris Observatory. The Nancay Radioheliograph is funded by the French Ministry of Education, the Centre National de la Recherche Scientifique, and by the Region Centre. This research has also been supported by the Centre National d'Etudes Spatiales.

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Images to Accompany This Story

Radio Image of Coronal Mass Ejection

MPEG Movie (847K) of Coronal Mass Ejection

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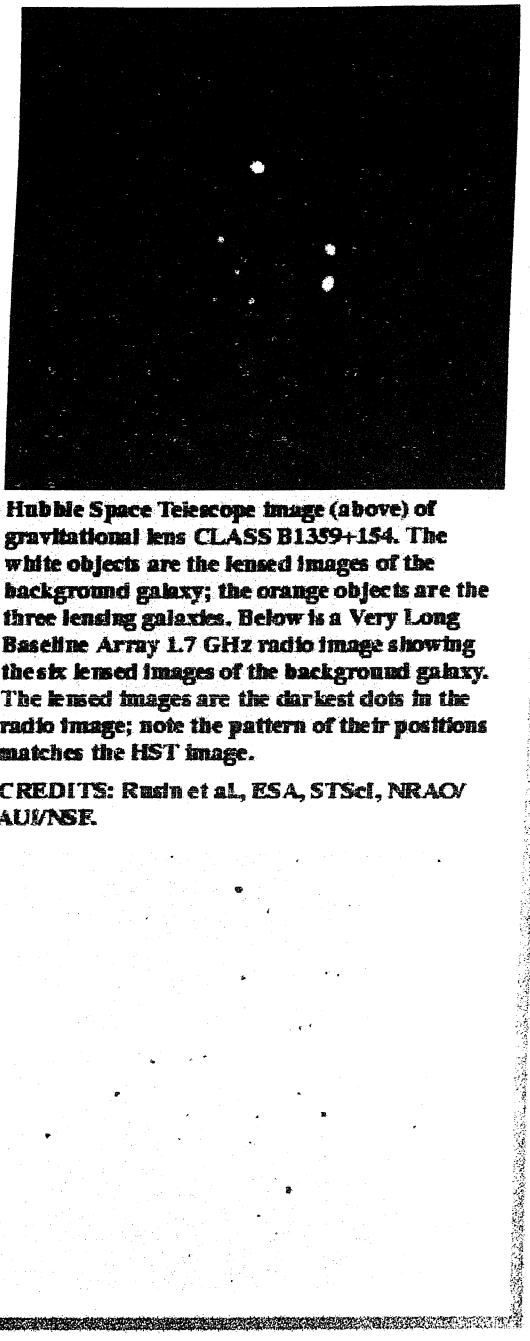
Astronomers Discover Six-Image Gravitational Lens

An international team of astronomers has used the National Science Foundation's Very Long Baseline Array (VLBA) radio telescope and NASA's Hubble Space Telescope (HST) to discover the first gravitational lens in which the single image of a very distant galaxy has been split into six different images. The unique configuration is produced by the gravitational effect of three galaxies along the line of sight between the more-distant galaxy and Earth.

"This is the first gravitational lens with more than four images of the background object that is produced by a small group of galaxies rather than a large cluster of galaxies," said David Rusin, who just received his Ph.D. from the University of Pennsylvania. "Such systems are expected to be extremely rare, so this discovery is an important stepping stone. Because this is an intermediate case between gravitational lenses produced by single galaxies and lenses produced by large clusters of galaxies, it will give us insights we can't get from other types of lenses," Rusin added.

The gravitational lens, called CLASS B1359+154, consists of a galaxy more than 11 billion light-years away in the constellation Bootes, with a trio of galaxies more than 7 billion light-years away along the same line of sight. The more-distant galaxy shows signs that it contains a massive black hole at its core and also has regions in which new stars are forming. The gravitational effect of the intervening galaxies has caused the light and radio waves from the single, more-distant galaxy to be "bent" to form six images as seen from Earth. Four of these images appear outside the triangle formed by the three intermediate galaxies and two appear inside that triangle.



Hubble Space Telescope image (above) of gravitational lens CLASS B1359+154. The white objects are the lensed images of the background galaxy; the orange objects are the three lensing galaxies. Below is a Very Long Baseline Array 1.7 GHz radio image showing the six lensed images of the background galaxy. The lensed images are the darkest dots in the radio image; note the pattern of their positions matches the HST image.

CREDITS: Rusin et al., ESA, STScI, NRAO/ AUI/NSF.

"This lens system is a very interesting case to study because it is more complicated than lenses produced by single galaxies, and yet simpler than lenses produced by clusters of numerous galaxies," said Chris Kochanek of the Harvard-Smithsonian Center for Astrophysics (CfA). "When we understand this system, we will have a much clearer picture of how galaxies are changed by being part of a bigger cluster of galaxies," he added.

B1359+154 was discovered in 1999 by the Cosmic Lens All-Sky Survey, an international collaboration of astronomers who use radio telescopes to search the sky for gravitational lenses. Images made by the NSF's Very Large Array in New Mexico and by Britain's MERLIN radio telescope showed six objects suspected of being gravitational-lens images, but the results were inconclusive. Rusin and his team used the VLBA and HST in 1999 and 2000 to make more-detailed studies of B1359+154. The combination of data from the VLBA and HST convinced the astronomers that B1359+154 actually consists of six lensed images of a single background galaxy. The VLBA images were made from data collected during observations at a radio frequency of 1.7 GHz.

"This is a great example of modern, multi-wavelength astronomy," said Rusin. "We need the radio telescopes to detect the gravitational lenses in the first place, then we need the visible-light information from Hubble to show us additional detail about the structure of the system."

Armed with the combined VLBA and HST data about the positions and brightnesses of the six images of the background galaxy as well as the positions of the three intermediate galaxies, the astronomers did computer simulations to show how the gravitation of the three galaxies could produce the lens effect. They were able to design a computer model of the system that, in fact, produces the six images seen in B1359+154.

"Our computer model certainly is not perfect, and we need to do more observations of this system to refine it, but we have clearly demonstrated that the three galaxies we see can produce a six-image lens system," said Martin Norbury, a graduate student at Jodrell Bank Observatory in Britain. "We think this work will give us an excellent tool for studying much-denser clusters of galaxies and the relationships of the individual cluster galaxies to the 'halo' of dark matter in which they are embedded," he added.

Clusters of galaxies are known to produce gravitational lenses with up to eight images of a single background object. However, the number of galaxies in such a cluster makes it difficult for astronomers to decipher just how their gravitational effects have combined to produce the multiple images. Researchers hope to be able to understand the lensing effect well enough to use the lenses to show them how galaxies, gas and unseen dark matter in clusters are distributed. A system such as B1359+154, with only three galaxies involved in the lensing, can help astronomers learn how complex gravitational lenses work.

"The next big step is to use HST to see the pattern of rings produced by the galaxy surrounding the black hole. We already see hints of them, but with the upgrades to HST in the next servicing mission we should be able to trace it completely both to pin down the structure of the lens and to have an enormously magnified image for studying the distant host galaxy," Kochanek said.

In addition to Rusin, Kochanek and Norbury, the researchers are: Emilio Falco of the CfA; Chris Impey of Steward Observatory at the University of Arizona; Joseph Lehar of the CfA; Brian McLeod of the CfA; Hans-Walter Rix of the Max Planck Institute for Astronomy in Germany; Chuck Keeton of Steward Observatory; Jose Munoz of the Astrophysical Institute of the Canaries in Tenerife, Spain; and Chien Peng of Steward Observatory. The team published its results in the *Astrophysical Journal*.

The VLBA is a system of 10 radio-telescope antennas that work together as a single astronomical instrument. The antennas are spread across the United States, from Hawaii in the west to the U.S. Virgin Islands in the east. A radio telescope system more than 5,000 miles across, the VLBA produces extremely detailed images.

The National Radio Astronomy Observatory is a facility of the National Science Foundation, operated under cooperative agreement by Associated Universities, Inc. The Space Telescope Science Institute is operated by the Association of Universities for Research in Astronomy, Inc., for NASA,, under contract with the Goddard Space Flight Center, Greenbelt, MD. The Hubble Space Telescope is a project of international Cooperation between NASA and the European Space Agency.

Images to Accompany This Story

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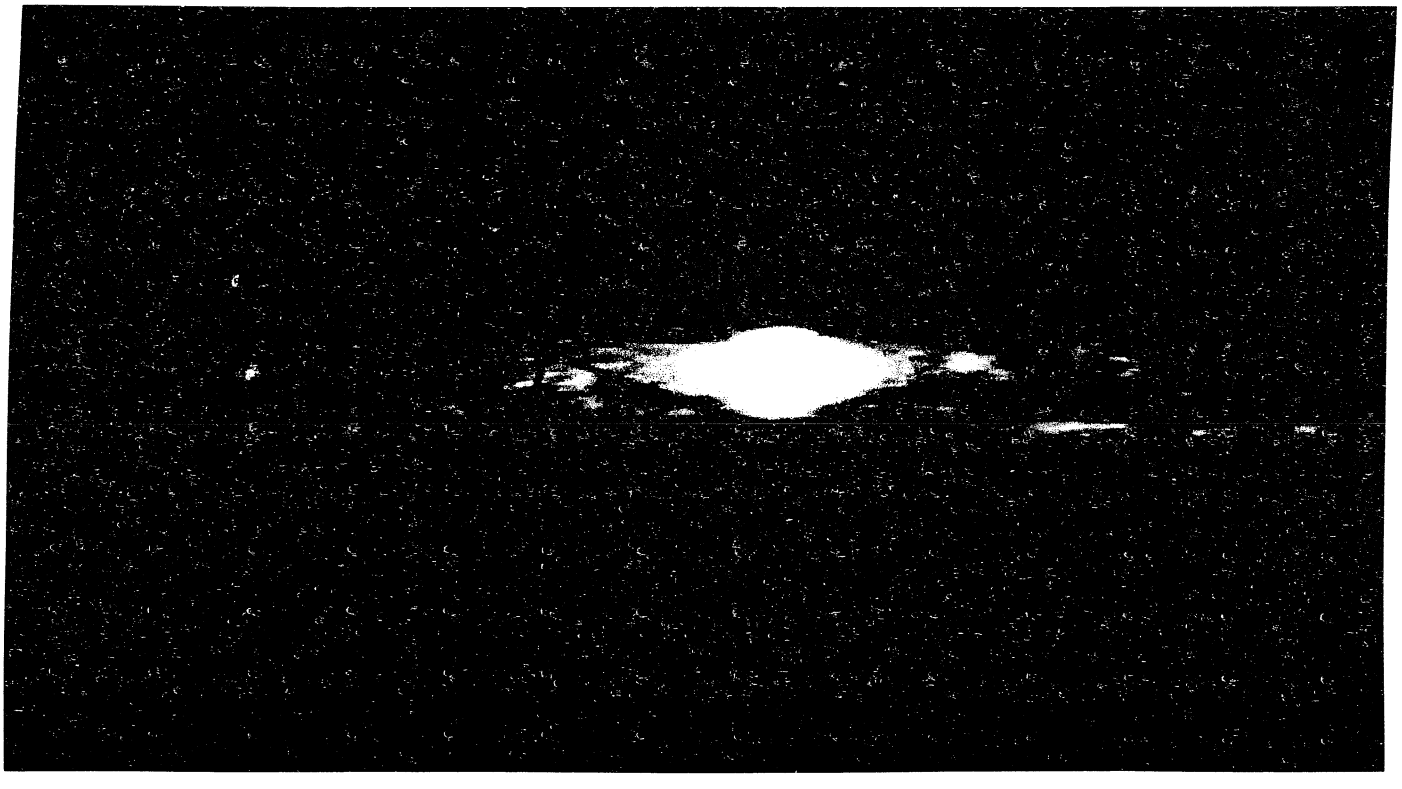
Ancient Black Hole Speeds Through Sun's Galactic Neighborhood, Devouring Companion Star



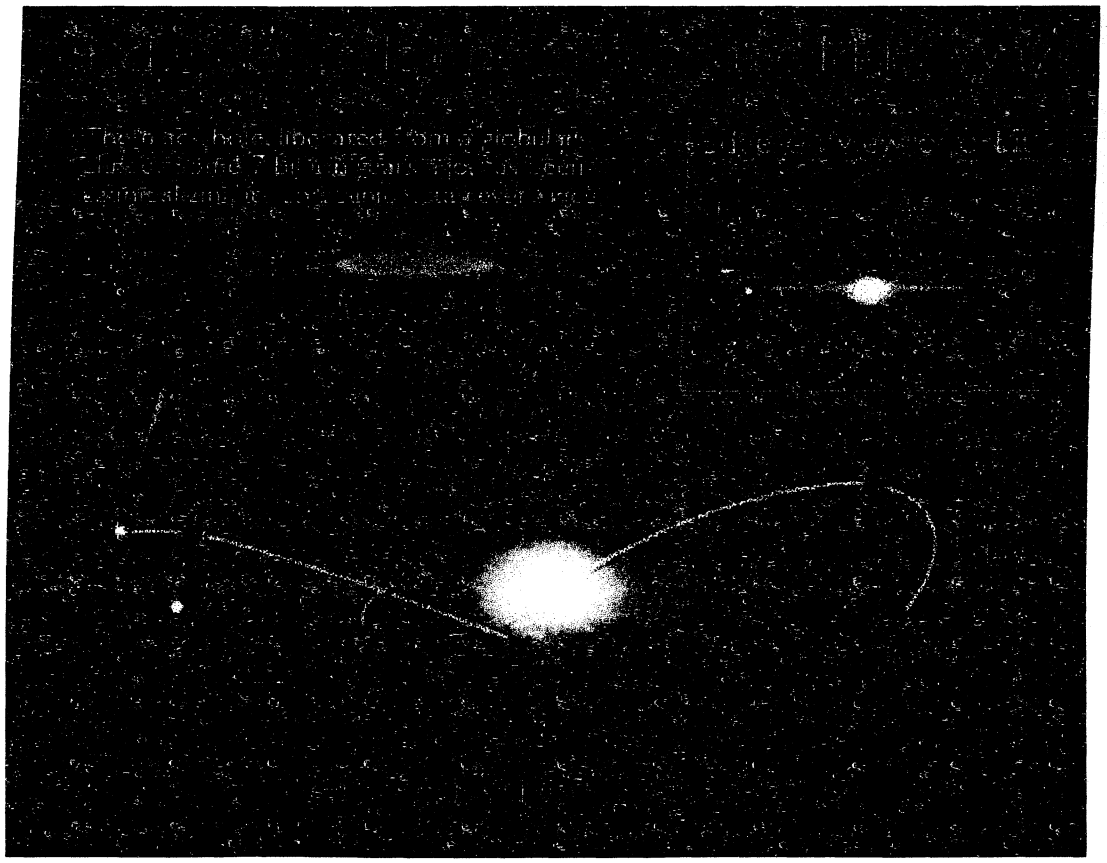
Orbital Path (red line) of Black Hole and its Companion Through the Milky Way Galaxy Over the Past

230 Million Years. Yellow circle indicates the Sun's Current Position
CREDIT: I. Rodrigues and I.F. Mirabel, NRAO/AUI/NSF.

Astronomers using the National Science Foundation's Very Long Baseline Array (VLBA) radio telescope have found an ancient black hole speeding through the Sun's Galactic neighborhood, devouring a small companion star as the pair travels in an eccentric orbit looping to the outer reaches of our Milky Way Galaxy. The scientists believe the black hole is the remnant of a massive star that lived out its brief life billions of years ago and later was gravitationally kicked from its home star cluster to wander the Galaxy with its companion.

"This discovery is the first step toward filling in a missing chapter in the history of our Galaxy," said Felix Mirabel, an astrophysicist at the Institute for Astronomy and Space Physics of Argentina and French Atomic Energy Commission. "We believe that hundreds of thousands of very massive stars formed early in the history of our Galaxy, but this is the first black hole remnant of one of those huge primeval stars that we've found."

"This also is the first time that a black hole's motion through space has been measured," Mirabel added. A black hole is a dense concentration of mass with a gravitational pull so strong that not even light can escape it. The research is reported in the Sept. 13 issue of the scientific journal *Nature*.



The object is called XTE J1118+480 and was discovered by the Rossi X-Ray satellite on March 29, 2000. Later observations with optical and radio telescopes showed that it is about 6,000 light-years from Earth and that it is a "microquasar" in which material sucked by the black hole from its companion star forms a hot, spinning disk that spits out "jets" of subatomic particles that emit radio waves.

Most of the stars in our Milky Way Galaxy are within a thin disk, called the plane of the Galaxy. However, there also are *globular clusters,* each containing hundreds of thousands of the oldest stars in the Galaxy which orbit the Galaxy's center in paths that take them far from the Galaxy's plane. XTE J1118+480 orbits the Galaxy's center in a path similar to those of the globular clusters, moving at 145 kilometers per second (90 miles

per second) relative to the Earth.

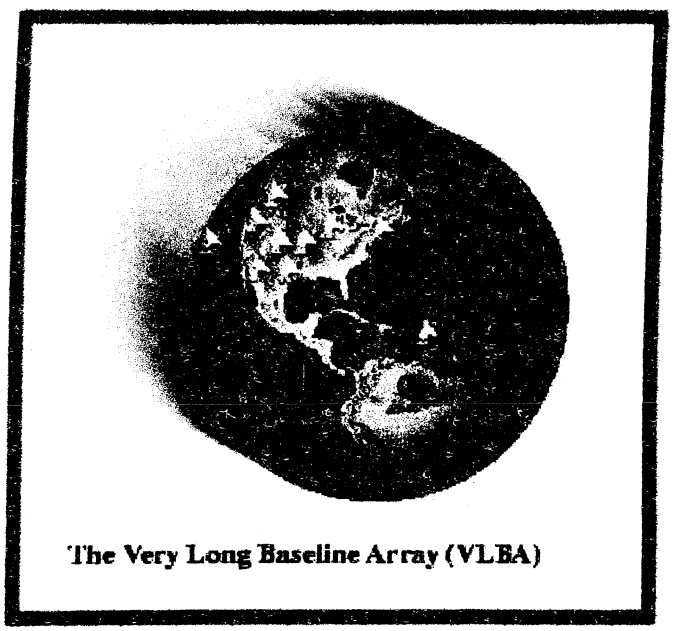
How did it get into such an orbit? "There are two possibilities: either it formed in the Galaxy's plane and was somehow kicked out of the plane or it formed in a globular cluster and was kicked out of the cluster," said Vivek Dhawan, an astronomer at the National Radio Astronomy Observatory (NRAO) in Socorro, New Mexico.

A massive star ends its life by exploding as a supernova, leaving either a neutron star or a black hole as a remnant. Some neutron stars show rapid motion, thought to result from a sideways "kick" during the supernova explosion. "This black hole has much more mass -- about seven times the mass of our Sun -- than any neutron star," said Dhawan. "To accelerate it to its present speed would require a kick from the supernova that we consider improbable," Dhawan added.

"We think it's more likely that it was gravitationally ejected from the globular cluster," Dhawan said. Simulations of the gravitational interactions in globular clusters have shown that the black holes resulting from the collapse of the most massive stars should eventually be ejected from the cluster.

"The star that preceded this black hole probably formed in a globular cluster even before our Galaxy's disk was formed," Mirabel said. "What we're doing here is the astronomical equivalent of archaeology, seeing traces of the intense burst of star formation that took place during an early stage of our Galaxy's development."

The black hole has consumed so much of its companion star that the inner layers of the smaller star -- only about one-third the mass of the Sun -- now are exposed. The scientists believe the black hole captured the companion before being ejected from the globular cluster, as if it were grabbing a snack for the road.



The Very Long Baseline Array (VLBA)

"Because this microquasar happened to be relatively close to the Earth, we were able to track its motion with the VLBA even though it's normally faint," said Mirabel. "Now, we want to find more of these ancient black holes. There must be hundreds of thousands swirling around in our Galaxy."

The astronomers used the VLBA to observe XTE J1118+480 in May and July of 2000, using the VLBA's great resolving power, or ability to see fine detail, to precisely measure the object's movement against the backdrop of more-distant celestial bodies. The VLBA observations were made at radio frequencies of 8.4 and 15.4 GHz.

In addition, they found that the object appears in optical images made for the Palomar Observatory Sky Survey (POSS) taken 43 years apart. The POSS images were digitized to allow for rapid search and analysis by the Space Telescope Science Institute. The data from both the radio and optical images allowed the astronomers to calculate the object's orbital path around the Galactic center.

"With the VLBA, we could start observing soon after this object was discovered and get extremely precise information on its position. Then, we were able to use the digitized data from the Palomar surveys to

extend backward the time span of our information. This is a great example of applying multiple tools of modern astronomy -- telescopes covering different wavelengths and digital databases -- to a single problem," said Dhawan.

In addition to Mirabel and Dhawan, the research was performed by Roberto Mignani of the European Southern Observatory; Irapuan Rodrigues, who is a fellow of the Brazilian National Research Council at the French Atomic Energy Commission; and Fabrizia Guglielmetti of the Space Telescope Science Institute in Baltimore, MD.

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Still Images to Accompany This Story

MPEG Animation (Sun/UNIX) of Black Hole's Orbital Path (2.04 MB)

Windows Version of MPEG Animation (1.08 MB)

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October 1, 2001

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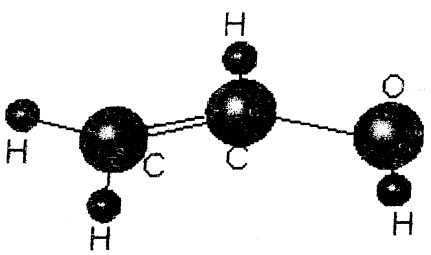
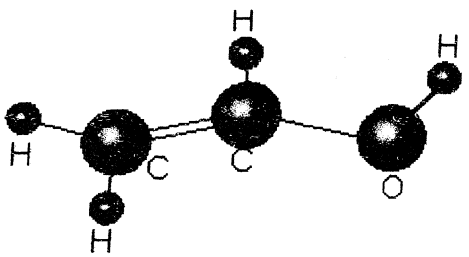
Scientists Toast the Discovery of Vinyl Alcohol in Interstellar Space

Astronomers using the National Science Foundation's 12 Meter Telescope at Kitt Peak, AZ, have discovered the complex organic molecule vinyl alcohol in an interstellar cloud of dust and gas near the center of the Milky Way Galaxy. The discovery of this long-sought compound could reveal tantalizing clues to the mysterious origin of complex organic molecules in space.

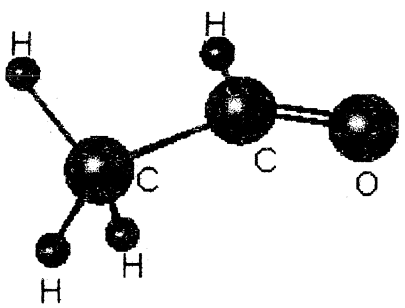
"The discovery of vinyl alcohol is significant," said Barry Turner, a scientist at the National Radio Astronomy Observatory (NRAO) in Charlottesville, Va., "because it gives us an important tool for understanding the formation of complex organic compounds in interstellar space. It may also help us better understand how life might arise elsewhere in the Cosmos." Vinyl alcohol is an important intermediary in many organic chemistry reactions on Earth, and the last of the three stable members of the C_2H_4O group of isomers (molecules with the same atoms, but in different arrangements) to be discovered in interstellar space.



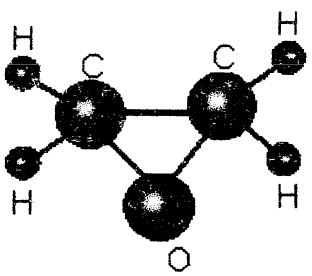
Vinyl alcohol (syn)



Vinyl alcohol (anti)



Acetaldehyde



Ethylene oxide

Turner and his colleague A. J. Apponi of the University of Arizona's Steward Observatory in Tucson

detected the vinyl alcohol in Sagittarius B -- a massive molecular cloud located some 26,000 light-years from Earth near the center of our Galaxy. The astronomers were able to detect the specific radio signature of vinyl alcohol during the observational period of May and June of 2001. Their results have been accepted for publication in the *Astrophysical Journal Letters*.

Of the approximately 125 molecules detected in interstellar space, scientists believe that most are formed by gas-phase chemistry, in which smaller molecules (and occasionally atoms) manage to "lock horns" when they collide in space. This process, though efficient at creating simple molecules, cannot explain how vinyl alcohol and other complex chemicals are formed in detectable amounts.

For many years now, scientists have been searching for the right mechanism to explain how the building blocks for vinyl alcohol and other chemicals are able to form the necessary chemical bonds to make larger molecules - those containing as many as six or more atoms. "It has been an ongoing quest to understand exactly how these more complex molecules form and become distributed throughout the interstellar medium," said Turner.

Since the 1970s, scientists have speculated that molecules could form on the microscopic dust grains in interstellar clouds. These dust grains are thought to trap the fast-moving molecules. The surface of these grains would then act as a catalyst, similar to a car's catalytic converter, and enable the chemical reactions that form vinyl alcohol and the other complex molecules. The problem with this theory, however, is that the newly formed molecules would remain trapped on the dust grains at the low temperature characteristic of most of interstellar space, and the energy necessary to "knock them off" would also be strong enough to break the chemical bonds that formed them.

"This last process has not been well understood," explained Turner. "The current theory explains well how molecules like vinyl alcohol could form, but it doesn't address how these new molecules are liberated from the grains where they are born."

To better understand how this might be accomplished, the scientists considered the volatile and highly energetic region of space where these molecules were detected. Turner and others speculate that since this cloud lies near an area of young, energetic star formation, the energy from these stars could evaporate the icy surface layers of the grains. This would liberate the molecules from their chilly nurseries, depositing them into interstellar space where they can be detected by sensitive radio antennas on Earth.

Astronomers are able to detect the faint radio signals that these molecules emit as they jump between quantum energy states in the act of rotating or vibrating.

Turner cautions, however, that even though this discovery has shed new light on how certain highly complex species form in space, the final answer is still not in hand.

"Although vinyl alcohol and its isomeric partners may well have formed on grains," said Turner "another important possibility has been found. The grain evaporative processes near star formation appear to release copious amounts of somewhat simpler molecules such as formaldehyde (H_2CO) and methanol (CH_3OH), which may be reacting in the gas phase to produce detectable amounts of vinyl alcohol and its isomers." A program to search for other families of isomers is planned, which the astronomers believe could distinguish between these two possibilities.

The astronomers used 2- and 3-mm band radio frequencies to make their observations with the 12 Meter Telescope. This telescope was taken off-line by the NRAO to make way for the Atacama Large Millimeter Array, and is now operated by the Steward Observatory of the University of Arizona. Built in 1967, the

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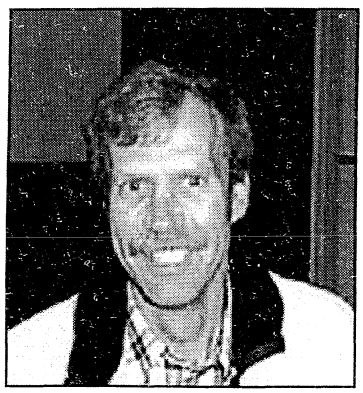
NRAO Names New Head of New Mexico Operations

The National Radio Astronomy Observatory (NRAO) has named Jim Ulvestad the new Assistant Director for New Mexico Operations in Socorro, New Mexico, effective December 15. As Assistant Director, Ulvestad will oversee the operation and management of two of NRAO's principal research facilities, the Very Large Array (VLA) and the Very Long Baseline Array (VLBA). He succeeds W. Miller Goss, who is stepping down as Assistant Director after serving in that capacity since 1988.

"We are delighted that Jim will assume this vital position for our observatory," said NRAO Director Paul Vanden Bout. "His solid background as a researcher, his broad knowledge of the astronomical community and his detailed understanding of the VLA and the VLBA will help us keep these facilities at the cutting edge of science in the coming years."



Vanden Bout also praised Goss, who will remain on the observatory's research staff, for his leadership of the VLA and VLBA over the past 14 years. "Miller's goal always was to make these radio telescopes the most productive possible tools for science, and to serve the scientific community with distinction. He succeeded, and the excellent reputation of NRAO's Socorro Operations among scientists is a tribute to his efforts," Vanden Bout said.

"I look forward to continuing to work with NRAO's outstanding New Mexico staff in a new capacity," Ulvestad said. "I am confident they will meet the challenge of operating the most scientifically productive ground-based telescope of the last 20 years, at the same time that we are dramatically expanding the technical capabilities of the VLA and planning for improvements to the VLBA," he added.

Ulvestad, currently NRAO's Deputy Assistant Director in Socorro, joined the observatory in 1996 after spending 12 years on the staff of NASA's Jet Propulsion Laboratory (JPL) in Pasadena, CA. He received his Ph.D in astronomy from the University of Maryland and worked as a postdoctoral research associate at the NRAO facility in Charlottesville, VA, prior to joining JPL. He has served on a number of professional panels and working groups, and is author of numerous scientific papers and reports.

Ulvestad's astronomical research has focused on active galaxies, galaxies with massive black holes at their cores, and the phenomena related to them. He also has done extensive work on the techniques of high-resolution radio interferometry, including the use of orbiting radio telescopes. Together with other NRAO-New Mexico staff, he led NRAO'ssuccessful effort to link the VLBA antenna at Pie Town, NM, to the VLA with a real-time fiber-optic connection, producing the capability to double the resolution, or ability to discern detail, of the VLA.

Goss, who joined NRAO in 1988, after working at radio observatories in the Netherlands, Germany, Australia and the U.S., will remain at NRAO as a staff scientist, pursuing a wide range of research interests as well as supervising graduate-student research projects. Under Goss' leadership, numerous technical improvements were made to the VLA. Also, the continent-wide VLBA's construction was completed and that instrument, which provides astronomers with the most detailed images available from any telescope, was brought on-line.

"After 14 years of managing the VLA and VLBA, I look forward to becoming a full-time user of these outstanding radio telescopes," Goss said. "I have worked with Jim Ulvestad for many years and know he will do an excellent job as the new Assistant Director," Goss added.

As Ulvestad assumes his new role, the NRAO is beginning the VLA Expansion Project, a two-step plan to increase the scientific capability of the VLA tenfold. Built during the 1970s and dedicated in 1980, the VLA has been used to advance the understanding of nearly every type of object in the universe. The VLA Expansion Project will replace obsolete original technology with current technology and add new facilities to the system, ensuring that the VLA remains at the leading edge of astronomical research.

In addition to the instruments headquartered at Socorro, the NRAO operates the Robert C. Byrd Green Bank Telescope in Green Bank, WV, the world's largest fully steerable radio telescope. NRAO also is collaborating with Europe and Japan on the design and construction of the Atacama Large Millimeter Array (ALMA), an array of 64 antennas that will be built in the Chilean Andes over the next decade.

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November 6, 2001

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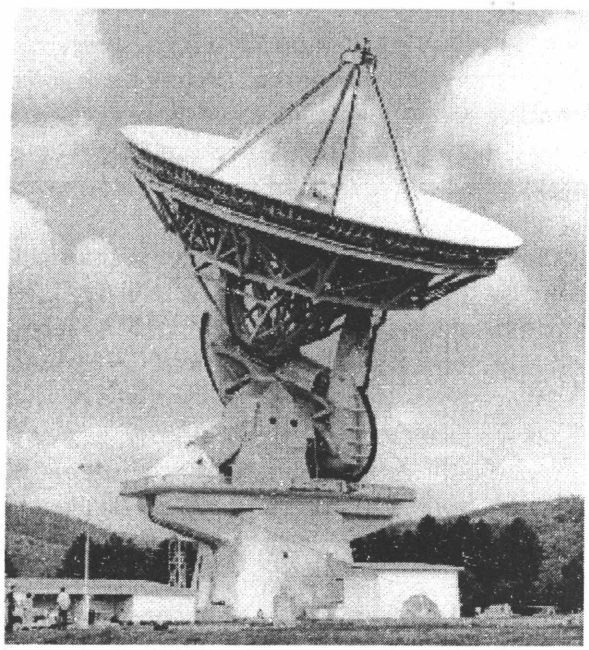
Scientists Detect Radio Emission from Rapidly Rotating Cosmic Dust Grains

Astronomers have made the first tentative observations of a long-speculated, but never before detected, source of natural radio waves in interstellar space. Data from the National Science Foundation's 140 Foot Radio Telescope at the National Radio Astronomy Observatory in Green Bank, W.Va., show the faint, tell-tale signals of what appear to be dust grains spinning billions of times each second. This discovery eventually could yield a powerful new tool for understanding the interstellar medium - the immense clouds of gas and dust that populate interstellar space.

"What we believe we have found," said Douglas P. Finkbeiner of Princeton University's Department of Astrophysics, "is the first hard evidence for electric dipole emission from rapidly rotating dust grains. If our studies are confirmed, it will be the first new source of continuum emission to be conclusively identified in the interstellar medium in nearly the past 20 years." Finkbeiner believes that these emissions have the potential in the future of revealing new and exciting information about the interstellar medium; they also may help to refine future studies of the Cosmic Microwave Background Radiation.



The results from this study, which took place in spring 1999, were accepted for publication in *Astrophysical Journal*. Other contributors to this paper include David J. Schlegel, department of astrophysics, Princeton University; Curtis Frank, department of astronomy, University of Maryland; and Carl Heiles, department of astronomy, University of California at Berkeley.

"The idea of dust grains emitting radiation by rotating is not new," comments Finkbeiner, "but to date it has been somewhat speculative." Scientists first proposed in 1957 that dust grains could emit radio signals, if they were caused to rotate rapidly enough. It was believed, however, that these radio emissions would be negligibly small - too weak to be of any impact to current radio astronomy research, and the idea was

largely forgotten.

In the 1990s this perception began to change when scientists and engineers designed sensitive instruments to detect the faint afterglow of the Big Bang, which is seen in the Universe as the Cosmic Microwave Background Radiation. While making detailed maps of this faint and cold radiation, scientists also detected signals at approximately the same wavelength and intensity as the background radiation, but clearly emanating from within the Milky Way's galactic plane. The researchers expected to detect some emission from the Milky Way, but what they encountered was much brighter than anticipated.

This discovery caused some concern among researchers because of the need to have a very clear "window" on the Universe to study the background radiation in great detail. If there were a source of radio emission in our own galactic "back yard," then studies of the microwave background radiation would need to recognize these emissions and correct for them. "We want to be clear, however, that nothing we have found invalidates the current interpretation of the Cosmic Microwave Background Radiation," assured Finkbeiner. "Nobody has done anything wrong in neglecting these signals - so far."

Scientists considered several plausible mechanisms for this anomalous emission, but these theories failed to explain the observed spatial distribution of this emission across the sky. This predicament prompted theorists to rethink the spinning dust idea, leading to a 1998 model by Bruce Draine (Princeton University) and Alex Lazarian (University of Wisconsin), which proposed rotational dust-grain emission as an important mechanism. Draine and Lazarian assumed that small dust grains, perhaps having no more than 100 atoms each, would populate many interstellar dust clouds in the Galaxy. Each grain would have a small electric dipole and would therefore react to the charged ions that race through the clouds at tremendous speeds. As an ion either strikes or passes near a dust grains, the grain would "spin up," reaching speeds of up to one trillion revolutions per minute, causing it to radiate. The rate of rotation of these dust grains directly correlates to the frequencies at which they radiate. For example, a dust grain rotating 10 billion times each second would emit radio waves at 10 gigahertz (GHz).

In looking for this elusive signal, the researchers narrowed their search to 10 dust clouds within the Milky Way Galaxy. These specific clouds were selected because their location and properties would help to eliminate other possibilities for these emissions. "Our goal was to find those areas within the Milky Way Galaxy that would help us rule out other sources of emission," said Finkbeiner. "By selected these specific targets, we believe that the signals we received are very indicative of rapidly rotating dust grains."

The researchers emphasize, however, that additional observations will be required to confirm their results, and other potential emission mechanisms have not been ruled out. Particularly, it is possible that a portion of this radiation is due to the presence of ferro-magnetic minerals within the dust grains. Additional studies with more sensitive equipment will be necessary to confirm these results conclusively.

"What we think is the most intriguing, however," said Finkbeiner, "is that with further advances in radio astronomy, the faint emissions from rotating dust grains may reveal previously unknown details about the dynamics of the interstellar medium. By detecting and understanding this emission we also hope to give astronomers a tool to greatly refine future studies of the Cosmic Microwave Background Radiation."

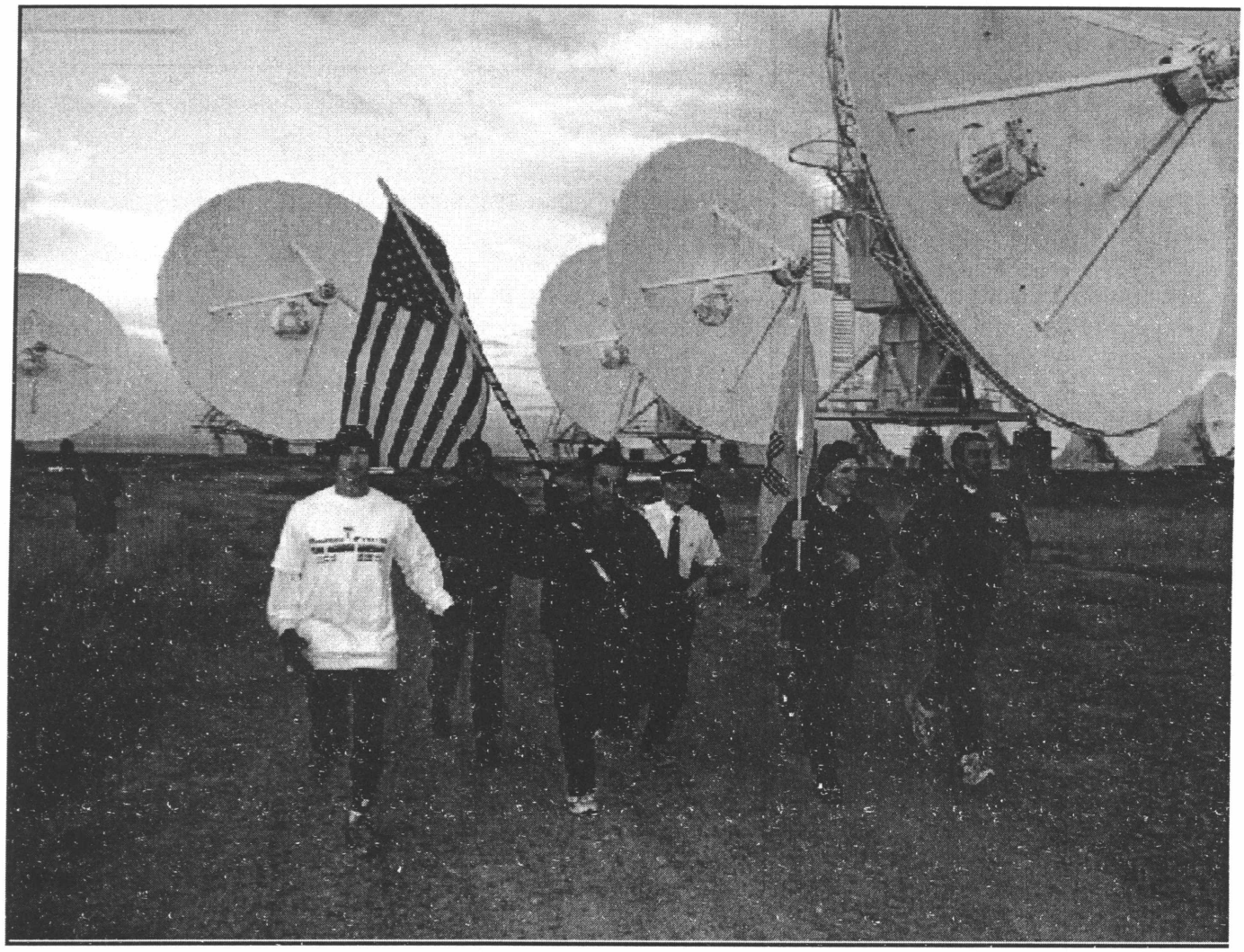
The NSF's 140 Foot Radio Telescope now is decommissioned after a long and highly productive career. Research will continue on the newly commissioned Robert C. Byrd Green Bank Telescope, which is the world's largest fully steerable radio telescope.The National Radio Astronomy Observatory is a facility of the National Science Foundation, operated under cooperative agreement by Associated Universities, Inc.

National Radio Astronomy Observatory
P.O. Box O
Socorro, NM 87801
http://www.nrao.edu

November 7, 2001

Contact:

Dave Finley, Public Information Officer
(505) 835-7302
dfinley@nrao.edu



Kelly D. Gatlin, NRAO/AUI

Runners carry U.S. and New Mexico flags past the 230-ton dish antennas of the VLA early on November 5, 2001

VLA Hosts "Flag Across America"

The National Radio Astronomy Observatory (NRAO) hosted the runners and support personnel of the "Americans United Flag Across America" run as the transcontinental memorial and fundraising effort came through New Mexico. The flag run arrived at NRAO's Very Large Array (VLA) radio telescope west of Socorro, NM, early in the post-Midnight morning of Monday, November 5, and departed after sunrise that morning en route to the Arizona border.

Drivers, runners and support personnel stayed overnight at the VLA. During the night, a "VLA Night Owl Run" kept the flag moving around the VLA area until the westward trek resumed after dawn.

The run began Oct. 11, one month after the terrorist attacks on New York and Washington. Organized by employees of American and United Airlines to honor the flight crews lost in those attacks, to show support for U.S. troops and to raise funds to help the victims' families, the run will take an American flag from Boston Logan Airport to Los Angeles International Airport.

The Boston-to-Los Angeles trip represents the intended journey of American Flight 11 and United Flight 175, both of which were crashed by terrorists into the World Trade Center.

"Our observatory was proud to host this group and honored that they brought this flag through our facility," said Miller Goss, NRAO's director of VLA operations.

The runners carried a flag that flew in a U.S. F-16 over Iraq in support of Operation Southern Watch on Oct. 2, and has visited Ground Zero in Manhattan. The flag is scheduled to arrive in Los Angeles on Veterans Day, Nov. 11.

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

Policy and Site News

reaching for the *heavens*

When It Comes To Telescopes, This One Is In A Galaxy Of Its Own

story by **Luanne Austin** ■ News-Record staff writer

photos by **Allen Litten** ■ News-Record photographer

GREEN BANK, W.Va. — It's the most massive moving structure on land. Forty motors move its 8,500 tons. Its surface is two acres large.

There is no other radio telescope like the Green Bank Telescope.

"The real story of astronomy is the building of bigger, more sensitive equipment than the previous generation," says Phil Jewell, site director. "We can learn more than we ever knew before about the origins of the universe."

After 10 years of building, the GBT is ready to be used by astronomers.

The GBT stands, like the obelisk on "2001: A Space Odyssey," in contrast to its surroundings. The National Radio Astronomy Observatory is located in the Deer Creek Valley, which runs between ridges of the Appalachian Mountains in Pocahontas County.

When ground was broken for the GBT in 1990, the plan was to complete construction by the fall of 1995. But since nothing of this size or precision had ever been built, problems arose. The most recent problem was in the azimuth track upon which the structure moves. The bolt heads were breaking off.

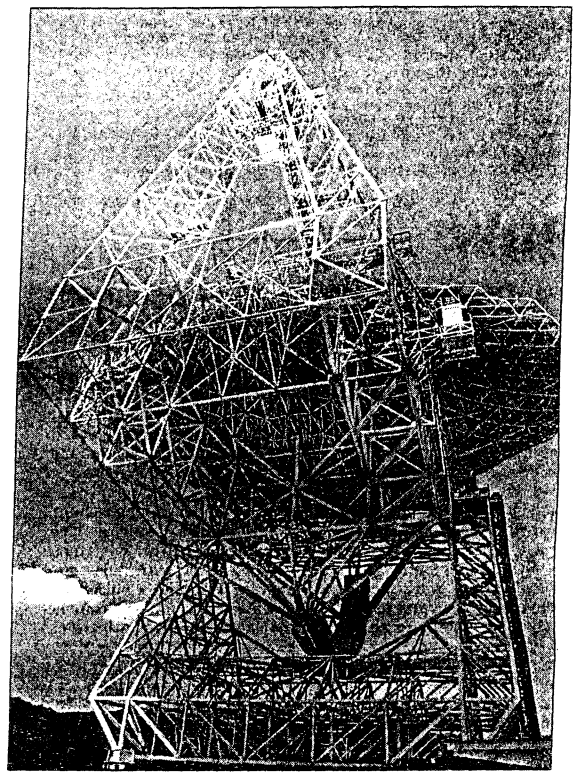
So the number of bolts in each of the 48 track segments was more than doubled — from 14 to 36.

Testing of the azimuth track is complete, says Jewell. Testing of the dish itself has resumed and science projects began in mid-August. The GBT should be in 24-hour operation in January.

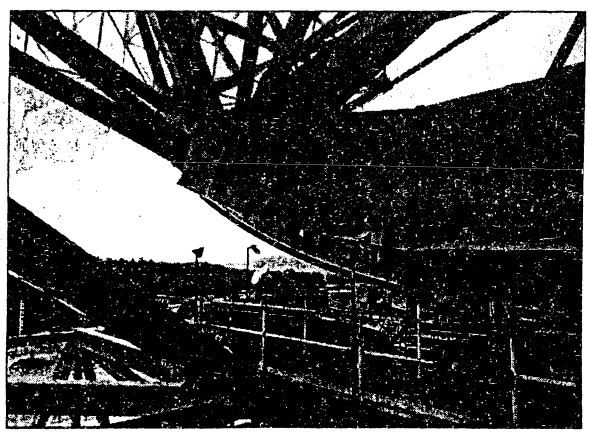
The telescope is used by astronomers from the United States and around the world, along with physicists and chemists from universities and research institutions who are interested in astronomy problems.

There is no charge for using the GBT or any of the telescopes at Green Bank. Everything is paid for by the National Science

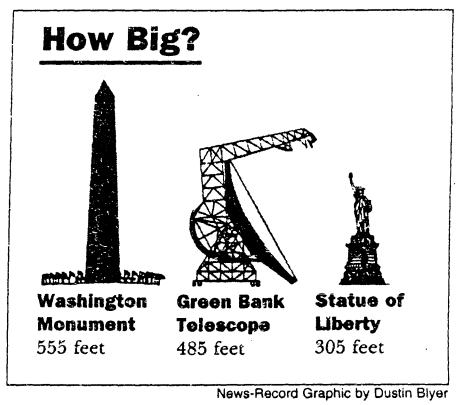
See TELESCOPE, Page 10



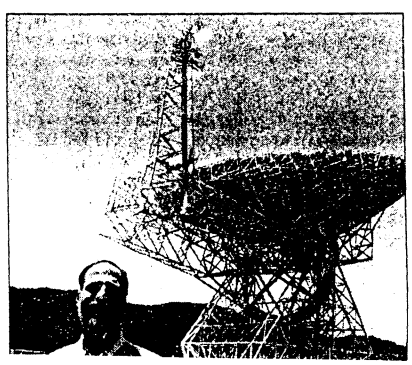
The Green Bank Telescope was completed earlier this year, and the telescope is now ready to be used by astronomers. The telescope is the most massive moving structure on land.



Just one part of the telescope (above) shows how massive it is. Phil Jewell, site superintendent (in photo at right) says the telescope will help scientists understand even more about the origins of the universe.



News-Record Graphic by Dustin Blyer



Telescope

Continued from Page 9

Foundation. Scientists submit applications explaining their projects.

"It will be in high demand," says Jewell.

Because the GBT is already in high demand, the scheduling committee has been able to satisfy only 20 of the 80 initial proposals to use the new telescope, says Jewell.

One Of A Kind

The GBT is unique in its design, with capabilities far exceeding any previous radio telescope.

For one thing, the telescope's aperature, or opening, is unblocked, so incoming radiation reaches the whole surface. Conventional telescopes have their feed arms projecting up from the center of the surface, so the supports cause an obstruction. But the GBT's feed arm is offset, at the dish's edge, and the dish surface is asymmetrical.

Another of the GBT's features is the laser-ranging system that monitors its surface. Lasers on the feed arm pick up data from each of the surface panel's retroflectors (mirrors). Any distortions that are detected are corrected immediately: Each of the 2,004 surface panels are mounted at their corners on actuators, little motor-driven pistons that move the panel up and down to maintain the correct shape.

Lasers in the ground stations that surround the telescope in a broad ring send data from below to determine where it is pointing. So, in spite of its size, the GBT is a fine instrument. It can hold its position to within 1 arc second, or 7/10 of a millimeter.

"That's a lot of why this was a painstaking exercise to build," says Jewell.

The GBT is controlled from a room located several miles away. The room is shielded, its walls lined with copper and steel to prevent the radiowaves from the computers from interfering with the telescope's receptors. The telescope controller works in a circle of computers.

if you **GO**

Green Bank Tours

What: Free daily tours are offered fom Memorial Day through Labor Day and on weekends in September and October.
Where: Green Bank, W.Va.
Information: (304) 456-2164

The data from the telescope comes to this room. When the signals come in on a high frequency, they are "mixed down" to a low frequency, then a channel machine breaks them down to smaller, specific frequencies to be analyzed. Scientists work in the control room among another set of computers.

How It Works

Radio waves from anything are everywhere. That's why Green Bank is in a National Radio Quiet Zone. Radio emissions in the area are controlled to avoid interference with the radio waves from space.

"You won't see any cell phone towers in the Green Bank area," says Jewell.

Radio emissions from cell phones and microwaves can interfere with the telescope operation. The neighbors, says Jewell, are cooperative.

Radio waves from the universe hit the surface of the dish and reflect up to the subreflector at the dish's focal point, then down into a feedhorn on the large arm. The feedhorn channels the weak signals into a receiver in the control room, which amplifies them. Then the signals are passed to backend equipment, which can analyze them in numerous ways. From the data recorded, scientists can create images from the points.

Since it relies on sound, not light, radio telescopes can be used day or night.

Sometimes scientists use telescopes in collaboration. When the strength of two or more telescopes are combined, it's called an interferometer. One such project featured a radio telescope working with the Hubbel, which is in outer space, to create an image of two galaxies colliding. Last year, the GBT was used in collaboration with a large, stationary radio telescope in Arecibo, Puerto Rico, to study the rings of Venus.

Other Telescopes

Before the GBT was built, the workhorse of the observatory at Green Bank was the 140-foot telescope. Completed in 1965, it preceded the GBT in its status as the largest equatorially-mounted telescope in the world. Until 1989, when it literally broke, it was used extensively by scientists worldwide.

Now the 140-foot is not being used.

"The new one supercedes it in every way," says Jewell.

The Tatel telescope, built in 1959, is the oldest telescope on the site. Presently it's being used to find extra-terrestrial intelligence.

The 20-meter telescope is part of the National Earth Orientation Service telescope network, a program run by NRAO and funded by the U.S. Naval Observatory. The experiments are designed to measure the small wobbling motions of Earth's polar axis and irregularities of Earth's rotation.

The 40-foot educational telescope was constructed in the 1960s for the purpose of determining if radio waves are variable. Now, students from fifth grade through graduate students use the telescope to learn about the radio universe. Teachers who participate in Green Bank's summer programs do research projects on this telescope. Amateur astronomers also use it.

Plans For The GBT

"Most of what we observe is far, far away," says Jewell.

The GBT is sensitive to weak emissions that originated early in the age of the universe, so much can be learned about its formation, says Jewell.

Scientists at Green Bank will also study the process of how stars are formed of gas and dust in our galaxy and other galaxies, says Jewell. They will study exotic molecules that exist in the gas and dust in between stars (interstellar), which are the precursors of biological systems. They will study pulsars, which are dense neutron stars that have collapsed. Pulsars rotate quickly, emitting radio energy.

Jay Lockman, an astronomer on staff at Green Bank, says he and other astronomers study the structure of the Milky Way, what it's made of and find areas where star formation is going on. There are also plans to do more radar imaging of solar system objects in conjunction with the telescope at Arecibo.

"It's a fabulous thing to do, to have the opportunity to learn about the universe," says Lockman.

"There's always something more to be learned," says Jewell. "Although discovery leads to understanding more things, you uncover more questions than answers. Those are the questions for the next generation."

Luanne Austin can be reached at laustin@dnronline.com.

By The Numbers

17,000,000	1,000,000	$55 million	$74.9 million	10	2
moving weight (in pounds), the same as 20 Boeing 747s	weight (in pounds) on each drive unit	cost for the antenna	entire cost of the project	years needed to build the telescope	diameter (in acres): that's 1 1/2 times the size of a football field

the Charleston Gazette

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Today

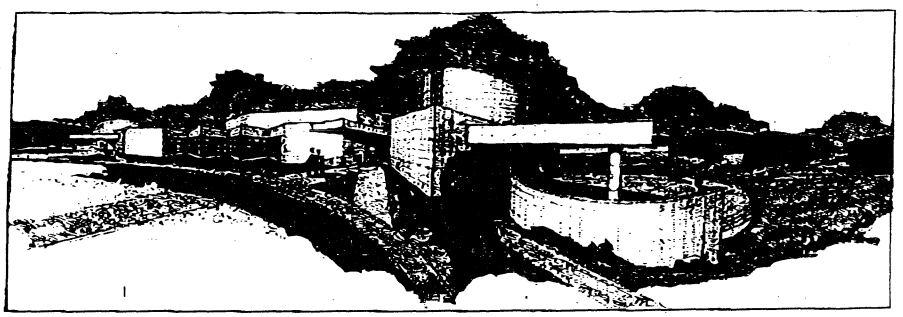
Work on Green Bank visitor center to begin

By Rick Steelhammer
rsteelhammer@wvgazette.com

Construction of a new $6.1 million, 25,000 square-foot visitor and education center for the National Radio Astronomy Observatory in Green Bank is scheduled to begin next week and be complete by next fall.

"By combining this world-class facility with a state-of-the-art education center, the observatory will be able to offer an outstanding learning opportunity to astronomers and the public alike."

Phil Jewell, observatory director of operations



The new $6.1 million visitor and education center at the Green Bank National Radio Astronomy Observatory will include nearly 25,000 square feet of exhibits, classrooms, computer labs and auditorium space, as well as a gift shop, café and outdoor party patio.

Sen. Robert C. Byrd, D-W.Va., who added funding for the building to previous appropriations bills, announced Monday that a contract for the freestanding building has been awarded to Multiplex Inc. of Summersville.

The building will replace a converted warehouse structure that has been used to house public tours at the observatory, home of the world's largest steerable radio telescope. Currently, about 25,000 visitors annually stop at the small existing tour center building.

With the new building, "We hope to at least triple that number," said Michael Holstine, project manager for the new visitor and education center.

"The number and quality of the exhibits will go up dramatically," Holstine said. "They will be totally hands-on, and will include everything from why the observatory needs to be shielded from radio interference to an exhibit that lets you listen to pulsars."

A functional 8-foot-tall model of the new 480-foot-tall Green Bank Telescope, controlled by students, will be the centerpiece of the new exhibit area.

A major goal for the educational element of the new center is to eventually host every school student in West Virginia at least once before they graduate from high school. A planned second phase for the center is a new dormitory for visiting school groups.

The new center will have full-time science educators on staff to guide students and answer questions from visitors. The exhibits are designed to immerse students in a real-world research environment.

"Since part of our charter is education, it's really exciting for us to be able to add this huge, new educational component," Holstine said.

"Radio telescopes have been one of the principal tools used by astronomers to learn about the origin and structure of the universe," said Phil Jewell, director of operations at the Green Bank observatory.

"They have also captured the public's imagination as larger-than-life symbols of scientific discovery and technological achievement. By combining this world-class facility with a state-of-the-art education center, the obser-

Please see CENTER, 2C

CHARLESTON GAZETTE OCT 2, 2001

CENTER

Continued from 1C

vatory will be able to offer an outstanding learning opportunity to astronomers and the public alike."

The new visitor and education center follows last year's completion of the $75 million Green Bank Telescope, one of the most powerful and sophisticated tools available to astronomers.

The new telescope "studies everything from the formation of galaxies in the early universe, to the chemical makeup of the dust and gas inside galaxies, to the birth process of stars," Byrd said. "I am pleased to have been able to provide not only the funds to construct this scientific marvel, but also the additional funding for the education center to make the telescope and the observatory a classroom for students and other visitors."

"It will be quite a striking building, with a lot of interesting architectural elements."

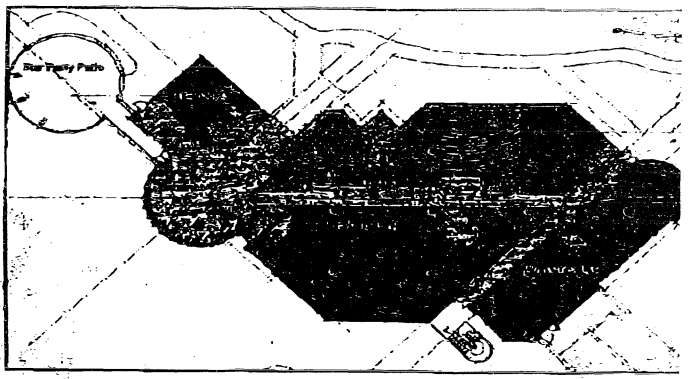
Michael Holstine, project manager

Holstine said the new building will be located just off W.Va. 92, immediately inside the observatory's perimeter fence.

"It will be quite a striking building, with a lot of interesting architectural elements," he said.

Work on the structure is expected to last through the winter, weather permitting.

To contact staff writer Rick Steelhammer, use e-mail or call 348-5169.



The new center will have full-time science educators o staff to guide students and answer questions from visitor

10 great places to soak up science

He aims his award-winning cable TV show at 10-year-olds because "studies show that's as old as you can be to get excited about science." But **Bill Nye**, the bow-tied host of *Bill Nye the Science Guy*, directs USA TODAY's **Laura Bly** to beyond-the-laboratory locations guaranteed to wow even the most jaded parents.

Monterey Bay Aquarium

Monterey, Calif.

The "coolest aquarium in the world" owes much of its appeal to the deep canyons just offshore, where scientists collected predatory tunicates and more than 40 other species that "most people never even knew existed" for display in a new Mysteries of the Deep exhibit. *831-648-4888; www.mbayaq.org.*

Rancho La Brea Tar Pits

Los Angeles

Hordes of Ice Age saber-toothed cats, mastodons and giant sloths "went to the wrong tar pit at the wrong time about 30,000 years ago. They're still here," just off Wilshire Boulevard. At the adjacent Page Museum, "lift the metal rod resting in a tar box, and feel how easy it would be to get stuck — forever." *323-934-7243; www.tarpits.org.*

Meteor Crater

near Flagstaff, Ariz.

When a meteorite slammed into the rocky plains of northern Arizona 50,000 years ago, the impact created "a hole the Washington Monument wouldn't poke out of. It could happen again, and that's worth thinking about for us taxpaying voters, who might want an asteroid deflection system." *520-289-5898; www.meteorcrater.com.*

Ashfall Fossil Beds

Royal, Neb.

This "frozen moment in ancient time is way off the beaten path (in northeast Nebraska), but worth it." About 10 million years ago, rhinos, three-toed horses and other animals "headed here for a drink and were buried by ash from a volcano. Their skeletons are perfectly preserved in gray ash as dry and fine as flour. You can lean over and see seeds from their last grass meals." *402-893-2000; ngp.ngpc.state.ne.us/parks/ashfall.html.*

Science Museum of Minnesota

St. Paul, Minn.

Escape from the cold in the Human Body Gallery, where you can "check out wiggling, writhing, giant arteries of 'blood.' " *651-221-9444; www.smm.org.*

Hawaii Volcanoes National Park

Hilo, Hawaii

Home to Kilauea, the planet's most active volcano, this is a place where "you can drive right up to where cooled, jet-black lava blocks the road." Flowing lava "creates steam-driven boulders that get tossed higher than a small office building ... it's like in the movies, only real." *808-985-6000;www.nps.gov/havo/.*

Dinosaur National Monument

Dinosaur, Colo.

Straddling the Utah-Colorado border, this "bone jam of history" is home to "the kind of dinosaurs I remember from my childhood." At the Dinosaur Quarry Visitor Center, you can ogle a 150-foot-long wall filled with the remains of ancient ecosystems and watch paleontologists work in the lab. "It helps anyone see how big and world-dominating these creatures must have been." *435-781-7700; www.nps.gov/dino/.*

Kennedy Space Center

Cape Canaveral, Fla.

"If you've never seen a rocket launch, go and see one. It is more power than most of us can imagine." Astronaut wannabes can buy launch-viewing tickets online at the center's Web site; the next scheduled liftoff is Jan. 18. *321-452-2121; www.kennedyspacecenter.com.*

Boston Museum of Science

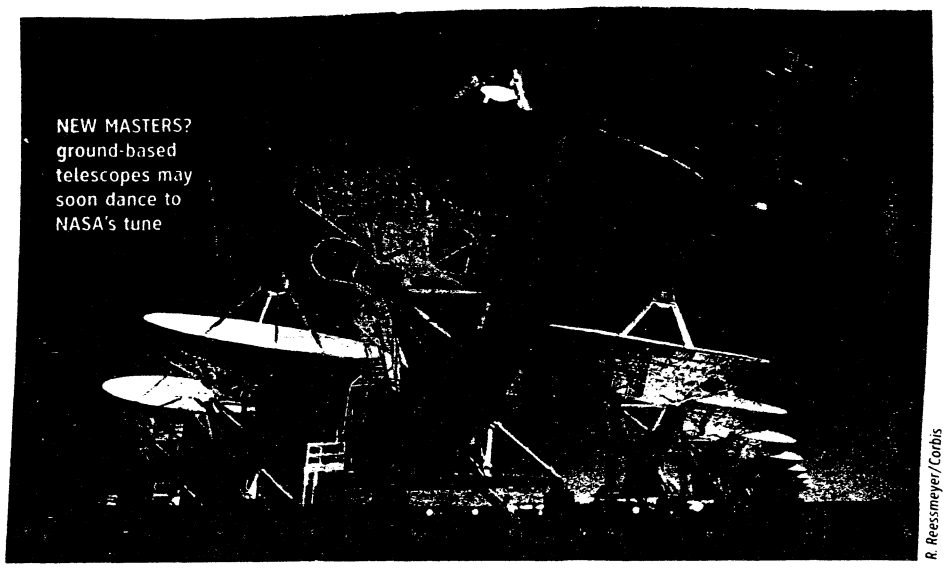
Used as a research tool in early atom-smashing and high-energy X-ray experiments, the museum's static electricity generator gives new meaning to the term hair-raising. "You'll see blue-bright arcs bigger than houses shoot across the room." *617-723-2500; www.mos.org.*

The Very Large Array

near Socorro, N.M.

A supporting player in the Jodie Foster movie *Contact*, this sonic sculpture of 27 dish-shaped antennae forms the world's premier radio telescope. A visitors center is open daily: "Just listen to the dishes turning as they track some unseen object, and imagine what they might be gathering." *505-835-7000; www.nrao.edu.*

USA Looking for more travel ideas? Review "10 Great" lists on the Internet. Visit us on the Web at http://10greats.usatoday.com



NEW MASTERS? ground-based telescopes may soon dance to NASA's tune

R. Reessmeyer/Corbis

Ground control

NASA could take over the world's biggest and best telescopes

ASTRONOMERS across the US are cringing over a proposal to shift responsibility for funding ground-based telescopes to NASA. "I just don't see the point of this," says Paul Vanden Bout, director of the National Radio Astronomy Observatory in Charlottesville, Virginia. A panel studying the idea will report early next month.

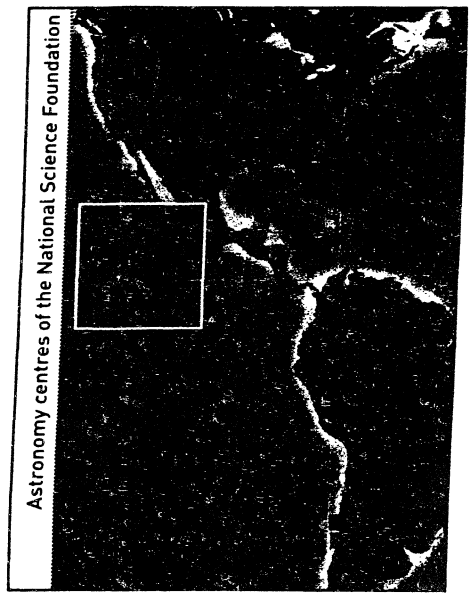
The change was suggested in President Bush's proposed budget for 2002. Many astronomers are appalled by the prospect, saying it will only make funding problems worse, and leave telescopes at the mercy of money-hungry space projects.

At stake is the future of the radio observatory, the National Optical Astronomy Observatory and the National Astronomy and Ionosphere Center. All are currently funded by the National Science Foundation (NSF). The centres run instruments ranging from the Very Large Array of radio telescopes in Socorro, New Mexico, and the giant 305-metre radar telescope in a crater near Arecibo, Puerto Rico, to optical telescopes in Arizona, Hawaii and Chile.

Vanden Bout argues that ground-based astronomy doesn't fit NASA's penchant for big, sharply defined projects. "NASA is a very mission-driven organisation," he says. "The NSF is a place where any idea gets a hearing and the ones that bubble to the top get the money."

If the move is made, a NASA budget crunch would probably squeeze out terrestrial projects, says Riccardo Giacconi, president of Associated Universities, the consortium that runs the radio observatory. "I don't see NASA cancelling the Next Generation Space Telescope to put money into a ground-based observatory," he says.

The NSF has not, however, been a blissful haven for astronomy. Funding has been stagnating for decades, says astrophysicist



Astronomy centres of the National Science Foundation

Michael Turner of the University of Chicago. Twenty years ago the NSF paid for roughly two-thirds of American astronomy, while NASA paid for a third. Today, the numbers are reversed, according to a National Research Council report. "I don't think we should be dumping on NASA," Turner says. "They're not the ones with the problem."

Ed Weiler, head of space science at NASA, says that if it happens, "we certainly would all do our best to ensure that the best interests of science are served". While they await the panel's report, astronomers are wondering who suggested the merger with NASA in the first place. "This didn't come out of the community that I'm part of," says astronomer Martha Haynes of Cornell University. Turner is equally baffled. "This thing has been dusted for fingerprints and DNA," he says. "No one knows where it came from." **Adrian Cho**

More at: www.nationalacademies.org/bpa/projects/brp

the Charleston Gazette Online
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Work on Green Bank visitor center to begin

Tuesday October 2, 2001

By Rick Steelhammer
STAFF WRITER

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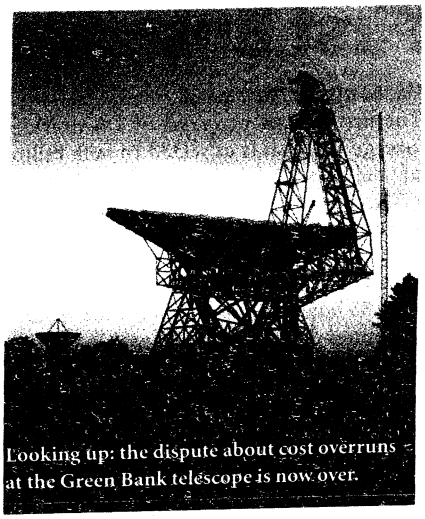

Looking up: the dispute about cost overruns at the Green Bank telescope is now over.

Small payout over Green Bank telescope cheers astronomers

Irwin Goodwin, Washington

An arbitrator has ruled that the government should pay only $4 million towards cost overruns encountered by the contractor that built a huge radiotelescope at Green Bank, West Virginia.

The decision — in the face of claims from the contractor for $29 million on top of its $55 million contract to build the world's largest fully steerable, single-dish telescope — was good news for US astronomers, who feared the settlement would eat into the astronomy budget at the National Science Foundation (NSF).

The contractor, Radiation Systems Incorporated — later part of the Comsat Corporation — began work in 1990, with completion planned for 1994. But the telescope achieved first light on 22 August 2000 and was accepted by the National Radio Astronomy Observatory (NRAO), on behalf of the NSF, on 13 October.

In 1998, Comsat sought a further $29 million, arguing that NRAO and its managing contractor, Associated Universities Incorporated (AUI), had forced it to perform extra work.

"This matter is finally resolved, and we can now focus our efforts on making Green Bank a world-class telescope," says Paul Vanden Bout, NRAO's director.

Three days after it achieved first light, the GBT was opened by its original sponsor, senator Robert Byrd (Democrat, West Virginia), whose name it now carries.

But even as AUI and NSF officials worried about the possibility of an expensive settlement, Byrd discreetly slipped $15 million into the NSF's budget bill for this year to cover astronomy facility costs, including $8 million specifically for the GBT. ■

MI-W1040 WEEKLY NEWSPAPER
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FEBRUARY 8, 2001

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As real as it gets

Teacher, students participate in radio observatory research

By Bonnie Caprara
Staff Writer

Grosse Pointe North High School astronomy teacher Ardis Maciolek defies the phrase "those who cannot do, teach."

Not only is Maciolek a research astronomer herself, but she has also provided her students with bonafide research opportunities in and out of the classroom.

Last summer, Maciolek worked at the National Radio Astronomy Observatory in Green Bank, W.Va., to do research on predicting optimal viewing times and weather conditions. This school year, independent study students and North's radio astronomy team are conducting their own research in studying good and bad viewing conditions at the radio observatory in Green Bank.

Although one would think that weather would have not as much to do with radio observations as visual observations, it's a major factor.

"Usually this kind of observing is done in more arid climates and at higher elevations," said Maciolek. "This observatory is in a mountain valley so we only have 20 to 30 percent of days during the year where we have optimal viewing. What we're trying to do is to predict good viewing times based on weather."

While Maciolek is continuing her research on her own time, her students have taken on other aspects of the research in their own projects, including studying poor weather and viewing conditions.

"Seeing the good without the bad is kind of pointless," said Maciolek.

Although the students at North are hundreds of miles away from Green Bank, they have been analyzing weather data from Green Bank through the observatory's FTP site over the Internet.

In the meantime, Maciolek and NRAO-Green Bank director Ron Maddalena have presented the student findings as well as their own in professional presentations. Members of North's radio astronom team, North seniors Isa Ireland and Tom Bay an South senior Mar Biolchino, are working on joint presentation to b entered in the Science an Engineering Fair Metropolitan Detroit whic will be held March 27-3 Students in Maciolek's fir semester astronomy clas also contributed to th research.

"It's a new trend in scienc education," said Maciolel "We're trying to give the real experiences instead cookbook labs. It's ver meaningful work and it done for a real reason. If w can resolve this problem, w can save the observator $100,000 in research."

Nook takes aim on telescope projec

By FRANK HAYES

When the National Radio Astronomy Observatory needed to move a nearly one-ton object with accuracy the diameter of a human hair back and forth 500 feet repeatedly, they called in Nook Industries of Cuyahoga Heights.

When operational in the first quarter of next year, scientists will use the giant, $75 million Robert C. Byrd Telescope in Green Bank, W.Va., to study things ranging from the formation of galaxies in the early universe to the chemical makeup of the dust and gas inside galaxies and in the voids that separate them.

Nook developed actuators to help aim a nearly one-ton subreflector mounted about 50 stories above the telescope's football-field-size main dish.

"A particular challenge was to provide a high level of performance under the harsh temperature and wind conditions to which these electric cylinders are subjected," said Rick Christyson, chief engineer at Nook.

The telescope is an engineering marvel. At 485 feet tall, it is comparable in height to the Terminal Tower. It weighs 16 million pounds; yet, it can be pointed in the sky with exquisite accuracy. Nook, with 200 employees, has been involved with the project since 1992.

The telescope creates images of the sky using radio waves instead of light waves. The largest fully steerable radio telescope in the world, its main dish reflector surface measures 328 feet in diameter. It can find images of objects that emit observable radio-wavelength radiation but that interstellar dust in visible light normally obscure.

Like a giant bucket, the main dish, which creeps along tracks positioned by a rack-and-pinion drive, collects radio signals from the sky. Because scientists analyze specific objects, they work with images only from a small portion of the main dish. The subreflector gathers the desired images from the main dish.

To move the subreflector, Nook furnished six precise positioning devices, called electric cylinder actuators. Each actuator provides linear motion by means of a large, rotating screw. The screws on the actuators are 21.5 inches in diameter, three to four feet long, and move equipment attached to them from 22 to 42 inches.

From their lofty vantage point on the subreflector tower, the actuators constantly adjust as the telescope control system feeds them information so they can stay on the same spot.

By meeting the stringent positioning requirements, Nook engineers achieved an accuracy 10 times that of conventional actuators. One reason was their use of a ball screw — like a ball bearing wrapped around a regular screw — with threads that are ground (as opposed to rolled) for higher efficiency and precision.

A remote access control system was another path to accuracy.

"In many cases, when engineers talk about accuracy, what they really want is repeatability," Mr. Christyson said. "In the case of positioning, it's so important to know not only what combination of mechanical actions will orient the device exactly as desired, but also, once that combination of actions is identified, to always be able to repeat it."

Those operating the telescope tell it where they want it to be positioned, and then software moves the actuators to achieve accuracy, Mr. Christyson said.

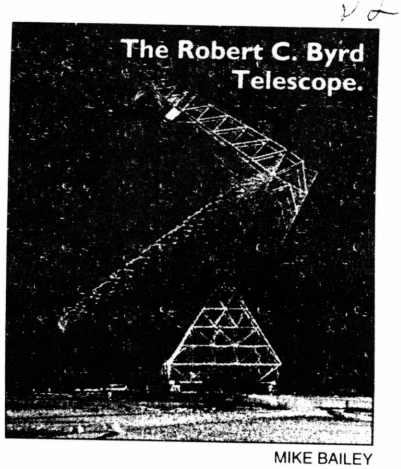
"We added a feedback mechanism to the actuators that tells exactly where the screws are positioned," he said. "That transducer actually rides inside the screw to give information back to the telescope's control system. Positioning resolution and repeatability is 0.00025 inch."

Nook Industries, founded 31 years ago by Joseph H. Nook Jr., chairman and chief executive officer, works in a burgeoning area that merges electric motors, computer controls and linear motion hardware to create electromechanical systems. The company's first product was high-quality mechanical screws that are components in today's actuators.

"Projects like Green Bank are relatively easy to do because it's the nature of our business," Mr. Christyson said. "We take responsibility for the whole actuator. All machining, assembly and inspection is done at Nook."

Larry Shindell, marketing manager, said Nook makes actuators with screws as small as a quarter-inch for medical diagnostic equipment to 6-inch diameter screws that can lift 100 tons.

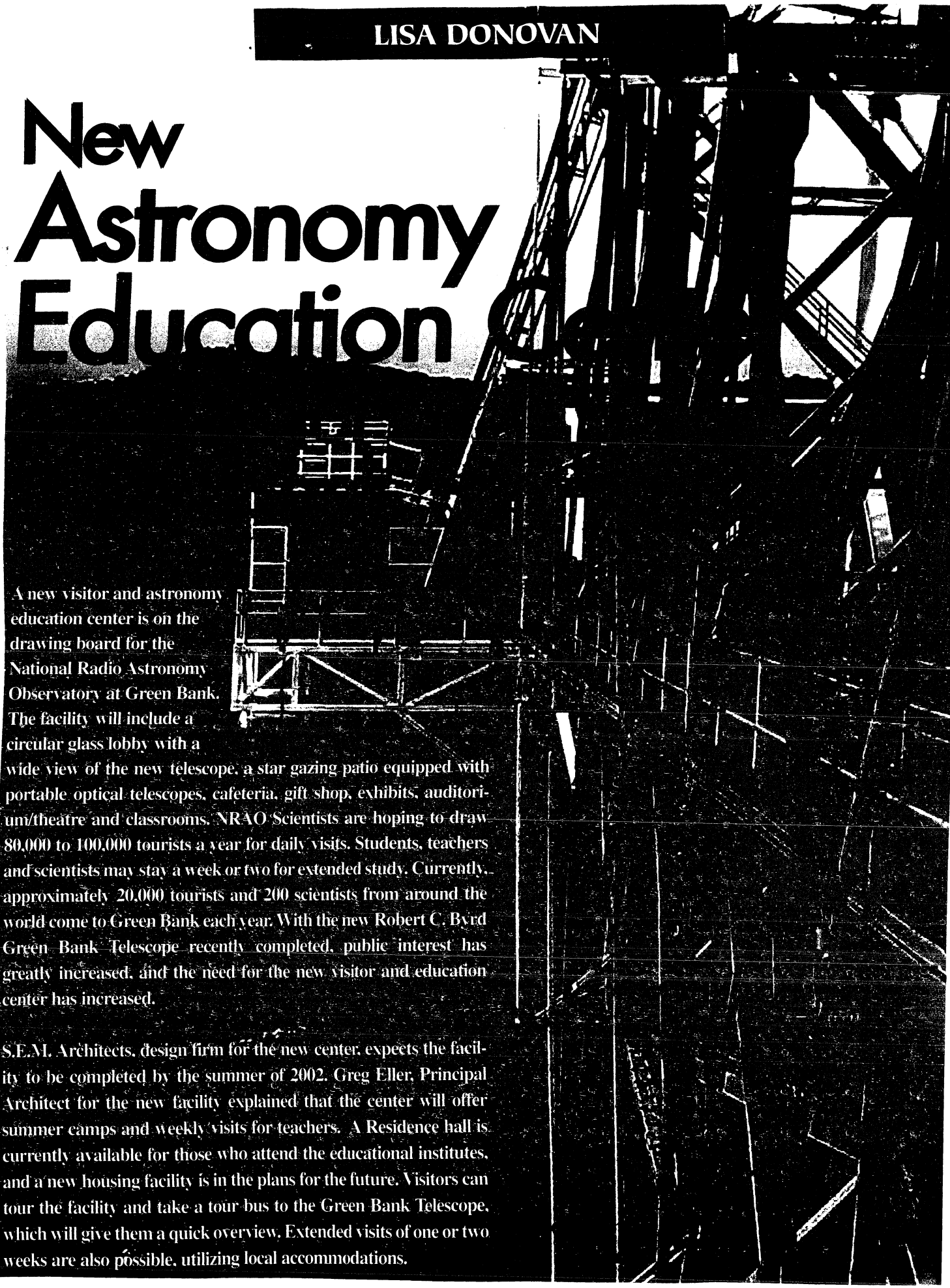
"We have applications in transportation, medicine, paper, chemical, food/beverage and communications," Mr. Shindell said.



MIKE BAILEY

LISA DONOVAN

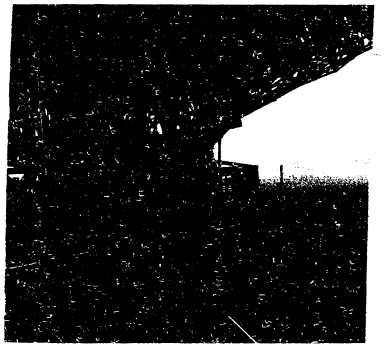
New Astronomy Education



A new visitor and astronomy education center is on the drawing board for the National Radio Astronomy Observatory at Green Bank. The facility will include a circular glass lobby with a wide view of the new telescope, a star gazing patio equipped with portable optical telescopes, cafeteria, gift shop, exhibits, auditorium/theatre and classrooms. NRAO Scientists are hoping to draw 80,000 to 100,000 tourists a year for daily visits. Students, teachers and scientists may stay a week or two for extended study. Currently, approximately 20,000 tourists and 200 scientists from around the world come to Green Bank each year. With the new Robert C. Byrd Green Bank Telescope recently completed, public interest has greatly increased, and the need for the new visitor and education center has increased.

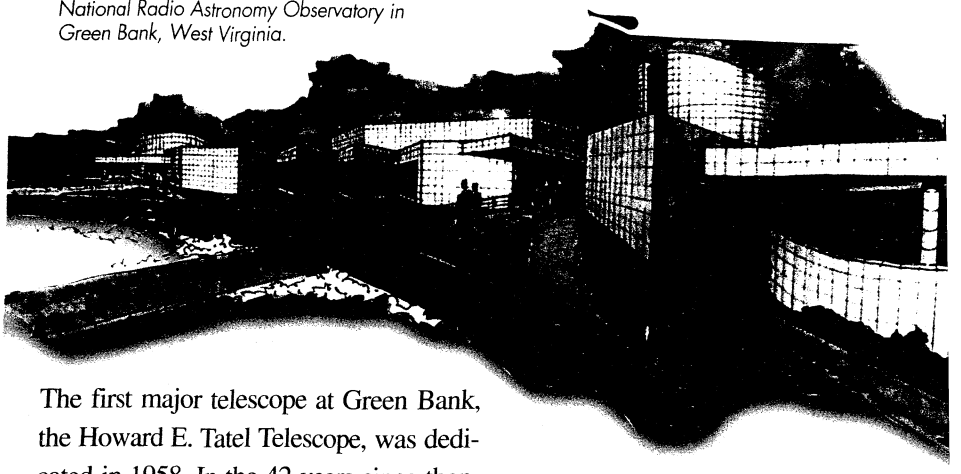
S.E.M. Architects, design firm for the new center, expects the facility to be completed by the summer of 2002. Greg Eller, Principal Architect for the new facility explained that the center will offer summer camps and weekly visits for teachers. A Residence hall is currently available for those who attend the educational institutes, and a new housing facility is in the plans for the future. Visitors can tour the facility and take a tour bus to the Green Bank Telescope, which will give them a quick overview. Extended visits of one or two weeks are also possible, utilizing local accommodations.

The state-of-the-art facility is sure to be an award winner and a boost to West Virginia tourism. Mike Holstine, business manager at the NRAO, discussed the budget for the new center: "We need to raise another $1.5 million to fund the construction of the new center. We currently have $2.9 million and we would like to have a total of $4 million for construction. We don't want to cut anything from the facility since every part is so integral and so important to the whole. We are thrilled with the design and are applying for grants, but we are also looking at the possibility for private individuals to donate to the project."



Key features of the telescope include: a huge collecting area of 100m x 110m; access to the whole sky—the telescope's mount allows it to view the whole sky above 5 degrees elevation, giving it access to 85% of the celestial sphere. The telescope weighs 16 million pounds and is the first of its kind, being the first fully steerable radio telescope at 485 feet tall—taller than the Statue of Liberty

Schematic design for a new Astronomy Education Center. National Radio Astronomy Observatory in Green Bank, West Virginia.



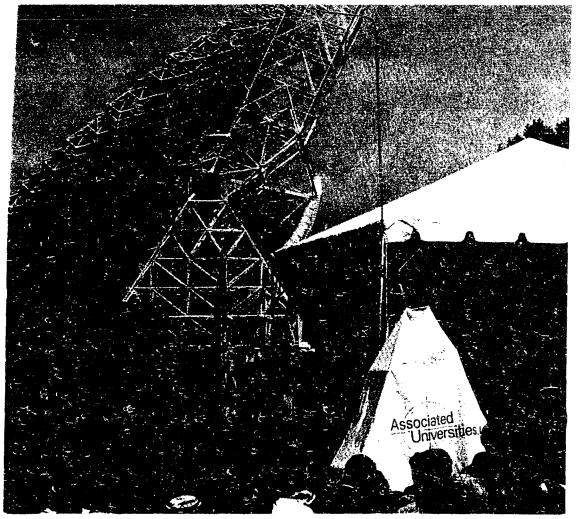
The first major telescope at Green Bank, the Howard E. Tatel Telescope, was dedicated in 1958. In the 42 years since then, telescopes at Green Bank have made huge contributions to astronomy, including the following:

Discovering the true sizes of galaxies: In the 1960's, astronomers using the Green Bank 300 Foot Telescope found that the hydrogen gas in nearby galaxies extended far beyond the galaxies' stars. Then, by studying how the outer parts of these gas 'envelopes' moved, astronomers found that most of a galaxy's mass must be invisible: it is 'dark matter,' the nature of which is still unknown.

Discovering many kinds of molecules in space, including the first organic one: Between the stars lie clouds of gas. These are laced with many kinds of molecules. Between 1963 and 1980, radio astronomers found 50 types of molecules in space, seven of them with telescopes at Green Bank. One was formaldehyde, the first organic cosmic molecule, detected with the 140 Foot Telescope in 1969.

About 120 kinds of cosmic molecules are now known. Radio emission from molecules helps scientists track how stars form in gas clouds. The discovery of ever more organic molecules in space raises interesting questions about where and how life originated.

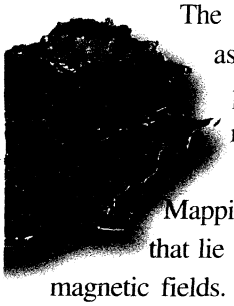
The new, fully steerable, 100-m (300 ft.) Robert C. Byrd Green I Telescope surpasses the capabilities of all other telescopes current use. It is the most sophisticated large single-dish telescope ever bu



The Dedication Ceremony for the new Robert C. Byrd Green Telescope was held on August 25th with Senator Byrd as the k speaker. Byrd was instrumental in obtaining funding for the $75 dollar telescope. The initial construction began in 1991.

Discovering the origin of pulsars: In 1968, the 300 Foot Telescope detected the pulsar in Crab nebula, which is a supernova remnant, the remains of an exploded star. The find linked pulsars and supernovae, indi-

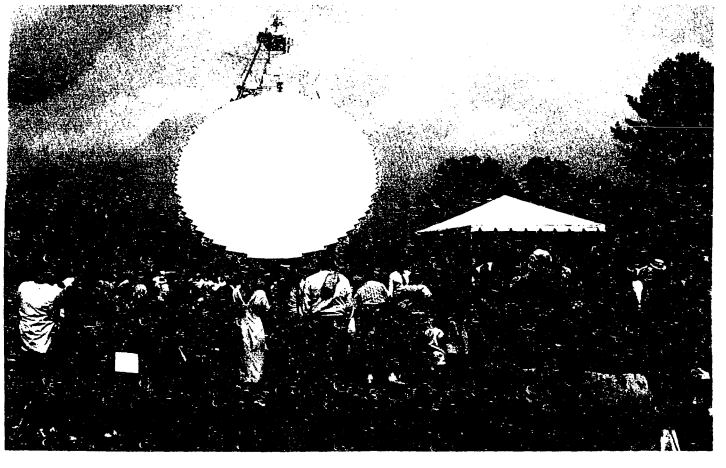
cating that pulsars are the compressed cores of exploded stars. The Crab pulsar was also the first one whose age was known: the explosion that created it was seen in 1054 A.D. The age plus the radio observations allowed astronomers to determine a fundamental property of the pulsar, the rate at which its rotation is slowing down.



Mapping magnetic fields in space: Clouds of gas that lie between the stars are threaded through by magnetic fields. This effect, the Zeeman effect, was first detected in space in 1968 with the Green Bank 140 Foot Telescope. It has since been used to determine the strength of magnetic fields throughout our galaxy. These fields are typically a hundred thousand times weaker than the Earth's field but are still strong enough to affect how interstellar gas clouds evolve, and how stars form in those clouds.

Finding a new way to measure cosmic distances: A 1977 study of 43 galaxies with telescopes at Green Bank showed that the width of the spectral line of hydrogen in a distant galaxy is well correlated with the galaxy's absolute magnitude (how bright it actually is). The distance to the galaxy is determined by comparing the galaxy's absolute magnitude with its apparent magnitude (how bright it looks from Earth). This has become a fundamental technique for measuring cosmic distances.

Finding a new way to map hydrogen: Hydrogen is the most abundant element in the Universe. In 1965, one of the first experiments done with the new 140 Foot Telescope discovered recombination lines of ionized hydrogen, which became an important new tool for seeing how this gas is distributed in our Galaxy and other galaxies. Radio recombination lines are radio emissions emitted when an atom has been stripped of its electrons (ionized) and recaptures them. Ionized hydrogen is found in star-forming regions, as ultraviolet radiation from young stars tears electrons from the grasp of their parent atoms. From recombination lines we can learn about the distance, size, temperature, density and chemical composition of star-forming regions.



'Taking stock' of the Universe: Both the 140 Foot and the 300 Foot Telescopes at Green Bank were used for numerous surveys, finding and cataloging thousands of radio sources that could then be used for further studies. As a result of all these surveys, NRAO became known to its users as 'Census Taker of the Universe'.

The new, fully steerable, 100-m (300 ft) Robert C. Byrd Green Bank Telescope surpasses the capabilities of all other Telescopes currently in use. It is the most sophisticated large single-dish telescope ever built. Its advanced technical features, many unique, will give its users unprecedented access to the radio sky and allow them to tackle a wide range of astrophysical problems. With its new capabilities, the Telescope is well positioned to make the first spectral-line observations of unlensed galaxies at extreme redshifts; make the most accurate measurements to date of the expansion and age of the Universe; detect new interstellar molecular species, including those of biological significance; and observe pulsar/black hole binary systems. (If you are wondering what a lot of these scientific terms mean, you'll just have to come out for a visit to Green Bank and ask the scientists to explain!)

No wonder Green Bank is expecting increased visits from international tourists, educators and scientists—West Virginia now has something more sophisticated than anywhere else in the world! ◆

Research Results

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Data offer glimpse of primeval galaxy

By LAWRENCE SPOHN
Scripps Howard News Service

Looking 12 billion years into the universe's past — almost before there was light — radio astronomers for the first time have observed a massive cold gas reservoir out of which some of the first stars were born.

The observations show celestial gas is beginning to feed the production of billions of stars in a primeval galaxy.

"This thing is at the edge of the dark ages," said Chris Carilli, a staff astronomer at the National Radio Astronomy Observatory in Socorro, N.M.

Researchers using the 27 radio telescopes of the Very Large Array [illegible] of Socorro peered back in time to the edge of the universe before the first stars of the universe were born, Carilli explained.

The astronomers say the galaxy, APM 08279+5255, is a quasar surrounded by a volume of cold gas sufficient to give birth to 100 billion suns.

And, as observed as a young galaxy just 1 billion years after the Big Bang began to form the universe, the quasar is experiencing a "burst" of young massive star formations and supernovae explosions.

"This is the first time anyone has seen the massive reservoir of cold gas required for these incredible star bursts to produce a galaxy," Carilli said.

The observations are reported in this week's issue of the British science journal Nature. They were made and analyzed by the team lead by Padeli Papadoupoulos of the Netherlands' Leiden University. Other members of the team were Carilli, Rob Ivison of University College London and Geraint Lewis of the Anglo-Australian Observatory in Australia.

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JANUARY 9, 2001

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Scientists find star, with planet potential

By Deborah Zabarenko
REUTERS

SAN DIEGO — Astronomers studying radio waves in space said yesterday they have found a massive embryonic star in the constellation Orion that might have the potential to form planets.

Scientists have identified dozens of possible planets outside the solar system, but all are believed to be orbiting stars about the mass of the sun. This is the first time astronomers have spotted a so-called protostar that has about 10 times the sun's mass.

The sign that planets might exist around the protostar — known to scientists as G192.16-3.82 and located some 6,000 light-years from Earth — is the presence of a disk of dust and gas circling it. A light-year is about 5.88 trillion miles, the distance light travels in a year.

This feature, called an accretion disk, has about the same diameter as the solar system, according to scientists at the National Radio Astronomy Observatory in New Mexico. In the case of stars like the sun, planets coalesce from material in the disk.

Astronomers have never seen accretion disks around such big developing stars before because star formation is generally shrouded in molecular gas, and regular optical telescopes cannot see through the space murk. Even the orbiting Hubble Space Telescope could not make out the details.

But radio waves do penetrate the clouds, and that is what Debra Shepherd and her colleagues at the observatory used to observe the evolving space system.

Shepherd did not rule out the possibility of Earth-type planets forming in this case, but noted that such phenomena had not been seen before.

"We have never detected planets around a star this size where life might be a viable option," Shepherd said at the annual meeting of the American Astronomical Society in San Diego.

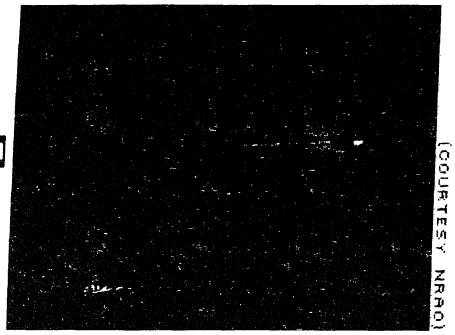
"Part of that is because massive stars are too rare for us to get up close and personal like we do with low-mass systems," she said.

"This is the first one where an accretion disk the size of our solar system, the actual powering source of the flow, has been detected."

"Flow" refers to jets of material that are being flung outward from the top and bottom of the protostar. An artist's conception of the discovery (online at http://www.nrao.edu/pr/bigyso-disk.html) shows the outflow as two blue funnel-shaped jets.

Neutron star Scorpius in intergalactic thriller

June 6, 2001 Posted: 7:51 AM EDT (1151 GMT)



The star system Scorpius X-1 hurls a flare in a frame from a radio telescope movie

By Richard Stenger
CNN

(CNN) -- Astronomers have teamed up to direct an intergalactic thriller, starring a voracious neutron star as it unleashes pulsating jets of super-hot, super-fast subatomic particles.

Drawing from observations of large telescopes around the world, the movie shows two narrow jets from the star blasting out clouds of heated plasma at nearly the speed of light.

As the drama unfolds, bursts of even faster energy from the jets seem to brighten the clouds with periodic jolts, according to astronomers.

"We have directly measured the speed of energy flow in a cosmic jet for the first time," said Ed Fomalont, a scientist with the National Radio Astronomy Observatory, last week.

Fomalont and colleague used radio telescopes in the United States, Japan, Australia and South Africa to put together the video collage of the neutron star system, which includes a companion star from which the neutron star draws material to fuel the jets.

VIDEO

Watch a radio image movie of Scorpius X-1 (Courtesy NRAO)

Play video (QuickTime)

The movie is unprecedented but cosmic jets are not. Such speeding bursts of particles emanate from many binary star systems in our galaxy. In a similar manner, double jets shoot out particle streams from the cores of numerous galaxies. Massive black holes are thought to be the driving engines of the latter, much larger jets.

"Studying one of the closer, smaller examples will help us understand how they all work, including the bigger ones," said Barry Geldzahler, a George Mason University scientist who took part in the celestial cinema project.

The star of the movie is Scorpius X-1, which contains a neutron star with roughly 1.5 times the mass of the sun and a conventional star about the same mass as the sun. The pair is more than 9,000 light-years from Earth in the constellation Scorpius.

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In the movie, the jets push two clouds in opposite directions away from the core. The one heading in the direction of Earth seems much brighter and faster, the scientists said.

The core flared up twice, shooting bursts of electrons at more than 95 percent the speed of light. The slower clouds brighten considerably when overtaken by the speeding subatomic particles.

The scientists published their report in the May 20 issue of the Astrophysical Journal Letters. They made the movie from 56 hours of continuous observation.

"Scorpius X-1 put on a great show for us. Now it's up to us to figure out how it performs its act," Fomalont said.

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Cloud Spotted Ready to Burst With Star Formation

By Robert Roy Britt
Senior Science Writer
posted: 07:00 am ET
15 June 2001

PASADENA -- Whether in our galaxy or elsewhere, stars are born in clouds of gas and dust that collapse under their own gravitational force, often after being disrupted by interactions with other material in a galaxy. But astronomers say the actual moment of starbirth remains a mystery.

Now researchers have spotted what they think is a key moment in the process, a massive interstellar cloud on the verge of a burst of star formation.

Using a ground-based radio telescope to peer deep into our own Milky Way Galaxy, scientists at the National Radio Astronomy Observatory (NRAO) say they have captured what may be the first image of a cloud in transition between atomic and molecular states.

Before stars begin forming in them, interstellar clouds are cold and are made up mostly of hydrogen atoms. As part of a cloud begins to contract, potentially into several clumps that could form stars, these atoms begin to combine and form molecules, which are heavier.

"These may be the first observations of a cloud that is in the transition between the neutral atomic hydrogen and molecular phases," said NRAO scientist Felix J. Lockman, who conducted the study with colleague Anthony H. Minter. The research was presented here earlier this month at a meeting of the American Astronomical Society.

The observation was made with the National Science Foundation's 140-foot radio telescope at the NRAO in Green Bank, West Virginia, and maps out different temperatures in the cloud. Hotter temperatures indicate greater density.

The researchers called the cloud "uncharacteristically massive," at some 500 light-years across and with an estimated mass of atomic hydrogen some 100,000 times that of our Sun. Other clouds this massive have been found to already be forming stars, a hint that this one is likely on the brink of doing so.

"We think we have caught something in a special state," Lockman said. "It could be one of the missing links in the

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The cloud appears as a ring, at right, due to the center being very cold, -390 F (-233 C), while the outside of the cloud is warmer, 260 F (127 C).

cycle of star formation."

Another recent study observed an interstellar cloud at a slightly later stage, as individual globs of material had begun to form. Combined, the two new studies should help astronomers zero in on exactly what happens when stars are born.

The newly observed cloud is about 16,300 light-years from Earth and sits along the inner plane of our galaxy. It appears to be near one of the galaxy's spiral arms, and Lockman and Minter speculate that as the cloud slams into the arm, a shock wave results that could be the catalyst for the converting atomic hydrogen to the molecular state.

Click here for more news and information about stars and other deep space objects.

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Scope assists in Venus project

BY A.J. HOSTETLER
TIMES-DISPATCH STAFF WRITER

In its first scientific outing, the new Green Bank radio telescope teamed with the world's biggest telescope for a peek through the clouds shrouding Venus.

Paired with the huge surface of the Arecibo, Puerto Rico, telescope and its radio transmitter, Green Bank's 330-foot telescope created detailed radar images of the planet and of a small asteroid passing near Earth for its freshman project.

"These images are the first of many scientific contributions to come from the Robert C. Byrd Green Bank Telescope and a great way for it to begin its scientific career," said Paul Vanden Bout, director of the National Radio Astronomy Observatory. Green Bank is part of the observatory, whose headquarters are in Charlottesville.

Venus' veil of dense, white clouds can be penetrated by radar waves to reveal the planet's rocky surface. Radio astronomers previously had lacked the kind of power needed for such a look from the ground until the Arecibo telescope could be combined with the newly rebuilt telescope [illegible]. W. Va.

The $75 million Green Bank [illegible] is the world's largest [illegible] radio telescope. It is named for Democratic Sen. Robert C. Byrd, the powerful West Virginia politician who sought the federal funds to replace the principal radio telescope that collapsed from metal fatigue in 1988.

More Info

■ **On the Internet:**
www.gb.nrao.edu/GBT/GBT.html

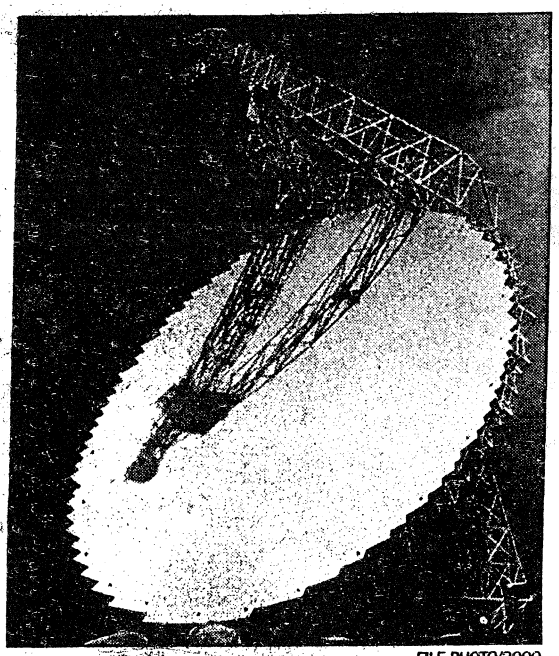
The observatory was created in 1958 in the remote area to ensure against man-made radio interference. Seven radio telescopes operating at the site use the entire electromagnetic spectrum to pick up radio waves that many cosmic objects emit and absorb.

"Having a really big telescope like the new Green Bank Telescope . . . will be a real boon to radar studies of the solar system," said Cornell University astronomer Donald Campbell, who led the research team.

The last good look at the Venusian surface came 10 years ago when the Magellan spacecraft used radar to probe though the clouds. The one-two punch of Green Bank and Arecibo is producing images showing ground features as small as 6/10 of a mile.

Scientists believe that Venus may be geologically similar to Earth. The paired telescopes will look for physical changes from volcanic activity, landslides and other processes that may have reshaped the surface since Magellan flew by. The telescopes will also produce images that, when combined, will allow scientists to measure the altitude of some of Venus' mountain ranges.

• Contact A.J. Hostetler at 649-6355 or ahostetler@timesdispatch.com

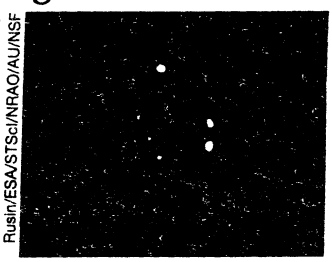


The Green Bank radio telescope, which was dedicated last year, has begun its scientific career.

FILE PHOTO/2000

. . . and a sextet of images

Another team of astronomers has for the first time discovered a gravitational lens in which the image of a distant galaxy has been split into six distinct images. This unusual configuration is caused by three galaxies acting as a compound lens, strung out along the line of sight between the distant galaxy and Earth.



Rusin/ESA/STScI/NRAO/AUI/NSF

The trio of galaxies in orange form a gravitational lens that split the image of a background galaxy into six images (white).

Simpler than a lens produced by a galaxy cluster, yet more complicated than that generated by a single galaxy, this type of lens is expected to be rare. Study coauthor David Rusin of the University of Pennsylvania in Philadelphia says, "[It] will give us insights we can't get from other types of lenses." The team expects to learn about the structure of the galaxies serving as lenses.

The galaxy whose image has been split lies 11 billion light-years from Earth. The galaxies that act as a lens lie 4 billion light-years closer to Earth. Rusin and his colleagues describe their work in the Aug. 20 ASTROPHYSICAL JOURNAL.

Both the Very Large Array Radio Telescope in Socorro, N.M., and the MERLIN network of radio telescopes in England showed hints of six objects that astronomers suspected were images generated by a gravitational lens. Follow-up data from the Hubble Space Telescope and the Very Large Baseline Array, a group of 10 radio telescopes spread across the United States, confirmed the finding and provided additional details about the structure of the system. —*R.C.*

Surprise in the Heavens as Energy Is Detected in a Brown Dwarf

By JAMES GLANZ

A dim, fading object wandering alone through space, something between a large planet and a tiny star, turns out to be roiled by storms several times more powerful than the most energetic flares on the Sun, a team of radio astronomers has found.

The existence of such powerful, stormy radio emissions in this kind of celestial object, a brown dwarf, is highly unexpected and could shed light on the dividing line between stars and planets.

The research had been considered so unpromising that the discovery was made not as part of any large-scale astronomical search but as an accidental find in a student project at the Very Large Array, a set of radio-telescopes at the National Radio Astronomy Observatory near Socorro, N.M.

The students happened to have the array trained on the brown dwarf when it flared. Two senior radio astronomers, Dr. Dale A. Frail of the National Radio Astronomy Observatory and Dr. Shrinivas Kulkarni of the California Institute of Technology, then became involved in follow-up observations, which were led by Edo Berger, a graduate student at Caltech.

The follow-up observations showed that the object's magnetic fields were extremely weak, another surprise, since flares are normally powered by the energy in magnetic fields.

A paper on the study has been accepted at the journal Nature and was posted Monday on a Web site at the Los Alamos National Laboratory (arXiv.org/abs/astro-ph/0102301) where most astronomers place their new work.

The existence of brown dwarfs, which are cool, dim and difficult to observe, was confirmed only five years ago by a team led by Dr. Kulkarni. Thought to have masses less than 8 percent that of the Sun, their cores never become hot enough to ignite the fusion process that allows ordinary stars to shine for billions of years.

Instead, brown dwarfs gradually cool and fade after they form. Because brown dwarfs have an identity somewhere between that of large, gaseous planets like Jupiter and that of the smallest ordinary stars, astronomers said the new discovery should illuminate the structure of a crucial link between the two better-known classes of astronomical objects.

Dr. Adam Burrows, an astrophysicist at the University of Arizona, said energetic particles and waves in the magnetic fields around Jupiter spit out radio emissions that could be detected on Earth. But Dr. Burrows said that at the distance of the brown dwarf, more than a dozen light-years into deep space, those emissions could never be picked up.

"That they do see emission from a sister object at such a distance is quite amazing," he said.

Ordinary stars with relatively low masses do show energetic flar Dr. Burrows said, but their magn fields are also much stronger. Fl on the Sun often occur when mag ic fields "reconnect," or sudd snap like rubber bands after t break and then splice together in configurations. So a weak magn field would not be expected to cr strong flaring.

Another astrophysicist, Dr. J rey Linsky of the University of C rado, said those apparent myste might carry a message about difference between true stars brown dwarfs. The cooler core brown dwarfs, like a pot of soup on a low flame, might create less turbulence inside the dwarfs, Dr. Linsky said. That relative quiescence might generate weaker magnetic fields — but possibly with conformations, or geometries, that make them more likely to reconnect.

If that is the case, Dr. Linsky said, then perhaps "the geometry is very different in such a way that it produces a few very large flares."

Dr. Lars Bildsten, an astrophysicist at the Institute for Theoretical Physics at the University of California at Santa Barbara, cautioned that because brown dwarfs were so different from the Sun, it was hard to know what to expect from them. The radio observations were at least consistent with sketchy observations in other bands of the spectrum, Dr. Bildsten said.

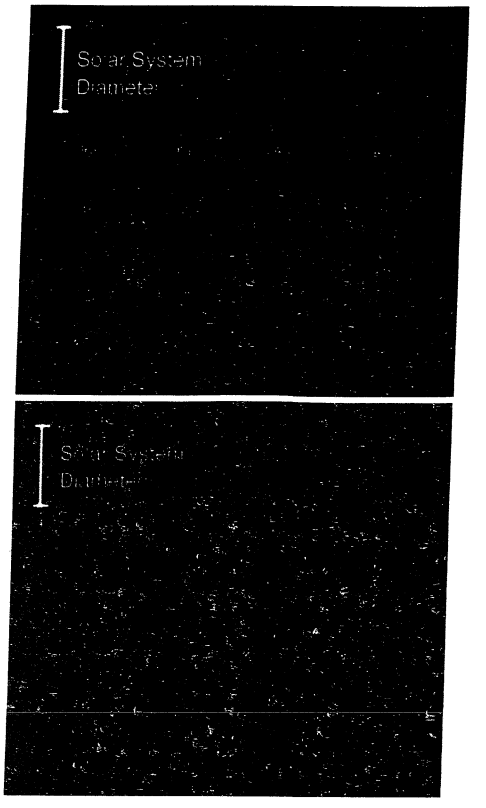
Other scientists said they were at a loss to explain the puzzling findings, whose authors include Mr. Berger, Dr. Kulkarni and Dr. Frail as well as about a dozen graduate and undergraduate students from places like Oberlin College in Ohio, Agnes Scott College in Decatur, Ga., and New Mexico State University in Las Cruces.

"This is a pretty amazing result," said Dr. Jill Knapp, a Princeton astronomer. "There seem to be some quite unexpected things going on with these very cool, low-mass objects."

Telescope Pair Spots Hefty Stellar Cradle

By linking two sets of radio telescopes, astronomers have gotten their first look at the accretion disk that surrounds a massive protostar—a place where stars and planets are being born. Some 150 billion kilometers across, the new disk is only slightly larger than disks previously found around less massive protostars, but it is tens to hundreds of times more massive, says Debra Shepherd of the National Radio Astronomy Observatory (NRAO) in Socorro, New Mexico. Comparing these bulky baby stars with normal-sized ones, Shepherd says, will help theorists predict how a disk feeds its growing star and whether the leftovers congeal into planets and other orbiting bodies. The observations are "a boon to theorists," agrees Alain Lecavelier des Etangs of the Institute of Astrophysics in Paris.

Astronomers have long been eager to peer into the inner sanctums of rare massive protostars. Although many smaller protostars lie within viewing range, the nearest massive protostar is thousands of light-years away—too far for ordinary telescopes to resolve its disk. But last year, NRAO linked the 27 dishes of its Very Large Array (VLA) radio telescope to another 25-meter antenna in Pie Town, 50 kilometers away. In effect, the link created a much larger instrument able to "see" in extremely sharp detail. Right now, says Marc Claussen of the NRAO, a collaborator on the project, "in terms of the combination of sensitivity and [angular] resolution, the Pie Town link is unsurpassed."

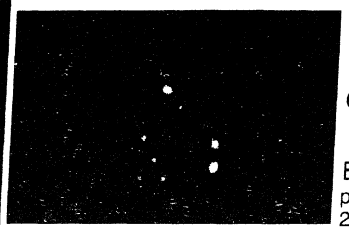


CREDIT: D. SHEPHERD, M. CLAUSSEN, S. KURTZ/NRAO, AUI, AND NSF

Massive protostar. Radio emissions from Orion reveal a stellar accretion disk, cones of ejected gas, and a small companion star.

Using the new setup, Shepherd examined a massive protostar known as G192.16-3.82. This giant, some 6000 light-years away in the constellation Orion, is probably just 200,000 years old and weighs 8 to 10 times as much as the sun. The mass of the protostar's accretion disk is about 20 solar masses. The new observations also hint that the blob of radio emission hides a nearby companion protostar. "In our models, we had to add this companion to match the observations," Shepherd says. The presence of the neighboring star may be the cause of a tilt that the astronomers observe in the disk around the massive star.

The researchers expect to gather many more high-resolution glimpses of nascent solar systems in the future, after the VLA is linked to nine new antennas in what will be known as the Expanded Very Large Array.



Astronomers Discover Six-Image Gravitational Lens

By SPACE.com Staff
posted: 04:35 pm ET
27 August 2001

A team of astronomers has discovered a bizarre image resembling a six-times exposure of a distant galaxy, the light from which has been split and bent by an intervening cluster of three galaxies.

The image, an example of an astronomical process called gravitational lensing, is the first of its kind. It's the result of the gravitational effect of three galaxies along the line of sight between the more-distant galaxy and Earth.

"This is the first gravitational lens with more than four images of the background object that is produced by a small group of galaxies rather than a large cluster of galaxies," said David Rusin, who just received his Ph.D. from the University of Pennsylvania.

"Such systems are expected to be extremely rare, so this discovery is an important stepping stone," he said. Because this is an intermediate case between gravitational lenses produced by single galaxies and lenses produced by large clusters of galaxies, it will give us insights we can't get from other types of lenses."

The team used the National Science Foundation's Very Long Baseline Array (VLBA) radio telescope and NASA's Hubble Space Telescope (HST) to obtain the image. The team published its results in the *Astrophysical Journal*.

Inside and outside a triangle

The more distant galaxy, called CLASS B1359+154, is more than 11 billion light-years away in the constellation Bootes, with a trio of galaxies more than 7 billion light-years away along the same line of sight.

The more-distant galaxy shows signs that it contains a massive black hole at its core and also has regions in which new stars are forming.

The gravitational effect of the intervening galaxies has caused the light and radio waves from the single, more-distant galaxy to be "bent" to form six images as seen from Earth. Four of these images appear outside the triangle formed by the three intermediate galaxies and two appear

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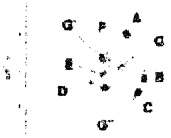
images

Hubble image of the gravitational lens system -- the white objects are the multiple lensed images of the background galaxy, more than 11 billion light-years away. The orange objects are images of the three galaxies some 7 billion light-years away whose gravity is "bending" the light from the background galaxy to produce the multiple images.



Hubble telescope image of the gravitational lens system, with labels indicating the individual components. A, B, C, D, E and F are the lensed images of the background galaxy. G, G' and G" are the three lensing galaxies. Credit: Rusin et al., STScI, NRAO, AUI, NSF. Click to enlarge.

multimedia

SPACE.com Photo Gallery: Intergalactic Fantastic

inside that triangle.

SPACE.com Photo Gallery: Hubble's Highlights, 2000-2001

B1359+154 was discovered in 1999 by the Cosmic Lens All-Sky Survey, an international collaboration of astronomers who use radio telescopes to search the sky for gravitational lenses.

Images made by the NSF's Very Large Array in New Mexico and by Britain's MERLIN radio telescope showed six objects suspected of being gravitational-lens images, but the results were inconclusive.

Multi-wavelength astronomy

Rusin and his team used the VLBA and HST in 1999 and 2000 to make more-detailed studies of B1359+154. The combination of data from the VLBA and HST convinced the astronomers that B1359+154 actually consists of six lensed images of a single background galaxy.

"This is a great example of modern, multi-wavelength astronomy," Rusin said. "We need the radio telescopes to detect the gravitational lenses in the first place. Then we need the visible-light information from Hubble to show us additional detail about the structure of the system."

Armed with the combined VLBA and HST data about the positions and brightnesses of the six images of the background galaxy as well as the positions of the three intermediate galaxies, the astronomers did computer simulations to show how the gravitation of the three galaxies could produce the lens effect.

They were able to design a computer model of the system that, in fact, produces the six images seen in B1359+154.

"Our computer model certainly is not perfect, and we need to do more observations of this system to refine it, but we have clearly demonstrated that the three galaxies we see can produce a six-image lens system," said Martin Norbury, a graduate student at Jodrell Bank Observatory in Britain.

"We think this work will give us an excellent tool for studying much-denser clusters of galaxies and the relationships of the individual cluster galaxies to the 'halo' of dark matter in which they are embedded," he said.

Hoping for that Hubble servicing mission

Clusters of galaxies are known to produce gravitational lenses with up to eight images of a single background object. However, the number of galaxies in such a cluster makes it difficult for astronomers to decipher just how their gravitational effects have combined to produce the multiple images.

Researchers hope to be able to understand the lensing effect well enough to use the lenses to show them how galaxies, gas and unseen dark matter in clusters are distributed. A system such as B1359+154, with only three galaxies involved in the lensing, can help astronomers learn how complex gravitational lenses work.

"The next big step is to use HST to see the pattern of rings produced by the galaxy surrounding the black hole," said Chris Kochanek of the Harvard-Smithsonian Center for Astrophysics (CfA).

"We already see hints of them," he said, "but with the upgrades to HST in the next servicing mission we should be able to trace it completely both to pin down the structure of the lens and to have an enormously magnified image for studying the distant host galaxy."

Full credit

In addition to Rusin, Kochanek and Norbury, the researchers involved in the finding are Emilio Falco of the CfA; Chris Impey of Steward Observatory at the University of Arizona; Joseph Lehar of the CfA; Brian McLeod of the CfA; Hans-Walter Rix of the Max Planck Institute for Astronomy in Germany; Chuck Keeton of Steward Observatory; Jose Munoz of the Astrophysical Institute of the Canaries in Tenerife, Spain; Chien Peng of Steward Observatory.

The VLBA is a system of 10 radio-telescope antennas that work together as a single astronomical instrument. The antennas are spread across the United States, from Hawaii in the west to the U.S. Virgin Islands in the east. A radio telescope system more than 5,000 miles across, the VLBA produces extremely detailed images.

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Astronomy Picture of the Day

Discover the cosmos! Each day a different image or photograph of our fascinating universe is featured, along with a brief explanation written by a professional astronomer.

2001 September 5

3C175: Quasar Cannon
Credit & Copyright: Alan Bridle (NRAO Charlottesville) VLA, NRAO, NSF

Explanation: 3C175 is not only a quasar, it is a galaxy-fueled particle cannon. Visible as the central dot is quasar 3C175, the active center of a galaxy so distant that the light we see from it was emitted when the Earth was just forming. The above image was recorded in radio waves by an array of house-sized telescopes called the Very Large Array (VLA). Shooting out from 3C175 is a thin jet of protons and electrons traveling near the speed of light that is over one million light-years long. The jet acts like a particle cannon and bores through gas cloud in its path. How this jet forms and why it is so narrow remain topics of current research.

Tomorrow's picture: moon AND stars

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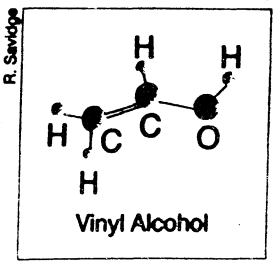
Authors & editors: Robert Nemiroff (MTU) & Jerry Bonnell (USRA)
NASA Technical Rep.: Jay Norris.
A service of: LHEA at NASA/ GSFC

New alcohol added to space-stuff catalog

Astrochemists have discovered another organic chemical in the same region of space where other researchers had identified the first extraterrestrial sugar (SN: 6/24/00, p. 405). On Earth, the alcohol is used to make packaging polymers.

The finding of space-based molecules such as sugar and the newly identified vinyl alcohol could help researchers determine how complex molecules first formed in the cosmos, says Barry Turner of the National Radio Astronomy Observatory in Charlottesville, Va. The findings will appear in a forthcoming issue of ASTROPHYSICAL JOURNAL LETTERS.



Radio emissions revealed the telltale signature of vinyl alcohol's arrangement of two carbons, four hydrogens, and one oxygen.

Turner and A.J. Apponi of the University of Arizona's Steward Observatory in Tucson found vinyl alcohol near the center of the Milky Way in the gas and dust cloud Sagittarius B2. The astrochemists used the 12 Meter Telescope on Kitt Peak near Tucson to detect the molecule's characteristic radio emissions.

"Scientists understand these regions of space very poorly," says Eric Herbst of Ohio State University in Columbus. "The more data we have, the better," he says.

Researchers say that most extraterrestrial molecules form when atoms and small molecules collide in interstellar gas clouds. But such reactions can't efficiently produce molecules with the modest complexity of vinyl alcohol, which has seven atoms, says Lewis E. Snyder of the University of Illinois at Urbana-Champaign. Instead, many astronomers suspect that such molecules form on dust grains.

Vinyl alcohol could offer extra insight into space chemistry because it's part of a molecular trio in which the other members already have been found in space, says Turner. Acetaldehyde, ethylene oxide, and vinyl alcohol are isomers—they have the same atoms but in different arrangements.

"I think it's becoming clearer that isomerization in space is important" for understanding extraterrestrial chemistry, notes Jan M. Hollis of NASA's Goddard Space Flight Center in Greenbelt, Md. When he and his colleagues found sugar in Sagittarius B2 last year, that molecule completed the first known cosmic isomeric triplet. The other members are acetic acid and methyl formate, already known space residents.

Finding the last member of an isomer set is "like completing the inventory," notes Steven Charnley of NASA's Ames Research Center in Mountain View, Calif. Understanding how such isomers form in space could help researchers learn how even larger molecules form.

Snyder says he's particularly interested in whether space chemistry can produce complex molecules that could have jump-started life on Earth. —*J. Gorman*

Par une nuit claire, un petit coup d'œil à la voûte céleste mène rapidement à la conclusion qu'entre les étoiles, il n'y a que le vide. Et pourtant, il existe là d'immenses nuages de gaz et de poussières dans lesquels sont forgées des molécules complexes ; des chaudrons qui, une fois n'est pas coutume, s'avèrent trop froids et trop sombres pour être vus. C'est dans l'un de ces nuages, à 26 000 années-lumière de la Terre, près du centre de la galaxie, que des scientifiques de l'Observatoire américain de radioastronomie ont détecté pour la première fois de l'alcool vinylique. *"Cette découverte revêt une grande importance*, précise l'un d'eux, Barry Turner. *Cela nous offre un outil pour comprendre la formation des composés organiques complexes* [c'est-à-dire les éléments à base de carbone, ndlr] *dans l'espace interstellaire. Cela pourrait également nous aider à mieux appréhender la façon dont la vie pourrait émerger ailleurs dans le cosmos."* Car l'alcool vinylique n'est pas une molécule comme les autres. Constituée de deux atomes de carbone, quatre atomes d'hydrogène et un atome d'oxygène, elle sert d'intermédiaire dans de nombreuses réactions chimiques sur la Terre.
"Depuis le début des années soixante-dix, on a pu repérer un peu plus de 120 espèces différentes dans ces nuages composés principalement d'hydrogène", souligne Alain Baudry, de l'Observatoire de Bordeaux. Une véritable prouesse étant donné les très petites quantités mises en jeu. *"Toutes ces molécules d'une remarquable complexité ne sont présentes que sous forme de traces*, ajoute l'astronome français. *Pour les déceler, il faut donc utiliser des détecteurs vraiment performants."* Ces détecteurs ne sont autres que les radiotélescopes, qui écoutent l'Univers au lieu de le regarder. *"Chaque molécule vibre et tourne sur elle-même*, explique Alain Baudry. *Ce faisant, elle émet un rayonnement très particulier."* Véritable code barre, ce rayonnement permet d'identifier rapidement l'espèce présente. C'est de cette façon que Barry Turner et ses collègues ont pu dénicher l'alcool vinylique. Reste à savoir comment ces molécules prennent forme. Car si les collisions entre atomes peuvent créer les structures les plus simples, elles se révèlent vite inefficaces pour les plus compliquées, comme celle de l'alcool vinylique ou des sucres. *"Nous soupçonnons que les grains de poussières servent de catalyseurs*, indique Alain Baudry. *Mais les mécanismes précis demeurent encore très mystérieux."* Les astronomes poursuivent donc leur inventaire des espèces chimiques de l'espace. Le salut ne viendra que de la compréhension de leur chimie et de leur environnement.

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http://www.aoc.nrao.edu/pr/sugar.html

Milky Way wonder

Astronomers turn galactic archaeologists as they track - with the help of a radio telescope headquartered in Socorro - a truly ancient black hole that's slowly devouring its companion.

By Dave Finley

It was one of the first stars born in our Milky Way Galaxy, bursting into brilliant life 11 billion years ago, its fresh light spreading across a galaxy still forming in a tumultuous, youthful universe.

A giant more than 30 times more massive than our sun, this star was fated to die in a spectacular explosion fewer than 10 million years after its birth. That's a mere tick of the cosmic clock, compared with the sun's, our star's, expected 10 billion-year lifetime.

When this huge star's powerful death blast briefly outshone the rest of the galaxy, the light rays from its birth had barely reached the nearest neighboring galaxies.

What remained after that explosion was a black hole, nature's densest concentration of matter, wielding a gravitational pull so strong that not even light can escape it. This black hole is the remnant of one of hundreds of thousands of gigantic stars that astronomers say they believe formed at the beginning of our galaxy's history and then quickly burned their way to dramatic destruction.

Until now, however, scientists had little direct evidence of such ancient relics from the Milky Way's infancy.

That changed recently when a team of researchers using the National Science Foundation's Very Long Baseline Array, a continentwide radio telescope headquartered in Socorro, tracked the motion of a black hole, dubbed XTE J1118+480. It is speeding at more than 320,000 mph through the galactic neighborhood 6,000 light-years away from our solar system.

And this black hole's path through our galaxy was the key to revealing its fascinating past.

Our solar system and the majority of stars in the galaxy form a relatively thin disk as they

orbit the Milky Way's center.

The oldest stars in the galaxy, however, are found in what astronomers call globular clusters, collections of hundreds of thousands of stars each. The globular clusters orbit the galaxy's center in paths that take them far above and below the Milky Way's main disk.

The researchers, who have reported their findings in the journal Nature, found that XTE J1118+480 is following an orbital path similar to that of the globular clusters.

How did it get into such an orbit?

"There are two possibilities: Either it formed in the galaxy's disk and was somehow kicked out of the disk, or it formed in a globular cluster and was kicked out of the cluster," said Vivek Dhawan, an astronomer at the National Radio Astronomy Observatory in Socorro.

"We think it's much more likely that it was gravitationally ejected from the cluster," said Dhawan, who is part of the team that tracked the black hole backward in time.

If, as the astronomers think, this black hole comes from a globular cluster, that makes it the remnant of a very ancient star. Globular clusters today contain our galaxy's oldest stars, but the stars we now see in those clusters are much less massive than the one from which XTE J1118+480 originated.

The more massive a star, the shorter is its lifetime. The black hole of XTE J1118+480 is seven times more massive than our sun. The star from which it originated had more than four times that much matter before shedding some of its mass during its lifetime and then throwing off even more in the supernova explosion that marked its death. Fewer than 10 million years elapsed between this star's birth and its explosive death.

Astronomers say they believe that, as the Milky Way was starting to form, its first stars were very massive, ones such as XTE J1118+480's precursor.

"The star that preceded this black hole probably formed in a globular cluster even before our galaxy's disk was formed," said Felix Mirabel, another team member and an astrophysicist at the Institute for Astronomy and Space Physics of Argentina and the French Atomic Energy Commission.

Other astronomers had done computer simulations indicating that the black holes left over from these giant early stars began an ever-closer gravitational dance in which the partners finally flung each other completely free of the globular cluster.

That means that there should be hundreds of thousands of lonely black holes wandering the galaxy in eccentric, looping orbits. But so far, XTE J1118+480 is the only one to be found.

"This discovery is the first step toward filling in a missing chapter in the history of our galaxy," Mirabel said. "This also is the first time that a black hole's motion through space has been measured."

The discovery required some luck. The first piece came more than 7 billion years ago, when the black hole's travels began with a partner. Before being flung from its home star cluster, the black hole captured a smaller star that now orbits it. Without the companion, astronomers would not have been able to detect the black hole.

Because light cannot escape a black hole, we cannot see one directly. However, this black hole is sucking material from its captured companion star, and this process makes it visible to a variety of telescopes. XTE J1118+480 is one of several "microquasars" discovered since 1994.

In a microquasar, astronomers say, a black hole or neutron star pulls material from a companion. That material forms a tightly circling disk around the black hole or neutron star before falling onto the denser object. Friction heats this disk to temperatures so great that the in-falling material can emit X-rays. Also, strong magnetic fields in the spiraling disk spit out subatomic particles that emit radio waves.

The first microquasar was discovered by Mirabel and Luis Rodriguez, an astronomer at Mexico's National Autonomous University, using the 27-dish Very Large Array radio telescope west of Socorro. Until now, all known microquasars were part of the Milky Way's disk.

On March 29, 2000, the Rossi X-Ray satellite detected X-rays coming from XTE J1118+480. Astronomers using radio and optical telescopes identified the object as a microquasar.

Mirabel and Dhawan teamed with Roberto Mignani of the European Southern Observatory; Irapuan Rodrigues, who is a fellow of the Brazilian National Research Council at the French Atomic Energy Commission; and Fabrizia Guglielmetti of the Space Telescope Science Institute in Baltimore.

Together they decided to use the Very Long Baseline Array to study the newly found microquasar.

The array is a system of 10 radio-telescope antennas spread from Hawaii to St. Croix in the Virgin Islands. Two of its antennas are in New Mexico, at Pie Town and Los Alamos, and the entire system is controlled from an operations center in Socorro.

With more than 5,000 miles separating its farthest antennas, the array provides astronomers with the greatest ability to discern fine detail, called resolving power, of any telescope on Earth or in space. This resolving power is equivalent to the ability to stand in New York and read a newspaper in Los Angeles.

The astronomers pointed the array at XTE J1118+480 in May and July of 2000. Because the array could pinpoint the object's location in the sky with extreme precision, the scientists were able to see that it had moved between the times of their observations.

Even though it is 6,000 light-years away - 1,300 times more distant than the sun's nearest stellar neighbor - the powerful array could track its motion. Again, however, luck played a part. The microquasar had experienced an outburst of activity and was only visible to radio telescopes for about 100 days.

"Because this microquasar happened to be relatively close to the Earth, we were able to track its motion with the VLBA even though it's normally faint," Mirabel explained.

Had the object been farther away in its peculiar galactic orbit or not flared while relatively nearby, the key fact of its galactic motion would have remained hidden.

After discovering the microquasar's motion using the array, the astronomers used an additional tool to learn more abut the object's orbit.

In the 1950s, Palomar Observatory in California made a photographic survey of the sky. The photographic plates from that survey later were scanned and digitized by the Space Telescope Science Institute. Using this digital database, the astronomers were able to trace the motion of the black hole's companion star back 43 years.

Combined with the data from the array, this information allowed them to calculate XTE J1118+480's orbital path backward for millions of years, clearly showing that it moves far above and below the galaxy's disk.

Since its violent exile from the star cluster 7 billion years ago, the black hole has been devouring its companion star. That star now has only about one-third the mass of the sun. The black hole's lengthy meal has stripped the smaller star of its outer layers, exposing its innards.

This whole tale, spanning nearly the entire history of our galaxy, was revealed by creatively using the best resources available to astronomers.

"This is a great example of applying multiple tools of modern astronomy - telescopes covering different wavelengths and digital databases - to a single problem," Dhawan said.

Explained Mirabel: "What we're doing here is the astronomical equivalent of archaeology, seeing traces of the intense burst of star formation that took place during an early stage of our galaxy's development."

Next will come efforts to learn more about both the gigantic stars that first lighted our galaxy and the gravitational dance that flung them out of their stellar clusters.

With excitement, Mirabel looks to new research: "Now we want to find more of these ancient black holes. There must be hundreds of thousands swirling around in our galaxy."

And, the researchers say, each of them can tell us a new tale about how our galaxy began.

TODAY'S BYLINE Dave Finley is a science writer and public information officer for the National Radio Astronomy Observatory in Socorro. The observatory operates both the Very Large Array and the Very Long Baseline Array radio telescopes for the National Science Foundation.

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Added Antenna Unveils Star Secrets

■ *Observation proves feasibility for array of radio telescopes across N.M.*

By John Fleck
Journal Staff Writer

New Mexico astronomers have successfully demonstrated technology needed to expand the Very Large Array telescope's radio antennas across New Mexico.

Using a prototype of the Expanded VLA, they took a first-ever picture of a disk around a massive young star-in-the-making, one of the key ingredients needed for planets to form.

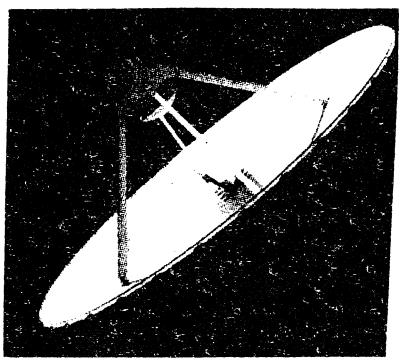
They did it by adding an extra antenna to the VLA, which uses large antennas to study natural radio emissions from distant stars and galaxies.

The extra antenna doubled the precision of the telescope image, according to astronomer Debra Shepherd, revealing a disk of gas and dust around a newly forming giant star.

The results of Shepherd's observations are being published today in the journal Science.

It was a test of technologies needed for the proposed Expanded Very Large Array, which astronomers hope will be an array of antennas across New Mexico to give them unprecedented views of the heavens.

See **ANTENNA** *on* **PAGE A2**



RICHARD PIPES/JOURNA

EYES TO THE SKY: Astronomer connected this radio antenna nea Pie Town to the Very Large Arra to demonstrate technology neec ed to expand the radio telescop with an array of antennas aroun New Mexico.

Antenna Unveils Star Secrets

from **PAGE A1**

Shepherd and her colleagues chose a star known by the unromantic name of "G192.16-3.82" for one of the first tests of the prototype system.

It is an example of a class of massive stars far larger than our sun that are difficult to study with conventional telescopes.

The life of such a giant star is nasty, brutish and short.

While small stars like our sun eke out existences of relative equanimity, their giant brethren live fast and die young.

Shepherd had been staring at the star since graduate school, using more and more powerful telescopes to figure out what it was up to.

But no telescope was powerful enough to see the star's distant details.

Shepherd was about to give up when she got the chance last year to try an experimental new instrument being developed on the Plains of San Agustin, west of Socorro — think of it as "Very Large Array-Plus."

The array gets its power by combining data collected by 27 antennas to make one sharper picture of the natural radio waves emitted by stars or galaxies.

To expand its power, astronomers would like to add antennas spread across New Mexico.

To test how that might work, engineers have taken an existing antenna at Pie Town, part of a second radio telescope called the Very Long Baseline Array, and linked it to the Very Large Array.

The extra antenna had the effect of doubling the precision with which Shepherd could see the details of the disk forming around the star G192.16-3.82.

For the first time after eight years of study, she could see into the inner region around the forming star.

The formation and life of large and small stars is very different.

Low-mass stars like our sun can take as long as 10 billion years to burn all of their nuclear fuel.

High-mass stars like Shepherd's, which is 10 times the mass of our sun, tend to form in clusters, burning so wildly they blast nearby neighbors with radiation.

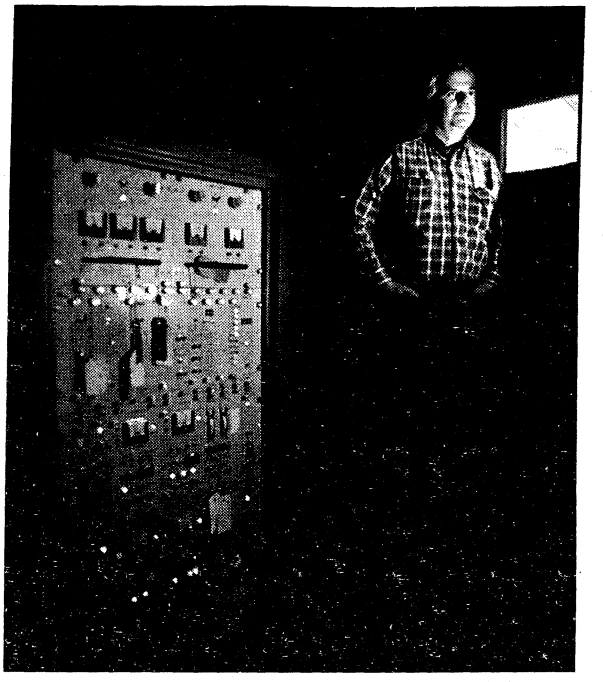
"It's really chaotic," Shepherd said.

They burn so hot that, even with their greater mass, they burn out and die in as few as 20 million years.

The star-forming region is dense with dust and gas, so dense that starlight cannot escape. All astronomers can see with telescopes that capture visible light is a dark cloud.

But the star's radio emissions penetrate the dust, making radio telescopes like the array ideal tools to study them.

As low-mass stars are born, they can be surrounded by disks of dust and gas, the stuff scientists believe formed the planets that circle our sun.



RICHARD PIPES/JOURNAL

FIBER-OPTIC CONNECTION: Kelly Galin, a technician for the Pie Town radio antenna, explains a rack of gear used to connect the antenna with the Very Large Array.

The question for Shepherd and her colleagues: Can the same thing happen in the torrid storms around a newly forming high-mass star?

Shepherd's observations suggest the first ingredient — a disk around the forming star — is possible around high-mass stars.

Now she wants to see if she can see the same thing happening around other stars. An expanded VLA with more antennas would help improve the precision with which she can study the stars, Shepherd said.

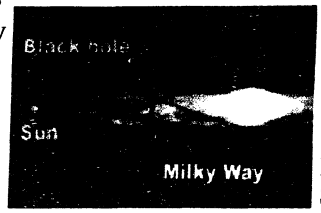
The test done with the Pie Town antenna is the first of a series of steps to the upgrade, said Jim Ulvestad, an astronomer with the federal observatory.

The first step is to replace the array's communication system, built over 20 years ago, with new fiber-optic connections between the antennas and the central computer that compiles the telescope's data.

The prototype Pie Town linkup used a new fiber-optic connection to test out the technology.

Officials with the National Science Foundation-funded observatory also would like to replace the central computer. The one now in use was built 25 years ago.

Addition of the new antennas around New Mexico, if it receives federal money, would happen some time later this decade.



Wayward Black Hole Staggers Through Galaxy, Passes Nearby

By Robert Roy Britt
Senior Science Writer

Conducting a bit of astronomical archaeology, researchers have dug up 43-year-old photographic evidence of an ancient black hole and used the information to learn that the object has been wandering at high speed on an odd, looping path through the Milky Way Galaxy for 7 billion years.

The study, discussed in the Sept. 13 issue of the journal *Nature*, represents the first measure of a black hole's movement through space, said researchers involved in the work.

The object's travels take it above and below the main plane of the galaxy, where the Sun and most other stars reside and orbit around the galactic center in relatively orderly fashion. The wayward black hole zooms along at 90 miles per second (145 kilometers per second) relative to the Earth, currently carving an arc up and over our solar system.

In pinning down the vagabond's trajectory and piecing together a picture of its past, researchers say they are adding pages to at least one chapter in the book that explains how the galaxy formed.

The object is estimated to have been around more than 2 billion years before our Sun was born, a time when the Milky Way was a toddler of a galaxy.

"We believe that hundreds of thousands of very massive stars formed early in the history of our Galaxy, but this is the first black hole remnant of one of those huge primeval stars that we've found," said lead researcher Felix Mirabel, an astrophysicist at the Institute for Astronomy and Space Physics of Argentina and the French Atomic Energy Commission.

Retracing the route

In a telephone interview, Mirabel explained that long ago a massive star exploded, its remaining mass imploding and forming the black hole he and his colleagues studied.

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This graphic explains the black hole's odd orbit and how it feeds off a companion star. Click to enlarge.

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In the intervening eons, the black hole, which has a travelling companion star to feed off of, has taken an ever-changing course through the galaxy. The path has now brought the object relatively near to our Sun. At just 6,000 light-years away, it is close enough to study.

Though this black hole and all its brethren can't actually be seen, researchers examine radiation generated by violent interactions near such objects, a surrounding sphere called the "event horizon" beyond which all things, including light, become irrevocably trapped.

Mirabel said the wandering black hole just discovered is at a safe distance, and its orbit won't affect our solar system.

The probability of any similar objects ever interacting with the solar system is very remote, he said, even though he expects there are hundreds of thousands of them winging through the galaxy at odd angles.

Four decades of data

Determining the black hole's orbit was the first step in figuring out where it came from and how old it is.

The object, officially called XTE J1118+480, was discovered by the Rossi X-ray satellite on March 29, 2000. Mirabel and his colleagues used the National Science Foundation's Very Long Baseline Array of radio telescopes to observe it in May and July of 2000.

But the key evidence was dug up from optical images taken 43 years apart for the Palomar Observatory Sky Survey. The researchers used the object's movement during those years to calculate the orbit.

Each 230 million years, the black hole and its companion complete one trip through the galaxy, the new research shows. But because the Milky Way's mass is distributed so widely -- some in the center, some in the galactic plane, and some in a vast "halo" that surrounds the entire galaxy -- the trajectory changes slightly with each orbit, Mirabel explained.

Booted out

The orbit indicates that some 7 billion years ago the black hole was ejected from what astronomers call a globular cluster. These dense groupings of stars -- hundreds of thousands in each cluster -- represent some of the oldest stars in the galaxy and are frequently found in the galaxy's halo, which is otherwise sparsely populated.

Some researchers speculate that globular clusters formed shortly after the Big Bang and might help explain the formation of the universe as a whole.

"The star that preceded this black hole probably formed in a globular cluster even before our galaxy's disk was formed,"

Mirabel said. "What we're doing here is the astronomical equivalent of archaeology, seeing traces of the intense burst of star formation that took place during an early stage of our galaxy's development."

The newly studied black hole's wild ride likely resulted from an ejection caused by the gravitational interaction with other massive objects in the globular cluster.

Mirabel and colleague Vivek Dhawan, an astronomer at the National Radio Astronomy Observatory (NRAO) in New Mexico, say there are two other possible explanations for the black hole's strange orbit: It might have formed in the galactic plane and been gravitationally booted out; or it could have been introduced into the Milky Way when another, smaller galaxy was absorbed in a merger.

"We think it's more likely that it was gravitationally ejected from the globular cluster," Dhawan said.

Packing for a picnic

For snacking purposes, the travelling black hole has taken along a companion star, an object that was once large but after billions of years has been reduced to roughly one-third the size of our Sun, partially eaten and with its innards exposed.

The researchers think the black hole gravitationally enlisted its travelling buddy just prior to being ejected from the globular cluster. Ever since, it has been siphoning matter from the star as the two objects orbit each other.

Theory holds that the matter disappears forever into the intense gravitational grip of the black hole.

This particular arrangement of a star and a black hole is referred to by astronomers as a microquasar because of the violent interaction at the surface of the black hole, where strong jets of radio waves and other emissions are shot out into space.

Some microquasars emit incredibly violent winds of energy when material from the companion star smacks into the black hole. Others stream energy into space in the form of jets that race out in two opposite directions.

Larger cousins

Microquasars, though relatively small, have been likened to full-blown quasars, huge objects only found in the distant universe and therefore very far back in time.

Quasars, or quasi-stellar radio sources, are far more massive and energetic. They are powered by supermassive black holes that snatch all nearby matter into a colossal well of no return that can hide a mass equal to billions of stars.

In yet another black-hole configuration, a similar but less active black hole with a mass of about 2.6 million Suns is thought to sit at the center of our galaxy. Astronomers recently provided some of the best evidence to date that this object exists.

Microquasars, on the other hand, are anchored by black holes that are typically called "stellar" black holes, with a mass equal to only a handful of stars.

About a dozen microquasars have been found, mostly in the plane of the Milky Way. Some, instead of involving a black hole, are powered by a neutron star. These objects were formed from stars not quite large enough to evolve into black holes, yet they are still said to be 10 trillion times denser than steel.

Also participating in the new study were Roberto Mignani of the European Southern Observatory, Irapuan Rodrigues of the Brazilian National Research Council at the French Atomic Energy Commission, and Fabrizia Guglielmetti of the Space Telescope Science Institute in Baltimore.

Click here for more news and information about black holes.

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