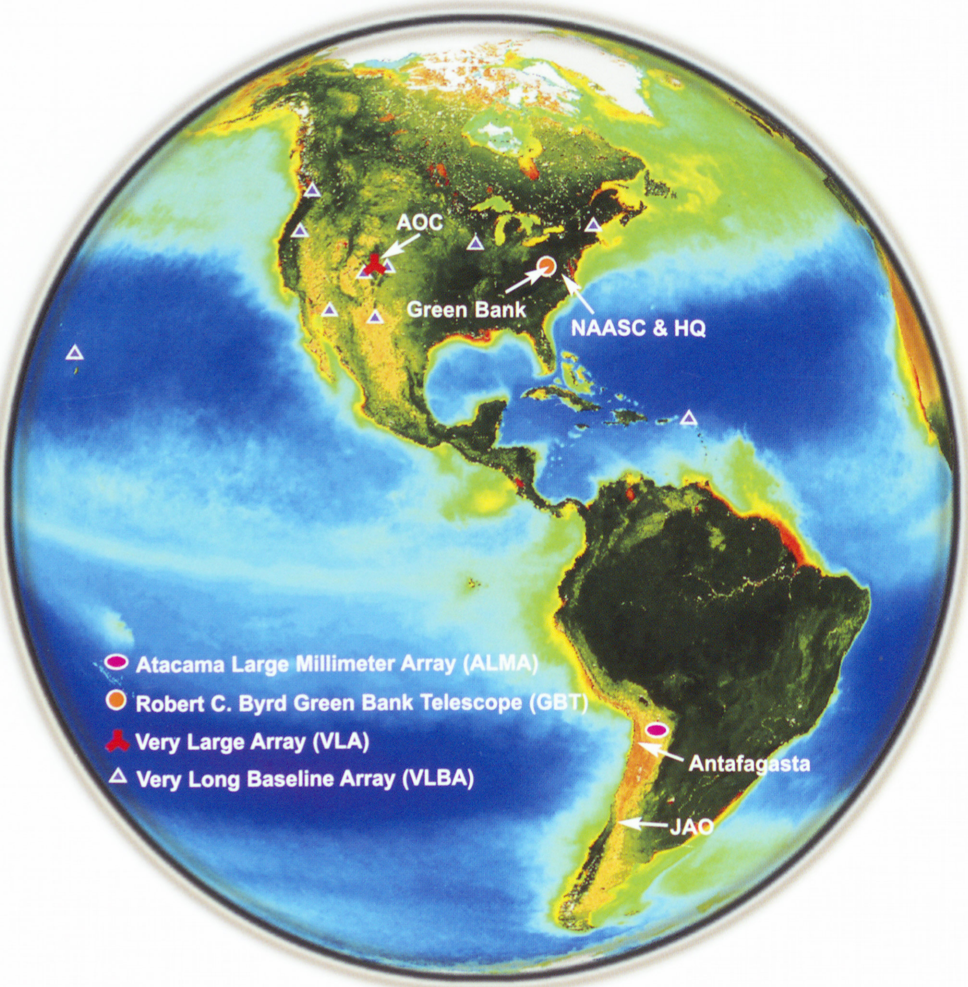
National Radio Astronomy
Newsletter
April 2005
Issue 103

ALMA Progress Update

The GBT and VLBA Observe the Huygens Probe Descent to Titan

Heating the Hot Gas in Galaxy Clusters by Energetic Radio Jets



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

If you have an interesting new result obtained using NRAO telescopes that could be featured in the NRAO Newsletter, please contact Jim Condon at *jcondon@nrao.edu*. We particularly encourage Ph.D. students to describe their thesis work.

Editor: Mark T. Adams (*mtadams@nrao.edu*); Science Editor: Jim Condon (*jcondon@nrao.edu*); Assistant Editor: Sheila Marks; Layout and Design: Patricia Smiley

Cover Image: Map showing NRAO telescope sites and other major locations: the Array Operations Center (AOC) in Socorro, NM; the Green Bank, WV site; the North American ALMA Science Center (NAASC) and NRAO Headquarters (HQ) in Charlottesville, VA; Antafagasta, Chile and the Joint ALMA Office (JAO) location in Chile. The Atacama Large Millimeter Array (ALMA) is an international astronomy facility. ALMA is an partnership between Europe, North America, and Japan in cooperation with the Republic of Chile.

The map used in this image is courtesy of the SeaWiFS Project NASA/GSFC and ORBIMAGE.

Atacama Large Millimeter Array (ALMA)

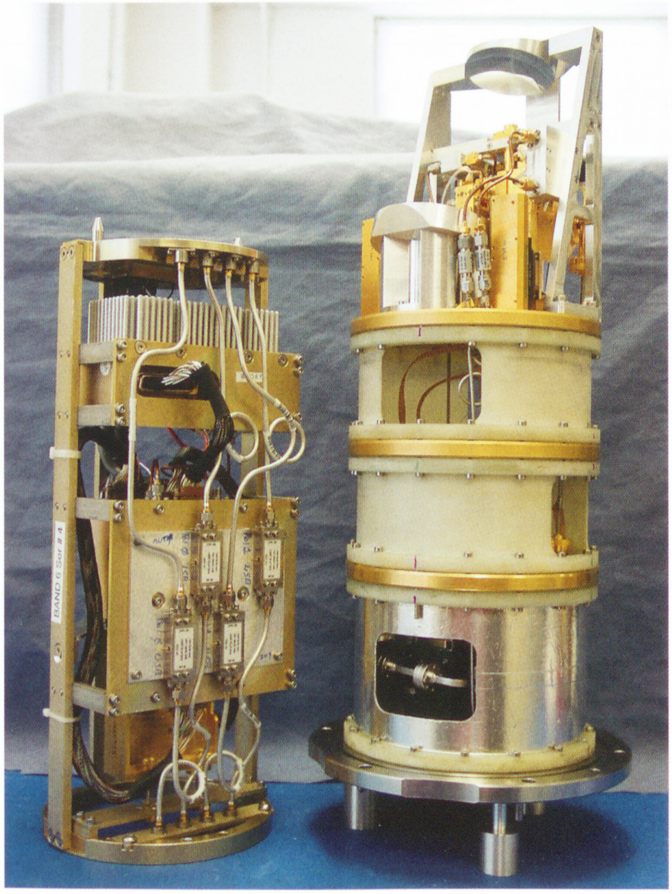
ALMA News

ALMA construction continues at sites worldwide. U.S. President Bush signed the FY2005 budget, which allocates $49.30M to ALMA construction, the fourth year of full ALMA construction funding and, including the design and development phase, the seventh year of ALMA funding. The FY06 request seeks full funding for the fifth year of construction, at $49.24M. At the end of January, the ALMA-Japan partner announced signature of a contract to build three 12m antennas to be incorporated into the ALMA Compact Array. Contracts for the balance of the antennas are imminent.

An ALMA Town Meeting was held on January 11, 2005 (Tuesday) during the 205th AAS Meeting in San Diego, CA. The meeting was an outstanding success, with discussion continuing afterward such that the room had to be cleared so that the next session could begin. At the meeting, an ALMA booth was staffed by ALMA personnel to answer questions. Booths are planned for the upcoming AAS meeting in Minneapolis May 29-June 2 and also at the CASCA meeting in Montreal May 15-17. ALMA will also be discussed at the 2005 IEEE International Conference on Acoustics, Speech, and Signal Processing, held March 18-23, 2005 in Philadelphia, as one element in a special session entitled "*Towards A New Generation of Radio Astronomical Instruments: Signal Processing for Large Distributed Arrays*".

Phil Myers left the ALMA Science Advisory Committee (ASAC). Andrew Blain of Caltech was nominated by NSF and confirmed by the ALMA Board at its January 27, 2005 telecon. Jean Turner is currently Chairperson of the ASAC. Jim Crocker of Lockheed Martin has replaced Dominick Tenerelli as a North American ALMA Management Advisory Committee member.

In electronics labs around the world, engineers are assembling ALMA components into functioning units and measuring performance against specifications. In



Completed Band 6 receiver.

Tucson, the Local Oscillator (LO) system is undergoing phase drift measurements; the prototype of the LO Photonics Line Length Corrector and Second Laser Synthesizer are under test. At the Array Operations Center (AOC) in Socorro, tests focus on elements of the backend, including data transmission system, prototype correlator, samplers, and digitizers. ALMA Computing in North America is also carried out in Socorro. At the NRAO Technology Center (NTC) in Charlottesville, assembly of the first quadrant of the ALMA correlator is nearing completion. The multipliers (tunerless!) have been assembled and delivered to receiver cartridge builders around the world. In the NTC, the first Band 6 (1.3mm) cartridge has been assembled and tested; others are in an advanced state of assembly. Soon, these elements will be brought together at the Antenna Test Facility and assembled into a one-baseline forerunner of ALMA for prototype system integration and astronomical testing.

As ALMA construction has led to realization of its various elements, from prototype antennas through samplers and correlators to front ends, the project has evolved from the baseline set down at the outset of construction. Over the winter, the project has engaged in using the information gleaned from construction of the elements of ALMA to rebaseline the project as it is currently envisioned. This process has been informed by the realization last fall of an integrated project schedule, which defines critical paths through the many parts of ALMA. The rebaselined project will be discussed with the ALMA Board, itself consulting with its scientific and management advisory committees (ASAC and AMAC respectively) before being finalized.

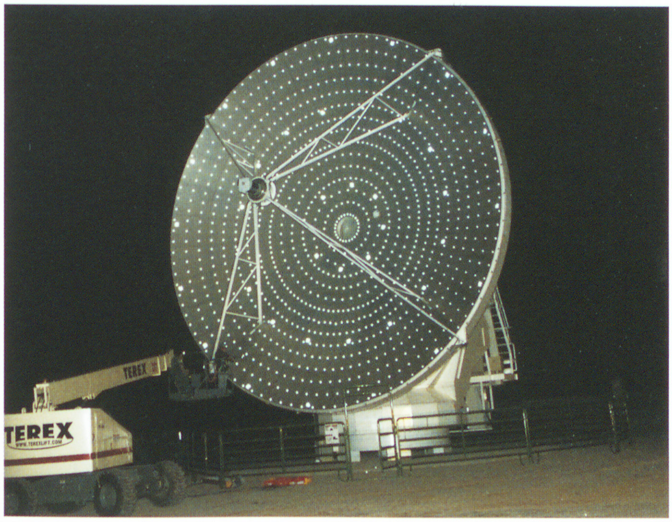
Any task of this magnitude requires a fully-staffed Joint ALMA Office. Only one remaining JAO position, that of the ALMA Project Scientist, remains to be filled. Advertisements have been placed with a goal of speedily identifying and hiring the most qualified candidate.

At the ALMA Camp adjacent to the site of the Operations Support Facility (OSF) near San Pedro de Atacama, the focus is on support of the imminent effort to construct the ALMA facilities at both the OSF and at the Array Operations Site on the Chajnantor plateau. To this end, the road between the two sites is being finished, and the ALMA Camp and the Construction Camp are being enlarged.

H. A. Wootten

ALMA Test Facility

Since the turn of the year, activity has ramped up at the ALMA Test Facility (ATF) located at the Very Large Array site. All bids received for production antennas were based on the prototype antennas located at the ATF. The Antenna Evaluation Group (AEG) performed a number of tests on these antennas aimed at demon-



A nighttime photograph of the AEC prototype antenna, taken as final preparations are made for photogrammetic measurements. (Photograph by Fred Schwab)

strating their performance relative to the technical specifications for the antennas. Owing to a number of factors—antenna delivery schedule, weather at the VLA site, and poor optical seeing at the ATF among them—the data sets earlier produced by the AEG left interpretation of the performance relative to specifications open to question.

Since the performance of prototypes relative to the technical specifications was a key issue in bid evaluation, a Joint Antenna Technical Group consisting of experts in antenna design and testing was assembled at the ATF to conduct a new series of tests aimed at resolving issues remaining from the report of the Antenna Evaluation Group. These tests have been run during January through the beginning of March 2005. Tests included holography using a transmitter on a nearby tower, photogrammetry of the antennas over a range of elevations, out-of-focus beam maps and out-of-focus holography of astronomical sources, pointing with the optical pointing telescope, and radiometry of astronomical sources. While still under scrutiny, it appears that these tests have resolved most remaining questions. The testing concludes with a period of ten-second fast-switching cycles on the antennas. This involves continuously fast-switching the antennas for about 100,000 cycles: 24 hours per day for about 14 days or 42 eight-hour shifts.

Vertex antenna (foreground) being fitted with photogrammetry targets at the ATF. Mitsubishi antenna shown in background. (Photograph by Fred Schwab)

A model of the Observatory's expanded Edgemont Road facility that will house the North American ALMA Science Center (NAASC) located in Charlottesville, VA.

At the conclusion of this round of tests, the project will contract for the production antennas armed with a more complete understanding of the performance of the prototype antennas.

Independent of the testing of the two antennas supplied by the ALMA bilateral partners, a Japanese prototype has also been tested at the ATF. Based on these tests and an independent bidding process, Japan selected Mitsubishi to produce three 12m antennas which will be included in the Atacama Compact Array and signed a three-year contract with them on January 31, 2005.

H. A. Wootten

North American ALMA Science Center

The North American ALMA Science Center (NAASC) will be the main interface between the North American user community and the Joint ALMA observatory. In addition to hosting a complete copy of the ALMA archive, the NAASC will provide North American astronomers support with proposal submission, observing scheduling, data reduction, and outreach activities such as workshops and Summer Schools. More information can be found at the NAASC website at: *http://www.cv.nrao.edu/naasc/*.

The NAASC is poised to occupy its new offices in the addition to the NRAO Edgemont Road Building, located on the grounds of the University of Virginia in Charlottesville, Virginia. The move is expected to be complete by early April. Initially, the Science Center will be located in a suite of offices on the third floor, above the office of the North American ALMA (Construction) Project. Others moving into the new space include NRAO Administration and Human Resources. Renovation of the Library, Auditorium, and common spaces will provide excellent facilities for visitors to the NAASC and for ALMA workshops.

The ALMA North American Science Advisory Committee (ANASAC) provides scientific advice on the operation of the NAASC to NRAO as representatives of the wider North American astronomical community. The ANASAC welcomed new members for a three-year term at its meeting on February 18, 2005: Andrew Baker (Jansky Fellow, U. Maryland), John Bally (U. Colorado), Crystal Brogan (JCMT Fellow, U. Hawaii), Paul Ho (CfA, Harvard), Jonathan Williams (U. Hawaii), and Mel Wright (U. C. - Berkeley). Members continuing for two years are: Andrew Blain (Caltech), Xiaohui Fan (U. Arizona), Doug Johnstone (HIA/DAO, Victoria), Lee Mundy (U. Maryland), Jean Turner (U. C. L. A.), and Christine Wilson

(McMaster U.); and for one year: Chris Carilli (NRAO), Richard Crutcher (U. Illinois), Jason Glenn (U. Colorado), Mark Gurwell (CfA, Harvard), Joan Najita (NOAO), and Min Yun (U. Mass.). Special thanks go to members completing their service on the ANASAC: Phil Myers (CfA, Harvard), Dave Hollenbach (NASA - Ames), Dan Jaffe (U. Texas - Austin), Luis Rodriguez (UNAM), Dave Sanders (U. Hawaii), and Dick Plambeck (U. C. - Berkeley).

P. A. Vanden Bout

Green Bank

The Green Bank Telescope

This winter, the Robert C. Byrd Green Bank Telescope (GBT) has successfully moved into long millimeter wave observing with commissioning of the Ka-band (26 - 40 GHz) receiver and production use of the Q-band (40 - 50 GHz) receiver. We have made significant progress on several other initiatives, including the new IDL data-reduction package, the Precision Telescope Control System (PTCS) project for 3 mm observing, the Penn bolometer camera, the Caltech Continuum backend, and GBT Spectrometer upgrades. Results from the December engineering review of the GBT Azimuth Track project are described, as well as notable science results, including follow-up pulsar observations of the Terzan 5 globular cluster and important contributions to the Cassini-Huygens mission to Titan.

The new Ka-band receiver is a two-beam, dual-polarization, pseudo-correlation receiver and is the first of its type on the GBT. It is capable of kHz-rate switching between the two beams and is designed to give wide-bandwidth continuum noise performance that approaches radiometer-equation predictions, i.e., with 1/f noise greatly minimized. It also has sensitive spectral-line performance. This receiver will be used for a number of significant science projects including high-redshift molecular line searches and sensitive continuum observations, particularly for foreground point-source correction of cosmic background radiation fields. Two of four spectral channels have been successfully commissioned and were released for initial science projects in March. An upgrade will be made this summer to bring all channels into operation and to allow for integration with a future cross-correlation wideband spectrometer.

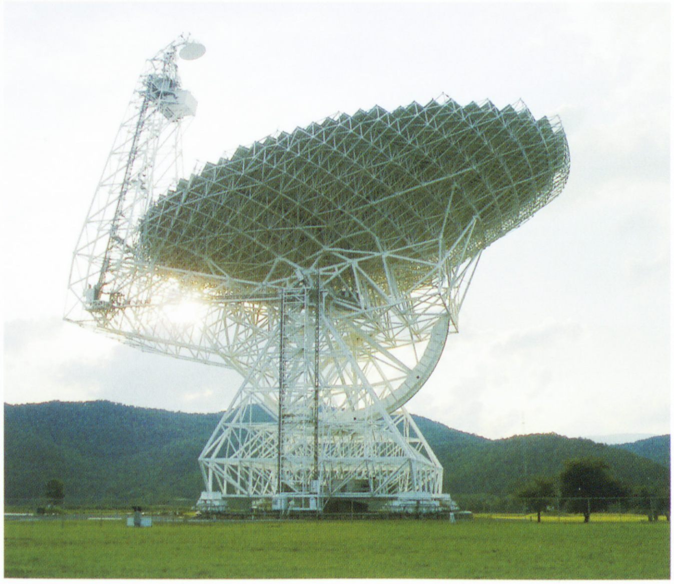
The Q-band receiver was modified last summer to improve its gain stability. The receiver has performed very well in several observing runs this winter, and in particular has yielded very flat spectral baselines for wideband high-redshift line searches. The useful tuning band for this receiver is presently ~42 - 48 GHz. Work is planned this summer to investigate broadening the band back to its original specification of 40 - 50 GHz.

The software and science groups have been working to develop a set of single-dish data reduction modules using IDL, known as GBTIDL. The new system combines the best capabilities of the old Unipops package with some useful features from aips++/dish. The design and features of GBTIDL are heavily influenced by successful systems developed by T. Bania and others, and cleanly separates the data from the algorithms ensuring that the package will support GBT's current and future observing modes. The package imports and exports data from the SDFITS format and will be available for real-time use at the GBT as well as for post-observing run processing. Although we intend to provide a package with all the basic features for observing at single positions on the sky, it will be accessible for expansion and enhancements by others. For example, users who wish to perform custom calibration will be able to easily plug in the modules they write themselves and use them within the context of existing GBTIDL capabilities. The package is also serving as the exploratory platform for developing a science data model for the GBT, which is critical for the development of next-generation data-reduction systems which are aligned with Observatory-wide efforts. The GBTIDL package is presently being tested internally and by a small group of external users while development continues. Plans include a public release by June of this year.

The PTCS project has concentrated on "out-of-focus" holography measurements, precision pointing system design, and investigations of a new-generation laser metrology system. The out-of-focus holography measurements have been plagued by poor weather on scheduled test nights this winter. In one session with good weather, maps were made, and surface corrections were computed and input into the active-surface controllers. Observations made alternately with the new and old surface figures showed that the new figure produced significant improvements in Q-band aperture efficiency. Work will continue through the winter and spring with hopes for better luck with the weather. The project team has also spent considerable time developing a system design to achieve the required pointing accuracy of ~1 arcsec. Simulations and error analyses of the concepts are promising. Work also proceeds on the development and prototyping of next-generation metrology instrumentation.

The Penn Array bolometer camera, a 64-pixel full-sampling array for the 90 GHz band, continues to proceed well in the labs at the University of Pennsylvania and at Goddard Space Flight Center. Present plans call for integration tests on the GBT this summer and first commissioning observations this fall. The first season will be devoted to engineering shakedown, initial astronomical characterization, and continued development. The Penn camera is a joint project of UPenn, GSFC, NIST, U. Cardiff, and NRAO, and is supported by the NRAO's university-built instrumentation program.

The Caltech Continuum backend, a collaboration between Caltech and NRAO, is also proceeding well. This backend will work in conjunction with the Ka-band and future W-band (68-92 GHz) correlation receivers, and will allow the full continuum capability of these receivers to be exploited scientifically. The design and construction work is scheduled for completion by fall, with astronomical commissioning to proceed next fall and winter.



The Robert C. Byrd Green Bank Telescope (GBT). Photograph by Andrew Clegg.

The digital group has been working on two upgrades to the GBT Spectrometer, a redesign of the long-term accumulator (LTA) cards and development of a cross-correlation mode test fixture. The existing LTA cards have been problematic and occasionally result in correlation lag dropouts. Design of the new card, which should correct this problem, is complete and the first prototype board has been received from the fabricator for testing. The cross-correlation test fixture will allow the cross-correlation mode of the spectrometer to be verified and released for spectral-polarimetry and other cross-correlation observing needs. The design of the test fixture is complete, and it is presently under construction.

The GBT azimuth track engineering review panel met in Green Bank on December 7-8, 2004. The panel was again chaired by Karl Frank (U. Texas). The status of the project, the results of the trial retrofit, and the results of a number of classical and finite-element analyses were presented. Concepts for a full repair of the track were discussed in detail. These concepts are based largely on the trial retrofit, which consists of welded base-plate joints and overlapping (staggered) wear plates with balanced joints. The panel was well satisfied with the analyses and results presented and the overall concepts for the full repair. They recommended that we perform follow-up investigations of the effects of thicker, full-width wear plates, the attachment (bolting) scheme, and the benefits of replacing the base plates rather than field-grinding the existing ones. These investigations are underway and are expected to conclude this spring. The major retrofit work is not yet scheduled, but will likely be in the summer of either 2006 or 2007.

GBT observers continue to produce interesting and significant science results. As described in a science article in this newsletter, the number of millisecond pulsars detected in the Terzan 5 globular cluster is now up to 26 (Ransom et al.). In addition, as described in the accompanying article by Ghigo and Romney, the GBT and VLBA also provided major support to the Cassini-Huygens mission, including the acquisition of unique science data. Results from the GBT figured prominently in lists of scientific highlights from 2004 as chosen by several publications. These included the discovery of potential leftover building blocks of the Andromeda Galaxy (Thilker et al.), listed among the top astronomy results of 2004 by *Science News*, and the detection of complex, biologically significant molecules in the interstellar medium (Hollis et al.), included as one of the top 100 science stories of 2004 by *Discover* magazine. The double binary pulsar, discovered at Parkes and studied in detail at the GBT, was listed as one of the top ten breakthroughs of the year by *Science*.

P. R. Jewell

Socorro

VLA/VLBA Large-Proposal Deadline and Policy Change

Prospective proposers are reminded that the next large-proposal deadline for the VLA and the VLBA will be on June 1, 2005. Large proposals should be sent in by the same process as normal proposals (e-mail to *propsoc@nrao.edu*), using the same forms. All proposals requesting more than 200 hours will be considered to be large proposals. The large proposals have no page limit for the scientific justification, so proposers are strongly encouraged to provide information such as a data-reduction plan and evidence that their proposal team is capable of making full use of the large amount of data acquired. For more information on the large proposal process, see *http://www.vla.nrao.edu/astro/prop/largeprop/*.

A data-release plan is a mandatory part of the justification for any large proposal. We encourage proposers to think carefully about data products that would be of the most use to the community and to think about how their data products may be useful ultimately to the National Virtual Observatory.

Previously, we have accepted VLBA large proposals at any normal VLA/VLBA proposal deadline. However, beginning on June 1, 2005, we will accept large VLBA proposals only at the same 16-month intervals as for the VLA. Accepting individual large VLBA proposals at random deadlines forces the Large Proposal Review Committee to conduct ad-hoc meetings to consider single proposals and also prevents them from evaluating these proposals in the overall context of the other proposals seeking large amounts of observing time. Therefore, any large proposals received after June 1, 2005 will be held over until the October 2, 2006 deadline.

J. S. Ulvestad

VLA Configuration Schedule; VLA/VLBA Proposals

Configuration	Starting Date	Ending Date	Proposal Deadline
B	18 Feb 2005	06 Jun 2005	1 Oct 2004
CnB	17 Jun 2005	05 Jul 2005	1 Feb 2005
C	08 Jul 2005	26 Sep 2005	1 Feb 2005
DnC	07 Oct 2005	24 Oct 2005	1 Jun 2005
D	28 Oct 2005	09 Jan 2006	1 Jun 2005
Large VLA/VLBA	27 Jan 2006	07 May 2007	1 Jun 2005
A(+PT?)	27 Jan 2006	08 May 2006	3 Oct 2005
BnA	19 May 2006	05 Jun 2006	1 Feb 2006
B	09 Jun 2006	11 Sep 2006	1 Feb 2006
CnB	22 Sep 2006	09 Oct 2006	1 Jun 2006
C	13 Oct 2006	08 Jan 2007	1 Jun 2006
DnC	19 Jan 2007	05 Feb 2007	2 Oct 2006
D	09 Feb 2007	07 May 2007	2 Oct 2006

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

VLA: The maximum antenna separations for the four VLA configurations are A-36 km, B-11 km, C-3 km, and D-1 km. The BnA, CnB, and DnC configurations are the hybrid configurations with the long north arm, which produce a circular beam for sources south of about -15 degree declination and for sources north of about 80 degree declination. Some types of VLA observations are significantly more difficult in daytime than at night. These include observations at 90 cm (solar and other interference; disturbed ionosphere, especially at dawn), deep 20 cm observations (solar interference), line observations at 18 and 21 cm (solar interference), polarization measurements at L-band (uncertainty in ionospheric rotation measure), and observations at 2 cm and shorter wavelengths in B and A configurations (trophospheric phase variations, especially in summer). Proposers should defer such observations for a configuration cycle to avoid such problems. In 2005, the C configuration daytime will involve RAs between 06^h and 12^h; and the D configuration daytime will involve RAs between 13^h and 19^h. Current and past VLA schedules may be found at *http://www.vla.nrao.edu/astro/prop/schedules/old/*. EVLA construction will continue to impact VLA observers; please see the web page at *http://www.aoc.nrao.edu/evla/archive/transition/impact.html.*

Approximate VLA Configuration Schedule

Year	Q1	Q2	Q3	Q4
2005	A,B	B,C	C	D
2006	A	A,B	B,C	C
2007	D	D,A	A	A,B

VLBA: Time will be allocated for the VLBA on intervals approximately corresponding to the VLA configurations, from those proposals in-hand at the corresponding VLA proposal deadline. VLBA proposals requesting antennas beyond the 10-element VLBA must justify, quantitatively, the benefits of the additional antennas. Any proposal requesting a non-VLBA antenna is ineligible for dynamic scheduling, and fixed-date scheduling of the VLBA currently amounts to only about one quarter of observing time. Adverse weather increases the scheduling prospects for dynamics requesting frequencies below about 10 GHz. See *http://www.vlba.nrao.edu/astro/schedules/* for a list of dynamic programs which are currently in the queue or were recently observed. VLBA proposals requesting the GBT, the VLA, and/or Arecibo need to be sent only to the NRAO. Note also the possibility to propose for the High Sensitivity Array. Any proposal requesting NRAO antennas and antennas from two or more institutions affiliated with the European VLBI Network (EVN) is a Global proposal, and must reach both the EVN scheduler and the NRAO on or before the proposal deadline. VLBA proposals requesting only one EVN antenna, or requesting unaffiliated antennas, are handled on a bilateral basis; the proposal should be sent both to the NRAO and to the operating institution of the other antenna requested. Coordination of observations with non-NRAO antennas, other than members of the EVN and the DSN, is the responsibility of the proposer.

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VLBI Global Network Call for Proposals

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

Dates	Proposals Due
02 Jun to 20 Jun 2005	01 Feb 2005
20 Oct to 10 Nov 2005	01 Jun 2005

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

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

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In General

The GBT and VLBA Observe the Huygens Probe Descent to Titan

On January 14, 2005 the NRAO participated in a unique and exciting event: the descent of the Huygens Probe through the atmosphere of Titan, the largest of Saturn's moons. This participation was organized in a joint proposal from JIVE (Joint Institute for VLBI in Europe) and JPL (Jet Propulsion Laboratory) by a large collaboration with co-investigators at many institutions worldwide.

Figure 1. The happy JIVE and JPL scientists following detection of the signal from Huygens at the GBT, from left to right: Max Avruch (JIVE), Sami Asmar (JPL), Kees van t'Klooster (ESA), Sergei Pogrebenko (JIVE), and Sue Finley (JPL).

The event was observed with three different systems. One was a VLBI observation involving eight VLBA stations, the GBT, and several telescopes in Australia, Japan, and China, coordinated by JIVE. This part of the project was designed to measure the precise angular position of Huygens using a variant of the phase-referenced astrometry commonly done on the VLBA. The remaining two systems aimed at detecting the Doppler shift of the Huygens signal. Both used specialized JPL recording systems. PC-based recording units were installed temporarily at four of the VLBA stations involved, while a more specialized Radio Science Receiver (RSR), normally used at the NASA DSN facilities, was stationed at the GBT. One major challenge of operating the multiple observing systems was to use the VLBA scheduling system to set up all the NRAO equipment required by all three systems, but to record only the VLBI signals.

While one might expect that the NASA DSN stations would observe the probe's descent, the 2040 MHz link from Huygens to the Cassini "mother ship" was outside the passbands of their receivers. Both the GBT and VLBA S-band receivers can observe quite well at this frequency, however, although front-end bandpass filters had to be removed temporarily at some of the VLBA stations. To minimize the impact of RFI on the observation, a number of known interference sources were asked to minimize transmissions during the encounter at Titan.

Some extensions to standard VLBI phase-referencing techniques were necessitated because the VLBI observation was eavesdropping on the comparatively short-range Huygens-Cassini communications, in a sidelobe of the Huygens telemetry antenna, and because Huygens was expected to be buffeted by winds in Titan's atmosphere. Both the weak signal and the accelerations led JIVE to develop an extensive software correlation technique for the Huygens signals, and this in turn required that these observations be recorded on Mark 5 VLBI recorders, which have a convenient computer interface. Mark 5A units, funded by ESA and NASA, were installed at the GBT and five VLBA stations.

Preparations for this event included test observing sessions in August and November involving the entire planned network. Several VLBA-only tests were also performed in December and January. In the November test, a crew from JPL brought the NASA RSR to Green Bank. The complex frequency-conversion and scheduling schemes were checked, the expected performance of the VLBA S-band systems at 2040 MHz was confirmed, the RFI environments at that frequency were explored at some stations, and interferometric use

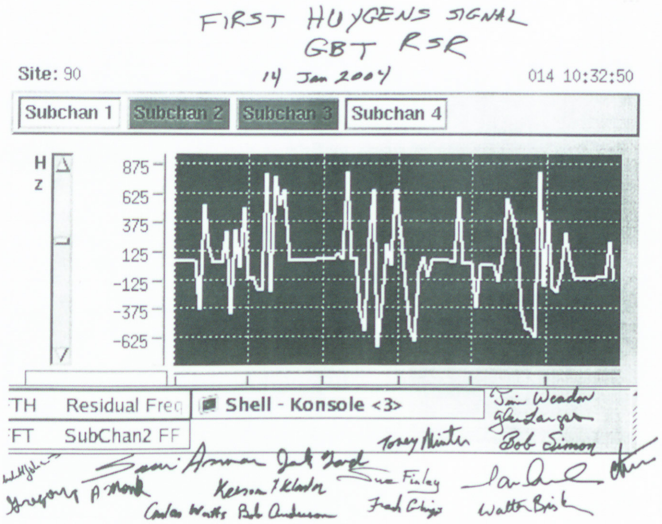

Figure 2. The signal as recorded by the RSR. The X-axis is about 20 minutes of time, and the Y-axis is the deviation from the expected frequency of the signal. The flat line parts are the signal from Huygens; the deviations occurred when the telescope was pointed to a nearby calibration source.

of the new Mark 5 units was demonstrated. These shakedown sessions were well worth the effort, bringing to light a number of unanticipated problems. In the actual observation, all these systems worked flawlessly.

On the morning of the big event, the GBT control room was crowded, with not only the JIVE and NASA crews, but also programmers, engineers, and telescope maintenance people standing by to fix quickly any problem that might occur. A webcam system provided images of this activity to the rather smaller number of us monitoring the VLBA's performance in the AOC. Bob Anderson, the GBT chief telescope engineer, was prepared to bend the bad-weather shutdown rules, but fortunately the predicted blizzard did not materialize. Extremely cold temperatures overnight at the VLBA North Liberty station left an azimuth brake frozen, but quick action by the site techs there resulted in only a negligible loss of observing time. North Liberty was also the only station where serious interference was seen in the absence of the front-end filters. The Mauna Kea station experienced unusually strong wind gusts throughout the run, which fortunately stayed just below the auto-stow limit except for a brief period when the antenna was pointed directly into the wind.

There was much nervous anticipation until the Huygens signal appeared at just about the predicted time. Those of us watching in Socorro saw everyone in the GBT control room suddenly congregate around one monitor and then break into cheers. Shortly afterward, Green Bank personnel heard the cheers from the ESA control center in Darmstadt over the speaker phone when Sami Asmar told them the GBT had detected the signal.

The Huygens Probe's power system outperformed its specifications; the probe was still transmitting as the end of scheduled observing approached on the VLBA. Huygens had set at all stations but Mauna Kea by that time, but we were able to continue observing there for another hour, until the start of the next scheduled program occurred with Huygens at a very low elevation. Indeed, Huygens continued to transmit for hours, and plans were made to observe at some European VLBI Network stations if it continued until rising there. An abrupt change in the Doppler shift, as Huygens finally landed on the surface of Titan, was reported from the Parkes radio telescope in Australia, and shortly afterwards the signal finally disappeared.

After the experiment, we learned that there had been a receiver failure on the Cassini orbiter, and all Doppler velocity data had been lost. Thus, the ground-based measurements, from Green Bank, the VLBA, and other participating observatories, will be the only measurements of velocity during the probe's descent through the atmosphere of Titan. The correlation and analysis of the 17-station VLBI data are in progress at JIVE. Fringes have been found from the phase-reference source on most baselines, and the Huygens signal has been seen in the autocorrelations. The work of extracting the correlated Huygens signal has begun.

NRAO personnel who participated in this exciting experience included: Bob Anderson, Walter Brisken, Pete Chestnut, Chris Clark, Juan Cordova, John Ford, Doug Gerrard, Frank Ghigo, Don Haenichen, Phillip Hicks, Glen Langston, Dan Mertely, Greg Monk, Roger Norrod, Jim Ogle, Peggy Perley, Tony Perreault, Paul Rhodes, Jon Romney, Bob Simon, Craig Walker, Galen Watts, Tim Weadon, and Brian Willard.

F. Ghigo and J. Romney

GBT Student Support Program: Announcement of Awards

Four awards were made in December as part of the GBT Student Support Program. This program is designed to support GBT research by graduate or undergraduate students at U.S. universities or colleges, thereby strengthening the proactive role of the Observatory in training new generations of telescope users.

The December awards were in conjunction with approved observing proposals submitted at the October deadline. Awards were made for the following students:

- Paul Demorest (UC Berkeley) in the amount of \$33,000 for the proposal entitled *"Precision Timing of Binary and Millisecond Pulsars"*.

- Laura Hainline (Caltech) in the amount of \$31,600 for the proposals entitled *"Survey for CO(1-0) from dusty submillimeter galaxies at known redshifts"*, *"Searching for cool molecular gas in high-z submillimeter-bright QSOs from CO(1-0) at GBT"*, and *"Detecting CO(1-0) in representative high-redshift dusty galaxies using giant gravitational lenses"*.

- Tim Robishaw (UC Berkeley) in the amount of \$2,100 for the proposal entitled *"Constraining the Magnetic Field in the Taurus Molecular Cloud"*.

- Tim Robishaw (UC Berkeley) in the amount of \$3,000 for the proposal entitled *"Threading the Magnetic Slinky: Mapping the Zeeman Effect in the Eridanus/Orion Region"*.

New applications to the program may be submitted along with new GBT observing proposals at any proposal deadline. For full details, restrictions, and procedures, select "GBT Student Support Program" from the GBT astronomers page. For a cumulative record of past awards under this program, select "GBT Student Support Status" from the GBT astronomers page.

K.E. Johnson (U Virginia), D.J. Nice (Princeton U), J.E. Hibbard, P.R. Jewell, F.J. Lockman, J.M. Wrobel

Japanese Film Crew Documents Space VLBI Research in Green Bank

On February 24 and 25, 2005 the Green Bank site was turned into a movie set for the filming of a documentary of the Japanese Space Very Long Baseline Interferometer (VSOP) mission. This documentary, funded by the Japanese government, was shot at several locations across the globe, with Green Bank being chosen due to the prominent roles that the Green Bank Earth Station and the 140 Foot Telescope played in this mission. The documentary will be used for science education in high schools throughout Japan.

Two scientists from the VSOP mission, Phil Edwards and Yashuhiro Murata, along with three people from Image Science (the film's production company) arrived in Green Bank on the night of February 23 just in time to beat the arrival of a snowstorm. Filming proceeded continually over the next two days. Filming highlights included an interview of Ed Fomalont in front of the GBT, recreating a VSOP tele-conference (with Toney Minter, Ed Fomalont and Galen Watts "participating" in Green Bank), and the Green Bank Earth Station simulating a tracking pass. Many shots of the site were also made after four-wheeling through the snow (without getting stuck) to get the right camera angles on a gorgeous day after the snowstorm.

Filming the three-minute teleconference required almost an hour of preparation. The film crew set up additional lighting as a cloudy day failed to provide enough light for filming in the upstairs conference room. For context, the Green Bank participants were shown portions of the teleconference already shot and into which the Green Bank sequences would be edited. The on-site sequences were then shot from two different angles, and the Green Bank participants improvised a short "technical" conversation regarding the OVLBI tracking station. After the two days of filming, we have a new-found respect for those in the film industry.

Toney Minter, Galen Watts, Glen Langston

New Results

A Large Gas Disk Around a Small Galaxy

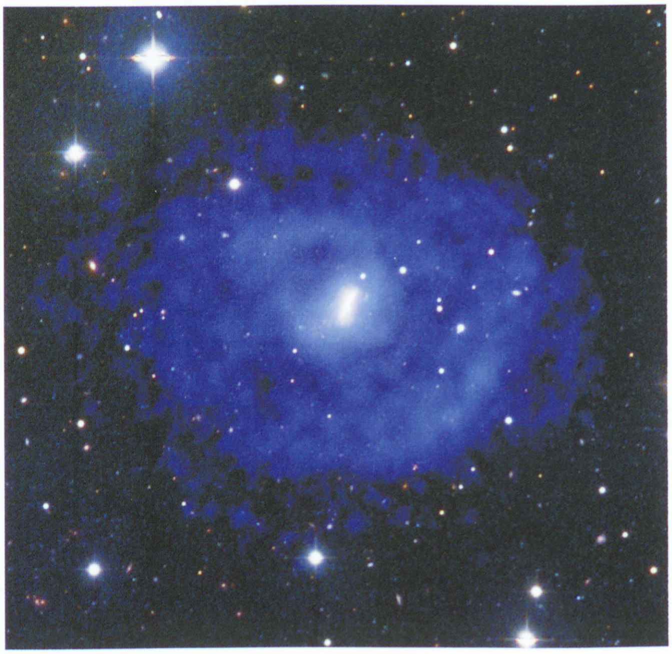

Figure 1: The HI disk of UGC 5288 is shown in blue in this optical/HI color composite image. The stellar component is confined within the inner pink/white region. The HI image is from the VLA, and the optical images were obtained with the KPNO 0.9m telescope.

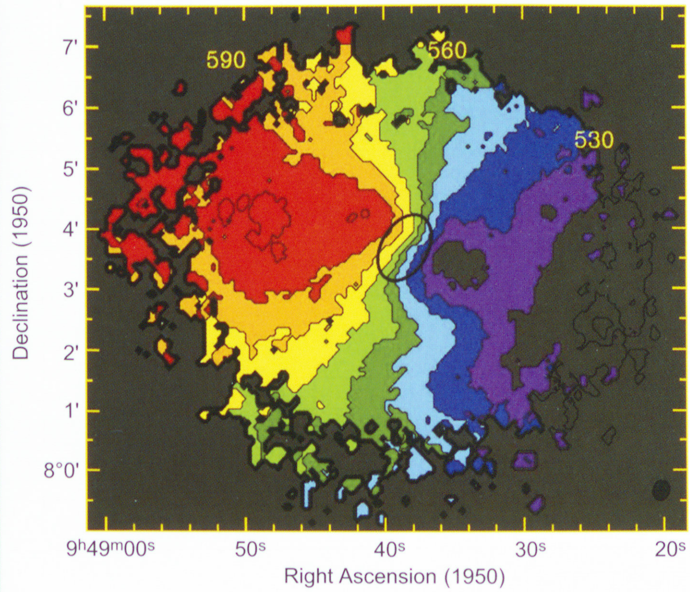

Figure 2: The velocity field of the neutral hydrogen gas. Although a slight warp is present, the outer gas disk is undergoing organized, coherent rotation. Combined with the lack of known near neighbors, the ordered kinematics indicates that the extended gas may be a remnant of the nascent HI envelope rather than the result of tidal interactions.

Neutral hydrogen (HI) observations with the Very Large Array (VLA) have revealed an extensive gas disk around the low-luminosity dwarf irregular galaxy UGC 5288 (van Zee 2004, AAS, 205, 9319). While most gas-rich galaxies have HI disks up to twice the diameter of the stellar component, the gas disk associated with UGC 5288 can be traced to a diameter more than seven times larger than the optical system (Figure 1). The large gas disk may be a remnant of the nascent envelope from which the galaxy collapsed. In addition, such a large gaseous envelope represents a reservoir for future star-formation activity in this low-mass galaxy.

The VLA observations of UGC 5288 were obtained as part of a study of the connection between the neutral gas distribution and the kinematics, star-formation activity, and metal enrichment of dwarf irregular galaxies (van Zee & Haynes, in preparation). UGC 5288 was selected for this study because it appeared to be a typical dwarf irregular galaxy. UGC 5288 is a low-luminosity galaxy ($M_B = -14.44$) with blue colors ($B-V = 0.46\pm0.06$) and a modest current star-formation rate (0.0083 solar masses per year). The stellar component has an optical diameter of 1.8×1.2 kpc and a scale length of 0.23 kpc. Prior optical imaging and spectroscopy did not suggest that this galaxy would reside in a large reservoir of neutral hydrogen.

The VLA observations revealed that the HI disk has a diameter of 12.7×8.7 kpc (i.e., it can be traced to more than 27 optical scale lengths). The majority of the HI is located outside the optical disk; less than 1/8 of the HI is coincident with the optical galaxy. The gas density peaks in two knots offset from the optical and kinematic centers. The knot having the highest column density is spatially coincident with the bright ionized hydrogen region in the northwest. The outer gas is distributed asymmetrically; a large clump of neutral gas is located 150-170 arcsec to the southwest. Inspection of deep optical images obtained with the WIYN 3.5m telescope indicates that there is no optical emission associated with this clump to a surface-brightness level of 27.5 mag arcsec^{-2} in the R band.

The gas kinematics (Figure 2) indicates that the extended gas distribution has coherent ordered rotation along an axis (PA = 74 deg) nearly perpendicular to the optical axis (PA = 145 deg). With a maximum rotation velocity of 68 km s^{-1} at a radius of 6.4 kpc, UGC 5288 has a dynamical mass of 6.98×10^9 solar masses, which is a factor of 30 more than the mass of HI. Thus, like most dwarf irregular galaxies, UGC 5288 is a dark-matter-dominated galaxy.

Possible origins of the diffuse gas disk around UGC 5288 include (1) the disk is the remnant of a galactic fountain (perhaps created after a past starburst episode); (2) the disk is tidal debris created during a recent encounter; and (3) the disk is a remnant of the nascent material from which the galaxy collapsed. Possibilities (1) and (2) are unlikely since the distribution and kinematics of the extended gaseous disk around UGC 5288 indicate that the gas is relatively quiescent and is in stable orbits. For example, if the extended gas were the result of infalling material raining down in the gravitational potential, one would expect higher velocity dispersions and less order to the velocity field than observed. The disk does have a significant warp, which could be the result of a recent encounter. However, the nearest known galaxy at a similar redshift is another low-luminosity dwarf irregular galaxy, IC 559, 220 kpc away. Thus, it is unlikely that the extended gas distribution is a remnant of a tidal tail, although a previous encounter may have been sufficient to warp the disk.

The HI envelope around UGC 5288 appears to be dynamically stable, which supports the hypothesis that the large gaseous disk is primordial in nature. In particular, the surface density of the disk falls significantly below the Toomre instability threshold for star formation at all radii. In fact, the gas density of the outer gas disk is more than a factor of 10 below the instability threshold. Given the low gas density and apparent stability of the disk, it should not be surprising that there is no significant star-formation activity in the outer disk, despite the presence of a significant gas mass.

The existence of quiescent, extended gaseous disks around a handful of dwarf irregular galaxies is puzzling. At present, there are no obvious unifying features among the three isolated galaxies known to have large quiescent gas envelopes: UGC 5288, DDO 154, and NGC 2915. All three are gas-rich low-luminosity galaxies, but UGC 5288 and NGC 2915 are high-surface-brightness compact galaxies whereas DDO 154 is a low-surface-brightness diffuse galaxy. DDO 154 inhabits an over-dense region of the nearby universe, while UGC 5288 and NGC 2915 are relatively isolated. Further, since all of these extended gaseous disks were discovered serendipitously, it is difficult to quantify the fraction of dwarf irregular galaxies that could host such disks. Clearly, such disks are relatively rare, but it is also quite likely that additional extended gas disks will be discovered as more galaxies are imaged in the neutral hydrogen line. Future detections of extended, quiescent gas disks will be necessary to quantify the fraction of galaxies with extended gas distributions and to enable a statistical examination of the host galaxies, their environments, morphologies, and the role of the gaseous disks in their evolution.

Liese van Zee (Indiana University)

Heating the Hot Gas in Galaxy Clusters by Energetic Radio Jets

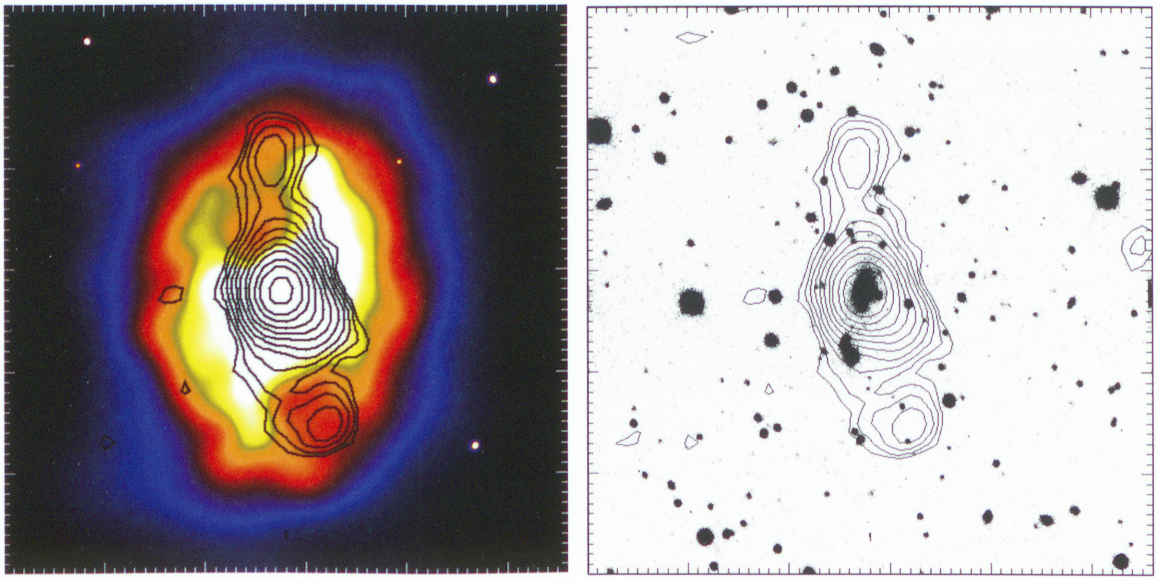

Figure 1. The relationships among the X-ray, radio, and optical sources in MS0735.6+7421. The smoothed X-ray image (left) and optical image (right) are superposed on the 1.4 GHz radio contours. The 40 ksec X-ray image was obtained with the Chandra X-ray Observatory on December 1, 2003. The radio map, with 4 arcsec resolution, was made with the Very Large Array telescope in the C configuration. The X-ray cavities are filled with radio emission. Each cavity is roughly an arcmin in diameter (200 kpc) centered approximately 125 kpc to the north-east and to the south-west of the cluster center. Each image is 250×250 arcsec (875×875 kpc) on a side.

Radio jets emanating from the nuclei of galaxies are the outward conduit for gravitational binding energy and momentum generated by accretion onto supermassive black holes. Jets transport energy and momentum over decades in distance from a region in the nucleus the size of our solar system into the halo of the host galaxy. There the jet and its accompanying shock front interact with the surrounding matter causing gas clouds to glow in emission lines, and occasionally trigger star formation. But perhaps the most spectacular examples of jet interactions are the giant X-ray cavity systems that NASA's Chandra X-ray Observatory has discovered in the hot halos of many galaxies, groups, and clusters of galaxies.

The cavities are usually about 10 kpc (about 30,000 light years) in diameter and are devoid of gas at ambient temperatures. However, they are often filled with radio emission. Because the X-ray emissivity of the hot gas surrounding them is sensitive to the density and temperature of the gas, the pressure p exerted by the hot gas on the cavities can be deduced. Diameters and, by geometry, the volumes V of cavities can be measured to fairly high precision, yielding the work $W = pV$ done on the surrounding hot gas by the jets during the inflation phase of the cavities. This method gives a direct measurement of the jet energy and requires no knowledge of magnetic field strength or energy partitioning. Nor does it require a radio map.

Cavity systems in rich clusters, like jets, are usually found in pairs with typical energies of 10^{59} erg. The enthalpy of a cavity (free energy), the important quantity for jet heating, ranges between $\sim 2\,pV$–$4\,pV$, depending on the state of the matter filling it. Knowledge of this quantity is relevant to a variety of problems including the quenching of cooling flows, the growth of supermassive black holes, cluster and group "preheating," the creation and dispersal of large-scale magnetic fields, and the nature of radio sources themselves.

My colleagues and I recently discovered an enormous pair of "supercavities" in the $z = 0.22$ cluster MS 0735.6+7421, each of which is nearly 200 kpc in diameter. Observations with the Very Large Array (VLA) show that the X-ray cavities are filled with radio emission at 1.4 GHz (Figure 1) and are surrounded by a weak (Mach 1.4) but powerful shock front resembling a radio cocoon. The shock energy is an astonishing 6×10^{61} erg, which agrees with the cavity enthalpy to within the measurement error.

To put this figure in perspective, it represents the combined energy of several hundred million supernova explosions and gamma-ray bursts. It's enthalpy is roughly 250 times larger than the heralded cavity system in the Perseus cluster and is more than four orders of magnitude larger than the cavity system in M87. Furthermore, the power generated by the jets over the 100 Myr age of the shock front exceeds the cluster's bolometric X-ray luminosity by 15 times. This outburst is having a significant impact on the entire gaseous halo.

At the same time, the radio source is relatively weak in spite of its large size (550 kpc long). The shock energy exceeds the 1.4 GHz radio luminosity by more than five orders of magnitude! We know from the aggregate properties of cavities that jet power can exceed the 1.4 GHz luminosity by factors of 100-1000, but never before have we seen such a powerful outburst accompanied by such a feeble radio source.

The consequences of this discovery are far reaching. Periodic nuclear activity punctuated now and then by powerful outbursts would supply enough energy to the hot gas to balance radiative cooling and reduce or quench a cooling flow. It now appears that cooling flows are governed by a feedback cycle in which the hot gas cools and accretes onto the central cluster galaxy, fueling star formation and the active galactic nucleus. (In fact the roughly one billion solar-mass black hole that created MS0735's cavities must have accreted nearly one third of its mass during the outburst.) The ensuing outburst heats the gas and stops the inflow until cooling can be reestablished, and the cycle repeats. This is the prescription for galaxy formation governed by supermassive black holes.

Finally, powerful outbursts could be the key to understanding the the long-standing "preheating" problem with groups and clusters. The relationship between the temperature and luminosity of the hot gas in these systems is steeper than expected from a collapse governed by gravity alone. The outburst in MS 0735.6+7421 has contributed $\sim 1/3$ kev per particle of heat to the surrounding gas, which is a significant fraction of the $1-3$ keV of preheating required steepen the slope to the observed level. Evidently only several outbursts of this magnitude over a cluster's lifetime would do the job.

Although the most powerful outbursts must be relatively rare, my colleagues and I have already found two other systems with burst strengths that lie within an order of magnitude of MS 0735.6+7421. So it appears that the supermassive black holes lurking at the centers of galaxy clusters play an important role in the development of the giant galaxies in which they reside and the vast halos of gas surrounding them.

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A Pulsar Jackpot in Terzan 5 with the GBT

For over 20 years astronomers have known that globular clusters over-produce millisecond pulsars (MSPs) compared to the Galactic disk per unit mass. Because timing observations of multiple MSPs in a cluster provide unique probes into pulsar physics, cluster dynamics, and binary evolution (e.g. Freire et al. 2003, MNRAS, 340, 1359), and the fact that clusters can (theoretically) produce truly exotic objects (such as MSP-MSP or MSP-black hole binaries), several groups have expended significant effort searching clusters deeply for radio pulsars. One of the most promising, but previously disappointing, targets has been the globular cluster Terzan 5 (Figure 1).

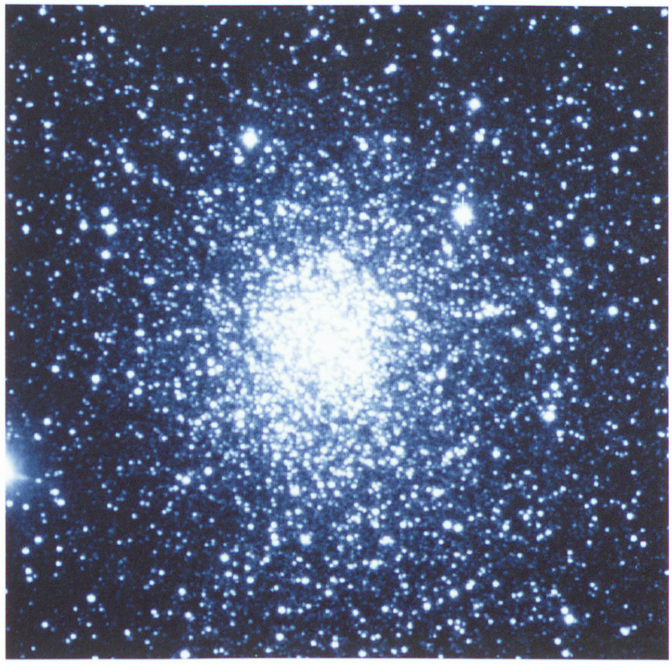


Figure 1. An I-band image of Terzan 5 taken with the NTT telescope during exceptional seeing conditions (~0.3"). Image courtesy S. Ortolani/ESO.

Terzan 5 is a dense, massive, and pre-core-collapse globular cluster located near the center of our Galaxy (D~9 kpc, l=3.8 deg, b=1.7 deg) that has been predicted to contain tens or even hundreds of pulsars, more than perhaps any other cluster (e.g. Kulkarni & Anderson, 1996, IAUS, 174, 181). VLA imaging of Terzan 5 (Fruchter & Goss, 2000, ApJ, 536, 865) supported these predictions by detecting steep-spectrum point sources and diffuse emission near the core, indicating that perhaps 60-200 unresolved pulsars were contributing to the measured radio flux. However, deep pulsation searches had only uncovered three pulsars.

With the Green Bank Telescope (GBT) and the new Spigot pulsar backend (produced by a collaboration between Caltech and NRAO), we observed Terzan 5 for six hours in July 2004 at the higher-than-usual frequency of 2 GHz where 600 MHz of relatively interference-free bandwidth is available. The large gain of the GBT, the wide observing bandwidth, and the decreased scatter broadening and dispersive smearing caused by observing at 2 GHz resulted in an observation that was 5-20 times more sensitive than the best searches of Terzan 5 conducted to date. As we began searching the data (using a tremendous number of CPU cycles at both Green Bank and McGill University), new pulsars began appearing in our candidate lists with a startling regularity: we had hit the pulsar jackpot. From that observation alone, we uncovered 14 new MSPs, by far the most pulsars ever discovered in a single pointing.

Additional GBT observations have resulted in at least nine additional MSPs, bringing the total known in Terzan 5 to 26, the most of any globular cluster. 47 Tucanae was the previous record holder with 22 known pulsars. The spin periods of the pulsars in Terzan 5 (Figure 2) span a much wider range than those in 47 Tuc and appear to be drawn from a different underlying distribution, which may indicate different dynamical conditions in the cluster cores. In addition, the four fastest MSPs known in any Galactic globular cluster are in Terzan 5.

Fourteen of the new MSPs are members of binary systems, several of which appear to be of significant scientific interest individually. Ter5E is in ~60 day orbit, which is very long for a cluster pulsar and may indicate that it resides in the relatively placid outskirts of Terzan 5. Ter5N appears to have a Carbon-Oxygen white dwarf as its companion, the first such system known in a cluster. Ter5O and P are the third and

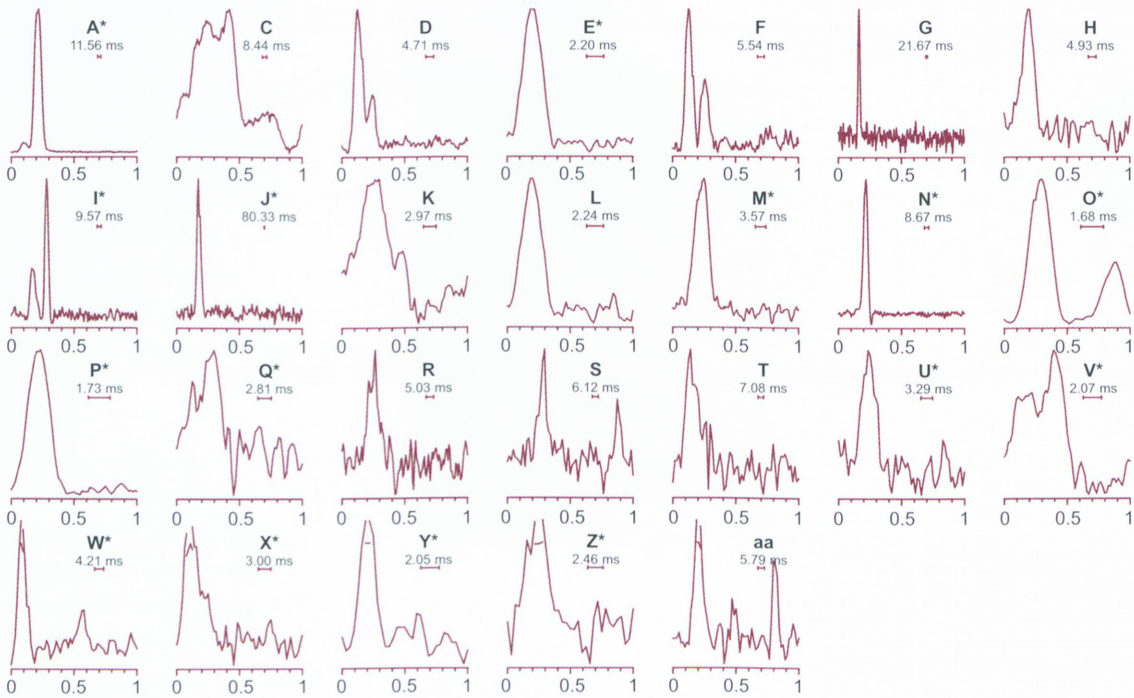


Figure 2. Average pulse profiles and periods for the 26 currently known pulsars in Terzan 5. Asterisks indicate that the pulsar is in a binary system, and the length of the horizontal error bar (0.3 ms) is the effective system time resolution at a center frequency of 1950 MHz.

fourth fastest known MSPs and are also eclipsing systems. Ter5O is a "Black Widow" system consuming its very low-mass companion (~$0.04M_{\odot}$), while the irregularly eclipsing Ter5P seems to have exchanged its original white-dwarf partner for a strange evolved star with a mass of ~0.4 $M_{\odot}$.

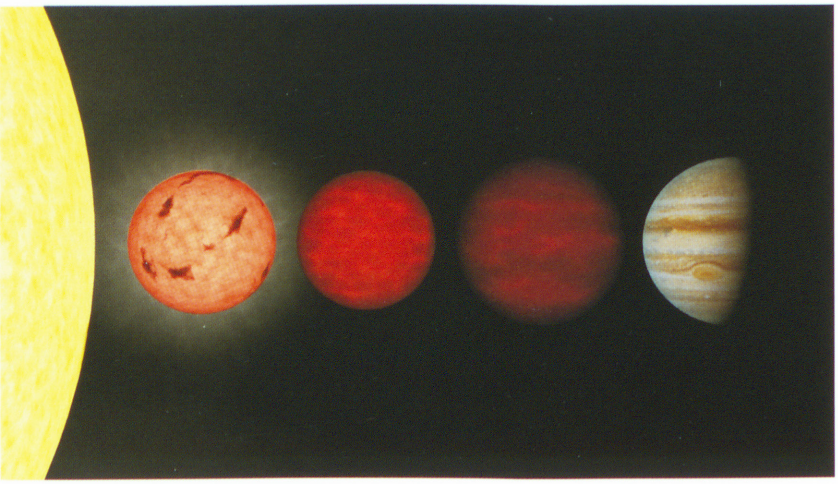
The truly stand-out systems so far, though, are Ter5I and J. These pulsars are both in compact (~30 hour orbital period) but highly eccentric (e~0.4) orbits around what are likely white-dwarf companions of mass 0.3-0.4 $M_{\odot}$. We have measured the precession of periastron for both systems to be ~0.3 deg/yr, which if due to general relativity, indicates that the total masses of each of the systems are ~2.2 $M_{\odot}$. When combined with our knowledge of the mass functions, this implies that the pulsars are significantly more massive than any well-measured pulsar to date: at 95 percent confidence, at least one of these pulsars has a mass >1.68 $M_{\odot}$. If proven correct over the next year or two by more detailed timing observations, such high masses will rule out several "soft" equations of state for matter at nuclear densities.

Our ongoing timing observations will result in precise positions for each of the pulsars by the end of the summer (and thereafter possible infra-red or X-ray identifications), and a wealth of science about the pulsars and Terzan 5 itself will soon follow. In addition, new search algorithms, observations at different frequencies, and improvements to the Spigot make future searches very encouraging: our measurements of the flux densities of the currently known pulsars indicate that perhaps one hundred more MSPs remain to be detected in Terzan 5.

Note: Additional details of the observations, data analysis, and results can be found in Ransom et al. 2005, Science, 307, 892. Significant thanks go to the Canada Foundation for Innovation for funding the Beowulf cluster at McGill University upon which we have been highly dependent.

Scott Ransom (NRAO), Jason Hessels (McGill Univ), Ingrid Stairs (UBC), Paulo Freire (Arecibo), Fernando Camilo (Columbia), Victoria Kaspi (McGill Univ), David Kaplan (Caltech/MIT)

VLA Investigates Radio Emission from Brown Dwarfs



Artist's conception of, from left to right, the relative sizes of the Sun, an M dwarf, an L dwarf, a T dwarf, and Jupiter.

Astronomers now suspect that radio emission from brown dwarfs indicates magnetic activity on these sub-stellar objects, in possible agreement with magnetic activity signatures seen on higher-mass stars. Magnetic fields are known to be important in producing both persistent and variable atmospheric heating in late-type stars, heating plasma to temperatures from 10^4–10^6 K (seen at optical, ultraviolet, and X-ray wavelengths), and accelerating the energetic particles which produce nonthermal radio emission.

Many recent results give conflicting evidence about the survival of and nature of magnetic activity on extremely cool dwarfs. The decrease in the fraction of chromospherically active stars at spectral types later than M8 suggests that magnetic activity is dying in ultracool stellar objects (West et al. 2004). This has been explained theoretically as a temperature effect—the increasingly neutral and dense cool atmospheres in late M/early L objects have large resistivities and thereby prevent the buildup of magnetic stresses and subsequent magnetic heating of their atmospheres (Mohanty et al. 2002). While the bulk of ultracool dwarfs do not demonstrate persistent magnetic activity, it is puzzling that any activity remains. There are lines of evidence which suggest that magnetic activity does survive in some form: the reports of dramatic Hα variability in some ultracool dwarfs (Liebert et al. 2003, Reid et al. 1999) which show no evidence for Hα emission outside of flares, frequent reports of sporadic X-ray flares with no detectable levels of quiescent emission (Rutledge et al. 2000, Hambaryan et al. 2004), and detections at radio wavelengths (Berger et al. 2001, Berger 2002).

The radio detections are important because radio emission from late-type stars is traditionally ascribed to gyro-synchrotron emission from a population of mildly relativistic electrons in magnetic fields. If the interpretation of the origin of radio emission from ultracool stars/brown dwarfs is the same as that from active stars, then this is confirmation that magnetic activity is indeed surviving into the brown-dwarf regime. Radio observations can address magnetic activity in the brown-dwarf regime in two ways: the first is to assess how common radio emission from brown dwarfs is, and the second is to explore the nature of the radio emission via its spectral and polarization characteristics.

The first is being addressed by a volume-limited VLA survey of 65 late M, L, and T dwarfs closer than 13 pc. We observed at a frequency of 8 GHz to match the frequencies where previous detections have been made and to allow for a comparison of radio properties with nearby M dwarf stars. An NRAO summer student, Lynnae Quick, from the North Carolina Agricultural and Technical State University, spent the summer of 2004 reducing the first parts of the data set. She presented her results at the 205th meeting of the American Astronomical Society in San Diego, CA. Out of the ten objects she studied, three (2 L dwarfs and a T dwarf) showed signs of being radio emitters. The reduction and analysis of this dataset is ongoing. The systematic trends of radio emission with spectral type, rotation rate, age, and mass (or internal structure), as well as correlations with other magnetic activity signatures, will be explored.

The second is being addressed by sensitive multi-frequency observations of radio-detected objects. While the survey is guaranteed to improve the statistics of radio emission from brown dwarfs, it does not determine the origin of the emission. By studying the detailed characteristics of the radio emission, notably its spectral distribution and polarization, we can test the gyrosynchrotron emission mechanism and explore simple magnetic geometries. Astronomers R. A. Osten, T. Bastian (NRAO), and S. L. Hawley (U. of Washington) explored the radio emission from the M9 dwarf TVLM513–46546 in January 2004, using the VLA in its BnC configuration and observing at 20, 6, and 3.6 cm wavelengths. Detections at both 3.6 and 6 cm provide spectral-index measurements of -0.4 ± 0.1 (flux decreases as frequency increases), and an upper limit at 20 cm suggests that the spectral peak lies between 1.4 and 5 GHz. Upper limits of circular polarization at 3.6 and 6 cm are <15 percent. These characteristics agree well with typical parameters for early to mid-M dwarfs.

R. A. Osten

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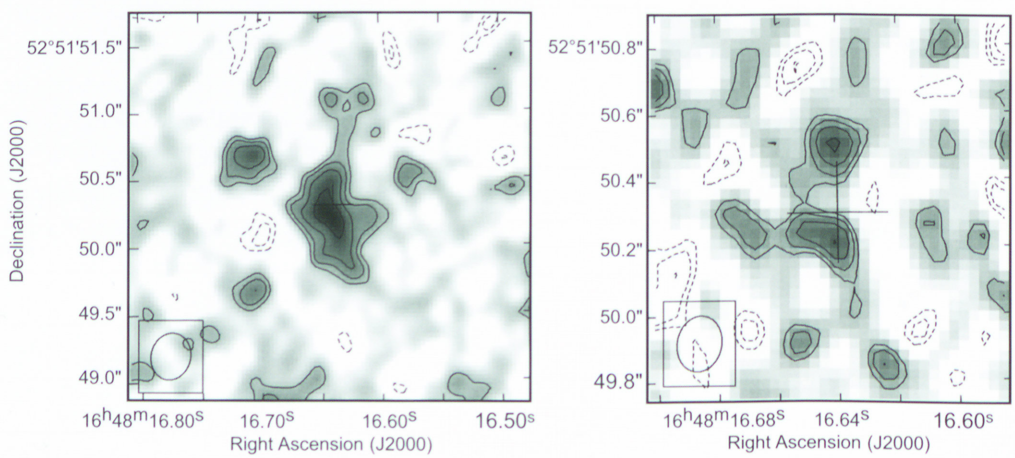
Molecular Gas in the First Galaxies



CO 3-2 emission from SDSS J1148+5251 at z=6.42. Left: The VLA image at 0.3" resolution. The beamsize shown in the lower left implies that the source is clearly resolved. Right: The VLA image at 0.15" resolution (Walter et al. 2003, 2004; Bertoldi et al. 2003). At this resolution the central source breaks up into two peaks. The cross shows the SDSS position of the optical QSO (White et al. 2005).

Also relevant to these studies of high-z QSO host galaxies is the the now well-established correlation between black-hole mass and the velocity dispersion of the stars in the host spheroidal galaxy (the "M_{bh}–σ_v relation"). This correlation suggests a causal relation between the formation of supermassive black holes (SMBH) and spheroidal galaxies (Gebhardt et al. 2000).

Walter et al. (2004) recently presented high-resolution Very Large Array (VLA) images of the carbon monoxide (CO) 3–2 emission from the quasistellar object (QSO) SDSS J1148+5251 at the highest known redshift: $z=6.42$. These observations have pushed radio studies of galaxy formation into the epoch of cosmic reionization when the first luminous sources (active galactic nuclei and stars) reionized the neutral intergalactic medium.

The low-resolution VLA image (left figure) reveals extended CO 3–2 emission on a scale of ~1", or 6 kpc (about 20,000 light years). The high-resolution VLA image (right figure) shows two compact emission features separated by 0.3", with the compact components comprising about half the total CO luminosity. Walter et al. speculate that SDSS J1148+5251 is a merging galaxy system havng extended tidal features and a double nucleus, although the relative radio-optical astrometric accuracy is insufficient to identify unambiguously the optical QSO with either compact molecular-gas component.

The intrinsic brightness temperature of the CO emission in the compact components is about 20 K. This value is similar the CO brightness temperatures in nearby starburst nuclei (Downes & Solomon 1998). The host galaxy of SDSS J1148+5251 shows starburst characteristics in a number of other ways: (i) it follows the radio/far-infrared (FIR) correlation (Carilli et al. 2004), (ii) the CO excitation ladder up to CO 7–6 is similar to that in the nucleus of the nearby starburst galaxy NGC 253 (Bertoldi et al. 2004), and (iii) the dust-to-gas ratio is comparable with those of nearby starbursts. If the FIR luminosity of SDSS J1148+5251 results from star formation, the implied star-formation rate is about 1,000 solar masses per year.

The CO image also allows a rough estimate of the dynamical mass of the host galaxy. We note that these observations are the only method for determining such a dynamical mass for the host galaxy of a high-z QSO. Walter et al. (2004) found that the host-galaxy dynamical mass inside a radius of about 3 kpc is $\sim 5\times 10^{10}$ solar masses, which is comparable with the total molecular-gas mass derived from the CO luminosity. This suggests that the mass in the inner few kpc is baryon dominated, as are nearby elliptical galaxies and ultra-luminous infrared galaxies, although for elliptical galaxies the mass is in stars, not molecular gas. Walter et al. also pointed out that the predicted spheroidal-galaxy mass based on the $M_{bh}-\sigma_v$ relation is more than a factor of ten larger than the measured dynamical mass. This suggests a breakdown in the $M_{bh}-\sigma_v$ relation at the highest redshifts, with the implication that the SMBH forms prior to the host galaxy.

Overall, the radio observations of the host galaxy of the z=6.42 QSO SDSS J1148+5251 suggest a massive starburst coeval with the nuclear activity in a merging galaxy system. The star-formation rate is sufficient to form a large spheroidal galaxy in a dynamical timescale, about 10^8 years. This conclusion is qualitatively consistent with the coeval formation of SMBH through Eddington-limited accretion and spheroidal galaxies, although the VLA observations suggest that the SMBH may form prior to the main stellar component of the host galaxy. Formation of massive galaxies in dramatic starbursts at high z is also consistent with the recent "downsizing" scenario for galaxy formation in the context of ΛCDM structure-formation models (Bundy et al. 2005).

Pushing into the earliest epochs of galaxy formation is a major goal for the Atacama Large Millimeter Array (ALMA) and the Expanded Very Large Array (EVLA). The VLA results on SDSS J1148+5251 have presaged such studies by finding massive reservoirs of molecular gas, the necessary fuel for galaxy formation, even at these extreme redshifts. Unfortunately, current radio telescopes are able to study only exceptionally luminous galaxies. The EVLA and ALMA will be able to detect relatively normal galaxies at these epochs and hence provide the necessary complement to future near-infrared telescopes such as the James Webb Space Telescope (JWST), with the near-infrared telescopes revealing the stars and ionized gas while the EVLA and ALMA provide the unique capability to image the molecular gas, dust, and star-formation activity in the first galaxies. Hence, future facilties at radio through near-infrared wavelengths will provide a panchromatic view of the earliest galaxies, constraining all key elements in galaxy formation.

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