ALMA Newsletter

October 2009

ALMA

Introduction

Dear ALMA newsletter recipients,

once more it's a pleasure for me to introduce the new edition of our newsletter.

It's a very special phase in the development of ALMA, since we successfully transported our first antenna to the high altitude Chajnantor plateau, at 5000 meter altitude. This is clearly the beginning of a new era of the life of ALMA as the first elements of this revolutionary instrument are now getting into place. In the first section of this newsletter, we relate the story of this memorable day and give you the possibility to download images from this undertaking. Then, we highlight three areas in the ALMA project. The first concerns the construction projects, both at the Array Operations Site (AOS) where data will be taken by the antennas and at the Operations Support Facility (OSF) where antenna tests are presently carried out. In a second area, we invite you behind the scenes of ALMA, to discover the day-to-day life of our round-a-clock revolutionary observatory. Finally, the third area is the first of a series of 2 "ALMA in Depth" article about the amazing process that led to the design and construction of the most sophisticated submillimeter wavelength antennas ever made.

Enjoy ALMA's universe!

Thijs de Graauw, ALMA Director

The Atacama Large Millimeter/submillimeter Array (ALMA), an international astronomy facility, is a partnership of Europe, North America and East Asia in cooperation with the Republic of Chile. ALMA is funded in Europe by the European Organization for Astronomical Research in the Southern Hemisphere (ESO), in North America by the U.S. National Science Foundation (NSF) in cooperation with the National Research Council of Canada (NRC) and the National Science Council of Taiwan (NSC) and in East Asia by the National Institutes of Natural Sciences (NINS) of Japan in cooperation with the Academia Sinica (AS) in Taiwan. ALMA construction and operations are led on behalf of Europe by ESO, on behalf of North America by the National Radio Astronomy Observatory (NRAO), which is managed by Associated Universities, Inc. (AUI) and on behalf of East Asia by the National Astronomical Observatory of Japan (NAOJ). The Joint ALMA Observatory (JAO) provides the unified leadership and management of the construction, commissioning and operation of ALMA.

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Focus on...

ALMA reaches new heights

The ALMA (Atacama Large Millimeter/submillimeter Array) astronomical observatory has taken another step forward and upwards. One of its state-of-the-art antennas was carried for the first time to the 5000m plateau of Chajnantor, in the Chilean Andes, on a custom-built giant transporter. This antenna, a Japanese contribution, weighs about 100 tons and has a diameter of 12 meters, was brought to the high-altitude Array Operations Site, where the extremely dry and rarefied air is ideal for ALMA's observations of the universe.

"This milestone is the culmination of 8 months of effort by ALMA engineers and scientists in assembling and verifying the performance of the antenna over the range of operations needed to confirm its readiness for scientific commissioning", said Joseph McMullin, ALMA Assembly, Integration and Verification (AIV) System Integration Lead.

In this picture, the antenna has just been lifted from its foundation at the OSF. From then, will start the move of the antenna to its final destination at 5000 meters.

"We in ALMA are living a very exciting moment with this epic transport of our first antenna to the definitive site. Day after day, the strength of our global collaboration leads us closer to the birth of what will be the greatest ground based astronomical observatory", said Thijs de Graauw, ALMA Director.

The conditions at the Array Operations Site on Chajnantor, while excellent for astronomy, are also very harsh. Only half as much oxygen is available as at sea level, making work there very difficult. This is why ALMA's antennas are assembled and tested at the lower 2900 m altitude of the ALMA Operations Support

Focus on...

Facility (OSF). It was from this relatively hospitable base camp that the ALMA antenna began its journey to the high Chajnantor site.

The trip began when one of the two ALMA transporters, lifted the antenna onto its back, carrying its heavy load along the 28 km road from the Operations Support Facility up to the Array Operations Site. While the transporter is capable of speeds of up to 12 km/hour when carrying an antenna, this first journey was made more slowly to ensure that everything worked as expected. This took about seven hours.

"Today, the first antenna, manufactured by Japan, was moved to the AOS at 5000 meters above sea level. As ALMA is a global partnership, we have coped with various difficulties due to differences in culture and language. However, we could reach here, thanks to the cooperation of the JAO staff working in Chile, NAOJ staff who worked hard for the evaluation of the antenna, and the Japanese vendor supporting the performance of the antenna", said Satoru Iguchi, East Asian ALMA Project Manager.

The ALMA antennas use advanced technology which has become available only in the last few years. These are the most sophisticated submillimeter wavelength antennas ever made. These are designed to operate fully exposed in the harsh conditions of the Array Operations Site. This means surviving strong winds and temperatures between -20 and +20 degrees Celsius while being able to point so precisely that they could pick out a golf ball at a distance of 15 km, and to keep their smooth reflecting surfaces accurate to better than 25 micrometers (less than the typical thickness of a human hair).

Above: The antenna on its way to the Chajnantor plateau. In the background is shown the OSF and the Atacama salt lake.

On the right: Quick stop along the ALMA road between the OSF to the AOS, in order to check all the components are working correctly.

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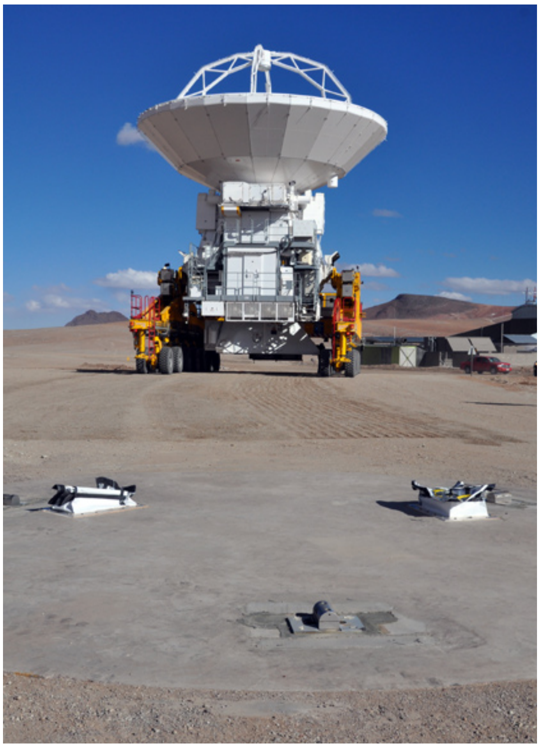

The transporter is shown carrying the antenna to the antenna foundation at the AOS

Once the transporter reached the high plateau, it carried the antenna to a concrete pad — a docking station with connections for power cables and fiber optics — and positioned it with an accuracy of a few millimeters. *"This is an important moment for ALMA. We are very happy that the first transport of an antenna to the high site went flawlessly. This achievement was only possible through contributions from all international ALMA partners"*, said Wolfgang Wild, European ALMA Project Manager.

"A Japanese antenna with North American electronics was carried by a European transporter! Now that we are starting to move the ALMA antennas to the high site, the real work begins and the exciting part is just beginning", said Adrian Russell, North American ALMA Project Manager

The transporter is guided by a laser steering system and, just like some cars today, also has ultrasonic collision detectors. These sensors ensure the safety of the state-of-the-art antennas as the transporter drives them across what will soon be a rather crowded plateau. Ultimately, ALMA will have at least 66 antennas which can be placed on any of about 200 pads, spread over distances of up to 18.5km and operating as a single, giant telescope. Even when ALMA is fully operational, the transporters will be used to move the antennas between pads to reconfigure the telescope for different kinds of observations.

The transporter is shown in the process of setting the antenna down on the antenna foundation. On the right side is a manlift, which if needed, allows to access the surface and subreflector of the antenna.

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This first ALMA antenna at the high site will soon be joined by others, and the ALMA team look forward to making their first observations from the Chajnantor plateau. They plan to link three antennas by early 2010.

ALMA will help astronomers answer important questions about our cosmic origins. The telescope will observe the Universe using light with millimeter and submillimeter wavelengths, between infrared light and radio waves in the electromagnetic spectrum. Light at these wavelengths comes from some of the coldest, but also from some of the most distant objects in the cosmos. These include cold clouds of gas and dust where new stars are being born and remote galaxies towards the edge of the observable universe. The Universe is relatively unexplored at submillimeter wavelengths, as the telescopes need extremely dry atmospheric conditions, such as those at Chajnantor, and advanced detector technology.

All these images and much more are available here.

Shown is a panorama of the AOS, with the antenna and transporter on the left, with the antenna positioned on its foundation. In the middle, on the hill, is the road from the OSF to AOS. To the right is the AOS Technical Building.

Progress at the ALMA site

Here is a short synopsis regarding the recent progress of the site construction work:

Array Operations Site (AOS)

The construction activities at the Array Operations Site (AOS) are moving forward at an impressive pace. It should be kept in mind that this is one of the largest, if not the largest, construction activities at such a high altitude.

There are three large-scale projects. The first is the pouring of concrete for the 197 antenna foundations. This was presented in detail in the last issue of this newsletter (more info here). This is complete for 152 foundations and work is ongoing for the remainder.

The second and third activities are the building of roads to allow access for transporting antennas to and from foundations and installation of utilities. This work is now underway. The contracts for the utilities are now settled, and the actual work begins at end August. The utilities include the optic fiber connections and also the power connections to each antenna. The cabling will be buried to insure temperature stability and also as a protection for the connections. The cabling will be connected to vaults in the antenna foundations and from there into the antennas. The power for the AOS will temporarily be provided by diesel-generators located at the AOS itself. The utilities construction is scheduled to be finished in 18 months time.

A photo of the work at the AOS site, at 5km elevation. In the foreground are antenna foundations for the Atacama Compact Array (ACA) for which the concrete pouring work is complete. For these, the power, signal connections and the antenna mounts must be installed. In the background is the AOS Technical Building.

Progress at the ALMA site

The more permanent solution for power is to be provided by an island mode power station located at the Operations Support Facility. The power source will be dual fuel (diesel or natural gas) turbines which drive generators. From this station, the power will be transmitted to the AOS via buried cables carrying the 23 KV current. At the AOS the power will be received in a substation containing transformers to provide the correct voltage at the site. There will be a flywheel arrangement to insure that the power has no voltage excursions that may damage the equipment at the AOS.

Operations Support Facility (OSF)

The Operations Support Facility (OSF) Technical Facility (TF) consists of three areas. These are: (1) the building containing the warehouse, electrical and carpenter shops, safety office and loading areas, (2) the antenna building which is closest to the antenna foundations, and (3) the Administration building, which is the largest structure. The installation of equipment in the OSF TF building for the Operations phase of ALMA is now approaching completion.

In the Administration building of the TF, one of the changes is equipping the large conference room for meetings, videocons and telecons. These modifications are nearly finished, and this is already being used for staff meetings. The carpentry and painting that make up the civil works in the computer room is largely finished. What remains is the installation of the high voltage supply. At present a provisional system is being installed, and the plans for the permanent system are finalized and this equipment should arrive soon. Likewise the civil works modifications of the ALMA control room are finished, and the handover to science is awaiting the installation of the high voltage power system. There are a number of laboratories in the TF administration building. For these, the civil works are finished, but the handover will occur after the high voltage supplies are installed.

In the foreground, workmen are in the process of constructing an additional foundation for an antenna on the terrace in front of the OSF TF. In the background is one Vertex antenna on the terrace, and another at the lower level, directly in front of the OSF TF.

Progress at the ALMA site

Future Control Room

Old Control Room in the Corridor

The Antenna building contains the control center for AIV (Assembly, Integration and Verification) tests in the corridor closest to the antenna foundations. This temporary center will be moved to a definitive control room in the near future. In addition, there will be a Central Local Oscillator laboratory and correlator laboratory installed in this building. All of the civil works are finished, and handover is awaiting the installation of the high voltage power supplies.

The Warehouse building is also being improved, with the installation of new chillers (to replace those damaged in transport) for the air conditioning system, and the installation of an electrical substation.

The OSF Technical Facility and two antennas at sunset

Progress at the ALMA site

A view of the AEM Site Erection Facility (SEF) in the foreground, showing part of one antenna structure, with the OSF building in the background. The left side of the OSF building is used for offices and laboratories, the right side for AIV tests and laboratories. In the background to the left is the MELCO SEF showing two 12 meter antennas and further to the left the Vertex SEF with the large erection hall and two 12 meter antennas outside.

First dynamic fringes obtained with 2 ALMA antennas - 2009, June 12

In the last few months ALMA has reported the measurement of fringes at the OSF. The first measurements were described as “static fringes”, and then later as “dynamic fringes”. The goal of this article is to explain the background and significance of these results.

First, we start with the fundamental limit to any optical system, including optical telescopes, radio antennas and even the human eye. This limit is diffraction. Diffraction theory gives us the ultimate limit of any optical device. This limit is determined by the ratio of the wavelength to the size of the optical system. For the human eye, the size is set by the pupil, which for most people has a maximum diameter of 5 millimeters. When looking at someone at a distance of 5 meters, diffraction tells us that the finest detail we can distinguish is half a millimeter. At a distance of 500 meters, this is 6 centimeters. Thus at this distance, we can recognize the outline of a face but not much detail. Diffraction gives us the limit to the sharpness of an image; this limit may be worse, given imperfections in our visual system, or atmospheric effects.

At a wavelength of 3 millimeters, an ALMA 12 meter antenna provides a sharpness that is about two times worse than the human eye, although the wavelength used for the ALMA measurements is 6000 times longer than the wavelength of light. This result is excellent, but for astronomy this is not good enough. For example, a single 12-meter ALMA antenna can measure the separation of a system consisting of our Sun and Earth only if the system is a distance of 0.06 of a light year. Since the nearest star is 4.3 light years, this is inadequate. Basically, outer space is far too large! By shortening the wavelength, one can improve the fineness of the image. However, even on the ALMA site, measuring at the shortest wavelength planned for ALMA, 0.3 mm, with a 12-meter antenna, we can resolve details in the system at 0.6 light years. We could expand the diameter of the antenna. The largest millimeter antenna in the world, being built in Mexico, has a diameter of fifty meters. So combining the shortest wavelength with the largest diameter, one might gain a factor of about 30. That is, on the basis of diffraction theory, imaging two objects with the earth-Sun separation at a distance of 1.8 light years. This is still not sufficient, and the mechanical stability of such an instrument would have to be 3 hundredths of a millimeter or better.

An alternative to image with even more detail is interferometry. In interferometry, one makes use of a collection of smaller antennas whose outputs are combined to produce an image with detail that is determined by the ratio of wavelength to maximum distance between the antennas.

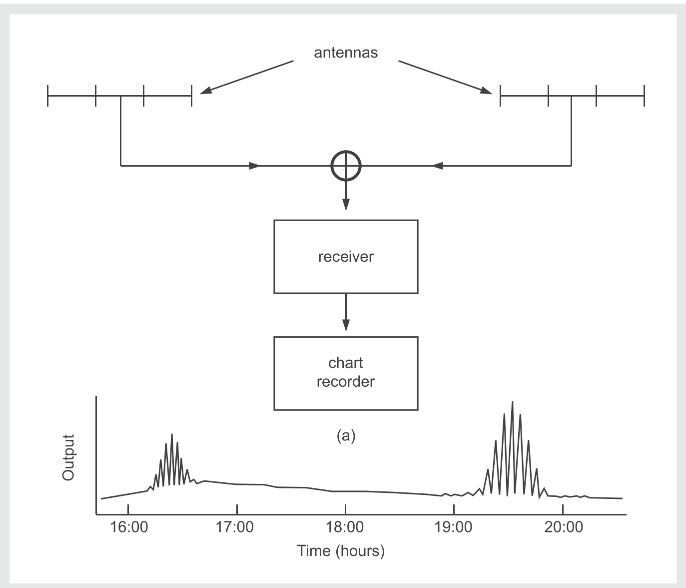
The first step to having a fully functioning interferometer is to combine the outputs of two antennas. This arrangement in principle could produce an image, but would require a great deal of observing time. However, for a first test of ALMA, a 2 element interferometer is essential.

Progress at the ALMA site

There was successful two antenna interferometry at the Antenna Test Facility in Socorro New Mexico, but this used prototype electronics. In the meantime, new software, production electronics systems have been delivered and these have been installed in Vertex and MELCO antennas. Thus at the OSF, the system is different from that used at ATF, with the antennas and electronics that will be used in ALMA. In addition to two fully equipped antennas, the tests require a correlator to combine the signals, and control software for interferometry.

A view of that part of the OSF TF used for tests of ALMA antennas. In this view, there are two Vertex antennas. There are fences around each antenna; these are required for safety. The antenna operators must shut down power to an antenna before personnel can start activity within the fence.

To successfully combine the outputs from the antennas, the arrival times of the astronomical signals must arrive at the correlator at the proper time. That is, depending on the position of the source, one or another of the outputs of each antenna must be delayed, so that the astronomical signals arrive at the correlator at the proper time. The first tests at OSF were carried out before the scheduled delivery of the software that is used to calculate the timing and adjust the hardware to insure that the outputs of the two antennas are combined properly to produce a result. A successful result is referred to as "seeing fringes on the source." The diagram shown below is an illustration of this terminology. In this example, from long ago, the antennas are pointed vertically, and the rotation of the earth shifts the positions of sources. In the language of astronomy, "the sources move through the beam." The time difference between signals from these two antennas causes a reinforcement of the outputs giving rise to a positive signal and then a cancellation leading to no signal. When looking at this output, one can understand how the expression "fringes" arose. Today, one plots fringe amplitude and fringe phase. This is equivalent to the result in the plot, but the display at OSF shows two sets of straight lines, with the amplitude offset from the zero level. In the "static" fringe test, the time delays were set for a precalculated source position, and then the measurement carried out. The source was detected, but then the timing correction slowly changed since the source apparently moved on the sky. The time was then recalculated and the source detected, and so forth. With the installation of the newest version of the software, the timing calculations for a given source position are carried out and the hardware is set for this source position. The result is the successful use of "dynamic fringes" for interferometry. The next step will be tests of additional features of this hardware/software combination. When these are completed, preparations for three antenna interferometry at the 5 km high site will be begin.



A sketch of an early radio interferometer; in this, two antennas are fixed in position as sources pass overhead. In this arrangement, the two antennas are receiving power from astronomical sources. The outputs from two antennas are added, and then processed in a receiver. In the receiver, the sum of the outputs is detected. The receiver output gives rise to an oscillating signal, so-called "fringes" shown at the bottom of the diagram.

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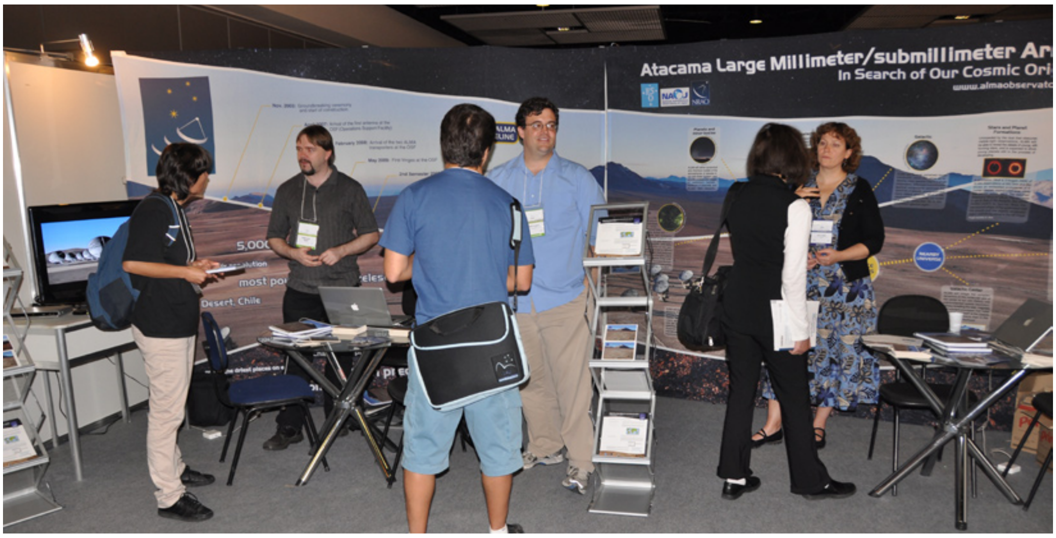
ALMA Events

ALMA at the XXVIIth IAU General Assembly in Rio, Brasil

2009
- aug -
3/14

The XXVII th General Assembly of the International Astronomical Union took place in Rio de Janeiro, Brazil, from August 1st to 14th. More than 2100 participants from around the world attended the event, including astronomers, students, and media. ALMA participated actively in this venue with a display stand that caught the attention of the participants as well as by means of interesting presentations given by some of our astronomers.



Three ALMA staff talking to visitors at the ALMA display in Rio. From the left facing the camera Mark Rawlings, Stuartt Corder and Alison Peck , the ALMA Deputy Project Scientist.

ALMA Events

Commissioning and Science Verification Review Meeting

2009 - sept - 2/3

The review of the Commissioning implementation plan were held on September 2 and 3 in the large meeting room of the Operations Support Facility (OSF) Technical Facility. Shown above in the front row is the review panel and ALMA staff. Front row, from the left, T. de Graauw (ALMA Director), R. W. Wilson (panel member, Harvard-Smithsonian Center for Astrophysics), N. Kuno (panel member, Nobeyama Radio Observatory, National Astronomy Observatory Japan), P. Schilke (panel member, I. Physikalisches Inst., Koeln University), M.C. H. Wright (panel member, Univ. of California, Berkeley), L-A Nyman (ALMA Head of Operations), R. E. Hills (ALMA Project Scientist) and T. Hasegawa (ALMA Deputy Project Manager). Not shown is C. Chandler (panel member participating from NRAO, Socorro). The speaker is R. Mauersberger, a member of the CSV staff. The review was successful, and the panel report will be discussed at the ALMA Scientific Advisory Committee (ASAC) and ALMA Board meetings.

The members of the review panel and attendees of the Implementation plan review assembled in front of an antenna transporter and a MELCO and VERTEX antenna outside of the OSF building.

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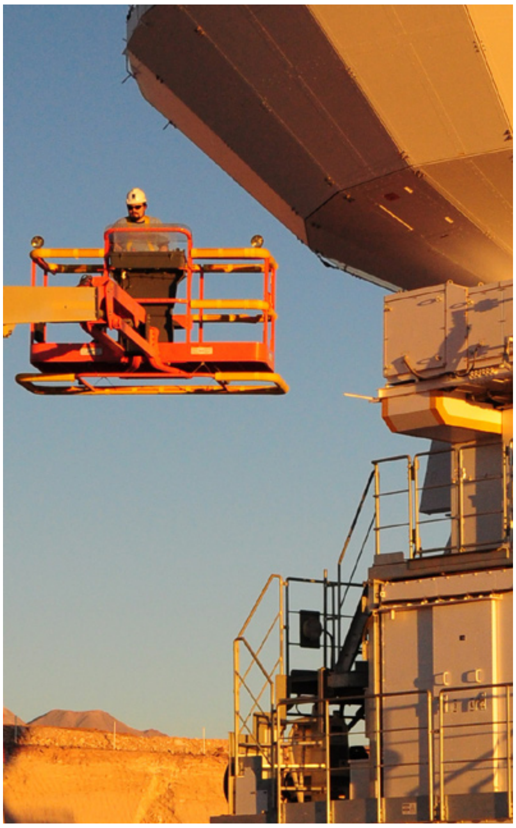
A view from the upper level of the OSF antenna area at the sunset, showing MELCO antenna #3 on the left, and Vertex antenna #2 on the right. In the background, the top of OSF TF and the topmost structure of two Vertex antennas can be seen.

Inside a round-the-clock Facility: From the Construction toward Operations



In this picture taken during daytime, technicians and engineers are shown performing some inspections and engineering tests on the ALMA antennas, before handing them to their colleague astronomers on nighttime shift.

Testing At Present

From early 2009 until recently, three antennas were actively being tested at the OSF Technical Facility (TF) by ALMA staff, having been provisionally accepted by the ALMA project from the suppliers Vertex and MELCO. The performance of these antennas must be verified by ALMA staff. The tests consist of checks of pointing, surface accuracy, beam characteristics and efficiency. In addition, the integration of the complete system of antenna plus receiver system must be carried out and evaluated at a number of frequencies. This process involves both single dish measurements and interferometry between two antennas. These activities must be fit into the schedules of different teams whose work occurs mostly during daylight hours. One example of daytime activity is “connectivity” (verification of the path of the signal from the astronomical source to the receiver and from the receiver to the correlator and archive, where data is stored, to the off-line computers, where the data is analyzed). Other activities consist of checks of the performance of software or electronics, and if needed, carrying out improvements. Also, daytime is reserved for such activities as the installation of new equipment, as well as the other very extensive activities needed for the transition from construction to operations. Specialized measurements made during day may require support by astronomers, and trouble shooting the problems found the night before must be done the following day but most of their work is done during night time. For example, carrying out the measurements of the positions of bright stars with small optical pointing telescopes (OPTs) mounted in the antennas to understand the behavior of the positioning of the antenna must be done after dark.

Inside a round-the-clock Facility: From the Construction toward Operations

Specific Details: One Day at OSF

The current level of equipment testing normally requires four to six astronomers at the OSF at any one time. For many, their official work day starts each afternoon at 15:00 with a teleconference involving colleagues in Santiago to discuss the results of the previous night and prepare the observations of the following night. At 15:30, they meet with the engineering and computing staff to discuss the work plan of the following 24 hours. This often involves requests for support for activities, or conversely, requests from the engineering staff for science support. Following this, there is often a handover period from 16:00 to 18:00 to insure that the hardware and software are in a state that allows testing on the sky to be carried out.

On the left is a specific example for a day of activity at the OSF on 23 July. Activities are scheduled on a 24-hour basis in terms of local time, so the specific example starts at midnight with astronomical tests until 04:00. After 04:00, technical activity begins. This ends at 12:00 with the handover to the scientists on duty for interferometry tests with 2 antennas until 20:00. Further testing is scheduled for the science team starting at 20:00 but the timing can vary depending on the types of activity taking place around the site. This continues until 04:00 the next day, when “Engineering Test Time” once again begins for all three antennas. On the day chosen for the example, there were only radio frequency measurements. However, sometimes the tests are devoted to aspects of antenna positioning using the small optical pointing telescopes (OPT) mounted in the antennas. Radio astronomical measurements can be carried out night or day, whereas OPT measurements are more accurate when done at night.

In the work listed here, there are many abbreviations. The AIV tests use a computer called an “STE” or “Standard Test Environment”, the “TF’s” are the numbers of the foundations at the OSF Technical Facility that the antennas stand on, the Vertex antennas are called DV01 and DV02, while the MELCO antenna

23 July (starting midnight)

All day

- **DV04:** Vertex Maintenance Verification

Until 04:00

- **DV01:** SCI/COMP Radio Pointing
- **DV02:** SCI/COMP/ENG OPT/Radio Pointing

04:00 - 12:00

- **DV01:** Engineering Test Time
- **DV02:** Engineering Test Time

04:00 - 08:00

- **PM03:** Engineering Test Time

08:00 - 12:00

- **PM03:** NAOJ Encoder Servo Work

12:00 - 20:00

- **DV01:** SCI/COMP/ENG Interferometer Testing
- **PM03:** Interferometer Testing COMP/ENG/SCI
- **DV02:** Opportunity Observations

20:00 - 04:00

- **DV01:** SCI/COMP Radio Pointing
- **DV02:** SCI/COMP/ENG OPT/Radio Pointing

Inside a round-the-clock Facility: From the Construction toward Operations

is called PM03. The plan for July 23 called for interferometery measurements between DV01 and PM03 in the daytime, while DV02 is used as a single antenna if necessary, or is available for engineering work. The simultaneous use of a two element interferometer and a single stand alone antenna at the OSF was the standard set up for several months, until the recent move of PM03 to the AOS. The situation now becomes more complicated, since testing will continue on all antennas simultaneously, at both the OSF and the AOS. Also, the number of antennas at both locations will increase very soon, so the model of 24-hour testing with round-the-clock shifts is here to stay.

One may ask: "Why were the electronics and software tests now being done at OSF not carried out at the Antenna Test Facility in Socorro New Mexico?" The answer is that full system verification can only be carried out using production antennas, electronics and software. This became possible when the conditionally accepted front ends became available at the end of 2008, and were installed on the first provisionally accepted antennas, Vertex DV01, and MELCO PM03. Installation on DV02 occurred in early 2009.

Future Developments

After verifying that the antennas meet specifications, further tests will be used to determine whether the receivers (front ends complete with back ends) meet specifications and then the entire system of antennas and receivers will be checked against specifications. Much of this activity can only be done with astronomical measurements. Tests at the highest frequencies must be done at the Array Operations Site (AOS) at 5 km elevation. For the most part, tests at OSF will involve ALMA Bands 3 (3 mm wavelength), Band 6 (1.3 mm) and Band 7 (0.8 mm). ALMA receiver Band 9 (0.6 mm) requires the very best weather, so is more easily tested at the AOS.

In addition to tests of new antennas in a stand alone mode, interferometer measurements between two antennas will continue to be carried out and there are a large number of details of the system that must be verified. A set of procedures for testing the specifications and requirements has

A view of night time activity at the OSF TF; the foreground antenna is illuminated by floodlights at the right side. The two Vertex antennas are being readied for astronomical tests, after daytime activities that include connectivity tests, hardware and software maintenance and upgrades.

Inside a round-the-clock Facility: From the Construction toward Operations

Astronomers, programmers and operators working in the temporary AIV antenna control area during nighttime.

been devised and these are now being carried out by the science and engineering teams. Since ALMA is a flexible instrument offering many observing possibilities, extensive tests are needed. The ultimate tests will be carried out at the AOS. After the transport of antennas from OSF to AOS, we will have access to the full ALMA correlator. Then interferometry with three antennas can start. This will mark the official beginning of the Commissioning and Science Verification (CSV) process. This is planned to start in early 2010.

In addition to the start of CSV, there are more than eight fully assembled antennas at the OSF waiting to be accepted by the ALMA project. The antenna characteristics have been tested by the antenna suppliers, but must be verified by ALMA. When the antennas meet all ALMA specifications, these will be accepted by the project. In addition, receiver systems must be installed and the performance of the entire system of antenna plus receiver must be verified and if needed, optimized. Then each complete antenna system will be integrated into the array at the AOS. This will mark the transition from AIV to CSV for this antenna. The array will grow during this process. Eventually, the entire process of AIV and CSV will result in the ALMA interferometer system.

The present plan is to have an instrument consisting of sixty-six antennas including the Atacama Compact Array (ACA), with the hope that it may be possible to add more during the lifetime of the project.

Before the completion of the construction phase, astronomical observations will be carried out to verify the accuracy of the data taken by ALMA. Some of these Science Verification tests will produce images that will be made available to the community to show how ALMA is progressing in the course of becoming ready for proposal-driven projects. In addition, there will be a period devoted to “Early Science”. In Early Science, a subset of the final ALMA instrument will be available, and this will be an end-to-end system in the sense that proposals will be submitted by the astronomical community, reviewed by an observing program committee and then the proposals selected will be put into a form so that the experiments can be carried out. The observations will be carried out by the ALMA staff and the data products will be delivered to the proposers in a manner similar to what will occur during full operations. The decision point for Early Science will be reached when the CSV testing shows that the system is performing according to specification, and that at least sixteen fully equipped antennas, and all associated hardware and software components, are available for science. The ensuing call for proposals will include a set of observing modes that will be available during Early Science, as well as instructions on where to find assistance in preparing the proposal.

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ALMA In Depth

The ALMA Antenna procurement

By Stefano Stanghellini (ESO), Jeff Zivick (NRAO), Junji Inatani (NAOJ)

Above: Before reaching the final design, each partner designed and tested a prototype. Here we see these prototype antennas at the ALMA Test Facility (ATF) in Socorro, New Mexico. After testing, the MELCO antenna was moved back to Japan, refurbished and is now at the MELCO Site Erection Facility (SEF) at OSF. In 2009, the tests carried out at the ATF have been shifted to the OSF. These tests are more realistic since at OSF the prototype electronics is installed on the antennas.

Visitors who come to the OSF at regular intervals find a growing population of antennas at various stages of assembly and testing. The long path from the start of the definition of antenna specifications to the start of science operations with the antennas was and still is a formidable endeavor. When completed, ALMA will comprise a 12-meter diameter antennas array, the bilateral interferometer array, of a minimum of fifty antennas and in addition, the ACA (Atacama Compact Array), composed of four 12-meter diameter antennas and twelve 7-meter diameter antennas. Out of the fifty antennas of the bilateral interferometer array, one-half are provided by the North American partners of ALMA, the other half by the European partners. The sixteen antennas that will comprise the ACA are provided by the East Asian Partners of ALMA. Here we review some key points of this challenging process and we provide a brief history and status of the ALMA antennas. Because of the length of the description, we will present this in a series of two articles. In this first part we concentrate mostly on the bilateral antenna procurement. A detailed description of the ACA will be presented in the next newsletter.

There were three millimeter/submillimeter interferometer projects before the joint ALMA project. NRAO (National Radio Astronomy Observatory) of USA proposed the concept of the Millimeter Array (MMA) in 1983; NAOJ (National Astronomical Observatory of Japan) built the concept of the Large Millimeter Array (LMA) in 1983, which evolved to the Large Millimeter and Submillimeter Array (LMSA), and Europe, through ESO (European Southern Observatory), proposed the Large Southern Array (LSA) in 1995. US-Japan Workshop on millimeter and submillimeter astronomy was held in 1997, and a possibility of a combined US-Japan array was discussed. ESO and NRAO (the latter operated by AUI (Associated Universities Inc.) under a cooperative agreement with the National Science Foundation), created a working group to take key decisions on antenna diameter and major performance goals for a common project. The diameters considered ranged

ALMA In Depth

The production of the antennas is spread among various countries. In this photo, the Asturfeito facilities in northern Spain where the steel structures of the European antennas are being built. Shown are the AEM antenna bases and yokes in different phases of assembly.

from 8m to 15m, subject to technical feasibility and economic tradeoffs. The diameter of 12m appeared to be a good compromise between performance risk and cost, but this had to be proven by building and testing prototypes. The prototyping phase started shortly after ESO and AUI had signed a formal agreement on collaboration for the development phase of the project. Shortly after this agreement was signed, the project was given the name "ALMA". Thereafter NRAO and ESO initiated the procurement of two antenna prototypes, to be installed at the VLA premises of the NRAO in New Mexico. These two prototypes would be evaluated on an agreed test program by a joint team of experts, the Antenna Evaluation Group (AEG). At about this time, NAOJ also decided to procure a 12 m antenna prototype and take part in the common testing campaign (picture 1).

The prototype antennas were delivered in 2003. The tests, carried out by the AEG, consisted of optical and radio measurements. These proved to be more challenging than anticipated due to atmospheric limitations on optical pointing at the VLA site, adjustments to the antennas and test equipment (receivers, holography systems, chopping secondary mirror (nutator) and optical pointing telescopes) and the integration of systems. To avoid a delay of the project due to the delivery of the final prototype evaluation report, parallel calls for tender to industry were issued in December 2003 by AUI and ESO for the supply of the production antennas based on revised antenna specifications, drawn up in a collaborative effort involving many groups. The call for tender was not restricted to any design, although information about the two prototypes was included as background information to industrial bidders. The bidders based their proposals on the design of the prototypes. Therefore further tests were done with the prototypes to finalize the data collected by the AEG. These additional tests of the prototypes, performed by panels of specialists, involved some testing methods that differed from those adopted by the AEG. Among these was "fast switching" between two nearby positions. For this, 100 000 cycles of rapid antenna movements were carried out to "stress test" the antenna drive systems and the reflector structures. The tests, which ended in April 2005, showed that antennas based on prototype designs should fulfill the ALMA specifications. This result brought to an end a campaign of tests spanning more than two years. This process demanded great effort and ingenuity from all of those involved, both in carrying out the tests and from those analyzing and interpreting the collected data.

The antennas of each manufacturer arrive in separate parts to Chile. In this picture is shown the shipment of the structure of a north american antenna at the Jacinto Terminal, Houston, Texas, USA. The antenna part is covered in blue material for protection during shipping.

ALMA In Depth

Shortly after the completion of the tests, in July 2005, AUI concluded negotiations with VertexRSI, a subsidiary of General Dynamics, by the signing of a contract for the supply of 25 antennas with options for up to 32 antennas. In December 2005, ESO followed with the signature of the contract for 25 antennas, also with options for up to 32 antennas, with the AEM Consortium (Thales Alenia Space, European Industrial Engineering and MT-Aerospace). These two contracts are, to date, the largest single contracts for any ground-based radio astronomy project. Both contracts foresaw an initial design phase terminated by a design review. In the design phase, the antenna vendors have incorporated design modifications demanded by the new ALMA specifications. Equally important were improvements based on findings discovered during testing and operating the prototype antennas. The vendors were also asked to perform qualification activities in the technological areas not yet validated on the prototype antennas.

The different parts of the antennas (wrapped in blue material for protection during shipping) are carried in a long journey to the OSF for their assembly. In this photo we can see the transportation of the first three japanese antennas in July 2007.

In a separate process, NAOJ ordered four 12-meter antennas and twelve 7-meter antennas from Mitsubishi Electric Corporation (MELCO) for the ACA.

In this phase the ALMA Antenna Integrated Product Team (IPT), consisting of members of the three organizations, conveyed the experiences accumulated in at least two years of testing and operation to the manufacturers. This unique information ranged from the science-related performance of the antennas to aspects related to reliability and maintainability. These are crucial for the proper operation of a large array at 5000m altitude. Each design modification required by ALMA, or proposed by the contractors, was reviewed in depth during the design phase. For all three antennas, the design phase was terminated by formal Pre-Production Design Reviews (PPDR) which included the participation of a large review group. The respective PPDRs for the three suppliers were held between November 2005 and September 2008.

The design of the North American antenna was jointly performed by Vertex Antennentechnik (VA) in Duisburg, Germany and VertexRSI in Kilgore, Texas. The Vertex antenna is equipped with a rim pinion drive system with double motors on both axes and a control system based on absolute encoders. The Carbon Fiber Reinforced Plastic (CFRP) Backup Structure (BUS) is joined to a steel cabin by means of a large Invar support cone. This cone decouples the effect of thermal expansion of the steel cabin from the thermally stable BUS. This design avoids that large temperature variations and gradients of the outdoor environment on the 5 km high ALMA site generates stresses and deformations that cause deviations from the specifications.

ALMA In Depth

In this picture we can see the arrival of the base of the first European antenna (wrapped in material for protection during shipping) arriving to the OSF in March 2009.

ALMA has reserved large areas in the OSF for the assembly work by the antenna vendors. These are the Site Erection Facilities (SEF). MELCO, having performed almost complete erection in Japan, has decided not to use any building for the final integration on site. Shown here is the mounting of the panels for the main reflector on the backup structure.

The main reflector panels are lightweight, machined from aluminum. To allow the antenna to perform measurements of the Sun, scattering of sunlight has been included in the design of the primary reflector panels by means of a proprietary chemical etching process. The drawing set of the production antenna is largely new, although many changes from the prototype are of minor nature. More significant changes are: (1) new architecture of the control system, (2) implementation of an automatic greasing system for the rim pinion drives and (3) simplification of the temperature control system of the receiver cabin.

Both the MELCO and AEM antennas have undergone major development from their prototypes. The conical base was adapted to the new triangular interface to the antenna stations. MELCO adopted linear drives for both azimuth and elevation axes, produced by MELCO itself.

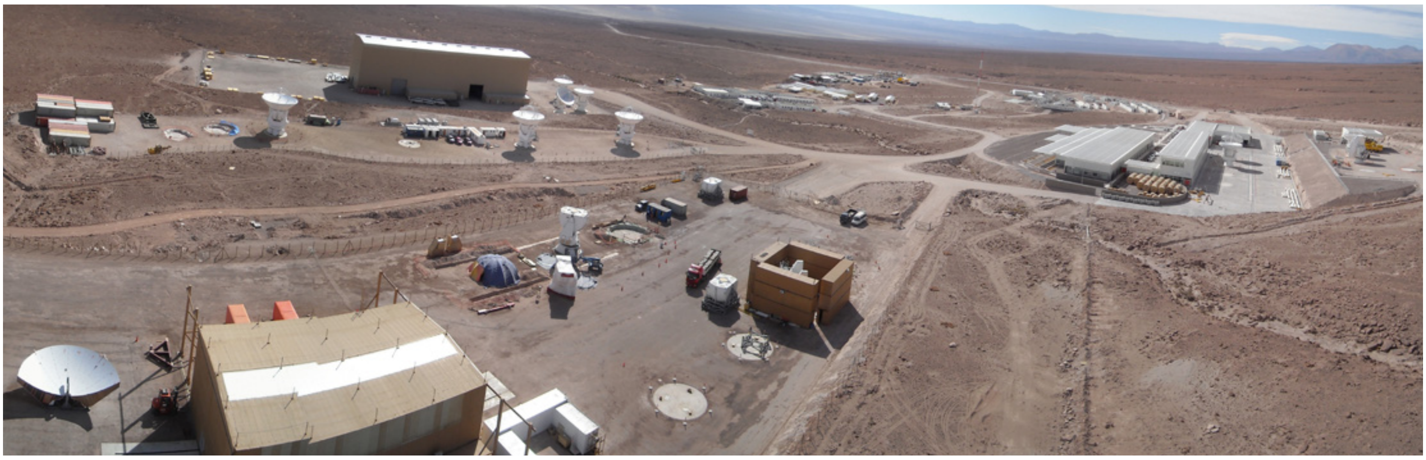
The most obvious changes of the AEM production antenna design from the AEC prototype are connected with the azimuth axis. The axis now employs a three-roller bearing, a tape encoder with eight reading heads in azimuth, a new, more compact cable wrap, and new azimuth motors. The AEM antennas use linear motors produced by Phase Motion Control. These are based on a distributed drive system, thus reducing the number of cables. The linear motor segments are now located outside the base, so are more easily accessible for maintenance.

The quadripod carbon fiber reinforced plastic (CRFP) truss structure used on the prototype was abandoned in favor of a new, simplified single beam design of increased cross section. The subreflector mechanism is now based on a customized, industrially produced hexapod, basically identical to the one used by VertexRSI. The antenna has been the subject of detailed fluid dynamical studies to study the deformation of the main dish and of the quadripod structure to assess the effect on the surface accuracy and the pointing performance and to study the thermal exchange coefficients.

The metrology system of the antennas is needed to meet the specifications. This system is used to measure internal deflection caused by temperature and wind, in order to compute, with micrometer accuracy, path length differences and to keep the pointing accuracy to sub-arcsec levels despite temperature

Once an antenna is fully assembled, it is transferred with the ALMA transporter to the outside stations for testing on the sky. In this picture, a VertexRSI antenna being assembled in their large hall in the OSF.

ALMA In Depth



ALMA has reserved large areas with a number of antenna stations for the assembly work by the antenna vendors, the Site Erection Facilities (SEF). In each of these work areas, more than one antenna station is available for parallel testing and acceptance. Shown in the foreground is the European SEF, to the left the MELCO SEF, and further to the left the Vertex SEF. In the background is the OSF TF. Slightly to the right of the OSF TF are two antnnas being tested by the ALMA AIV team. On the terrace further to the right are two additional antennas undergoing AIV testing.

changes, solar irradiation and wind at the ALMA site. Such a system poses a significant challenge both to the designers and to the ALMA staff who will later be in charge of commissioning at the ALMA site. Both VertexRSI and AEM vendors elected to perform dedicated verification of the metrology of the prototypes in New Mexico prior to finalizing their designs. The results of the test campaigns were presented to the ALMA personnel who verified the design. As a result the proposed modifications caused all three antenna manufacturers to revise the design of their metrology systems. The metrologies of the VertexRSI and MELCO antennas are now based on a stable internal reference structure, complemented by a number of thermal sensors. The AEM antennas use distributed thermal sensors and a proprietary developed inclinometer, specially developed for fast response, making its use possible during fast switching and scanning.

Setting up Production

The original schedule envisioned at the beginning of the call for tender in 2003 could not be maintained. The large delays encountered by the vendors are twofold. First the contracting phase between the Executives and industry took longer than anticipated, with the MELCO contract signed at the beginning of 2005, VertexRSI contract in July 2005 and AEM contract in December 2005. Second, the reality of implementing changes in the design and in parallel setting up the industrial processes with new suppliers proved to be more difficult than originally envisaged.

The production of the North American antennas is carried out in two locations. The pedestal steel structure is fabricated at the VertexRSI manufacturing facilities in Texas. Each antenna pedestal is pre-assembled at the factory with the integration of the base, the azimuth and elevation bearings, the azimuth cable wrap, the yoke, the cabin, the Invar cone and the majority of the internal cabling. Fabrication of the elevation structure is lead by the Vertex Antennentechnik (VA) division in Germany. The major suppliers to VA are: Airborne Composites B.V in the Netherlands for the CFRP BUS and quadripod structure; VA is directly responsible for the control system, including hardware and software; the aluminum reflector panels are manufactured by Zrinski in Germany; Rothe-Erde in Germany for the azimuth bearings and Physik Instrumente in Germany for the Hexapod positioner.

Production of the European antenna is spread among various countries. The steel structure is manufactured by Asturfeito in Northern Spain. The CFRP cabin is manufactured in France by

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Multiplast and Jallais. Multiplast is well established in the field of record setting sailing boats. The cabin is molded and assembled out of three CFRP parts at Multiplast, and then shipped to Jallais where all insertion and machining of interfaces is performed. The finishing includes flame-sprayed aluminum on the internal walls of the receiver room to minimize electromagnetic interference (EMC).

The BUS of the AEM antenna is also built in France, by Duqueine Composite. The BUS is assembled from 16 individual slices, of which 8 are glued together at the factory to produce two half BUS's. After transport at the OSF the two halves are finally joined together. The panel adjusters are produced by RUAG in Switzerland. The panels themselves are produced by nickel-deposited replication by Media Lario Technologies in Italy. These are identical to the ones used in the European antenna prototype. For thermal reasons the panels are Rhodium coated. The remaining subassemblies are being produced by various suppliers, with control system and metrology delivered by Microgate, the linear motors by Phase Motion Control in Italy and the quadripod legs manufactured in Germany by Xperion.

After assembly and testing by the suppliers, the antennas are ready to be thoroughly tested by the AIV team of engineers, technicians and scientists. In the foreground is a surface and support legs, in the background is an antenna surface and backup structure waiting to be mounted on the yoke and base.

Both VertexRSI and AEM performed some pre-assembly and some functional tests at factory, while MELCO antennas were almost completely assembled prior to shipping.

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On Site assembly and Acceptance

ALMA has reserved large areas with a number of antenna stations for the assembly work by the antenna vendors. In each of these work areas, more than one antenna station is available for parallel testing and acceptance. VertexRSI installed a large complete assembly hall for antenna integration. Once an antenna is fully assembled, it is transferred with the ALMA transporter to the outside stations for testing on the sky. AEM built a reduced integration facility, thermally controlled, but limited to the assembly and adjustment of the reflector and panels. Movable shelters around antenna pads are used to allow accurate mechanical integration is on-going. MELCO, having performed almost complete erection in Japan, has decided not to use any building for the final integration on site.

Once assembled and integrated, the antennas enter the verification process. In this picture, a Vertex antenna in this stage.

The acceptance process of these antennas is a complex process, since these antennas are truly state of the art and are at the limit of what is considered feasible today. To recall some key specifications: (1) the surface accuracy must be less than 25 micrometers RMS, under all conditions of temperature, wind and solar irradiation, (2) the stability of the structure in terms of elongation and distortion affects the baseline of the interferometer and the pointing accuracy, so for stability ALMA demands changes of order of 15 micrometers over a time of 3 minutes in the open air conditions, and (3) The relative (offset) pointing accuracy at 0.6 -arcsec level is also at the limit of what can be reasonably measured. The alignment of the antenna elevation, azimuth and boresight axes are also extremely challenging and need to be achieved and demonstrated by the suppliers. Further there are more characteristics of the antennas which need to be verified at the time of acceptance. These are characteristics, not directly linked to scientific performance, but which form the basis of the operation of the ALMA observatory, namely reliability, transportability, ruggedness, easy maintenance, adequate documentation and durability, and not least safety. The acceptance process has to be therefore sensibly rigorous

ALMA In Depth

than what would be normally done for laboratory equipment and involve a range of specialist collected across the complete ALMA, NRAO, ESO and NAOJ personnel spectrum.

The demanding specifications required an extensive acceptance process for the first antennas (MELCO and VertexRSI). Today, both vendors have successfully conditionally accepted their antennas while actively pursuing the completion of items which were identified as requiring additional verification testing. Antennas from these two vendors are actively being used by ALMA to perform more extensive system testing and recently achieved a major milestone of dynamic fringes using one MELCO antenna and one VertexRSI antenna. Very soon, the project expects to start with testing antennas at the 5 km high site.

For the AEM antennas, integration of the first two units on site started very recently. The schedule calls for acceptance starting at the beginning of next year. By that time a few AEM antennas will be in the integration process, so it is expected that these antennas will also be available for acceptance at a rate of about one every month, as it is the case for the two other vendors.

As of today, there are 12 antennas of VertexRSI on site of which 3 have been conditionally accepted, 2 are undergoing testing and 7 in various stages of assembly and integration. There are 4 MELCO antennas on site of which 1 has been conditionally accepted and 3 are undergoing testing. Further they have started the manufacturing of twelve 7-meter diameter antennas for the Atacama Compact Array. Three AEM antennas are under construction on site. At the time being the delivery of all antennas is planned for 2012, including the 7-meter MELCO antennas for the Atacama Compact Array. This will be the final conclusion of a long and complicated industrial process which has little or no equal in the ground based astronomy.

Once these stages are completed, antennas are taken to their definitve home in Chajnantor.

Job Opportunities

ALMA will be building up its scientific staff over the next few years. Specific positions will be advertised as they become available.

The Joint ALMA Observatory (JAO) is seeking

Test Scientists

for the ALMA Assembly, Integration and Verification.

Purpose and Scope of the Position: ALMA is opening positions for Test Scientists to participate in system tests during the Assembly, Integration and Verification processes.

The successful candidates will be part of the team responsible for ensuring that appropriate testing has been accomplished to verify that the system requirements have been met. These positions will develop qualification tests, analyze test results and approve reports. They support routine tests on antennas, such as holographic measurement and optical pointing, by performing data analysis, developing automated control and reduction scripts, and training operators, engineers and technicians. They also develop and execute tests to characterize integrated interferometric system behavior, including radiometric pointing, antenna and beam characterization, surface shape change with elevation, path delay, phase stability, bandpass stability changes, etc.

During array commissioning, Test Scientists will work with the engineering staff to develop tests and provide the analysis needed to help resolve problems with system performance. They will also work with the commissioning team to define tests needed to validate the system.

Test Scientists are expected and encouraged to conduct active astronomical research programs.

Qualifications: Applicants for this position have to fulfill the following requirements:

- An advanced degree in engineering, physics or astronomy at • the Doctoral level;
- At least 3 years of observational experience with radio astronomy; observing techniques and data reduction
- Experience in techniques used in radio astronomy observations;
- Willingness to travel to the ALMA sites near San Pedro de Atacama and abroad.

In addition to the above criteria, the successful candidates will meet the following requirements:

- Experience in software development for astronomical applications (C++, Python);
- Experience with and understanding of microwave and digital systems;
- Experience with and understanding of aperture synthesis arrays;
- Experience in working in a team environment;
- Working knowledge of or willingness to learn Spanish;
- High level of communication and negotiation in English.

Due to the frequent travel requirements and work at high altitudes, a successful high altitude medical check is a necessary condition of employment for this position.

Job Opportunities

Duty station: The positions are based in Santiago de Chile and will require frequent travelling to the ALMA Operational Support Facility near San Pedro the Atacama.

Starting date: As soon as possible.

Contract: These are International Staff positions that are hired as term appointments, which are needed during the construction period that is scheduled to be accomplished in 2012. There is a possibility for Test Scientists to be transferred to the observatory science operations team during or on completion of their term appointment.

Remuneration: ALMA international staff will be recruited as employees of either ESO or AUI/NRAO. Both ESO and AUI/NRAO offer attractive remuneration packages including a competitive salary, comprehensive social benefits and provide financial support in relocating families. Furthermore, an expatriation allowance as well as some other allowances may be added.

Review of applications began on 14 July 2009; however applications will be accepted until the position is filled.

The NRAO/ESO are equal opportunity employers. The post is equally open to suitably qualified female and male applicants.

For more information about the way to apply to this position, please see the web pages at (through NRAO), (through ESO)

ALMA Fellowships

With ALMA becoming operational in a few years, ESO offers ALMA Fellowships to complement its regular fellowship programme. Applications by young astronomers with expertise in mm/submm astronomy are encouraged. ESO offers several ALMA fellowship positions to be taken in the European ARC nodes - funded by the Marie-Curie COFUND Programme of the European Community - to complement its regular fellowship programme. For more information, application forms and deadlines: (through ESO) (through CORDIS)

JANSKY Fellowships

NRAO announces the 2010 Jansky Fellowship Program which provides outstanding postdoctoral opportunities for research in astronomy. Jansky Fellows formulate and carry out investigations either independently or in collaboration with others within the wide framework of interests of the Observatory. Prior radio experience is not required and multi-wavelength projects leading to a synergy with NRAO instruments are encouraged. The NRAO also encourages applications from candidates with interest in radio astronomy instrumentation, computation, and theory. (through NRAO)

ALMA Newsletter
October 2009

ALMA

If you wish to receive email announcements when new editions become available, please send an email to almanewsletter@alma.cl, with "subscribe ALMA newsletter" in the body.

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This newsletter is also available here.

Please send comments on the newsletter or suggestions for articles and announcements to the editors at twilson@alma.cl wgarnier@alma.cl

More information on ALMA and contact details can be found on the ALMA homepage www.almaobservatory.org

Regional newsletters: http://www.eso.org/sci/facilities/alma/newsletter/2009/

http://www.nrao.edu/ news/newsletters/

http://www.nro.nao.ac.jp/alma/E

Upcoming events

ESO-MPE-MPA-USM 2009 Joint Workshop: From circumstellar disks to planetary systems

The goals of the workshop will be to review the status of the field and to discuss transformational programs that will be made possible with the upcoming facilities, and especially by the combined use of the ESO present and future facilities. To achieve this, the workshop will bring together the communities working with ground based infrared large telescopes and interferometers, with space observatories and millimeter interferometers as well as theorists.

Dates: 3 to 6 November. **Location:** Garching, Germany.

More information: http://www.eso.org/sci/meetings/disks2009

American Astronomical Society Meeting

There will be an NRAO Town Hall at the American Astronomical Society Meeting in Washington, D. C. The session will be held Tuesday, January 5, 6:30 to 8:30 pm (room TBD).

The NRAO Town Hall will begin with a reception (including food & drink), that will be followed by brief presentations and an audience Q&A session. The status of ALMA will be addressed. In addition, there will be an ALMA section in the NRAO booth every day where there will be ALMA, EVLA, GBT and VLBA literature and personnel to answer questions. There will be ALMA and North American ALMA Science Center related posters available for viewing.

Dates: 3 to 7 January, 2010. **Location:** Washington, D.C., USA.

More information: http://aas.org/meetings/aas215

ESO Workshop: The Origin and Fate of the Sun: Evolution of Solar-mass Stars Observed with High Angular Resolution

The goal of this workshop is to review recent results on solar-mass stars obtained with infrared and millimeter interferometers, and to discuss their importance for our understanding of stellar evolution from star formation to stellar end products. The workshop will concentrate on the mass range from approximately 0.5 to 2 solar masses, will discuss what new results for one stage of stellar evolution mean for the next stage, and will bring interferometric results into context with our knowledge based on other observational techniques and with theory. It will also include prospects with 2nd generation instruments at the VLTI and with ALMA. Interferometry experts and non-interferometrists alike are welcome to attend the workshop and to bring together their different perspectives.

Dates: 2 to 5 March 2010. **Location:** Garching, Germany.

More information: http://www.eso.org/sci/meetings/stars2010