RevMexAA (Serie de Conferencias), **38**, 7–10 (2010)

ALMA AND HOT STARS

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RESUMEN

ALMA es un interferómetro milimétrico/submilimétrico actualmente en construcción a una altitud de 5000 m en el norte de Chile. Cuando esté terminado en 2012, proporcionará más que un orden de magnitud de aumento en sensibilidad, resolución, así como fidelidad de la imagen comparada con las actuales instalaciones existentes. Esto permitirá significativos "breakthroughs" en muchas áreas de la astronomía, incluyendo el estudio de estrellas calientes. Las capacidades de ALMA se describen, junto con algunas de las potenciales áreas de impacto en la investigación de estrellas calientes.

ABSTRACT

ALMA is a millimeter/submillimeter interferometer currently under constuction at 5000m altitude in northern Chile. When completed in 2012, it will provide more than an order of magnitude increase in sensitivity, resolution as well as image fidelity compared with existing facilities. This will enable significant breakthroughs in many areas of astronomy, including the study of hot stars. The capabilities of ALMA are described, along with some of the potential areas of impact on hot star research.

Key Words: instrumentation: interferometers

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1. INTRODUCTION TO ALMA

ALMA is a 66-element mm/sub-mm interferometer being built in a multi-national collaboration between North America, Europe and Asia. ALMA is designed to enable mm-wave synthesis imaging to be used in many different branches of astronomy. It will operate at wavelengths from 9 mm down to 350μm, where the atmospheric transmission is highly dependent on the water vapour content along the line of sight (measured by the precipitable water vapour, or pwv). Generally the highest, driest locations have the lowest pwv, consequently the site chosen for ALMA is at 5000 m altitude in Chajnantor, northern Chile, where the pwv is frequently less than 0.5 mm. The wavelength coverage of ALMA is divided into several bands, each limited mainly by the atmospheric windows. Table 1 shows the range of each band, and the zenith atmospheric transmission under reasonably good Chajnantor conditions.

Each ALMA band has its own frontend receiver cartridge, with slightly different capabilities. Also given in Table 1 are the instantaneous bandwidth coverages of the different receivers, and their configurations (either single sideband (SSB), double sideband (DSB) or dual simultaneous sidebands (2SB).

ALMA will be using four different types of antennas: currently there will be 25 US-built and 25 European-built dishes of 12 m diameter, and 4 Japanese-built 12 m dishes, plus 8 Japanese-built 8 m dishes. The antennas are transportable and can be located on any of $\sim$ 200 pads distributed over the high site, allowing full flexibility in the UV coverage and in the resolution. Figure 1 shows a transporter moving an antenna during tests at the mid-level facility in early 2009. Baselines will range from a few tens of metres up to 18 km in the most extended

TABLE 1

ALMA BANDS AND FREQUENCY COVERAGE

Band	λ (mm)	Freq. (GHz)	Zenith trans.[a]	Bwidth. (GHz)[b]	Config.
1	7	31–45	0.98	1x8	SSB
2	4	67–90	0.97	1x8	SSB
3	3	84–116	0.98	2x4	2SB
4	2	125–163	0.98	2x4	2SB
5	1.5	163–211	0.9	2x4	2SB
6	1.1	211–275	0.95	2x5.5	2SB
7	0.85	275–373	0.9	2x4	2SB
8	0.65	385–500	0.8	2x4	2SB
9	0.45	602–720	0.55	2x8	DSB
10	0.35	787–950	0.5	2x8	DSB

[a]Approximate transmission of atmosphere, at zenith, in best part of frequency band, for 0.5 mm pwv.

[a]Instantaneous bandwidth, per polarisation.

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Fig. 1. One of the ALMA 12 m antennas being moved on a transporter at the mid-level ALMA facility (OSF, altitude 2900 m). The high site (AOS, at 5000 m) lies just over the ridge in the far distance.

TABLE 2

SPATIAL RESOLUTION

Band	λ	Beamsize (Compact)	Beamsize (Extended)
3	3 mm	3.2″	40 mas
4	2 mm	2.5″	30 mas
6	1.1 mm	1.5″	18 mas
7	850μm	1.0″	12 mas
9	450μm	0.5″	6 mas
10	350μm	0.4″	4.5 mas

configuration, which gives the max/min resolutions in Table 2.

The sensitivity of ALMA will be more than an order of magnitude better than existing instruments, thanks to its large collecting area, high site, and low-noise receivers. Figure 2 compares the continuum sensitivity with existing and future radio and sub-mm facilities, assuming reasonable observing conditions. Also shown is the spectral energy distribution of warm dust at low redshift, assuming a modified black-body emission spectrum with emissivity $\beta \propto \lambda^{-1.5}$. It is clear that ALMA will be the most capable facility for detecting warm dust mass, with 850μm (band 7) likely to have the best sensitivity.

Equally important to making useful astronomical images, the large number and range of baselines will give ALMA excellent UV coverage and high image fidelity. Snapshot observations will have low sidelobe levels in the synthesised beam (less than 5%), and long tracks of observing will in many cases not be necessary.

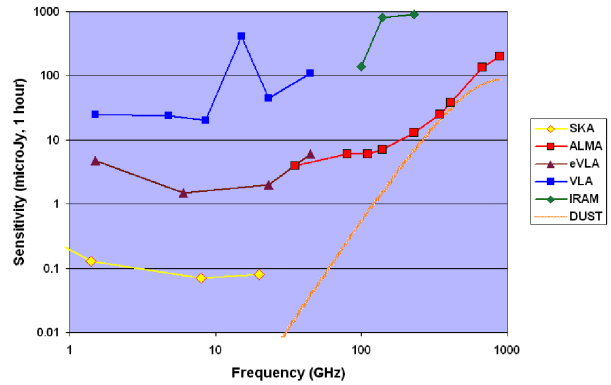

Fig. 2. Sensitivity of ALMA (large filled red squares) compared with other existing and future facilities. Also shown is the typical emission spectrum from warm interstellar dust.

There are many technical challenges to be overcome in the construction and commissioning of ALMA. Some examples are the use of radiometers to measure the line of site atmospheric emission and using this to calculate the phase errors, the use of a optical-fibre distribution of the local oscillator, and the use of mosiacing and on-the-fly interferometry to map large areas. As well, the operation of the antennas and correlator under the conditions at the high altitude will be challenging. The first antennas are currently being commissioned and tested at the mid-level facility (the OSF, see Figure 1), and will be transported to the high site (AOS) in late 2009. Early science, with 16 antennas and limited baseline configurations, is expected to start in early 2011, with full operations in 2013. The next section describes some of the potential uses of ALMA in the study of hot stars.

2. HOT STARS AND ALMA

2.1. *Disks and cores around hot stars*

For the closest massive star formation regions, spatial scales of ~5 AU will be accessible to ALMA, with the low dust opacity at mm wavelengths, enabling observations of the optically-obscured cores of massive disks. This allows several types of studies to be performed:

• The effects and presence of a young protoplanet may be seen in such disks; Wolf & D'Angelo (2005) and Narayanan et al. (2006) present simulated images which show measurable structure in both the dust continuum and line emission images. Do the disks around massive stars contain massive protoplanets, similar to their low-mass equivalents?

• High-mass star formation is associated with hot cores and complex chemistry driven by the subli-

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mation of icy dust grain mantles (e.g., Brogan et al. 2008). The understanding of this chemistry needs high spatial and spectral resolution, in order to separate out the complex interactions in the radiation field near the hot young star.

• Hot cores are a rich source of complex organic molecules; so far mm astronomy has detected species such as Methyl Formate, Ethyl Cyanide and Acetic Acid. We do not know how far this chemical complexity extends (van Dishoeck & Jorgensen 2008). High resolution and sensitivity is necessary for these studies.

2.2. *Debris disks around hot stars*

The high sensitivity and resolution of ALMA will make it the most sensitive instrument for detecting very low-mass debris disks at large distances. This will enable debris around less common and therefore more distant massive stars to be measured. This requires both sensitivity *and* resolution, in order to discriminate against the stellar photosphere. Some of the debris disk questions for ALMA are:

• ALMA will be able to detect 0.005 lunar mass of dust around nearby A stars – similar to the mass of the Sun's Kuiper Belt. We will be able to detect, for the first time, systems like our own.

• It will be possible to image the structure of debris disks out to 100 pc or more (see Figure 3), allowing the indirect detection of shepherding planets. This requires the resolution, sensitivity and dynamic range of ALMA.

• The distributions of grains of different sizes are predicted to be different in disks around luminous stars, where effects from the stellar wind and radiation pressure are relatively large. This is expected to result in differences in the observed structure depending on the wavelength. The ability of ALMA to image over more than an order of magnitude wavelength range will be important in this study.

• It will be possible to detect orbital motions of dust in the closer systems, studying dynamical interactions with orbiting planets.

• ALMA polarisation capability will enable the study of grain alignment and magnetic fields in these systems.

2.3. *Winds, jets and outflows from young and evolved stars.*

All young stars go through an outflow phase, and luminous stars are no exception. The large-scale outflows mapped in the last 20 years with single-dish mm-wave telescopes are generally thought to be driven by small-scale highly-collimated jets traced by hot gas seen in the optical or near-infrared. However, the launching mechanism of the collimated jets is still a matter of conjecture. Disk winds, X-winds and polar winds are all possible candidates. Some potential contributions of ALMA in this area are:

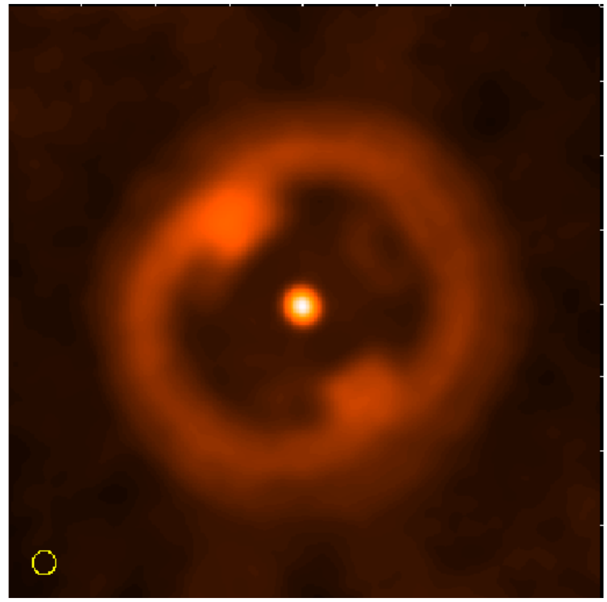

Fig. 3. Simulation of ALMA observation of a debris disk model (from Wyatt 2003) viewed at a distance of 100pc (Hales private comm.). The beam of ALMA in the extended configuration at 345 GHz is shown lower left. Much of the structure is due to an unseen shepherding planet inside the ring of dust debris.

• ALMA will be able to resolve the jet launch region (few AU) in nearby young stars, discriminating between the possible orgins of the jets.

• The inner magnetic field structure may be traced using polarimetry of dust and of line emission, elucidating the role of magnetic fields in the physics of jets.

• The extinction at mm wavelengths is ~ 10 times lower than the optical, allowing a view down to the central core of circumstellar disks.

• The available resolution and timescales of the flow are such that jet motion will be seen on week-long timescales; ALMA will make movies of the jet launch region

Winds from evolved massive stars, such as WR stars, are generally less collimated, but are thought to be clumpy (e.g., Blomme et al. 2002). With sufficient angular resolution, ALMA will be able to resolve the outer clumps in such winds, looking for structure and variations.

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2.4. *B[e] and Be stars*

The spatial resolution and fidelity will allow ALMA to resolve the structure of the disks around the closer Be stars, and around B[e] stars, such as MWC300. Moreover, it will be possible to search for molecular species in these disks.

2.5. *Other areas*

Several other areas of hot star reseach will be made feasible by ALMA, including imaging debris around luminous stars such as White Dwarfs, Pulsars and WR stars. ALMA will also allow measurement of dust polarimetry and magnetic fields or other alignment mechanisms on small angular scales, polarised emission from molecular gas, and detailed submm studies of the colliding winds in WR stars.

Perhaps the most important point is that ALMA will be opening up more than two dimensions of parameter space, each by more than an order of magnitude. The most interesting discoveries may be in areas we don't yet know about. The aim is that ALMA will be usable in as many areas as possible by as many different types of astronomer as possible. Get ready for early science in 2010–11.

DISCUSSION

D. Baade: *Potentially interesting targets are supernovae, e.g. (a) how and where does dust form? (b) searches for predecessors of SN1987A-like events, which may be recognisable by rings & loops.* — These will be excellent targets for ALMA, and the multi-wavelength capability will help discriminate between dust and other emission processes.

P. Benaglia: *Which bands will be offered during the science verification phase? And will observations at two IFs in a given band be possible?* — Early science will offer bands 3, 6, 7 and 9. And yes – in full dual-polarisation, dual sideband configurations, there are two sub-bands which can be positioned anywhere within the 4 GHz-wide IF (or 5.5 GHz-wide for band 6).

F. Rantakyro: *How quickly can one switch between bands?* — It should be rapid –within seconds– as long as the frontend cartridge for the second band is ready and 'warmed up'. Three cartridges can be ready at any one time.

M. Rubio: *Can you comment on software for data reduction?* — ALMA data reduction will use CASA, a general C++ package used both for real-time pipeline, and for offline reduction of interferometry and single-dish radio/submm data. CASA is also being used on other facilities (e.g. VLA, eVLA).

D. Gies: *What is the northern declination limit?* — About +40°.

D. Gunawan: *How bad is the shadowing from volcanoes?* — The lower elevation limit for normal operation is 20 degrees, so nearby volcanoes don't cause a problem.

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