Science with ALMA

Ast735: Submillimeter Astronomy
IfA, University of Hawaii
Science with ALMA

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Excellent (but unattributed) review paper found on the web
http://www.ifa.hawaii.edu/users/jpw/classes/alma/lectures/ALMA-science.pdf
INTRODUCTION

Figure 1: Left Sensitivity of ALMA, compared with some of the world’s other major astronomical facilities, for typical integration times of several hours.

Figure 1: Right Angular resolution of ALMA, compared with other major telescopes. The top of the band shown for ALMA corresponds to the compact 150 m configuration, and the bottom corresponds to the large array with 12 km baselines. For the VLT, the solid line corresponds to the seeing limited case, and the dashed line to the di-raction limited case with adaptive optics.

A site that is high, dry, large and flat is required, and a plateau at high elevation (5000 m) in the Atacama region of northern Chile is ideal - hence the Atacama Large Millimeter Array (ALMA).

Figure 1 shows the sensitivities and resolving powers of some of the world’s major astronomical facilities. These define the “front line” of astronomical research, and any new large telescope opening up a new part of the electromagnetic spectrum should have comparable performance. ALMA will be far more sensitive than either existing millimeter arrays or single telescopes with bolometer arrays. Furthermore, single-dish telescopes can only survey as deep as the confusion limit imposed by the finite beamsize. ALMA represents a giant step for millimeter/submillimeter astronomy, placing it in a unique position at the front line of astronomical research.

1.3 The Atacama Large Millimeter Array

The scientific objectives presented in the sections below lead to the high-level science requirements and technical specifications of the array. It is clear from HST observations of high-redshift galaxies that an angular resolution of at least 0.1 arcsec is required to image the features of star-forming regions in the early Universe, and an angular resolution of order 10 milli-arcsec is required to study the details of nearby protoplanetary systems. At the same time, high surface brightness sensitivity is required in order to image faint extended star-formation regions in our Galaxy and the total emission over nearby galaxies. Thus, a “zoom-lens” capability is called for, with movable antennas and the longest baselines extending to 10 km or more.

Sensitivity requirements → collecting area → 50 x 12m dishes
Resolution requirements → 10 km baselines
Wavelength requirements → very dry site

\{ Atacama \}
For constant system temperature, the noise in brightness temperature increases as the baseline length squared, and can rapidly dominate the signal, which is limited to a few tens of degrees by the emission physics. In the case of spectroscopic observations, the bandwidths are governed by the linewidths, not the receivers. Furthermore, in some of the millimeter/submillimeter windows, receiver performance is close to the atmospheric noise limits. Thus, for much of the spectral line research, the only way to increase sensitivity is to increase the collecting area. In particular, an angular resolution of \(< 0.1\)" can only be reached for thermal lines if the collecting area is increased by an order of magnitude over current values. The high sensitivity is also required for calibration purposes, and for image quality.

The collecting area of an array can be enhanced by increasing the number of antennas, their size, or both. There are clearly several trade-offs to be considered. Small antennas have higher precision, larger field of view, and their large number gives better image quality. The use of large antennas maximizes the collecting area, and reduces the number (and therefore cost) of receivers and the demands on the correlator. For ALMA, 64 antennas of 12-meter diameter gives a good solution.

Excellent imaging capabilities are important to achieve many of the scientific objectives. ALMA should provide instantaneous imaging capability, with the large number of antenna pairs allowing complete $uv$ coverage in snapshot mode. It should provide high fidelity imaging, and wide field imaging capability through the use of mosaicing techniques. The receiver bands should ultimately cover all the millimeter and submillimeter atmospheric windows. The atmospheric transparency at the high altitude of 5000m considered for ALMA is shown in Fig.2. In total, ten bands would cover the available spectral range, and the ALMA dewars will be built to accommodate all of them. Initially the four highest-priority bands will be provided. The system must be capable of high spectral resolution...
Science highlights (so far)

• Submillimeter galaxies
• Nearby galaxies
• Star formation
• Protoplanetary disks
• Evolved stars

ADS list of ALMA papers at https://science.nrao.edu/facilities/alma/pubs
Lensed SMGs

1 minute integrations! + spectral sweeping to get lines

Vieira et al. 2013, Nature
demonstrates that the fraction of dusty starburst galaxies imposed on the SPT sample due to gravitational lensing. The detection of radio-identified starbursts by spectroscopic observations of the molecular gas in the galaxies is shown in red/orange, though the majority are compiled in the blue distribution. The redshift distribution of luminous, dusty starbursts in the COSMOS survey is shown in red/orange, with 30 mJy offsets between sources for clarity.

The synthesized beam size ranges from 7′′, is shown in black. The existing samples of starburst galaxies, as measured at high-redshift, is shown in black. The existing samples of starburst galaxies, as measured at high-redshift, is shown in black. The existing samples of starburst galaxies, as measured at high-redshift, is shown in black. The existing samples of starburst galaxies, as measured at high-redshift, is shown in black. The existing samples of starburst galaxies, as measured at high-redshift, is shown in black. The existing samples of starburst galaxies, as measured at high-redshift, is shown in black. The existing samples of starburst galaxies, as measured at high-redshift, is shown in black. The existing samples of starburst galaxies, as measured at high-redshift, is shown in black. The existing samples of starburst galaxies, as measured at high-redshift, is shown in black.
A closer starburst

Herrera et al. 2012, A&A
Protostars are sweet!

Glycoaldehyde (HCOCH$_2$OH) in IRAS16293-2422

Fig. 1.— Spectra in the central beams toward the continuum peaks of IRAS16293A (upper) and IRAS16293B (lower). Fits from LTE models of the methyl formate (HCOOCH₃) and glycolaldehyde (HCOCH₂OH) emission are overplotted. The purple line indicates the model fit to the possible ethylene glycol transition. The X-axis represents the frequencies in the rest frame of the system (i.e., corrected for the systemic VLSR of 3 km s⁻¹). The green line is an indication of the RMS level (13 mJy beam⁻¹) represented by spectrum extracted from an off-source position. Note the much narrower lines toward IRAS16293B which facilitate identification of individual features.
Streamers in a planet forming disk?

Casassus et al. 2013, Nature
Fomalhaut’s debris disk

Fomalhaut’s debris disk
AU Mic’s debris disk

![Image of AU Mic's debris disk and model fit]

Table 2: Model Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Best-Fit</th>
<th>68% Confidence Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>$F_{\text{belt}}$</td>
<td>Belt flux density (mJy)</td>
<td>7.14</td>
<td>$+0.12, -0.25$</td>
</tr>
<tr>
<td>$x$</td>
<td>Belt radial power law index</td>
<td>2.32</td>
<td>$+0.21, -0.31$</td>
</tr>
<tr>
<td>$r_i$</td>
<td>Belt inner radius (AU)</td>
<td>8.8</td>
<td>$+11.0, -1.0$</td>
</tr>
<tr>
<td>$r_o$</td>
<td>Belt outer radius (AU)</td>
<td>40.3</td>
<td>$+0.4, -0.4$</td>
</tr>
<tr>
<td>P.A.</td>
<td>Belt position angle (°)</td>
<td>128.41</td>
<td>$+0.12, -0.13$</td>
</tr>
<tr>
<td>$\alpha_{\text{belt}}$</td>
<td>Belt spectral index</td>
<td>$-0.15$</td>
<td>$+0.40, -0.58$</td>
</tr>
<tr>
<td>$F_{\text{cen}}$</td>
<td>Gaussian flux density (mJy)</td>
<td>0.32</td>
<td>$+0.06, -0.06$</td>
</tr>
<tr>
<td>$\Delta x_{\text{cen}}$</td>
<td>Gaussian offset (AU)</td>
<td>0.71</td>
<td>$+0.35, -0.51$</td>
</tr>
<tr>
<td>$\sigma_{\text{cen}}^2$</td>
<td>Gaussian variance (AU$^2$)</td>
<td>$\leq 5.9$</td>
<td>(3$\sigma$ limit)</td>
</tr>
<tr>
<td>$\alpha_{\text{cen}}$</td>
<td>Gaussian spectral index</td>
<td>$-0.35$</td>
<td>$+2.1, -4.5$</td>
</tr>
<tr>
<td>$\Delta \alpha$</td>
<td>R.A. offset of belt center (°)</td>
<td>0.61</td>
<td>$+0.02, -0.02$</td>
</tr>
<tr>
<td>$\Delta \delta$</td>
<td>Decl. offset of belt center (°)</td>
<td>$-0.03$</td>
<td>$+0.02, -0.02$</td>
</tr>
</tbody>
</table>
Mass loss from an AGB star

Maercker et al. 2012, Nature
Figure 1: ALMA Early Science observations of the CO($J_{3-2}$) emission from the AGB star R Sculptoris. The panels in the figure show the emission in the different velocity channels. The color scale is given in Jy/beam. The stellar velocity is at $v_{LSR}=19.0$ km s$^{-1}$. The numbers in the top-right corners indicate the velocity in km s$^{-1}$ with respect to the stellar velocity. The spherical detached shell appears as a ring in the individual velocity channels, with its largest extent at the stellar velocity. The shell is clearly visible at 18.5" at the stellar $v_{LSR}$, as well as a spiral structure connecting the central star with the detached shell. The structure can be traced through all velocity channels.

R Sculptoris
binary AGB star
thermal pulse;
$t = 1800 yr, \Delta t = 200 yr$
$M = 3 \times 10^{-3} M_{\odot}$
$v_{ej} = 14.3$ km/s
Fiction
Fact
What are you waiting for?