ALMA Capabilities in Cycle 6

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Joint ALMA Observatory

SPF2: Star and Planet Formation in the Southwest
March 16, 2018
ALMA Overview

- 5000 m site in Atacama desert in Chile
- 66 reconfigurable antennas
- $\lambda \approx 0.3 - 3.0$ mm
- Array configurations between 0.16 and 16 km
  - angular resolution as fine as 0.014” at 300 GHz
- International partnership of North America, Europe, and East Asia
Capabilities

Imaging

8 receiver bands

Spectral lines

Continuum

Polarization

VLBI
12-m Array

50 x 12 m antennas

Atacama Compact Array (ACA)

12 x 7 m antennas

4 x 12 m antennas
ALMA Antenna Movements
from 2009-09-17 to 2014-12-07

- 66 reconfigurable antennas
- Array configurations between 0.16 and 16 km
Angular Resolution

\[ \theta \approx \frac{\lambda}{b_{\text{max}}} \]

- \( b_{\text{max}} = \) maximum separation between telescopes in the array
Field of View

\[ \Theta \approx \frac{\lambda}{D} \]

\[ D = \text{telescope diameter} \]
Largest Angular Scale

\[ \theta \approx \frac{\lambda}{b_{\text{min}}} \]

\( b_{\text{min}} \) = minimum separation between telescopes in the array
Angular scales

Resolution
- given by the largest distance between antennas (~\(\lambda / B_{\text{max}}\))

Field of view
- given by the diffraction limit of a single antenna (~\(\lambda / D\))
- If source is larger than the field of view, then make a mosaic

Largest angular scale that can be imaged
- given by the shortest distance between antennas (~\(\lambda / B_{\text{min}}\))

An interferometer is sensitive to a range of angular scales. Observe in multiple configurations to decrease \(B_{\text{min}}\) and increase \(B_{\text{max}}\).

\[ \frac{\lambda}{B_{\text{max}}} < \Theta < \frac{\lambda}{B_{\text{min}}} \]
# Angular Scales available in the Proposer’s Guide

Table A-1: Angular Resolutions (AR) and Maximum Recoverable Scales (MRS) for the Cycle 6 Array configurations

<table>
<thead>
<tr>
<th>Config</th>
<th>Lmax</th>
<th>Lmin</th>
<th>Band 3</th>
<th>Band 4</th>
<th>Band 5</th>
<th>Band 6</th>
<th>Band 7</th>
<th>Band 8</th>
<th>Band 9</th>
<th>Band 10</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>100 GHz</td>
<td>150 GHz</td>
<td>183 GHz</td>
<td>230 GHz</td>
<td>345 GHz</td>
<td>460 GHz</td>
<td>650 GHz</td>
<td>870 GHz</td>
</tr>
<tr>
<td>7-m Array</td>
<td>45 m</td>
<td>AR</td>
<td>12.5&quot;</td>
<td>8.4&quot;</td>
<td>6.8&quot;</td>
<td>5.4&quot;</td>
<td>3.6&quot;</td>
<td>2.7&quot;</td>
<td>1.9&quot;</td>
<td>1.4&quot;</td>
</tr>
<tr>
<td></td>
<td>9 m</td>
<td>MRS</td>
<td>66.7&quot;</td>
<td>44.5&quot;</td>
<td>36.1&quot;</td>
<td>29.0&quot;</td>
<td>19.3&quot;</td>
<td>14.5&quot;</td>
<td>10.3&quot;</td>
<td>7.7&quot;</td>
</tr>
<tr>
<td>C43-1</td>
<td>161 m</td>
<td>AR</td>
<td>3.4&quot;</td>
<td>2.3&quot;</td>
<td>1.8&quot;</td>
<td>1.5&quot;</td>
<td>1.0&quot;</td>
<td>0.74&quot;</td>
<td>0.52&quot;</td>
<td>0.39&quot;</td>
</tr>
<tr>
<td></td>
<td>15 m</td>
<td>MRS</td>
<td>28.5&quot;</td>
<td>19.0&quot;</td>
<td>15.4&quot;</td>
<td>12.4&quot;</td>
<td>8.3&quot;</td>
<td>6.2&quot;</td>
<td>4.4&quot;</td>
<td>3.3&quot;</td>
</tr>
<tr>
<td>C43-2</td>
<td>314 m</td>
<td>AR</td>
<td>2.3&quot;</td>
<td>1.5&quot;</td>
<td>1.2&quot;</td>
<td>1.0&quot;</td>
<td>0.67&quot;</td>
<td>0.50&quot;</td>
<td>0.35&quot;</td>
<td>0.26&quot;</td>
</tr>
<tr>
<td></td>
<td>15 m</td>
<td>MRS</td>
<td>22.6&quot;</td>
<td>15.0&quot;</td>
<td>12.2&quot;</td>
<td>9.8&quot;</td>
<td>6.5&quot;</td>
<td>4.9&quot;</td>
<td>3.5&quot;</td>
<td>2.6&quot;</td>
</tr>
</tbody>
</table>

- **Min/max antenna separations**
- **Angular resolution**
- **Maximum recoverable scale (largest angular scale)**

**Configuration**
Single dish + Interferometer

• 12m array reveals information on small spatial scales
• ACA reveals information on larger scales
• Combine both to recover small and large scales

Kong et al. (2018)
Flux density and brightness temperature

\[ S_v = \frac{2kTB}{\lambda^2} \Omega \]

- \( S_v \): flux density (Janskys)
- \( \Omega \): solid angle of “beam”
- \( T_B \): Brightness temperature (Kelvin)

1 Jansky = \( 10^{-26} \) Watt/meter\(^2\)/Hz
Sensitivity

System Temperature: product of sky and receiver

\[ \Delta S_v \propto \frac{k T_{sys}}{A \sqrt{N(N-1)} \Delta \nu t_{int}} \]

- Kelvin-Boltzmann constant
- Area of 1 Antenna
- Number of Antennas
- Frequency Resolution
- Integration Time

\[ \Delta S_v : \text{Independent of the angular resolution. However, } \Delta T_B \propto \frac{\Delta S_v}{\theta^2} \]
Example: Imaging an extended source

- Source diameter = 12”
- $S_{\text{tot}} = 15$ mJy
Example: Imaging an extended source

- ALMA Configuration 1 (3.5 h)
  - $\theta = 1.7$ arcsec @ 230 GHz
  - $\Delta S_\nu = 9.5$ microJy / beam
  - $\Delta T_B = 0.07$ milliK
  - $N_{\text{beams}} \sim (12/\theta)^2 \sim 50$
  - $<S_\nu> = 300$ microJy / beam
  - $<\text{SNR}> \sim 32$

- Configuration 1 and 4
  - $\theta = 0.52$ arcsec
  - $\Delta S_\nu = 9.5$ microJy / beam
  - $\Delta T_B = 0.75$ milliK
  - $N_{\text{beams}} \sim (12/\theta)^2 \sim 532$
  - $<S_\nu> = 28$ microJy / beam
  - $<\text{SNR}> \sim 3$

- Configuration 1, 4, and 8
  - $\theta = 0.086$ arcsec
  - $\Delta S_\nu = 9.5$ microJy / beam
  - $\Delta T_B = 27$ milliK
  - $N_{\text{beams}} \sim (12/\theta)^2 \sim 19000$
  - $<S_\nu> = 0.8$ microJy / beam
  - $<\text{SNR}> \sim 0.1$
Top quartile weather conditions
ALMA Receiver Bands in Cycle 6

Median weather conditions
Setting the Correlator

Flux density (Jy/beam)

Atmospheric transmission

Frequency [GHz]

PILS spectrum of IRAS 16293-2422b
Setting the Correlator

Atmospheric transmission

Flux density (Jy/beam)

Frequency [GHz]

Setting the Correlator for PILS spectrum of IRAS 16293-2422b
Setting up the correlator: Basebands

- Each baseband is a 2 GHz wide
- The 4 basebands can be in one sideband or distributed between the two
- Each baseband can be split into 4 spectral windows
Spectral windows

<table>
<thead>
<tr>
<th>Bandwidth (MHz)</th>
<th>Spectral resolution (MHz)</th>
<th>Spectral resolution @ 345 GHz (km/s)</th>
<th>Number Channels</th>
</tr>
</thead>
<tbody>
<tr>
<td>1875</td>
<td>31.2</td>
<td>27.1</td>
<td>120</td>
</tr>
<tr>
<td>1875</td>
<td>0.976</td>
<td>0.85</td>
<td>3840</td>
</tr>
<tr>
<td>938</td>
<td>0.488</td>
<td>0.42</td>
<td>3840</td>
</tr>
<tr>
<td>469</td>
<td>0.244</td>
<td>0.21</td>
<td>3840</td>
</tr>
<tr>
<td>234</td>
<td>0.122</td>
<td>0.11</td>
<td>3840</td>
</tr>
<tr>
<td>117</td>
<td>0.061</td>
<td>0.051</td>
<td>3840</td>
</tr>
<tr>
<td>58.6</td>
<td>0.0305</td>
<td>0.027</td>
<td>3840</td>
</tr>
</tbody>
</table>

High spectral resolution reduces processed bandwidth. More spectral windows per baseband reduces spectral resolution.

For dual polarization mode and for 1 spectral window per baseband
Example Correlator Setups: Band 3

CO isotopologues and chemical survey

Viviana Guzmán
Example Correlator Setups: Band 6

Deuterated chemistry

Frequency [GHz]
Example Correlator Setups: Band 7

Chemical survey of disks
Applying for ALMA Time

• ALMA Call for Proposals released once a year
• Regular proposal deadline is end of April
  - Cycle 6: April 19, 2018
• Director’s Discretionary Time (DDT) proposals accepted any time

• Important documents @ ALMA Science Portal
  - Proposer’s Guide
  - ALMA Technical Handbook
  - ALMA Primer
  - Observing Tool Guide
New in Cycle 6

- CIRCULAR POLARIZATION
- SIMULTANEOUS 12M + ACA OBSERVATIONS
- Carbon
  - $^{12}\text{CO}$
  - $^{13}\text{CO}$
  - $^{18}\text{O}$
- BAND 8 STANDALONE ACA
- BAND 6 IF EXTENSION

point-like sources only
Minimum number of antennas

- Steady State: 43 10 3
- Cycle 6: 43 10 3
- Cycle 5: 43 10 3
- Cycle 4: 40 10 3
- Cycle 3: 36 10 2
- Cycle 2: 34 9 2
- Cycle 1: 32 9 2
- Cycle 0: 16

Legend:
- Blue: 12 m Array
- Red: 7m Array
- Green: Total Power
Hours of observing time

- **Steady state**: 4300 hours
- **Cycle 6**: 4000 hours
- **Cycle 5**: 4000 hours
- **Cycle 4**: 3000 hours
- **Cycle 3**: 2100 hours
- **Cycle 2**: 2000 hours
- **Cycle 1**: 800 hours
- **Cycle 0**: 700 hours

12 m Array
ACA
# Cycle 5 Oversubscription Rates

## Oversubscription Rate in Cycle 5

<table>
<thead>
<tr>
<th></th>
<th>Chile</th>
<th>East Asia</th>
<th>Europe</th>
<th>North America</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>12-m Array</strong></td>
<td>2.4</td>
<td>4.2</td>
<td>4.7</td>
<td>3.4</td>
</tr>
</tbody>
</table>

### Share of time per region

- **Chile**: 33.75%
- **East Asia**: 22.5%
- **Europe**: 33.75%
- **North America**: 10%
Definition of Regular Proposals

Regular Proposals
- < 50 hours on 12 m array
  - and -
- < 150 hours on ACA standalone

Review process
- Assigned to a panel of similar (but broad) topics
- 8 reviewers per panel with a range of expertise
- Proposals should appeal to a broad and knowledge review, but not necessarily an expert in your subtopic
Definition of Large Programs

Large Programs
• > 50 hours on 12 m array
  - or -
• > 150 hours on ACA standalone

Time available
• Up to 600 hours on the 12-m array
• Up to 450 hours on the ACA array in standalone mode

Reviewed by individual panels and all Panel Chairs
• Large Programs need to appeal to both experts and non-experts
How much time can I ask for?

• Request what you need to do your science

• Yeah, but how much time can I really ask for?
Cycle 5 Acceptance Rate (Grade A+B) vs. Requested Time
Proposal pressure per configuration

C43-1

C43-2

C43-3

C43-4

C43-5

C43-6

C43-7

C43-8

C43-9

C43-10

7-m Array

Total Power Array
<table>
<thead>
<tr>
<th>Start date</th>
<th>Configuration</th>
<th>Longest baseline</th>
<th>LST for best observing conditions</th>
<th>Resolution at 300 GHz (arcsec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2018 October 1</td>
<td>C43-6</td>
<td>2.5 km</td>
<td>~ 22h – 10h</td>
<td>0.10</td>
</tr>
<tr>
<td>2018 October 15</td>
<td>C43-5</td>
<td>1.4 km</td>
<td>~ 0h – 12h</td>
<td>0.18</td>
</tr>
<tr>
<td>2018 November 25</td>
<td>C43-4</td>
<td>0.78 km</td>
<td>~ 2h – 14h</td>
<td>0.31</td>
</tr>
<tr>
<td>2018 December 15</td>
<td>C43-3</td>
<td>0.50 km</td>
<td>~ 4h – 15h</td>
<td>0.47</td>
</tr>
<tr>
<td>2019 January 5</td>
<td>C43-2</td>
<td>0.31 km</td>
<td>~ 5h – 16h</td>
<td>0.77</td>
</tr>
<tr>
<td>2019 January 20</td>
<td>C43-1</td>
<td>0.16 km</td>
<td>~ 6h – 17h</td>
<td>1.13</td>
</tr>
<tr>
<td>2019 February 1-28</td>
<td></td>
<td></td>
<td><em>No observations due to February shutdown</em></td>
<td></td>
</tr>
<tr>
<td>2019 March 1</td>
<td>C43-1</td>
<td>0.16 km</td>
<td>~ 8h – 21h</td>
<td>1.13</td>
</tr>
<tr>
<td>2019 March 15</td>
<td>C43-2</td>
<td>0.31 km</td>
<td>~ 8h – 22h</td>
<td>0.77</td>
</tr>
<tr>
<td>2019 April 1</td>
<td>C43-3</td>
<td>0.50 km</td>
<td>~ 9h – 23h</td>
<td>0.47</td>
</tr>
<tr>
<td>2019 April 15</td>
<td>C43-4</td>
<td>0.78 km</td>
<td>~ 10h – 0h</td>
<td>0.31</td>
</tr>
<tr>
<td>2019 May 1-31</td>
<td></td>
<td></td>
<td><em>No observations due to major antenna relocation</em></td>
<td></td>
</tr>
<tr>
<td>2019 June 1</td>
<td>C43-10</td>
<td>16.2 km</td>
<td>~ 13h – 3h</td>
<td>0.014</td>
</tr>
<tr>
<td>2019 June 20</td>
<td>C43-9</td>
<td>13.9 km</td>
<td>~ 14h – 5h</td>
<td>0.019</td>
</tr>
<tr>
<td>2019 July 10</td>
<td>C43-8</td>
<td>8.5 km</td>
<td>~ 16h – 6h</td>
<td>0.032</td>
</tr>
<tr>
<td>2019 August 1</td>
<td>C43-7</td>
<td>3.6 km</td>
<td>~ 18h – 8h</td>
<td>0.070</td>
</tr>
<tr>
<td>2019 September 5</td>
<td>C43-6</td>
<td>2.5 km</td>
<td>~ 20h – 9h</td>
<td>0.10</td>
</tr>
</tbody>
</table>
Percentage of Time Available Per Band

- Band 3
- Band 4
- Band 5 (203 GHz), Band 6
- Band 7
- Band 8 (492 GHz)
- Band 5 (183 GHz), Band 9, Band 10
High priority capabilities for Cycle 7 and 8

Single dish
- continuum single dish
- Band 9-10 single dish

Polarization
- mosaicking
- better limits for linear and circular

High frequency
- long baselines
- ACA standalone
- “standard” mode
ALMA Receiver Bands

<table>
<thead>
<tr>
<th>Freq. (GHz)</th>
<th>Timescale</th>
<th>Key Science</th>
</tr>
</thead>
<tbody>
<tr>
<td>Band 1</td>
<td>35-50</td>
<td>Grain growth in disks, redshifted CO</td>
</tr>
<tr>
<td>Band 2</td>
<td>67-90+</td>
<td>Deuterated molecules, redshifted CO</td>
</tr>
</tbody>
</table>

Prototype under development
ALMA Support

• Documentation on ALMA Science Portal

• Help Desk [https://help.almascience.org](https://help.almascience.org)
  - Questions usually answered in 2 days
  - around-the-clock staffing near the ALMA proposal deadline

• ALMA provides calibrated data and representative images

• ALMA Archive [http://almascience.org/aq](http://almascience.org/aq)
  - 1 year proprietary period (6 months for DDT)
  - provides calibrated data and images
ALMA Support in North America

- North American ALMA Science Center (NAASC) - [https://science.nrao.edu/facilities/alma](https://science.nrao.edu/facilities/alma)
  - provides general support for the North American community

- Student support - [https://science.nrao.edu/facilities/alma/opportunities/student-programs](https://science.nrao.edu/facilities/alma/opportunities/student-programs)
  - Successful ALMA proposals will be invited to apply for up to $35k to support undergraduate and graduate student involvement

- Face-to-face visitor support - [https://science.nrao.edu/facilities/alma/visitors-shortterm](https://science.nrao.edu/facilities/alma/visitors-shortterm)
  - Teams can visit the NAASC for data reduction or proposal writing support. Up to 2 team members per visit and 2 teams per week.

- Page charges - [https://library.nrao.edu/pubsup.shtml](https://library.nrao.edu/pubsup.shtml)
  - Upon request, NRAO covers page charges for authors at US institutions when reporting ALMA results

- ALMA Ambassadors - [https://science.nrao.edu/facilities/alma/ambassadors-program](https://science.nrao.edu/facilities/alma/ambassadors-program)
  - Research grants and training of postdocs who wish to host their own ALMA Proposal Workshops
### ALMA Cycle 6

<table>
<thead>
<tr>
<th>Date</th>
<th>Milestone</th>
</tr>
</thead>
<tbody>
<tr>
<td>December 15, 2017</td>
<td>Pre-announcement</td>
</tr>
<tr>
<td>February 1, 2018</td>
<td>Configuration schedule &amp; Large Program information</td>
</tr>
<tr>
<td>March 20, 2018</td>
<td>Call for Proposals released</td>
</tr>
<tr>
<td><strong>April 19, 2018</strong></td>
<td><strong>Proposal deadline!</strong></td>
</tr>
<tr>
<td>June 18-23, 2018</td>
<td>Proposal Review meeting in Antwerp, Belgium</td>
</tr>
<tr>
<td>Late July 2018</td>
<td>Proposal review results announced</td>
</tr>
<tr>
<td>October 2018</td>
<td>Start of Cycle 5 observations</td>
</tr>
</tbody>
</table>

4000 hours offered on the 12-m Array  
3000 hours offered on the Atacama Compact Array