ALMA: Atacama Large Mm/submm Array
Overview For Early Science Cycle 0

Rachel Friesen
Postdoctoral Fellow
NRAO / North American ALMA Science Center

Atacama Large Millimeter/submillimeter Array
Expanded Very Large Array
Robert C. Byrd Green Bank Telescope
Very Long Baseline Array
The take-away message in one slide

• Proposals for ALMA Cycle 0 being accepted June 1-30
  ➢ All information you need is available via the ALMA Science Portal at https://almascience.nrao.edu

• If you have any questions or need any help, contact us at the North American ALMA Science Center (NAASC) at NRAO Headquarters via the Helpdesk link on the Science Portal
Talk Outline

• ALMA Overview
• ALMA Status & Test Data
• Early Science (“Cycle 0”) Capabilities & Considerations
• Proposal Logistics
• Support from the NAASC
ALMA Overview

• A global partnership to deliver a transformational millimeter/submillimeter interferometer
  North America (US, Canada, Taiwan)
  Europe (ESO)
  East Asia (Japan, Taiwan)
  In collaboration with Chile

• 5000m (16,500 Ft) site in Chilean Atacama desert

• Main Array: 50 x 12m antennas
  + Total Power Array 4 x 12m
  + Atacama Compact Array (ACA): smaller array of 12 x 7m antennas

• Total shared cost ~1.3 Billion ($US2006)
ALMA Overview

• Baselines up to 15 km (0.015” at 300 GHz) in “zoom lens” configurations

• Sensitive, precision imaging 84 to 950 GHz (3 mm to 315 µm)

• State-of-the-Art low-noise, wide-band SIS receivers (8 GHz bandwidth)

• Flexible correlator with high spectral resolution at wide bandwidth

• Full polarization capabilities

• Estimate 1 TB/day archived

• A resource for ALL astronomers

ALMA will be 10-100 times more sensitive and have 10-100 times better angular resolution compared to current millimeter interferometers
There are now >36 antennas in various stages of completion.
Array Operations Site (AOS) 5000m

AOS Technical Building - completed 2008

Home of the ALMA 12m correlator and the ACA correlator

photo by T. Burchell NRAO/AUI

Move of the ninth antenna to high site on December 12, 2010

Current antenna count = 10

**ALMA Timeline**

<table>
<thead>
<tr>
<th>All Last Year (2010)</th>
<th>Commissioning (began Late 2009)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>March 31 2011</strong></td>
<td><strong>1st call for Early Science Proposals</strong></td>
</tr>
<tr>
<td>4th Quarter 2011</td>
<td>Early Science observing begins</td>
</tr>
<tr>
<td>Late 2012</td>
<td>Pipeline images for standard modes</td>
</tr>
<tr>
<td>Late 2013</td>
<td>Baseline ALMA construction complete</td>
</tr>
</tbody>
</table>
Commissioning: Test Images

The heart of a star forming galaxy: NGC253

Dust continuum of the potentially planet forming debris disk: Beta Pictoris


Commissioning: Test Images

The heart of a star forming galaxy: NGC253

Dust continuum of the potentially planet forming debris disk: Beta Pictoris

Ionized Carbon (CII @ 158 μm) at z=4.43

Spectral line forest from a Galactic massive protostar

CO(2-1): 220 GHz; 1.3mm

Continuum: 670 GHz; 450 μm

ALMA 870 μm

ESO 3.6m ADONIS

BRI 0952-0115
Science Verification

Observations to validate ALMA Observing Modes

Expect to have links to a few datasets and calibrated data products posted by June

User portal currently lists potential targets and bands.
Talk Outline

- ALMA Overview
- ALMA Status & Test Data
- Early Science (“Cycle 0”) Capabilities & Considerations
- Proposal Logistics
- Support from the NAASC
ALMA 1st Call March 31, 2011

Cycle 0 Capabilities:
• 16 antennas (12m)
• Four Receiver bands 3, 6, 7, 9 ➔ 100, 230, 345, 670 GHz ➔ 3, 1.3, 0.8, 0.45 mm
• Two configurations: Compact and Extended
• Range of correlator modes: up to 4 spectral windows and 8 GHz bandwidth
• Mosaics with up to 50 pointings
• Dual polarization (not full)
• Moving targets (except Sun)

Process:
• Observing begins Fall 2011, spans 9 months, with ~600 hours available
• Observations will be conducted on a “best effort” basis
• Proposers should expect that significant experience in radio/mm interferometry will be an advantage in working with the data products
## Two configurations

<table>
<thead>
<tr>
<th>Band</th>
<th>Frequency (GHz)</th>
<th>Primary beam (&quot;&quot;)</th>
<th>Angular Resolution (&quot;&quot;)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Compact (18-125m)</td>
<td>Extended (36-400m)</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>84 - 116</td>
<td>62</td>
<td>5.3</td>
</tr>
<tr>
<td>6</td>
<td>211 - 275</td>
<td>25</td>
<td>2.3</td>
</tr>
<tr>
<td>7</td>
<td>275 - 373</td>
<td>19</td>
<td>1.6</td>
</tr>
<tr>
<td>9</td>
<td>602 - 720</td>
<td>9</td>
<td>0.8</td>
</tr>
</tbody>
</table>

Matched resolution can be obtained in Bands 3&7 or 6&9 (important in measuring SEDs of resolved objects)
Receivers

• All ALMA receivers have dual linear polarization feeds
• Downconvert two ranges of sky frequencies to Intermediate Frequency (IF)

- The first Local Oscillator (LO1) can be tuned to different frequencies
- Data will be correlated only in the spectral windows that are defined, which can be placed within one or both sidebands

Fixed Separation
Band 3, 7, 9: 8 GHz
Band 6: 10 GHz
Digitizers and Correlator

• Each antenna has 4 digitizers which can each sample 2 GHz * 2 polarizations, termed a **baseband**. Spectral windows are defined within basebands.

• Basebands can be distributed among the sidebands:

  - Edges of the baseband cannot lie outside the IF range & edges of the spectral window cannot lie outside the baseband

  **Cycle 0**: only one spectral window per baseband & all spectral windows must have the same configuration (bandwidth and spectral resolution). Bands 3, 6, 7 can only place even numbers of basebands in each sideband.
### Correlator Modes and Resolution

<table>
<thead>
<tr>
<th>Polarization</th>
<th># Channels per baseband</th>
<th>Bandwidth per baseband (MHz)</th>
<th>Channel Spacing (MHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dual</td>
<td>3840</td>
<td>1875</td>
<td>0.488</td>
</tr>
<tr>
<td></td>
<td></td>
<td>938</td>
<td>0.244</td>
</tr>
<tr>
<td></td>
<td></td>
<td>469</td>
<td>0.122</td>
</tr>
<tr>
<td></td>
<td></td>
<td>234</td>
<td>0.061</td>
</tr>
<tr>
<td></td>
<td></td>
<td>117</td>
<td>0.0305</td>
</tr>
<tr>
<td></td>
<td></td>
<td>58.6</td>
<td>0.0153</td>
</tr>
<tr>
<td>Single</td>
<td>7680</td>
<td>58.6</td>
<td>0.0076</td>
</tr>
<tr>
<td>Dual</td>
<td>128</td>
<td>2000</td>
<td>15.6</td>
</tr>
<tr>
<td>Single</td>
<td>256</td>
<td>2000</td>
<td>7.8</td>
</tr>
</tbody>
</table>

(MHz = km/s @300 GHz)

- Numbers are per baseband (you can use up to 4 basebands)
- **Note that the resolution is ~ 2*channel width (Hanning)**
- The required spectral resolution typically needs to be justified as does the number of desired spectral windows

### Typical purposes:

- Spectral scans
- Targeted imaging of moderately narrow lines: cold clouds / protoplanetary disks
- “Continuum” or broad lines
Continuum sensitivities (5σ in 1hr)

<table>
<thead>
<tr>
<th>Band</th>
<th>Frequency (GHz)</th>
<th>Sensitivity (mJy/beam)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>84 - 116</td>
<td>0.14</td>
</tr>
<tr>
<td>6</td>
<td>211 - 275</td>
<td>0.20</td>
</tr>
<tr>
<td>7</td>
<td>275 - 373</td>
<td>0.37</td>
</tr>
<tr>
<td>9</td>
<td>602 - 720</td>
<td>3.2</td>
</tr>
</tbody>
</table>

Only 3 receiver bands can be “ready” at one time (i.e. amplifiers powered on and stable temperature achieved). Required lead time to stabilize a new band is about 20 minutes. Scheduling issue.
ALMA in Context

Collecting Area

- Sensitivity goes as collecting area
- Image fidelity goes as # of baselines

<table>
<thead>
<tr>
<th>Telescope</th>
<th>Collecting Area</th>
<th># of Antennas</th>
<th>(# of baselines)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CARMA</td>
<td>8 (28)</td>
<td>23 (253)</td>
<td></td>
</tr>
<tr>
<td>SMA</td>
<td>16 (120)</td>
<td>64 (2016)</td>
<td></td>
</tr>
<tr>
<td>IRAM PdBI</td>
<td>6 (15)</td>
<td>8 (28)</td>
<td></td>
</tr>
</tbody>
</table>

SMA

ALMA

Cycle 0

Full Science

32 (1024)

Frequency (GHz)

100 200 300 400 500 600 700 800 900

Spectral Coverage

- SMA
- CARMA
- PdBI
- ALMA CyO
- ALMA FS

Talk Outline

• ALMA Overview
• ALMA Status & Test Data
• Early Science (“Cycle 0”) Capabilities & Considerations
• Proposal Logistics
• Support from the NAASC
## ALMA Cycle 0 Key Dates

<table>
<thead>
<tr>
<th>Date</th>
<th>Milestone</th>
</tr>
</thead>
<tbody>
<tr>
<td>31 March 2011</td>
<td>Cycle 0 CfP &amp; release of Observing Tool</td>
</tr>
<tr>
<td>29 April 2011</td>
<td>Cycle 0 Proposal “Notice of Intent” deadline</td>
</tr>
<tr>
<td>1 June 2011</td>
<td>Opening of archive for proposal submission</td>
</tr>
<tr>
<td>30 June 2011</td>
<td>Proposal deadline</td>
</tr>
<tr>
<td>July - Sept 2011</td>
<td>Technical Assessments by ALMA staff</td>
</tr>
<tr>
<td></td>
<td>Science-Themed ALMA Review Panels (ARPs)</td>
</tr>
<tr>
<td></td>
<td>ALMA Proposal Review Committee (APRC)</td>
</tr>
<tr>
<td>mid-Sept 2011</td>
<td>Announce Results</td>
</tr>
<tr>
<td>30 September 2011</td>
<td>Anticipated start of ALMA Cycle 0 observing</td>
</tr>
<tr>
<td>February 2012</td>
<td>Anticipated one month engineering shutdown</td>
</tr>
<tr>
<td>30 June 2012</td>
<td>Anticipated end of ALMA Cycle 0</td>
</tr>
</tbody>
</table>
ALMA Cycle 0 Logistics

• Proposal Deadline = 15:00 UT on 30 June 2011
  - Four science categories
  - Standard (≤100 hours) & Targets of Opportunity
  - 33.5% for NA-led projects

• HST/Spitzer-like review process: one international TAC
  - The ~6-member Science panels produce science-ranked lists
  - Panel members are not affiliated with ALMA/JAO
  - Panel outputs merged by Proposal Review Committee (chair=Neal Evans)
  - PRC consolidates grades and adjusts for partner shares

• Anticipate awarding 500-700 hours
  - Projects assigned maximum time and grade (A, B, C, rejected)
  - Aim for science that can be done in a few hours
Proposal Checklist

- Read Primer and Proposers Guide
- Create ALMA account by registering at the Science Portal
- Download Observing Tool (OT), try Sensitivity Calculator
- Download casa 3.2 (early May release), try simdata
- Prepare the Science & Technical Justifications (one PDF file)
- Prepare Science Goals (sources, frequency & correlator setup, integration times) within the OT
- Make use of the Helpdesk & the Knowledgebase
- Submit to Archive!
Register -
- to submit proposals as PI
- to be Co-I on proposals
- to submit helpdesk tickets
Science Portal

Documents/tools

Sensitivity Calculator

Proposers Guide
(Handbook after May 15)

ES Primer

Observing Tool
“Quickstart” guide & videos

CASA and CASA-based observing simulators

https://almascience.nrao.edu/
Talk Outline

• ALMA Overview
• ALMA Status & Test Data
• Early Science ("Cycle 0") Capabilities & Considerations
• Proposal Logistics
• Support from the NAASC
Science Support

- Three ALMA Regional Centers: ARCs
  - NA: Charlottesville, VA, USA
  - EU: Garching, Germany
  - EA: Mitaka, Japan

- North American ARC: US - Canada (7.25%) partnership for core support

- North American ALMA Science Center (NAASC) encompasses NA ARC and includes partnership with Taiwan

NAASC: One-stop shopping for:
- Proposal Help and Submission
- Observation preparation (Phase 2)
- Data archive
- Data processing
- Face-to-face visitor support
- Workshops and tutorials
- Community outreach

NAASC in Charlottesville, VA
ALMA Helpdesk
- Includes self-help capability
- Staffed world-wide
- Also at alma-help.nrao.edu
ALMA Data Products

- The Joint ALMA Observatory (JAO) operates the array in Chile.
- The JAO is responsible for data product quality, eventually using a pipeline (late 2012).
- In Early Science, quality assurance will be a manual process. Basic CASA scripts that were used to calibrate and image the datasets will be included.
- The ARCs are responsible for delivery of the data, but will also fulfill requests to re-process data.
Future Capabilities of ALMA

• >3× better sensitivity with 50 × 12m antennas in main array
  • Fantastic “snapshot” uv-coverage (1225 baselines)
  • Imaging fidelity ~10× better!
• Higher angular resolution: baselines ~15km, matched beams in all bands
• Better imaging of resolved objects and mosaics
  • TPA: 4 × 12m antennas with subreflector nutators
  • ACA: Atacama Compact configuration 12 × 7m antennas
  • “On-the-Fly” mosaics: quickly cover larger areas of sky
Future Capabilities of ALMA

• More receiver bands: 4, 8, 10 (2mm, 0.7mm, 0.35mm)
• Polarization: magnetic fields and very high dynamic range imaging
• “Mixed” correlator modes
  • (simultaneous wide & narrow, see A&A 462, 801)
• ALMA Development Program ➔ studies just beginning now
  • mm VLBI
  • More receiver bands
  • Higher data rates
NRAO Beyond ALMA

3 Other Cutting-Edge Facilities That Complement ALMA

EVLNA  GBT

VLBA  ALMA
Expanded Very Large Array

- The EVLA Era is here!
- Continuous spectral coverage 1-50 GHz (λ 0.6-30 cm)
- Powerful new WIDAR correlator (built by Canada)
- 8 GHz bandwidth: 10X VLA continuum sensitivity
- Early Science underway since March 2010
  - special issue of ApJ letters
Overall EVLA Performance Goals

- Providing orders of magnitude improvements in performance!

<table>
<thead>
<tr>
<th>Parameter</th>
<th>VLA</th>
<th>EVLA</th>
<th>Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continuum Sensitivity (1-σ, 1 hr.)</td>
<td>30 µJy</td>
<td>3 µJy</td>
<td>10</td>
</tr>
<tr>
<td>Maximum BW in each polarization</td>
<td>0.1 GHz</td>
<td>8 GHz</td>
<td>80</td>
</tr>
<tr>
<td># of frequency channels at max. BW</td>
<td>16</td>
<td>16,384</td>
<td>1024</td>
</tr>
<tr>
<td>Maximum number of freq. channels</td>
<td>512</td>
<td>4,194,304</td>
<td>8192</td>
</tr>
<tr>
<td>Coarsest frequency resolution</td>
<td>50 MHz</td>
<td>2 MHz</td>
<td>25</td>
</tr>
<tr>
<td>Finest frequency resolution</td>
<td>381 Hz</td>
<td>0.12 Hz</td>
<td>3180</td>
</tr>
<tr>
<td># of full-polarization spectral windows</td>
<td>2</td>
<td>64</td>
<td>32</td>
</tr>
<tr>
<td>(Log) Frequency Coverage (1 – 50 GHz)</td>
<td>22%</td>
<td>100%</td>
<td>5</td>
</tr>
</tbody>
</table>
EVLA K-band: massive young stellar objects in NGC6334-I

- Initial test for start of RSRO project AB1346
- 8 x 8 MHz subbands with 256 channels RR only; referenced pointing
- 10 minutes on source!
Green Bank Telescope

- Largest **fully-steerable** radio telescope – offset parabola

- **Sensitivity & frequency coverage**
  \( \nu: 300 \, \text{MHz} - 98 \, \text{GHz}; \lambda: 0.3 - 100 \, \text{cm} \)

- **Detector suite** for spectroscopy, pulsar observations, continuum, VLBI

- **Focal Plane Array (FPA)**
  - KFPA (1 cm), MUSTANG
  - developing W-Band (3 mm) array and Lband (~20 cm) cooled phased array
**Very Long Baseline Array**

- Ten 25m diameter radio telescopes
- Longest baseline: **8,600 km**
- **Highest resolution** imaging telescope: sub-milliarcsecond resolution
- **Highest precision** astrometric telescope: 10 μsec precision now!
- **Key Science Projects**
  - **Sensitivity Enhancement**: >2 Gbps BW, upgrade C-Band receivers (international collaboration)
Summary

• Amazing scientific promise of ALMA
• Steady progress in construction: 10 antennas now at high site
• Proposal submission June 1-30 (tools & documentation available now)
  • already more collecting area and spectral coverage than current arrays
• NAASC is your One-Stop for community support

Info common across project  \[
\text{http://almascience.nrao.edu/}
\]

NAASC specific programs  \[
\text{http://science.nrao.edu/alma/}
\]
The Atacama Large Millimeter/sub-millimeter 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.