Residual I map. Array: EVN
SN2007GR at 4.974 GHz 2007 Sep 06

SN 2007gr

e-EVN, 5 GHz
6-7 Sept. 2007

VLA

optical

Map center: RA: 02 43 27.960, Dec: +37 20 44.700 (2000.0)
Displayed range: -0.000317 → 0.000422 Jy/beam
The Atacama Large Millimeter / Submillimeter Array: ALMA

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Outline

• Millimeter and submillimeter astronomy
• Location requirements
• Existing arrays
• ALMA
  – Specifications
  – Configurations and sensitivity
  – Science drivers
  – Calibration issues
  – Operations and data flow
  – Progress and time line
• Concluding remarks
(Sub) millimeter astronomy

• Cold dust (10–100 K) emits at mm/submm
  – But optically thin unlike at infrared and visible wavelengths

• Molecules such as CO emit at mm/submm
  – H$_2$ does not emit radiation (except weak lines from >200 K gas in infrared)

• Study the cold Universe
• Study the dust-enshrouded Universe
• Locations where stars are born and galaxies shaped
A star-forming cloud

IRAM 30m: Motte et al. (1998)

1.3mm mosaic of ρOph main cloud

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A planet-forming disk

LkC15, OVRO: PhD work Qi and Kessler-Silacci

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Nearby galaxies

Helfer et al. (2003) - BIMA SONG
Gas in the early Universe

Image courtesy C. de Breuck, ESO
Location Requirements

- Atmosphere is partially transparent in (sub) millimeter wavelengths. Deep absorption by molecules (mostly water) separates various ‘windows’ or ‘bands’.
Location requirements

• Need to find
  – A high place (above most atmospheric water)
  – A flat place (need space for baselines)
  – A place without much turbulence in the atmosphere
    (phase stability)

  – (phase fluctuations are caused by variable path length
    through the atmosphere. In the case of (sub)mm
    frequencies, this is due to the passing of 'cells' of humid
    air over the array.)
Existing Arrays

BIMA + OVRO = CARMA: Combined Array for Millimeter Astronomy, Inyo Mountains, Calif.

NMA: Nobeyama Millimeter Array, Japan

SMA: Submillimeter Array, Hawaii

PdBI: Plateau de Bure, France

ATCA: Australia Telescope Compact Array
# Capabilities and Limitations

<table>
<thead>
<tr>
<th>Array</th>
<th>Wavelength(s) (mm)</th>
<th>Telescope Diameter</th>
<th>Maximum Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATCA</td>
<td>3</td>
<td>5 × 22 m</td>
<td>2″</td>
</tr>
<tr>
<td>PdBI</td>
<td>3+1</td>
<td>6 × 15 m</td>
<td>1.3″, 0.5″</td>
</tr>
<tr>
<td>OVRO</td>
<td>3+1</td>
<td>6 × 10.4 m</td>
<td>2″, 1″</td>
</tr>
<tr>
<td>BIMA</td>
<td>3+1</td>
<td>10 × 6.1 m</td>
<td>0.4″/2″/6″/14″</td>
</tr>
<tr>
<td>CARMA</td>
<td>3+1</td>
<td>6 × 10.4 m + 9 × 6.1 m</td>
<td>0.5″, 0.2″</td>
</tr>
<tr>
<td>NMA</td>
<td>3+2+1</td>
<td>6 × 10 m</td>
<td>1″…5″</td>
</tr>
<tr>
<td>SMA</td>
<td>1.3+0.87+0.44</td>
<td>8 × 6 m</td>
<td>0.4″, 0.3″, 0.15″</td>
</tr>
</tbody>
</table>

With the possible exception of CARMA, none of these arrays have many elements → poor uv filling; multiple tracks required for decent image quality

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(u,v) positions and beam shape
Mosaicing

- What if emission extends beyond the array’s primary field of view? -> mosaic

Fields need to be Nyquist spaced
Atacama Large Millimeter Array

• Need to bring (sub) millimeter interferometry at the same level as cutting edge facilities like HST and JWST: sensitivity and resolution
  – Large collecting area
  – Many baselines: imaging quality
  – Excellent site: access highest submm frequencies

• Europe + North-America + Japan, in cooperation with Chile
Existing Arrays & ALMA

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BIMA + OVRO = CARMA: Combined Array for Millimeter Astronomy, Inyo Mountains, Calif.

ALMA: Cajnantor, Chile

PdBI: Plateau de Bure, France

ATCA: Australia Telescope Compact Array

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Chajnantor
ALMA: Science Drivers

1. The ability to detect spectral line emission from CO or CII in a normal galaxy like the Milky Way at a redshift of $z = 3$, in less than 24 hours of observation.

2. The ability to image the gas kinematics in protostars and in protoplanetary disks around young Sun-like stars at a distance of 150 pc (roughly the distance of the star-forming clouds in Ophiuchus or Corona Australis), enabling the study of their physical, chemical and magnetic field structures and to detect the tidal gaps created by planets undergoing formation in the disks.

3. The ability to provide precise images at an angular resolution of 0.1 arcsec. Here the term "precise image" means being able to represent, within the noise level, the sky brightness at all points where the brightness is greater than 0.1% of the peak image brightness.
ALMA: Specifications

- All atmospheric bands between 30 and 950 GHz
- 0.01 km/s resolution at 100 GHz: thermal line widths
- Spectral dynamic range 1:10,000; imaging dynamic range: 1:50,000
- Detect <1 mJy in 10 min under median atmospheric conditions: 8 GHz bandwidth x 2 polarizations
- 50 antennas of 12m diameter
- 0.01" scales high fidelity imaging
- Baselines 150 m - 18.5 km
- Total power: 4 ants have nutating subreflectors
  - Additional array with 7m antennas for intermediate scales
- Phase correction better than 1 rad at 950 GHz, amplitudes better than 3% at 300 GHz and 5% at higher freqs
- Full polarization capability (<0.1% polarized intensity, <6 deg PA)
- Can look at Sun at all freqs
- Software for proposal and observations preparation
- Software for pipeline calibration and reduction
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ALMA bands

Atmospheric transmission at Chajnantor, pwv = 0.5 mm

Construction: 3,4,(5),6,7,8,9,(10)
Band 9 cartridge

Front ends

Band 7 cartridge

Cryostat

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...and backends
ALMA: Configurations
Current Transporter Concepts
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ALMA: Calibration

- Calibration strategy under development
- Hot & cold loads
- Suitable astrophysical calibrators
- Phase calibration may/will require continuous monitoring of the phases
  - Track water vapor at 22 GHz or 183 GHz
  - Derive path length variations -> phase correction
  - Developed for BIMA, OVRO, SMA
  - Still experimental, but essential for operations at higher frequencies

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Water Vapor Radiometers

Observed phases of calibrators

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After WVR phase corrections have been applied
Water Vapor Radiometers

+ apply selfcal to correct intermittent offsets

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From proposal to observations

Phase I proposal

TAC

Phase II proposal

JAO-Santiago

OSF-San Pedro

AOS-Chajnantor

NRAO

NAOJ

user

Science case
Source(s)
Lines/freqs
Sensitivity
Resolution

Minimally schedulable blocks
Weather conditions

Integration times
Configurations
Total power?
-> script
From observations to images

Science quality image + raw visibilities

European ALMA Regional Center
Archive copy

NAASC
Archive copy

NAOJ
Archive copy

JAO-Santiago
Archive

OSF-San Pedro
Data quality control

Pipeline calibration & reduction

AOS-Chajnantor

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Time line

- 2005 antenna contracts signed
- 2007 first antennas arrive in Chile
- 2008 assembly, integration, verification
- 2009 AIV, commissioning, science verification
- 2010 commissioning and early science (~16 ants)
- 2011 early science and commissioning
- 2012 fully operational
Concluding Remarks

- Interferometry at (sub) millimeter wavelengths has progressed
  - ~3 element arrays operating at 3 mm
  - 6-10 element arrays operating at 3 and 1 mm
  - Submillimeter arrays of 10-15 elements

- ALMA: quantum leap to 50 element array that will make submillimeter interferometry a standard tool for all astronomers.