Atacama Large Millimetre Array: Capabilities, Status & Future

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ALMA

Recent (but already out of date) photo of ALMA with 19 antennas at AOS

Credit: ALMA (ESO/NRAO/NAOJ) / W. Garnier (ALMA)

ALMA – aerial view

Credit: ALMA (ESO/NRAO/NAOJ) / ?

Outline

Capabilities

Current status

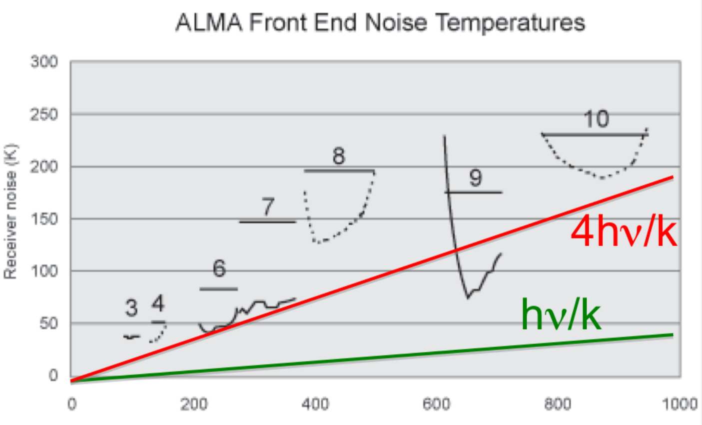
ALMA Development programme

Summary of key capabilities

1. Very high sensitivity to unresolved sources
2. Resolution as fine as 0.005 arcseconds
3. High image fidelity
4. Good surface brightness sensitivity (compact configuration + ACA + Total Power)
5. Small instantaneous Field-Of-View: $\frac{\lambda}{1\,\mathrm{mm}} \times 17\,\mathrm{arcsec}$
6. $2 \times 8\,$GHz instantaneous bandwidth
7. Full polarisation capability
8. Aiming for very high calibration accuracy
9. Very fast mosaicing (OTF interferometry)
10. Aiming for high observing flexibility (very short turnaround between projects, multiple arrays, multiple LOs, multiple correlators, target-of-opportunity, solar observing, solar system objects)

Unresolved source sensitivity

- For full ALMA expect total “gain” about ~ 1.7 K/Jy
- 16 GHz bandwidth for continuum
- Receiver noise temp spec: $\lesssim 6 - 15\ h\nu/k$



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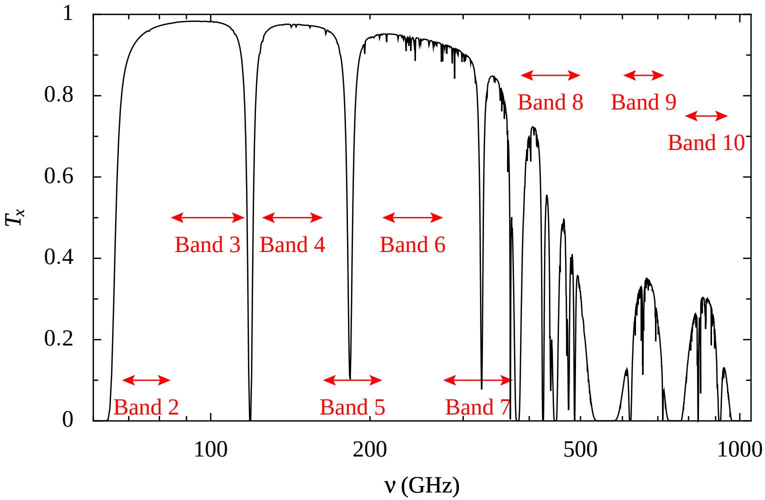
- 16 GHz bandwidth for continuum
- Receiver noise temp spec: $\lesssim 6 - 15\ h\nu/k$
  E.g., spec for Band 7 < 150 K, in practice much better (~ 90 K) (+add 40 K for atmosphere)
- $\Rightarrow$ at 850 μm approximately 1 mJy in one second continuum sensitivity will be routine
- $\Rightarrow$ Spectroscopy at 850 μm
  - 100 km/s spectral resolution $\rightarrow$ about 12 mJy / 20 mK sensitivity in one second
  - 1 km/s spectral resolution $\rightarrow$ about 120 mJy / 200 mK sensitivity in one second
- `http://almascience.eso.org/call-for-proposals/sensitivity-calculator`

ALMA spectral coverage

1 mm precipitable water vapour

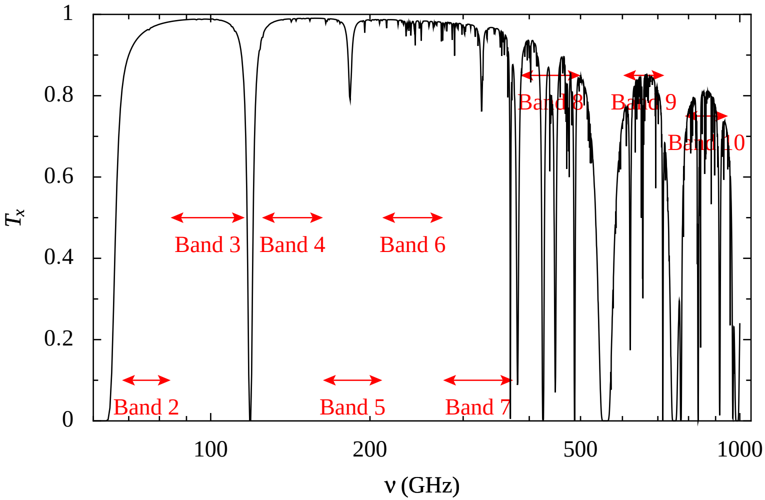


Bands 3, 4, 6, 7, 9 in production. Band 10 in development stage.

EC FP6 programme building 6 Band 5 cartridges.

ALMA spectral coverage

0.1 mm precipitable water vapour



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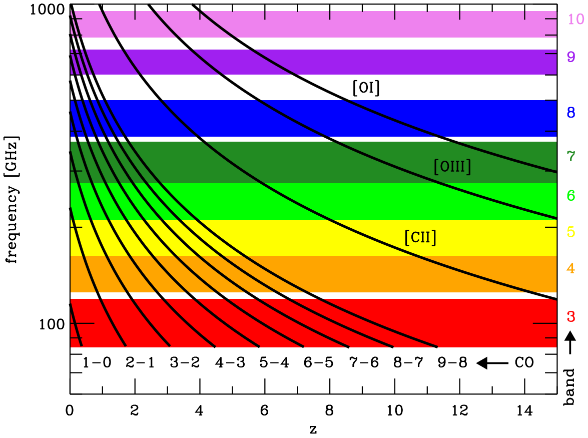
High-z line coverage



[Maiolino(2008)]

Resolution – 10+ km baselines

This is what we want to get to [Wolf & A'Angelo, 2005. (50+100pc, 1+5 M_{jupiter})]

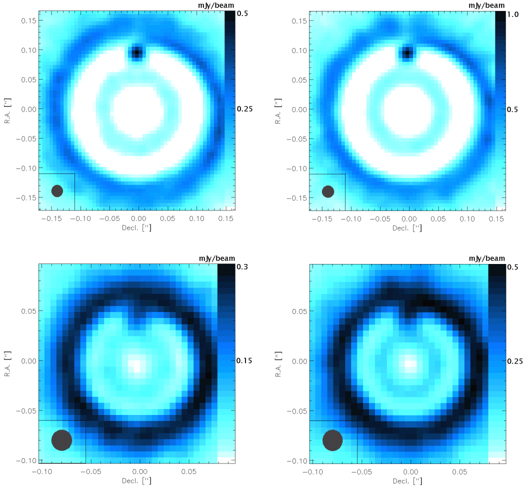


Image fidelity

One of three ALMA top-level science goals

The ability to provide precise images at an angular resolution of 0.1 arcseconds. Here the term precise image means accurately representing the sky brightness at all points where the brightness is greater than 0.1% of the peak image brightness. This requirement applies to all sources visible to ALMA that transit at an elevation greater than 20 degrees.

$\Rightarrow\ > 1000 : 1$ dynamic range

Image fidelity II

- $\sim$ 2000 instantaneous baselines
- $\sim$ 25 configurations – non-symmetric, minimally redundant optimised antenna positions with close to Gaussian radial distribution
- Fast slew (2 s to move 2 degrees and settle) means easy to revisit pointings
- Accurate primary beam calibration, other calibrations
- (Relatively low dynamic range of much of the sky!)

Calibration capability

- Amplitude calibration consistency over time/different directions in sky:
  - Better than 1% at $\nu < 370$ GHz (Bands 1-7)
  - Better than 3% at $\nu > 370$ GHz (Bands 8-10)
- Accuracy of overall flux density scale 5%
- Primary beam pattern: better than 1% at $\nu < 400$ GHz / 2% otherwise
- Polarisation accuracy: 0.1% flux error and 6 degree position angle
- Phase fluctuations $\lesssim 10\,\mu\mathrm{m}(1 + \frac{c}{1\,\mathrm{mm}})$ $\rightarrow \lesssim 20\,\mu$m in median conditions, even on 10 km baselines!

Mosaicing

- Should perform close to radiometer equation
- Move between pointing centres < 2 seconds
- On-the-fly interferometry: antennas continuously scanning
  (Commissioning of both hardware and software already started)
- 1000-pointing mosaics should be easy!

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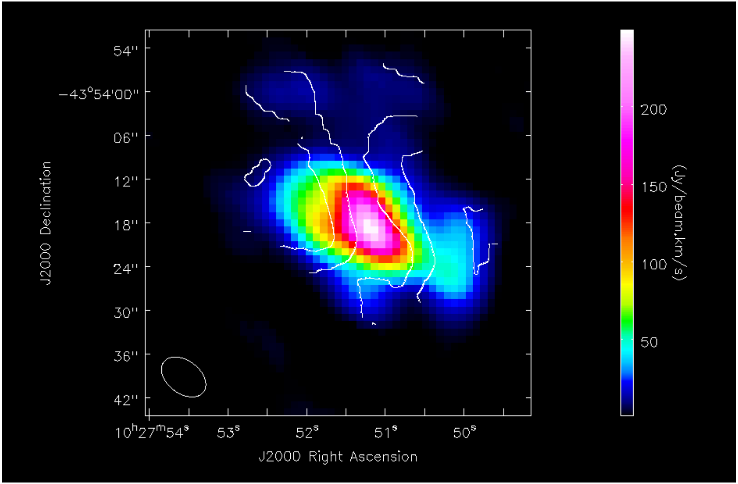
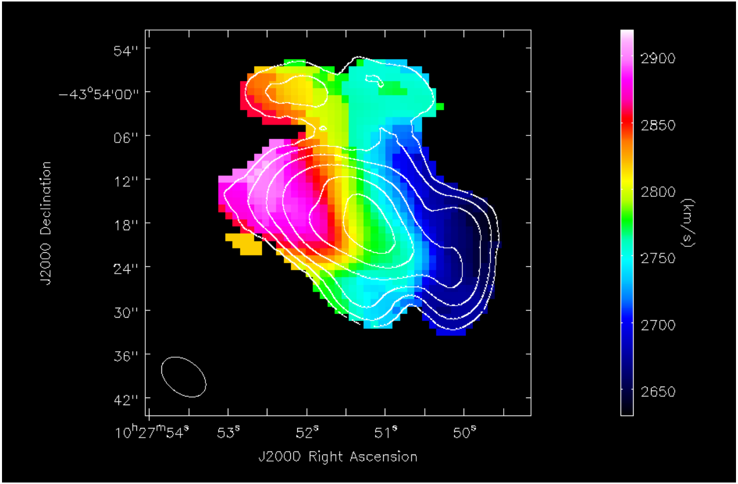
SV: Antennae Galaxies

SV: NGC 3625 I



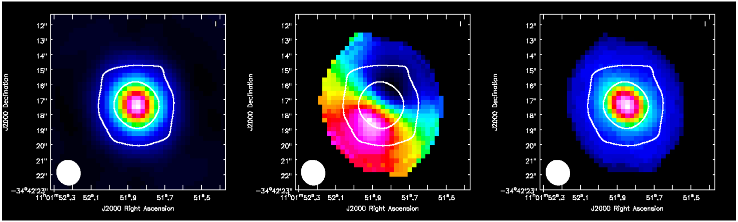
54''
−43°54'00''
06''
12''
18''
24''
30''
36''
42''
J2000 Declination
10h27m54s
53s
52s
51s
50s
J2000 Right Ascension
200
150
100
50
(Jy/beam.km/s)

SV: NGC 3625 II

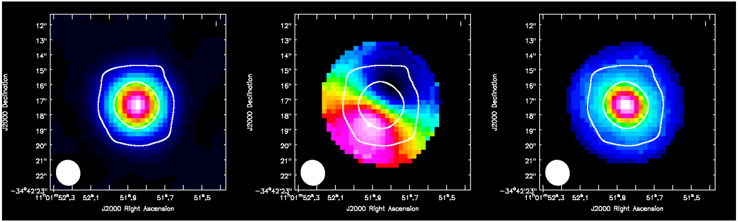


TW Hydra

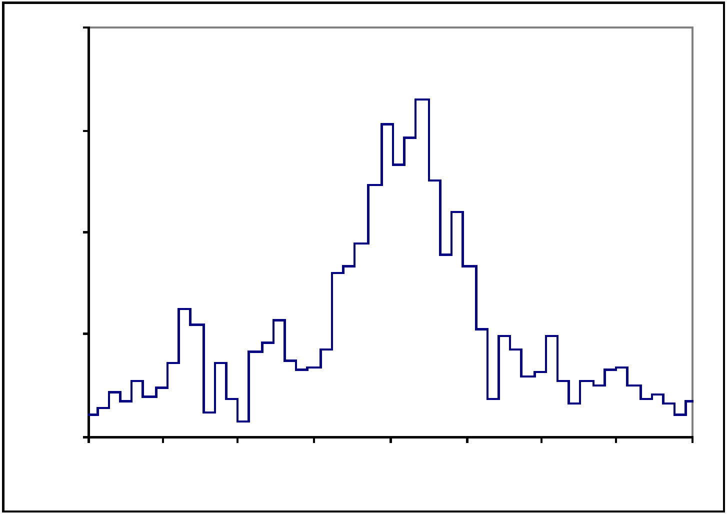
CO J=3 $\rightarrow$ 2:



HCN J=4 $\rightarrow$ 3:



SV: [C II] from a z∼4.4 QSO



ALMA Current Status

- Currently 26 antennas up at the AOS (22×12 m-diameter and 4×7 m-diameter)
- Bands 3, 4, 6, 7 and 9 are in use (4 not offered for Cycle 0)
- Baseline + ACA correlator. Both antenna transporters. Full set of WVRs. Sufficient number of FEs for available antennas. ACDs.
- Commissioning and Science Verification observations ongoing
- Short baselines only (< 250 m). Currently being commissioned: polarisation, solar observing, complex correlator modes, new releases of the software.

ALMA Early Science Cycle 0

- Over 900 proposals ($\lesssim$ top 10% are likely to be observed)
- Observing begun 30th September, right on schedule!
- 16+ antennas
- Observing in 5 $\times$ 12 hour blocks
- Data calibrated and reduced by JAO & ARC staff with delivery as science-grade data cubes
- First Cycle 0 data delivered to PIs last week

Note about availability

300 days of 24 hour/day observing would approximately allow every Cycle 0 proposal to be done!
That level is not quite feasible, but ALMA will do *a lot* of science

Cycle 1

Draft proposal (taken from Al Wooten's presentation, 30 Nov)

- Minimum 32×12 m-diameter antennas + ACA (5×7 m-diameter + $\geq 1 \times$ 12 m-diameter), maximum 1 km baselines
- Bands 3, 6, 7, 9 (same as Cycle 0)
- More flexibility in the correlator
- No large proposals
- Polarisation unlikely to be offered
- More programmatic flexibility (ToO/DDT)

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Overview of the development programme

- Aim to enhance ALMA beyond capabilities envisaged by the baseline project
- Not pre-committed to any particular area, science driven
- Ramp up between now and end of construction $\sim$ 5 M USD /partner/year budget (10% of operations)
- Coordinated by the JAO and the ALMA Board *implemented* by the executives (ESO/NRAO/NAOJ)
- Already started in Europe, about to commence in North America/East Asia

Development – Possibilities for Hardware

Ongoing already:

- Building 6 Band 5 receivers (EC FP6 funding)
- VLBI capability (NSF funding)

Some possibilities:

- Filling in bands in the system design: Bands 1, 2 & 5
- New bands: Band 11, combine Bands 2/3?
- Increase IF bandwidth? (currently 4 GHz / sideband with best performance for 2SB receivers)
- Faster correlator?
- Focal plane array receivers?
- Stopping down the aperture?? More antennas??

Development – Possibilities for Software

Some possibilities:

- Visualisation/analysis of spectral cubes
- Radiative transfer modelling?
- Better calibration software?
- Advanced model fitting

Development – Possibilities for scientific and operational efficiency

Some possibilities:

- Better scheduling?
- Continuous parallel observing in Band 3? (Needs also hardware + software)
- Archive tools?
- Spectral line databases?

References

Maiolino R., 2008, New Astronomy Review, 52, 339. `arXiv:0806.0695`