Atacama Large Millimeter/submillimeter Array

Development Vision for ALMA: Update from the Working Group

Pierre Cox (on behalf of the Working Group)

Development Workshop, Gothenburg, Sweden
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Membership of the Development Vision Working Group

- Al Wootten (IST)
- Leonardo Testi (IST)
- Daisuke Iono (IST)
- Nick Whyborn (Observatory System Engineer, JAO)
- John Carpenter (Observatory Scientist, JAO)
- Neal Evans (Board Representative to the Working Group)
- Pierre Cox (JAO Director, Chair)

And consultation within the community as needed

Preamble

- Fifteen years have passed since the original ALMA development specifications
- That plan is today nearly completed
- Cutting-edge technology has advanced tremendously since construction commenced
- This presents an opportunity for the community to outline a new strategy that will enable ALMA to extend the frontiers of science even further

Charges

- On behalf of the community, the Development Working Group shall propose a science-driven vision for the medium (5 years) to longer term (5 to 15 years) developments of ALMA
- This resulting plan should be prioritized and approximately costed, remaining commensurable within the anticipated ALMA budget.
- A first draft of the vision document outlining the plan shall be presented the ALMA Board by November 2016 with the goal to a have a final version for the Board in April 2017.

Procedure

- The ALMA2030 document provides an initial framework for the scientific vision and technical possibilities
- However, this plan cannot be implemented in its entirety and therefore it needs to be critically reviewed, prioritized, sequenced and supplemented with costing estimates
- The goal of the new document is to prioritize the developments suggested in ALMA 2030 and outline a roadmap for development over the next 15 years.
- The Development Vision Working Group will seek advice from throughout the ALMA community

Recommendations in ALMA2030

- The ALMA2030 document recommended four development paths, namely:

  1. *Improvements to the ALMA Archive: enabling gains in usability and impact for the observatory.*
  2. *Larger bandwidths and better receiver sensitivity: enabling gains in speed.*
  3. *Longer baselines: enabling qualitatively new science.*
  4. *Increasing wide field mapping speed: enabling efficient mapping.*

- The first path is being explored with current developments. While very important, improvements to the ALMA Archive are not very expensive, so we focus on longer-term, more expensive items.
- The ALMA 2030 report also noted that a large single dish equipped for fast surveys “would be an important scientific complement to the interferometer”, but that it was outside the scope of the development budget. We focus mainly on items 2 through 4 of the list above in this document.
- Finally, developments have consequences for operations; consequently we include a section on the impact on operations.

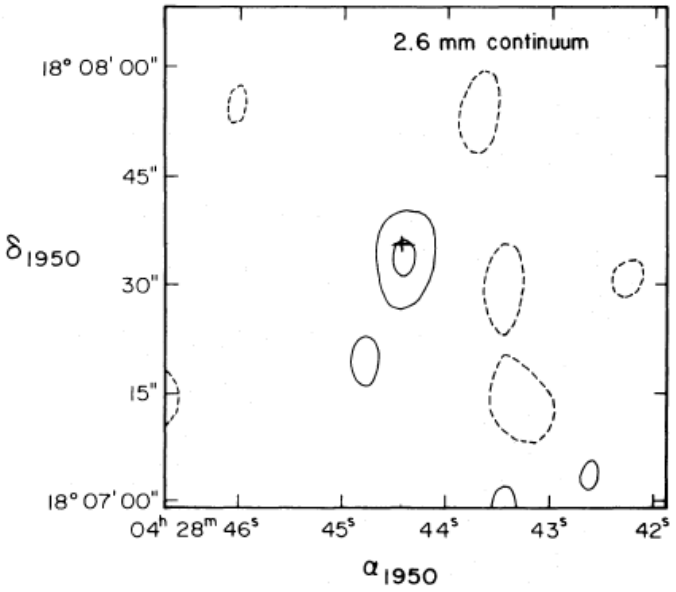
Outline of the Vision Document

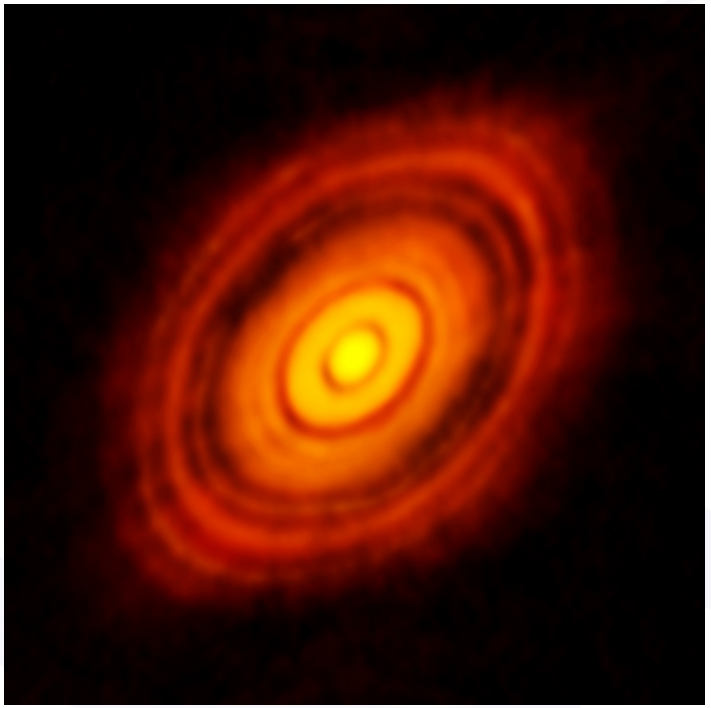
1. Executive Summary/Background
2. Science Drivers
3. Vision (derived from ALMA 2030) defines the three areas plus single dish
4. Process to turn Vision into Roadmap
5. Straw-person Roadmap (to be evolved based on iteration with technical and scientific groups): lays out a priority order in time.
6. Coordination with Operations Plan (deals with consequences for operations of the different developments, including vision for overall ALMA)
7. Synergies with other large facilities
8. Possible projects beyond scope of Development Funding
9. Summary
10. Appendices with detailed information on particular development paths

Points Addressed in the Vision Document

- ✓ Introduction: Finishing the original ALMA baseline project. It is timely to outline the next possible developments and ways forward and define a new strategy that will enable ALMA to extend the frontiers of science even further.
- ✓ Science Drivers: Revision of the 'Level One Science Goals'
- ✓ Goals and associated timelines.
- ✓ Constraints: Anticipated development budget of about 13.6 M$ per year i.e. over 15 years ~ 204 M$.
- ✓ Resolution/Throughput/Field-of-View/Single Dish
- ✓ Synergy with other large facilities (JWST, LSST, ELT, Ligo/Virgo/Kagra)
- ✓ 5-Year Plan
- ✓ Long-term infrastructure development plan/use of the Chajnantor plateau
- ✓ Long-term organizational plan for the JAO/ALMA

Towards New Eras





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Beckwith et al. (1986)

ALMA Partnership et al. (2015)

*** et al. (2030)

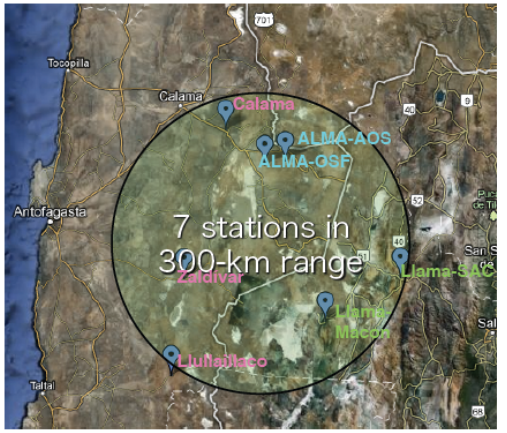
Science Drivers: Old & New

- Level one science goals of ALMA Baseline
  - *The ability to detect spectral line emission from CO or C^+ in a normal galaxy like the Milky Way at a redshift of z = 3, in less than 24 hours of observation;*
  - *The ability to image the gas kinematics in a solar-mass protostellar/protoplanetary disk at a distance of 150 pc, enabling one to study the physical, chemical, and magnetic field structure of the disk and to detect the tidal gaps created by planets undergoing formation;*
  - *The ability to provide precise images at an angular resolution of 0.1"*
- These goals have been basically achieved in the first years of ALMA operations.

- Proposed revised science drivers for the next decade(s)
- **Disks & Planets**
  - Chemical composition and evolution disks, including around planets, down to scales of 1 AU.
- **First Galaxies**
  - From the formation of metals (first stars) to the Peak of Star Formation
  - Identifying the first galaxies and imaging their surrounding

Long-Term Development Areas (1)

- Throughput
  - Larger bandwidth (lines and continuum): high-z galaxies (spectral scans); molecular complexity of disks; line surveys; outer Solar System
  - Continuum sensitivity and imaging (spectral index); Improved polarization measurements
  - Go up to (or above) 32 GHz with 2 polarizations → which Bands? Observing time & Sensitivity
  - Upgrading existing correlator; entirely new correlator: gain in sensitivity, flexibility
- Resolution
  - Imaging disks down to habitable zone scales (continuum)
  - Corresponding to 5 milliarcsec.
    - Band 6/7 corresponds to baselines of ~60 km.
    - Band 10 corresponds to 16 km.
  - Moveable or fixed outpost antennas?
  - Thermal emission & Maser emission



Kameno et al.

Long-Term Development Areas (2)

- Field-of-View
  - Mapping efficiently nearby galaxies & galactic molecular clouds/star formation regions; large deep field (spectral) surveys.
  - Multi-pixel or beam-forming arrays: which frequency? Bandwidth?

- Single Dish
  - Supporting survey instrument; finding sources (high-z, dense cores in galactic molecular clouds, nearby galaxies etc.)
  - Telescope of at least 24-meter located at the Chajnantor plateau; frequency coverage up to at least Band 7
  - Large bolometers and multi-pixel heterodyne arrays

Questions related to Long-Term Development Areas

- Throughput
  - What is the IF bandwidth that we can expect to achieve (band by band)?
  - Can we achieve the wide bandwidths without compromising the receiver temperature performance?
  - What improvements in receiver temperature can we anticipate for the various ALMA bands?
  - What would be the cost of a correlator that can process the entire IF bandwidth from all ALMA antennas?
  - What is the cost for an archive that can ingest all of the data for such a wideband correlator?
- Resolution
  - How long are the baselines required for specific science goals?
  - What is the minimum number of antennas needed on the long baselines?
  - Do we want fixed antennas on the long baselines or move existing antennas to new pads as needed?
- Field-of-View
  - What are the expectations for pixels/bandwidth for focal plane arrays on a 5 to 10 years timescale?
  - What are the minimum combinations of bandwidth/number-of-pixels that are acceptable scientifically?

Timeline

- April 2017: Final version of the document presented to the ALMA Board
- Further iterations including scheduling and cost estimates
- November 16-18, 2016: Discussion of draft vision document at the ALMA Board
- Teleconference of the WG to finalize vision and roadmap
- Early October 2016: Presentation to the ASAC
- September 2016: 'Current and Future Development Activities at ALMA' presentation/ panel discussion at the ALMA international conference.
- (Face-to-face) meetings of the Working Group (July-August 2016)
- *NA Development workshop: August 24, 2016 (Charlottesville)*
- *EA Development workshop: July 20-21, 2016 (Nobeyama)*

- ✓ *EU Workshop on Development: May 25-27, 2016 (Chalmers, Sweden)*
- ✓ *May 2, 2016: Deadline for submission of the NA Development Study proposals (call March 1, 2016)*
- ✓ *EU Development Studies Call: May/June with deadline in September*
- ✓ Interactions at technical centers of expertise in Europe, Japan & USA: May to September
- ✓ Teleconference of the WG (April)
- ✓ Presentation of roadmap to the Board (April 2016)
- ✓ Face-to-face meeting Feb. 23/24, 2016