The Atacama Large Millimeter / submillimeter Array

Rüdiger Kneissl
(Joint ALMA Observatory & ESO)
ALMA compact configuration

Main Array: 50 x 12m antennas
(NRAO / Vertex, ESO / AEM)

Compact Array (ACA): 12 x 7m and
4 x 12m antennas (NAOJ / Melco)

Chajnantor Plateau, Atacama Chile
at 5000m, dry site, LAT = -23
Outline of the Talk

• Description of the Telescope
  – Science Goals
  – Technical Specifications
  – Status of Construction

• Early Science Perspectives
  – Instrumental Set-up
  – First Test Data, Science Verification
  – Studies of Planck Sources

• Examples of Observatory Tasks
  – Calibrator Catalog Construction
  – Amplitude Calibration
High Level Science Goals

- Ability to detect spectral line emission from CO or C+ in a normal galaxy like the Milky Way at $z = 3$ in 24 h

- Ability to image the gas kinematics in a solar-mass protostellar/protoplanetary disk at ~150 pc (distance to Ophiuchus or Corona Australis)
  - Enabling study of physical, chemical, and magnetic field structure of the disk
  - Detect the tidal gaps created by planets undergoing formation.

- Ability to provide precise images at angular resolution 0.1”
  - 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.

- These requirements drove the technical specifications
ALMA Specifications

- Surface accuracy <25 µm, 0.6” reference pointing in 9m/s wind, 2” absolute pointing all-sky
- *Aperture Synthesis*: array configurations between 150m and ~15-18km
- Angular resolutions ~40mas at 100 GHz (5mas at 900GHz)
- 10 bands in 31-950 GHz + 183 GHz WVR
- 8 GHz IF bandwidth, dual polarization
- Interferometry, mosaicing & total-power observing
- Correlator: 4096 channels/IF (multi-IF), full Stokes
- Data rate: 6MB/s average; peak 64 MB/s
- All data archived (raw + images), pipeline processing
Receiver Bands

Cover Planck channels,
Early Science bands: 3 6 7 9
Angular Scales – UV response

• Covers scales from arcmins to tens of milliarcsec
• Complimentary to Planck
Antennas

North American
12m antenna

European
12m antenna

East Asian
12m antenna on transporter in foreground
7m in background
ALMA Components - Integration

- Antennas (also need Power, Foundations, Transport, …)
- Receivers (Front ends)
- Digitization and Data Transmission (Back end)
- Local Oscillator System (Frequency and Time reference)
- Correlator (both FX for ACA and XF designs)
- Many Sub-systems: e.g. Line Length Corrector
- Software: Control, Operations, CASA, pipeline, …
- Assembly, Integration, Verification
- Commissioning and Science Verification
- Science Operations, ALMA Regional Centers

Thank you to the many people contributing to ALMA!
Construction Status

- Design and development is successfully completed
- Well into series production of the items required for the 66-antenna system, foundations constructed – connection ongoing
- System assembly, integration and verification started in late 2008
- Commissioning and science verification started in January 2010
- Early Science readiness reviews in Oct/Nov 2010

*Eight (now 9) antennas in operation at the 5000m site*
Early Science (Cycle 0)

• Best effort / shared risk - Start late 2011 - CfP in March
• At least 16 antennas with 4 receiver bands
  – Number of antennas available will build up rapidly to 66 in 2013.
    (Sensitivity goes as N, imaging complexity as N^2 )
• Baselines of at least 250m to start with
• Single field imaging, restricted set of spectral modes
• Longer baselines, limited mosaic imaging, and some polarization capabilities may be offered (see CfP)
• Proper systems for user support in place
  – proposal process, tools for preparing observations (OT), data reduction (CASA), support from ALMA Regional Centers
Spectral Data Cube

- This shows the 345 GHz CO line from the disk around a Herbig Be star - left: integrated emission, center: map of velocity centroid showing rotation, right: spectrum at peak emission.
Beta-Pictoris Debris Disk

- Herschel ↓ 70 microns
- ALMA Band 7 ↓ (11th Nov)
C+ line in BRI 0952 (quasar at $z = 4.4$)

Band 7  16$^{th}$ Nov 2010 ↑ 1 h
← APEX
Another high-redshift object: the “Cosmic Eyelash”

A lensed star-forming galaxy at $z = 2.32$ observed in Band 6.

Main plot shows rising thermal continuum.

Insert shows atomic Carbon and CO lines.
ALMA studies of Planck sources (follow-up)

• Observatory tasks:
  – e.g. Calibrator catalog, flux calibration

• Planck high freq. sources: imaging and spectral analysis
  – CO and C+ redshift determination for high-z galaxies
  – Lensed high-z dusty galaxies (structure and gas dynamics)
  – Galaxy clusters (SZ signal and star-forming galaxies)
  – Proto-clusters (resolving extended sub-mm over-densities)
  – Cold cores (dust continuum, molecules, dynamic structure)
  – Quasar sub-mm variability (monitoring)
  – …

• Early Science proposals (timely, but reduced capability)
Calibrator catalog

• Ideally will need dense network of bright (> mJy), compact (sub-arcsec), constant flux sources over visible sky (Dec < 50) – a long-term project!
• Current catalog, mainly based on SMA / VLA (many with ICRF coordinates), lacks southern (Dec < -40) and high frequency sources, even at ~Jy flux levels
• *Planck provides advantageous selection via flux, SED, variability and polarisation at the high flux end*
• Approach uses sources correlated between our proto-catalogue and HFI channels
• Most new calibrators are southern from ATCA and Planck
• Some extended Planck sources only detected in CO
Planck based calibrator selection

- WMAP / ATCA (pred.) vs. Planck 100 GHz (for ALMA band 3)
- AT20G sources (> 0.5 Jy – 90 GHz prediction) not detected by WMAP: 101 (/154) not detected by Planck either
- Band 3 ALMA follow-up to complete the southern sky for all-sky pointing and baseline determination
- Band 6 and 7 measurements for high-frequency sources, detected sources in ~1 min integrations
ALMA fluxes of Planck sources

Data from recent 2 hour baseline run (including measurements with calibration devices), i.e. not taken simultaneously with Planck.

Scatter dominated by source variability.
Further work

- Improvements on flux calibration scheme ongoing
- Further tests of calibration loads (hot and ambient)
- First production load has arrived
- Aiming to collect simultaneous observations with Planck on bright quasars and planets over 2011
- Planck calibrated planet models (Mars, Neptune, Uranus, …) will be very valuable
- APEX-Laboca project (PI deBreuck) to measure asteroids for study of mm flux modelling – promising for ALMA
- Planck will provide valuable polarization information on all our current polarization calibrator candidates
The Atacama Large Millimeter/submillimeter 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.