The ALMA Band 1 Receiver Development Project

Building the lower frequency end of ALMA

Oscar Morata (ASIAA), Ciska Kemper (ASIAA), Ted Huang (ASIAA) and the Band 1 Science and Engineering Teams

ALMA 2030, National Radio Science meeting/URSI, Boulder, Colorado, January 5th 2018
What is ALMA Band 1?

- **Goal:** give access to ALMA to the frequencies ~40 GHz at high resolution and sensitivity from the southern hemisphere
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  - Initial (not now) consortium with NAOJ, Universidad de Chile, HIA (Canada) and NRAO
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ALMA-EA Band 1 contribution is responsible for:

- CCA+WCA, CPDS, bias modules and photomixers.
- Band 1 Prototype Development
- Band 1 Cartridge Production
- Maintenance
- Integration and testing at OSF
- Test line and its maintenance
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ALMA Band 1 in ALMA

Top view

ALMA Cryostat (interior)
Recent Timeline (2012-2017)

2012  NRAO joins Band 1 consortium (spring)
      North American ALMA Development Study (2012-13), led by NRC
      Kick-off meeting of the Band 1 consortium: ASIAA (PI Institute),
      Univ. Chile, HIA, NRAO, NAOJ

2013  Down-selection of components
      Approval of frequency change request to include the CS (1-0) line and
      reduce frequency overlap with JVLA
      Specification review passed

2014  Preliminary design review (PDR) passed; 3 pre-production cartridges
      approved

2016  Critical design review (CDR) passed
      ALMA Board approves production of all Band 1 cartridges (May)
Band 1 Team

Pl: Ciska Kemper (ASIAA)

Project Manager: Ted Huang (ASIAA)

Project Scientist: Oscar Morata (ASIAA, from 2014) [prev., Coordinator of Science Team]
    James Di Francesco (NRC, until 2014)

Engineering Team: ASIAA (Chau-Ching Chiong, Yuh-Jing Hwang, ++)
    Univ. Chile (Ricardo Finger, Nicolás Reyes, Valeria Tapia, ++)
    NRAO (John Effland, K. Saini)
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Science Team: long list!!

J. Di Francesco\textsuperscript{1,2}, D. Johnstone\textsuperscript{1,2}, B. Matthews\textsuperscript{1,2}, N. Bartel\textsuperscript{3}, L. Bronfman\textsuperscript{4}, S. Casassus\textsuperscript{4}, S. Chitsazzadeh\textsuperscript{2,5}, H. Chou\textsuperscript{6}, M. Cunningham\textsuperscript{7}, G. Duchêne\textsuperscript{8,9}, J. Geisbuesch\textsuperscript{10}, A. Hales\textsuperscript{11}, P.T.P. Ho\textsuperscript{6} M. Houde\textsuperscript{5}, D. Iono\textsuperscript{12}, F. Kemper\textsuperscript{6}, A. Kepley\textsuperscript{11}, P.M. Koch\textsuperscript{6}, K. Kohno\textsuperscript{13}, R. Kothes\textsuperscript{10}, S-P. Lai\textsuperscript{14}, K.Y. Lin\textsuperscript{6}, S.-Y. Liu\textsuperscript{6}, B. Mason\textsuperscript{11}, T.J. Maccarone\textsuperscript{15}, N. Mizuno\textsuperscript{12}, O. Morata\textsuperscript{6}, G. Schieven\textsuperscript{1}, A.M.M. Scaife\textsuperscript{16}, D. Scott\textsuperscript{17}, H. Shang\textsuperscript{6}, M. Shimojo\textsuperscript{12}, Y.-N. Su\textsuperscript{6}, S. Takakuwa\textsuperscript{6}, J. Wagg\textsuperscript{18,19}, A. Wootten\textsuperscript{11}, F. Yusef-Zadeh\textsuperscript{20}
Band 1 receiver: Change of specifications

Two important modifications with respect to the original specifications:

★ Frequency range: **35-50 GHZ (50-52 GHZ, best effort basis)**
  ○ Currently, only 35-51 GHz available

★ Receiver noise temperature:
  ○ 80% of the band: < 25 K
  ○ all the band < 32 K
Band 1 Receiver Design: specifications

- **RF**: 35-50 GHz, 35-52GHz (Best effort)
- **LO**: 31-40 GHz
- **IF**: 4-12 GHz, SSB
- **Trx**: 25 (80%) ; 32 K @ any frequency within RF band.
- **IF power variations**: peak-to-peak variation shall not exceed 4.0dB in any 2GHz portion. (Applying for change request from 4.0dB to 5.0dB)
- **Cross talk**: less than -63dB
- **Image band suppression**: >10dB
- **Amplitude Stability**: less than $4.0 \times 10^{-7}$ for timescales in the range of $0.05 \leq T \leq 100$ s and $3.0 \times 10^{-6}$ for $T = 300$ seconds.
- **Signal path phase stability**: Long term (delay drift) $20 \leq T < 300$ s : 22 fs
- **Optical**: Aperture Efficiency > 80%, Polarization Efficiency > 99.5%, Focus Efficiency > 98%
Band 1 Receiver Design: Overview

RF: 35-50 GHz,
35-52GHz (Best effort)
LO: 31- 40 GHz,
IF: 4-12 GHz, SSB
Trx: 25-32 K
IF power variation: better than 4dB in any 2GHz window
ALMA Level 1 science goals

➢ The ability to detect spectral line emission from CO or C II in a normal galaxy like the Milky Way at z=3 in less than 24 h of observation.

➢ The ability to image gas kinematics in a solar mass protostellar or protoplanetary disk at 150 pc, enabling the study of 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". Here the term "precise image" means an accurate presentation of 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.
Band 1 main science goals: CO emission at high-z

- Low-J CO lines at high-z
- 5σ detection in less than 5 hr
- Possibility of multiline detection, in combination with other bands
- HCN and HCO⁺ at high-z
- Normal galaxies up to z~6
- Massive galaxies, trace reionization epoch z~6-9
Band 1 main science goals: protoplanetary disks

- Dust particles emit up to wavelengths similar to their size: Band 1 ~ grains in the 7mm range
- Studies of coagulation of grain from mm to cm sizes: where and how
- Finding where protoplanets are forming, with a resolution of 0.08"
- Optically thin continuum emission

HL Tau at 1.3 mm (Band 6)
Band 1 Science Case: Other Science Cases

- Molecular tracers of star formation; large molecules (biologically interesting)
- Anomalous emission from very small grains
- Sunyaev-Zel'dovich effect (SZE) imaging of cluster gas
- Pulsars and radio supernovae
- CH$_3$OH and SiO masers
- Polarization and Zeeman effect
- ...

(74 pages, 37 authors)
**Performance of the ALMA Band 1 Receiver**

Table 2: Comparison of Point-Source Sensitivity between JVLA and ALMA ($T_{rx} = 25$ K)

<table>
<thead>
<tr>
<th></th>
<th>JVLA</th>
<th>ALMA</th>
</tr>
</thead>
<tbody>
<tr>
<td>no. of antennas</td>
<td>25</td>
<td>50</td>
</tr>
<tr>
<td>polarization</td>
<td>dual</td>
<td>dual</td>
</tr>
<tr>
<td>weather</td>
<td>winter</td>
<td>auto (5.2 mm PWV)</td>
</tr>
<tr>
<td>source position</td>
<td>zenith</td>
<td>zenith</td>
</tr>
<tr>
<td>weighting</td>
<td>natural</td>
<td>natural</td>
</tr>
<tr>
<td>on-source time</td>
<td>60 s</td>
<td>1 hr</td>
</tr>
<tr>
<td>bandwidth</td>
<td>1 MHz</td>
<td>1 MHz</td>
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</tbody>
</table>

<table>
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<tr>
<th>freq.</th>
<th>35 GHz</th>
<th>3.2 mJy</th>
<th>0.41 mJy</th>
<th>3.6 mJy</th>
<th>0.46 mJy</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>40 GHz</td>
<td>3.6 mJy</td>
<td>0.47 mJy</td>
<td>3.7 mJy</td>
<td>0.48 mJy</td>
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<tr>
<td></td>
<td>45 GHz</td>
<td>5.1 mJy</td>
<td>0.66 mJy</td>
<td>4.3 mJy</td>
<td>0.56 mJy</td>
</tr>
<tr>
<td></td>
<td>50 GHz</td>
<td>25.5 mJy</td>
<td>3.29 mJy</td>
<td>5.9 mJy</td>
<td>0.77 mJy</td>
</tr>
</tbody>
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<thead>
<tr>
<th>bandwidth</th>
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<tbody>
<tr>
<td>freq.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>40 GHz</td>
<td>50 $\mu$Jy</td>
<td>6.4 $\mu$Jy</td>
</tr>
<tr>
<td>45 GHz</td>
<td>78 $\mu$Jy</td>
<td>10 $\mu$Jy</td>
</tr>
</tbody>
</table>

*Morata (2016), after Di Francesco et al. (2013)*

ALMA B1 gives comparable to better PS sensitivity than JVLA
Improvements over the JVLA

- With current specs ($T_{rx} = 25$ K) and similar effective collecting area:
  - similar or better point source sensitivity for 35-45 GHz
  - huge improvement for $> 45$ GHz
- Much better imaging and mosaicking capabilities (factors $\sim 5-10$)
  - More instantaneous baselines, larger FOV, more compact configurations
- Better atmospheric conditions:
  - more available time
  - Fairly insensitive to PWV variations
- Band 1 covers 35-50 GHz with only one receiver!
- ACA and total power antennas (available)
- Synergy with other 8 (9) ALMA bands: CO transition ladder, grains from sub-mm to cm sizes, SZ effect in different bands,...
What does ALMA Band 1 bring to ALMA?

- Increases the volume of the observable universe by a factor of 8
- Probes the emission of grains as large as ~ 1 cm (planet formation)
- Very important for study of the bulk of gas in the Universe
- Very high image fidelity and sensitivity will help many scientific cases: SZ effect, protoplanetary disks and debris disks, chemistry, ...
- Bridge the gap between cm and mm radio astronomy (SKA)
- Other possible benefits: VLBI, calibration
Current status of the project: near future

- First cartridge test with actual cryostat: October 2016 @NRAO
- LO CDMR: December 2016
- Begin #1 to #3 pre-production cartridges: starting June 2017
- #1 to #6 pre-production cartridges integrated and tested
- Band 1 Manufacture Ready Review (MRR): early 2018 (TBC)
- First cartridge testing at OSF: early 2018 (TBC)
- Complete #73 cartridge delivery by ???
  - current technical capabilities: early 2020, latest
  - due to budget constraints: end of 2022??
- Science Verification schedule very unclear (2018-2020???)
- Full Band 1 originally planned for Cycle 8 (??? very unlikely)
Message to take home

Band 1 Receiver Development Project is entering the production phase

Deployment in ALMA antennas: 2018 - 2022???:

Band 1 Science Verification: during 2018-2020 ???

Start thinking about observing proposals, Band 1 is coming soon