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

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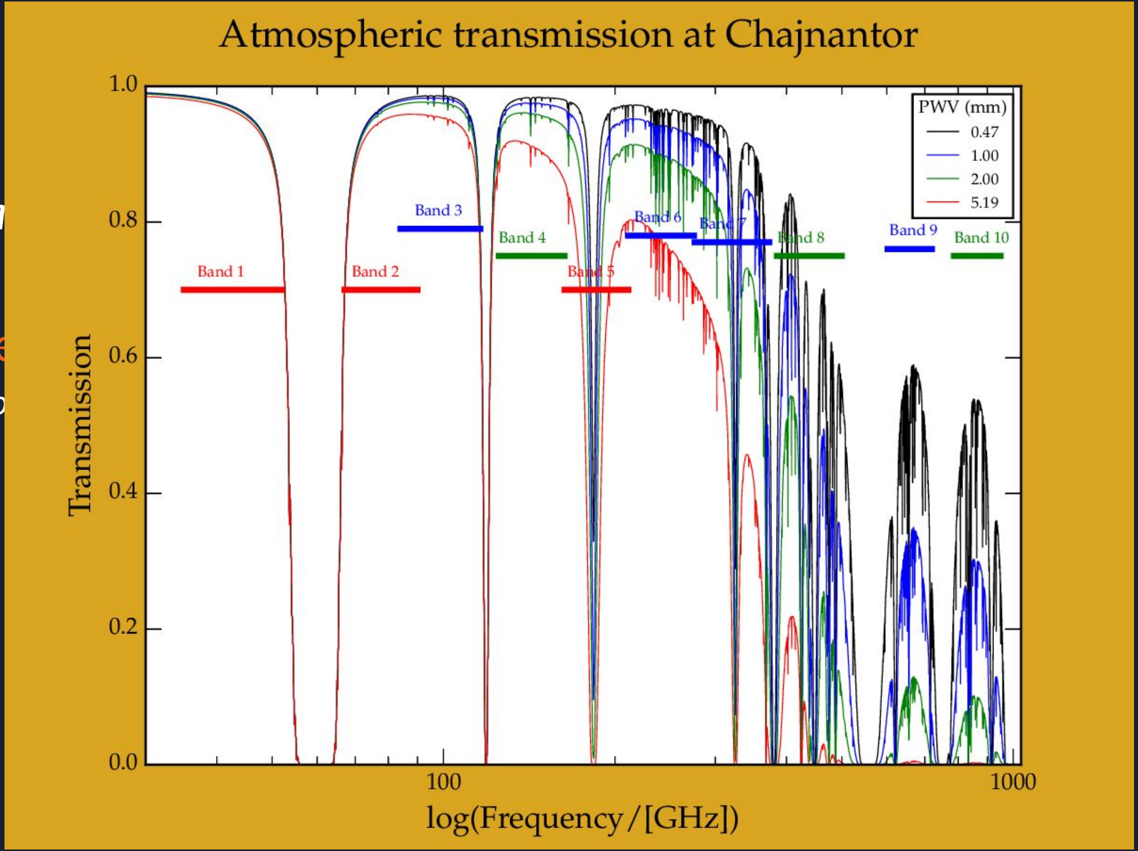
ALMA-EA Band 1 contribution is responsible for:

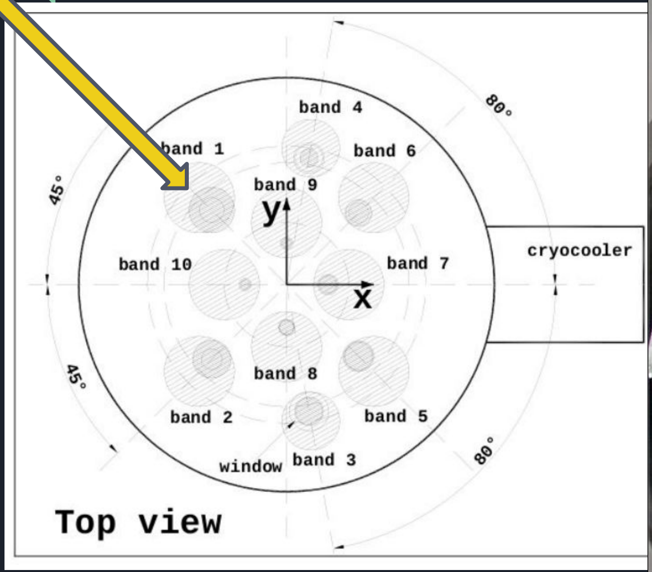
- CCA+WCA, CPDS, bias modules and photomixers.
- Band 1 Prototype Development
- Band 1 Cartridge Production
- Maintenance
- Integration and testing at OSF
- Test line and its maintenance

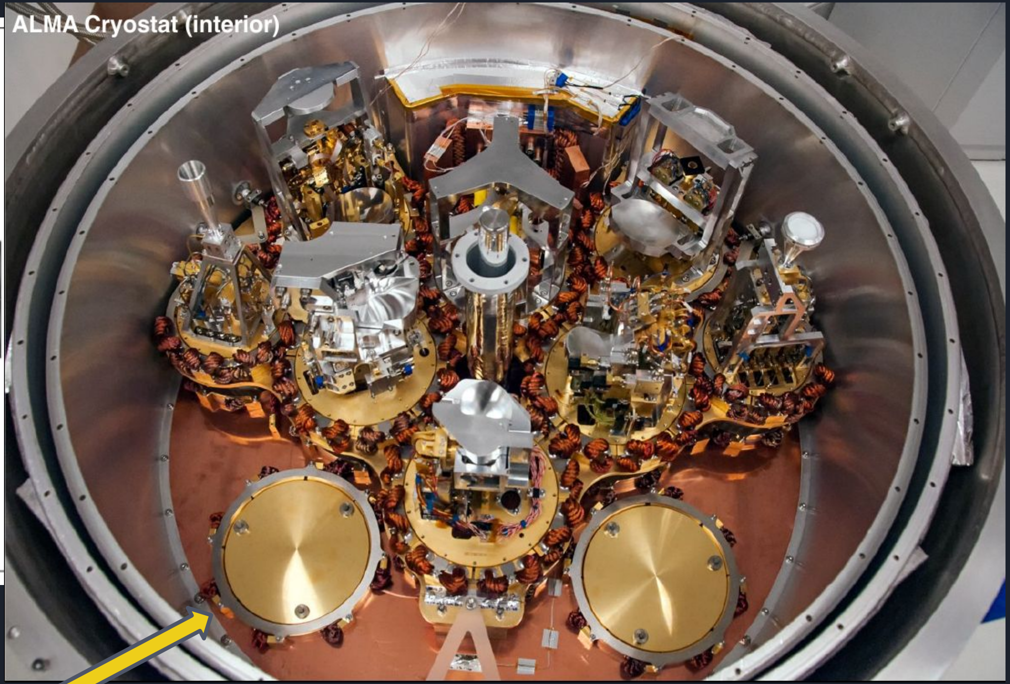
What is ALMA Band 1?

- **Goal:** give
  resolution a
- ASIAA-led
  Developme
  - *Initial (no*



ALMA Band 1 in ALMA





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

PI: 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)
NAOJ (Alvaro González)

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NRAO
NAOJ

Science Team: long list!!

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Band 1 receiver: Change of specifications

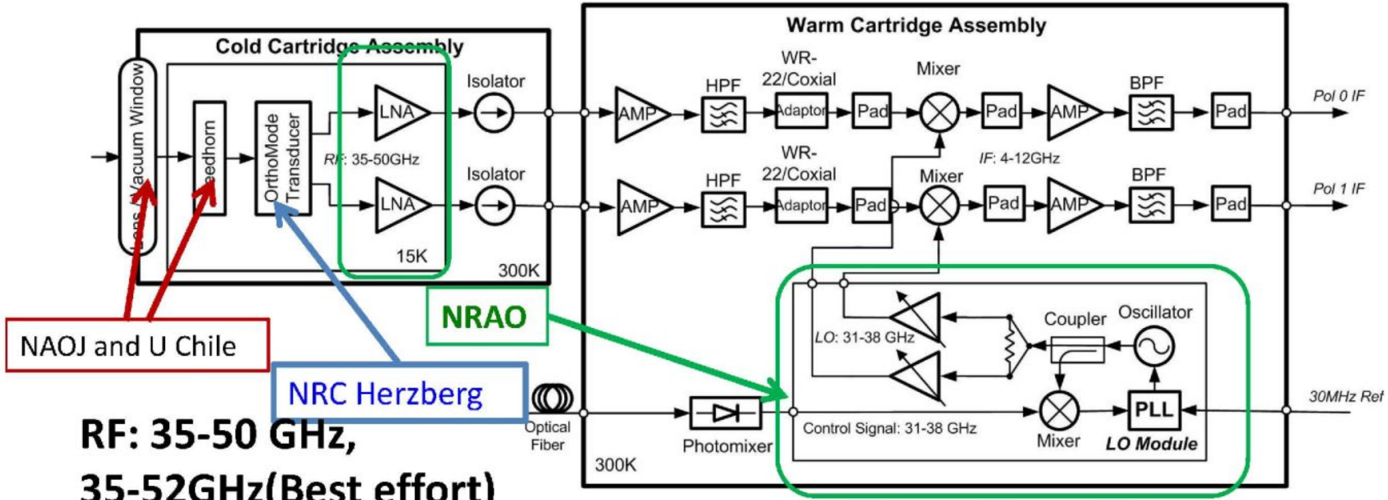
Two important modifications with respect to the original specifications:

- ★ 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

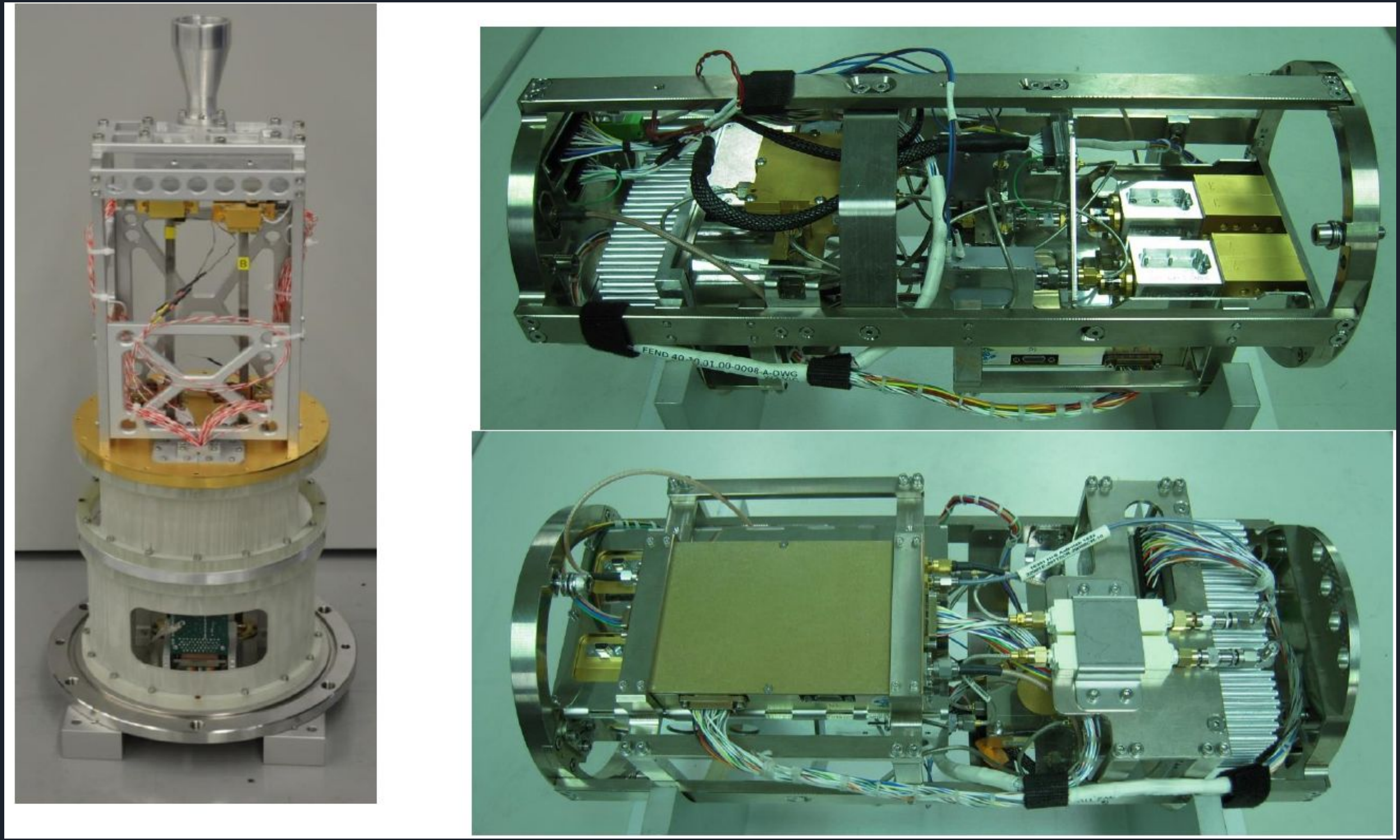
Band 1 Receiver Design: specifications

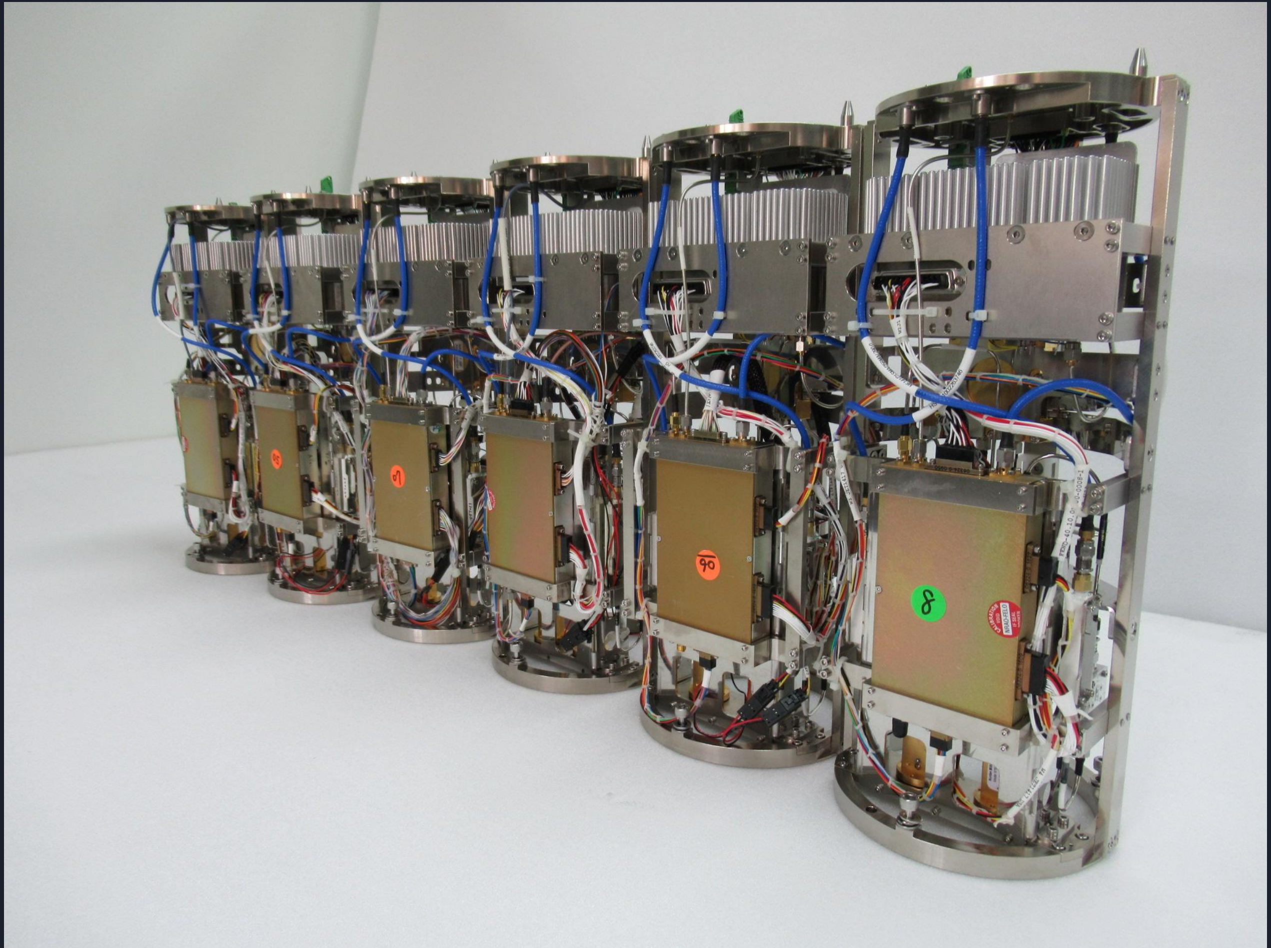
- **RF:** 35-50 GHz, 35-52GHz(Best effort)
- **LO:** 31- 40 GHz
- **IF:** 4-12 GHz, SSB
- **Trx:** 25 (80%) ; 32 K @any frequency within RF band.
- **IF power variations :**peak-to-peak variation shall not exceed 4.0dB in any 2GHz portion.(Applying for change request from 4.0dB to 5.0dB)
- **Cross talk :** less than -63dB
- **Image band suppression:** >10dB
- **Amplitude Stability:**less than 4.0 x 10-7 for timescales in the range of 0.05 s ≤ T ≤ 100 s and 3.0 × 10-6 for T = 300 seconds.
- **Signal path phase stability:** Long term (delay drift) 20 s ≤ 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



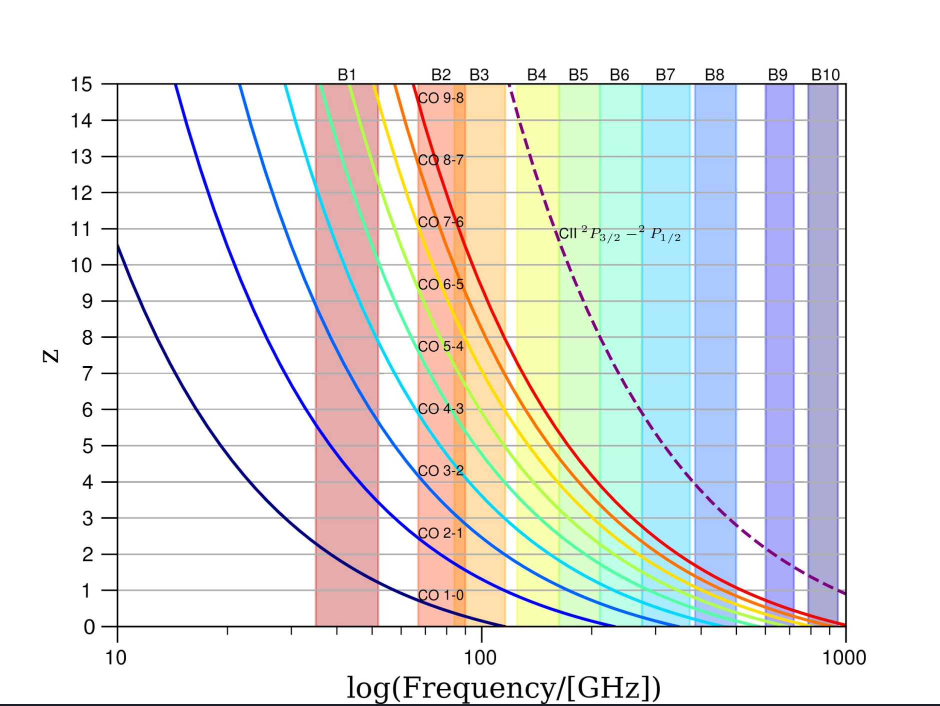


ALMA Level 1 science goals

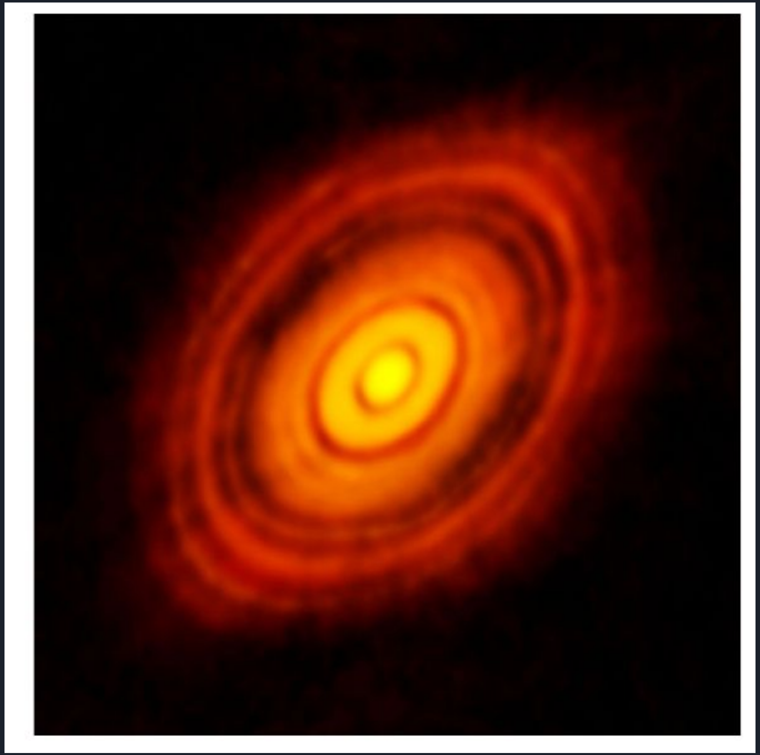
- The ability to detect spectral line emission from CO or C II in a normal galaxy like the Milky Way at z=3 in less than 24 h of observation
- The ability to image gas kinematics in a solar mass protostellar or protoplanetary disk at 150 pc, enabling the study of the physical, chemical and magnetic field 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



HL Tau at 1.3 mm (Band 6)

- ★ 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

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_3OH and SiO masers
- Polarization and Zeeman effect
- ...

Full ALMA Band 1 Science case: *http:/arxiv.org/abs/1310.1604*
(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)

		JVLA		ALMA		
no. of antennas		25		50		
polarization		dual		dual		
weather		winter		auto (5.2 mm PWV)		
source position		zenith		zenith		
weighting		natural		natural		
on-source time		60 s	1 hr	60 s	1 hr	
bandwidth		1 MHz		1 MHz		
freq.	35 GHz	3.2 mJy	0.41 mJy	3.6 mJy	0.46 mJy	Comparable!
	40 GHz	3.6 mJy	0.47 mJy	3.7 mJy	0.48 mJy	
	45 GHz	5.1 mJy	0.66 mJy	4.3 mJy	0.56 mJy	
	50 GHz	25.5 mJy	3.29 mJy	5.9 mJy	0.77 mJy	Much better!
bandwidth		8 GHz		8 GHz		
freq.	40 GHz	50 μJy	6.4 μJy	42 μJy	5.4 μJy	
	45 GHz	78 μJy	10 μJy	48 μJy	6.2 μJy	

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 ~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