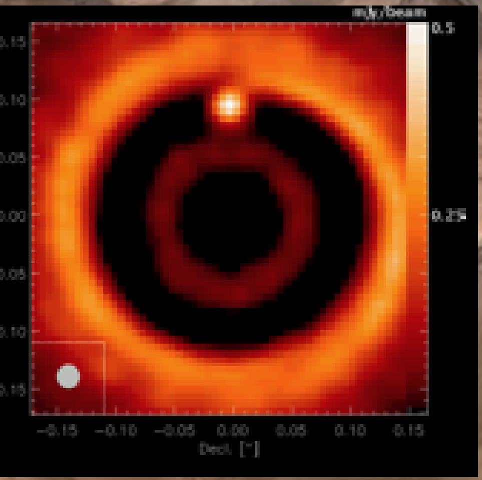
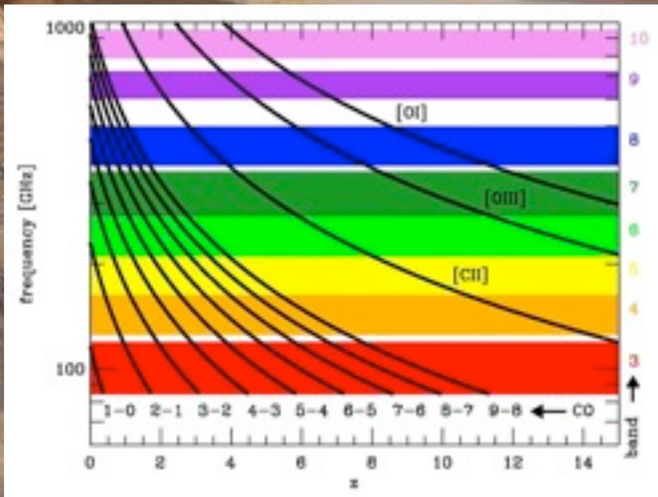
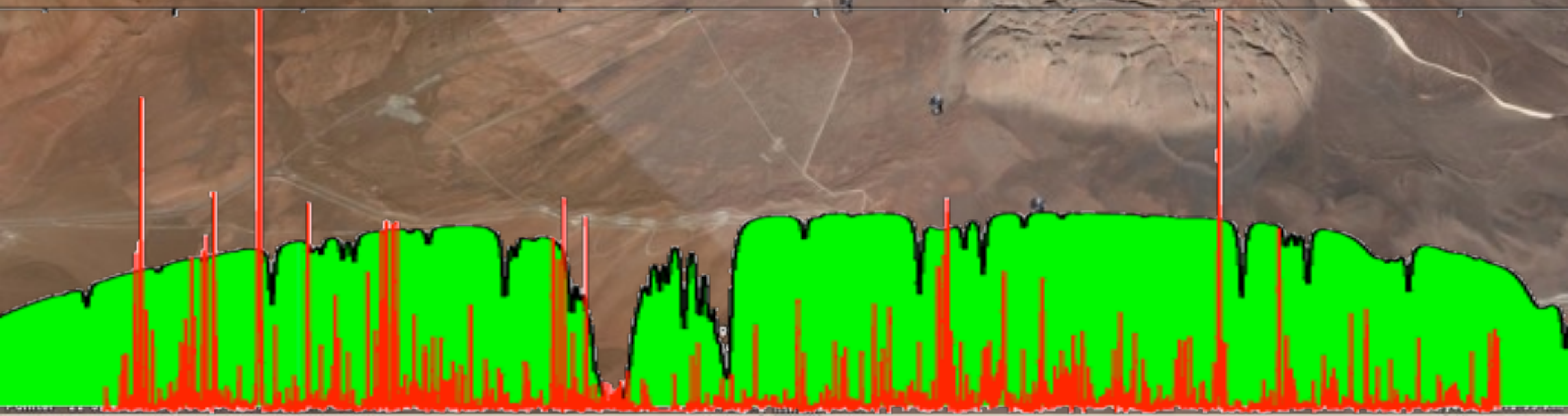
ALMA Science and SKA Synergies

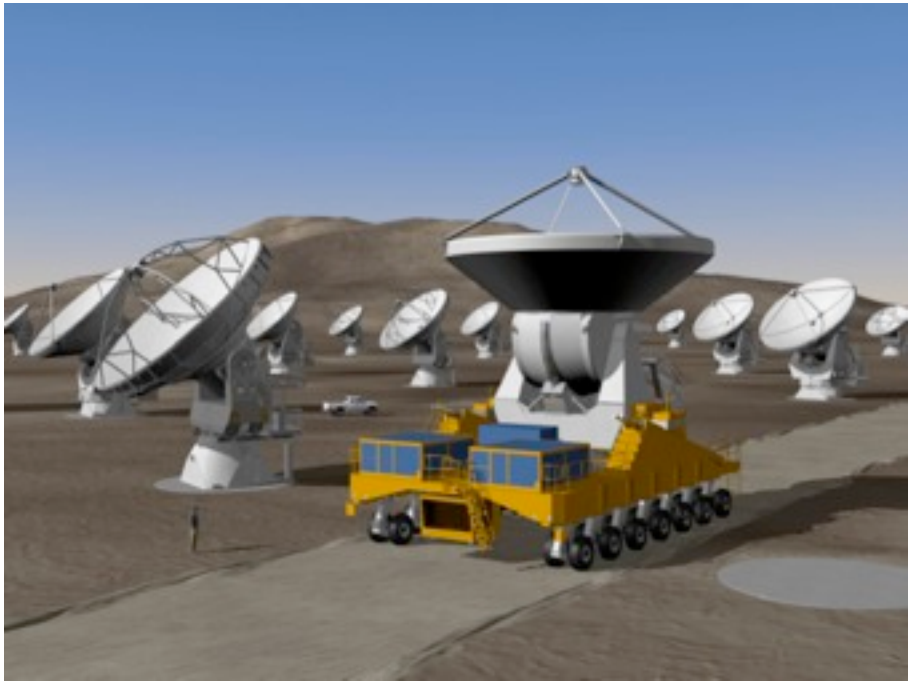
Leonardo Testi
ESO ALMA Program Scientist







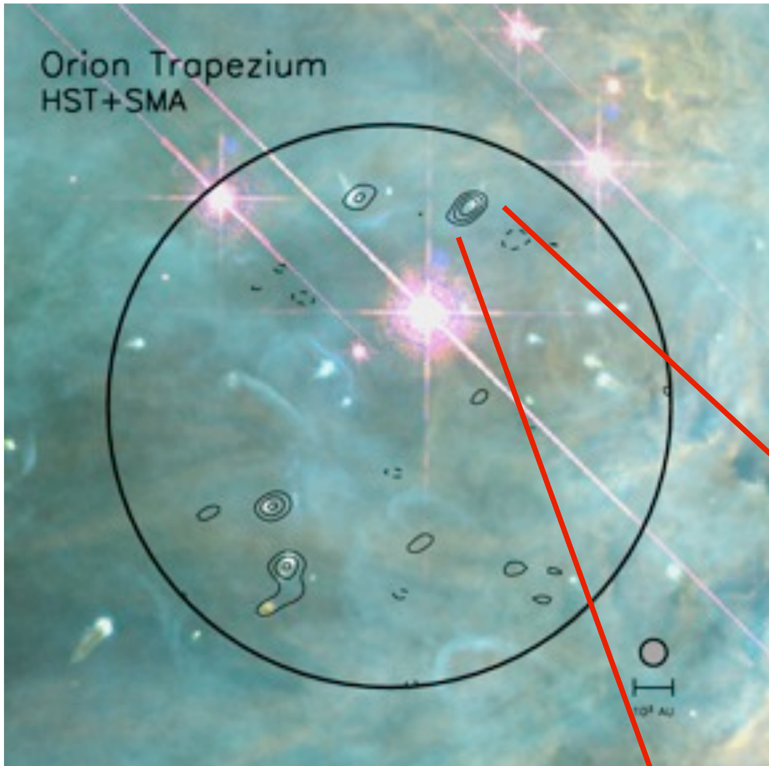
Atacama Large Millimeter Array



- At least 50x12m Antennas
- Frequency range 30-1000 GHz (0.3-10mm)
- 16km max baseline (<10mas)
- ALMA Compact Array (4x12m and 12x7m)

1. **Detect and map CO and [C II] in a Milky Way galaxy at z=3 in less than 24 hours of observation**
2. **Map dust emission and gas kinematics in protoplanetary disks**
3. **Provide high fidelity imaging in the (sub)millimeter at 0.1 arcsec resolution**

Birth of Planets

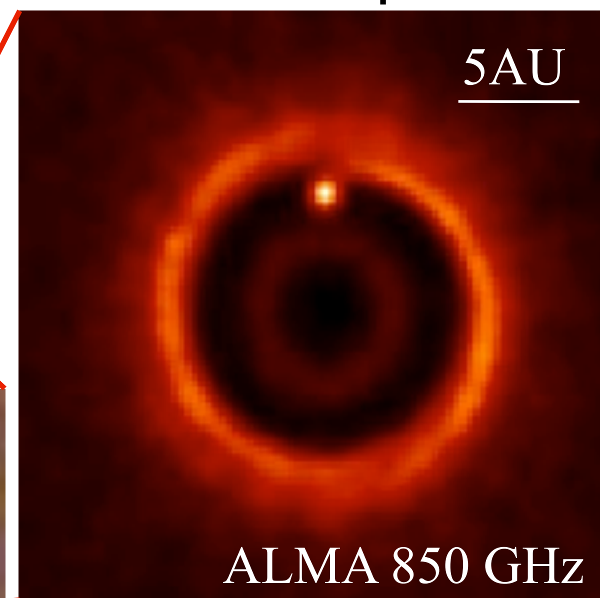


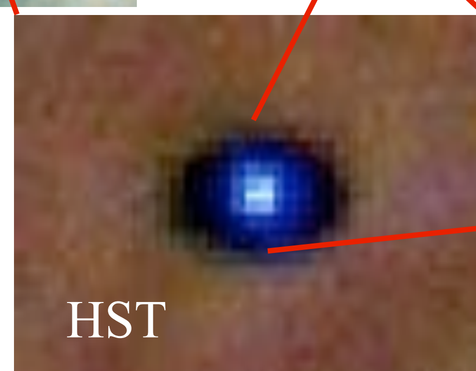
$M_{planet} = M_{Jup}$

$M_{star} = 0.5\ M_{sun}$

Orbiting at 5AU

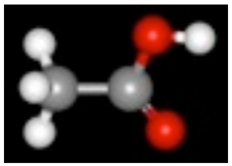
Distance 50pc



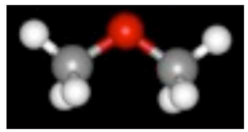


Complex Organic Molecules

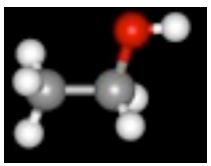
Detected



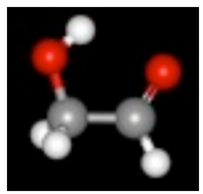
Acetic acid



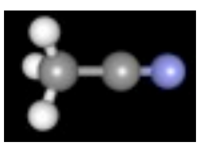
Di-methyl ether



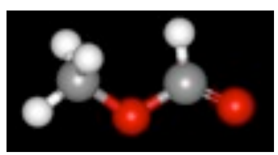
Ethanol



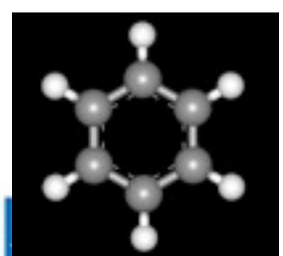
Sugar



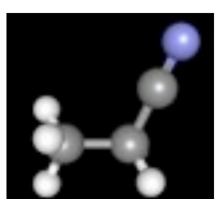
Methyl cyanide



Methyl formate



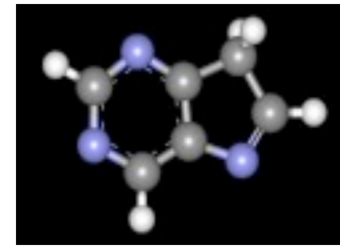
Benzene



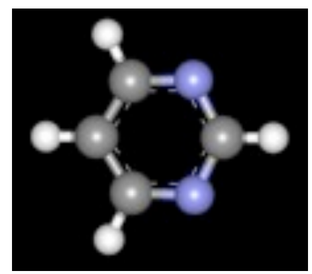
Ethyl cyanide

Not (yet) detected

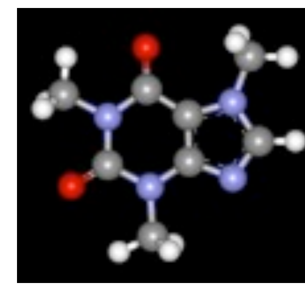
Glycine



Purine



Pyrimidine

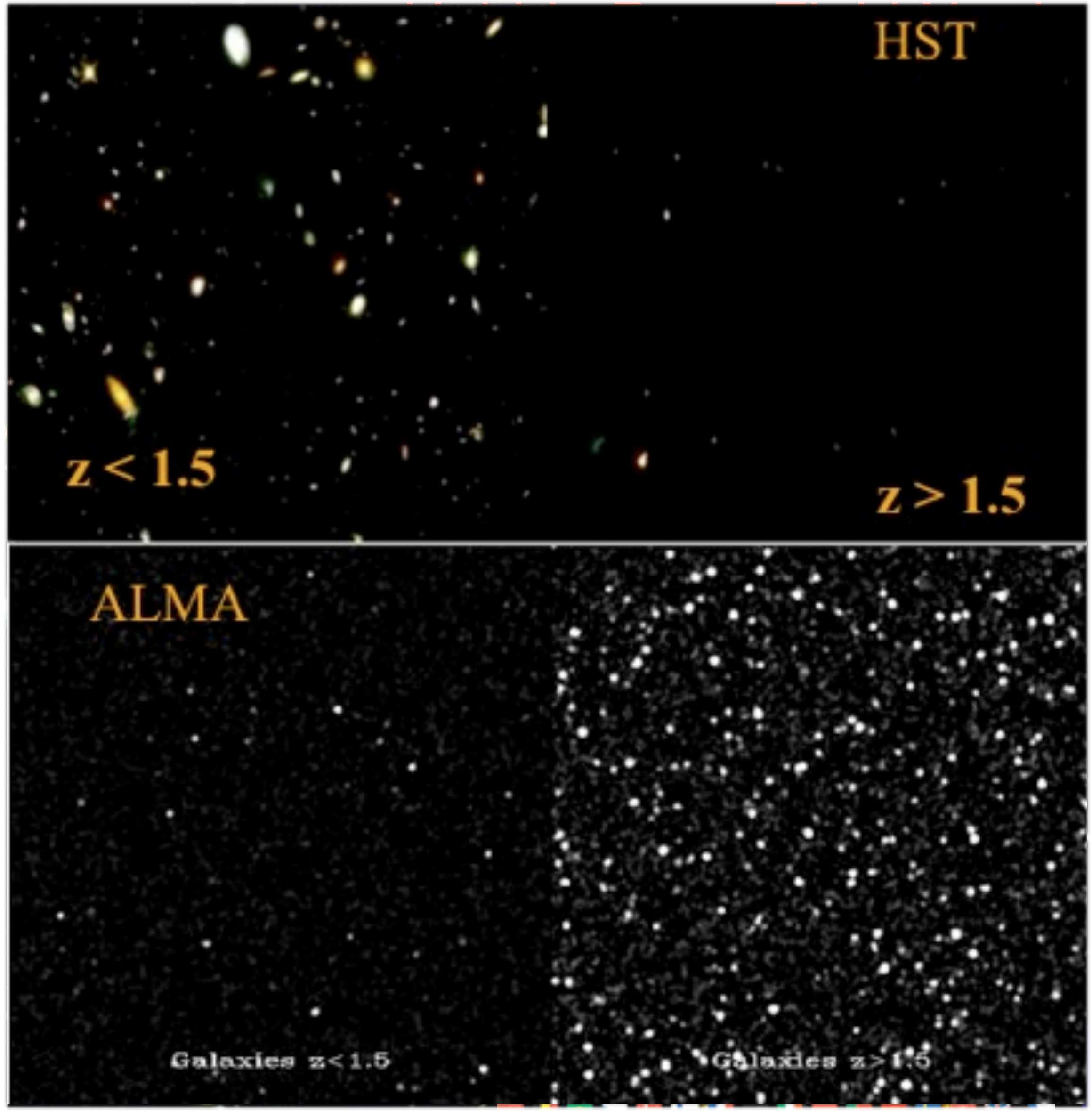


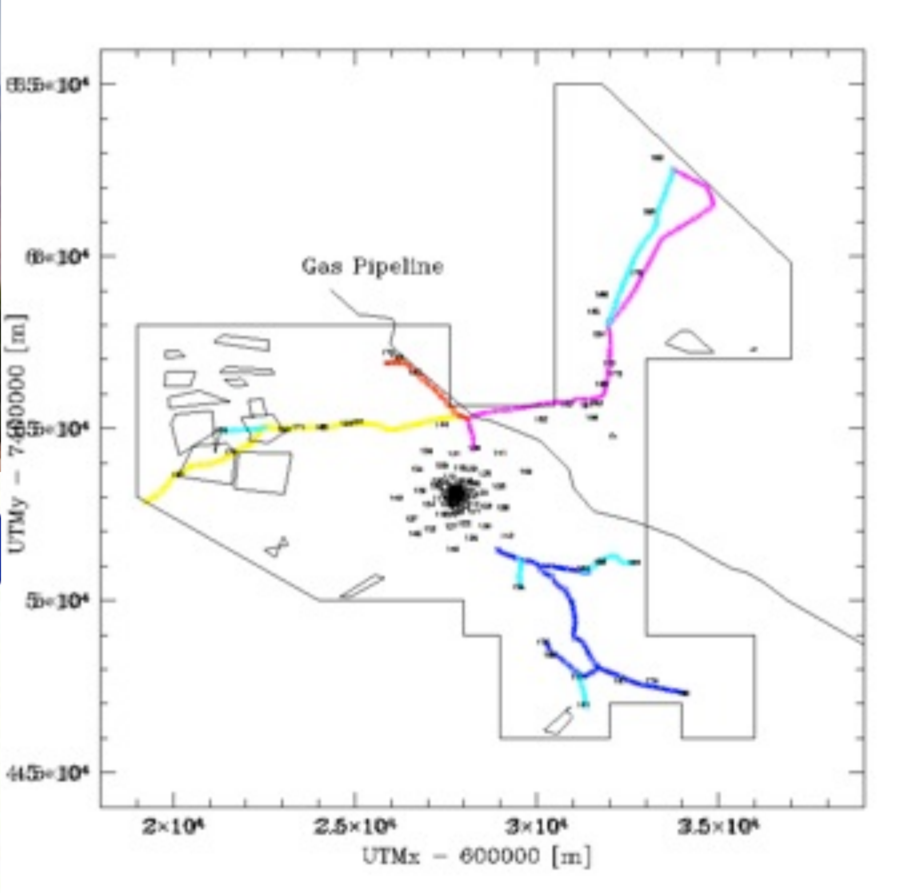
Caffeine

How far does chemical complexity go?
Can we find pre-biotic molecules in Disks?

Based on Ehrenfreund 2003

The Early Universe



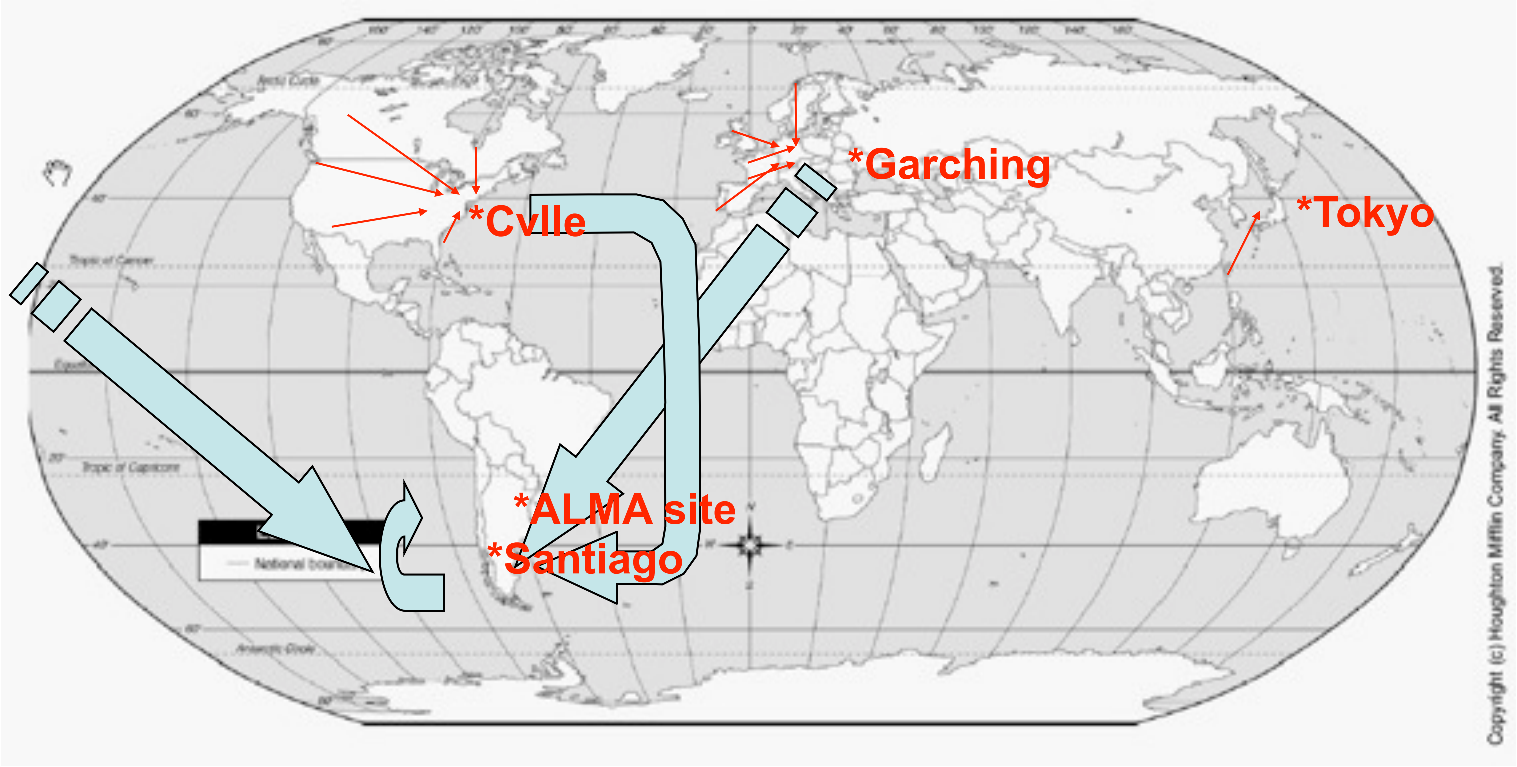

Gas Pipeline
UTMx − 600000 [m]
2×10⁴
2.5×10⁴
3×10⁴
3.5×10⁴
6.5×10⁴
6×10⁴
5.5×10⁴
5×10⁴
4.5×10⁴


ALMA Operations Site
AOS (5000m altitude)
Operations Support Facilities
OSF (2900m altitude)
Toconao

ALMA Operations

Chile: Program review, Execution of the observations, Quality assessment

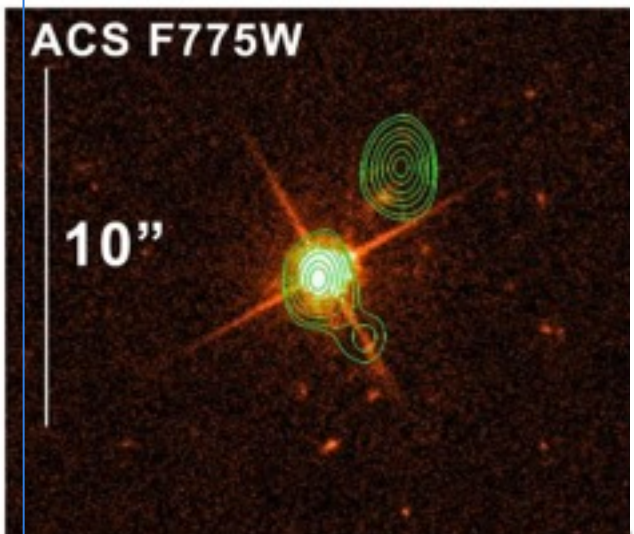
Regions: Interactions with users (Phase I and II)

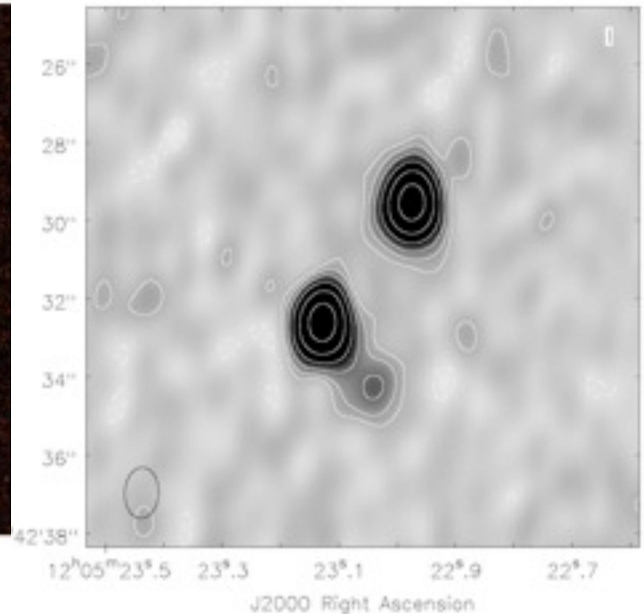


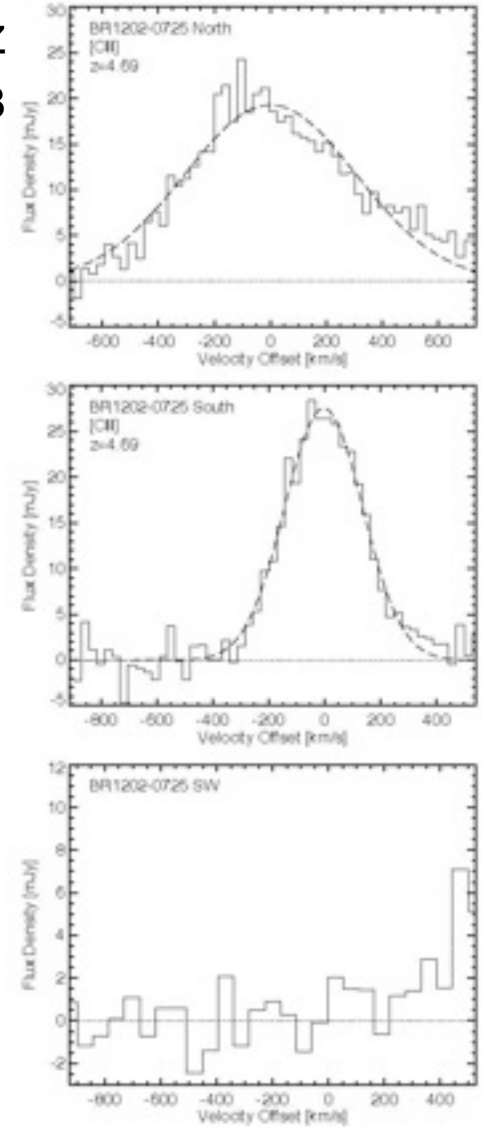
ALMA SV Science Results

- Star formation in the Early Universe: [CII] at high z
  - Wagg et al. 2012, ApJ Letters, submitted, arXiv:1205.3498

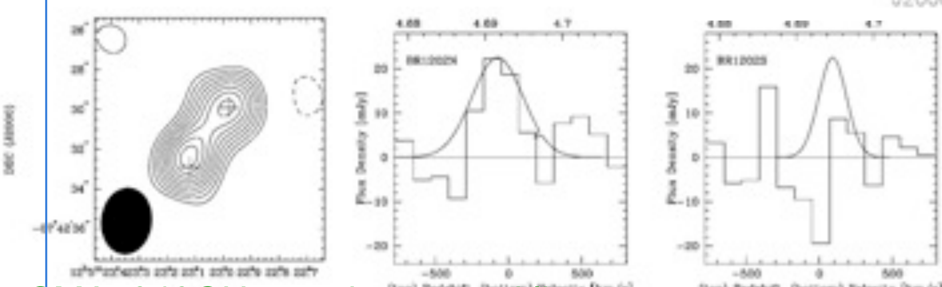
http://almascience.eso.org/alma-data/science-verification







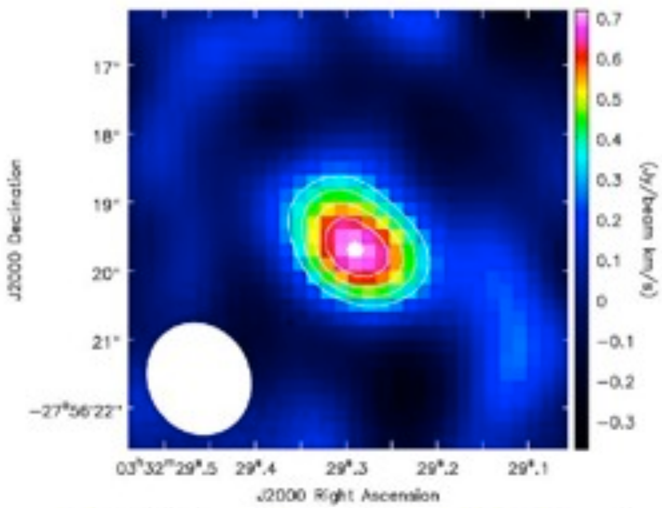
z=4.69

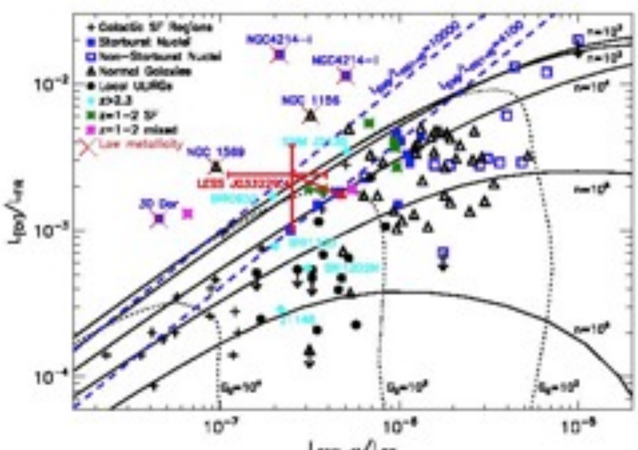


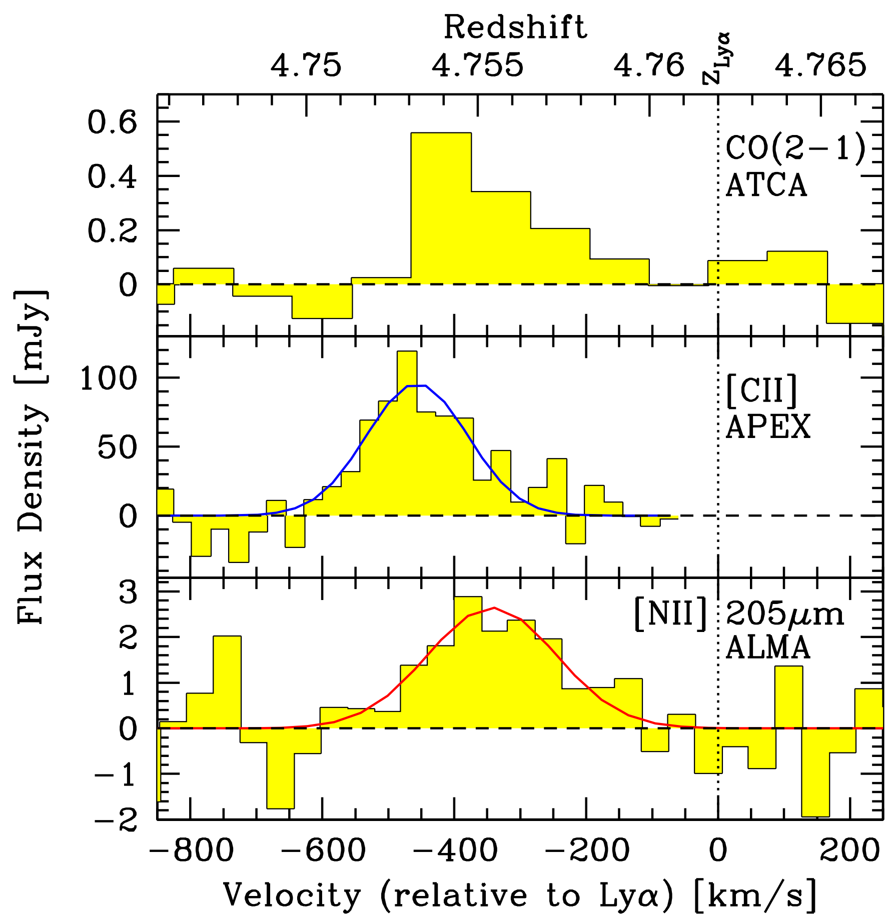
SMA: 340GHz continuum and line
Iono et al. (2006), [CII] (N only)+cont

ALMA ES Science Results

- ALMA Observations of the high-z galaxy LESS J03322
  - Nagao et al. 2012, A&A, in press
  - Detection of [NII] at z~4.76, first estimate of [CII]/[NII] at high-z

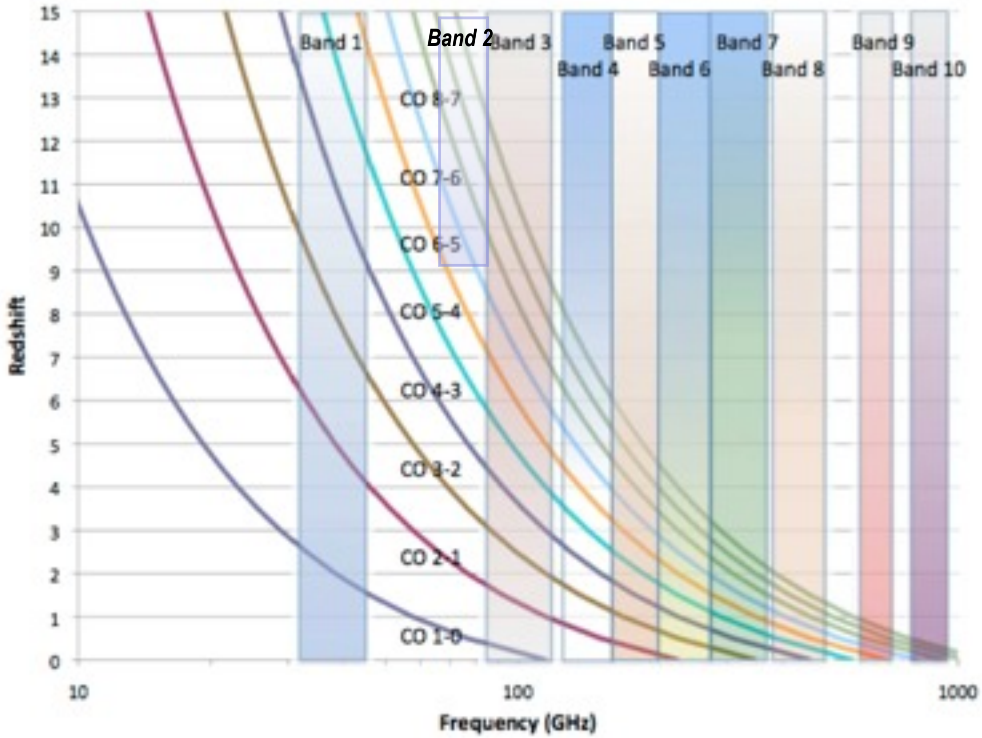


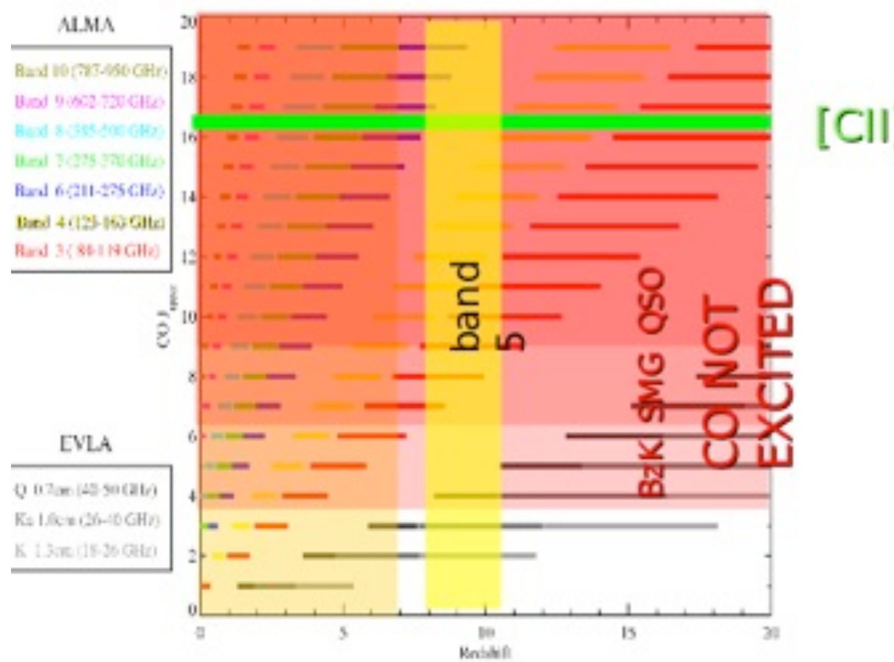




(de Breuck et al. 2011, APEX [CII])

The high redshift universe

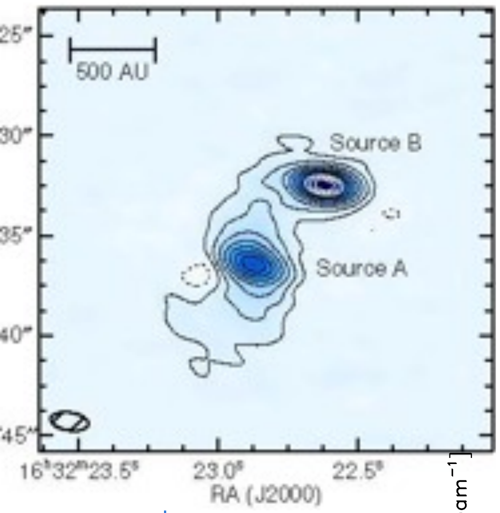


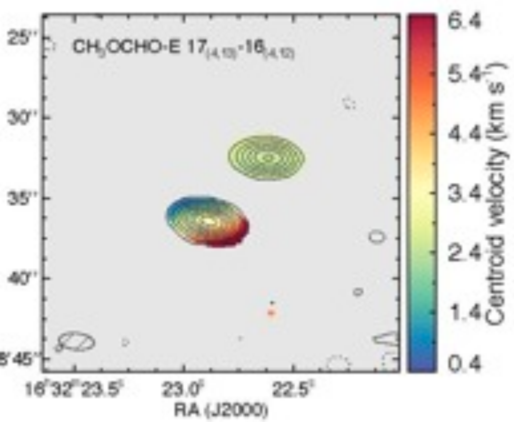


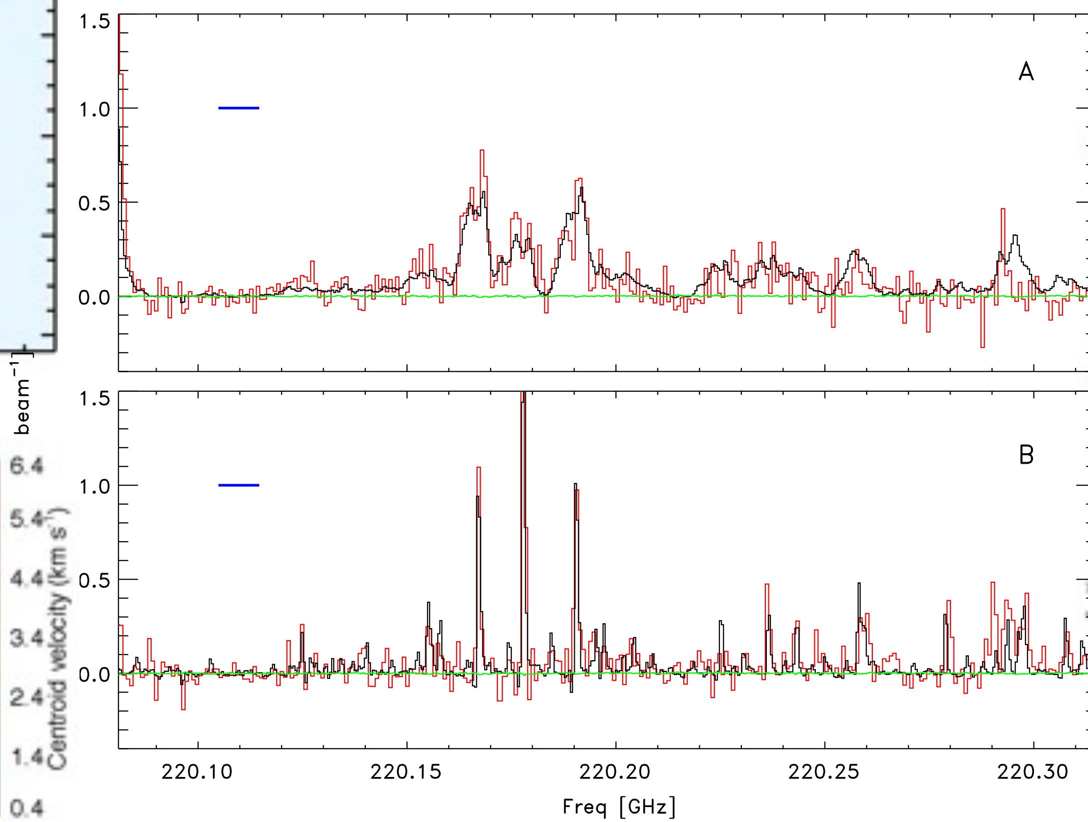
- Band 1&2 critical for low excitation molecular gas at high redshift
- Band 5 for [CII] in z~(8-10.5) range

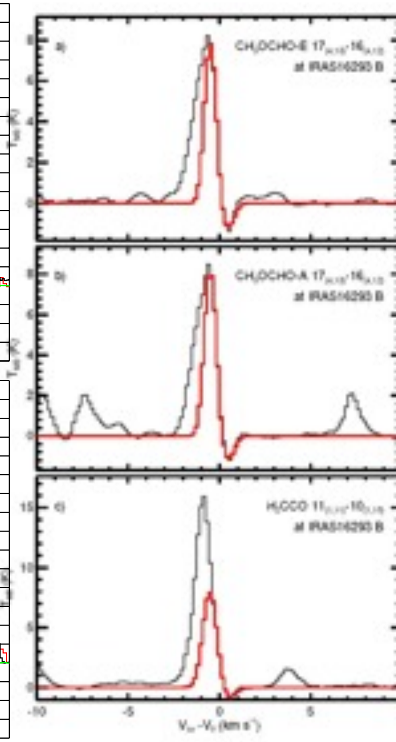
ALMA SV Science Results

- The multiple solar-mass protostellar system IRAS16293
  - Jorgensen et al. 2012; Pineda et al. 2012; Dumas et al. 2012





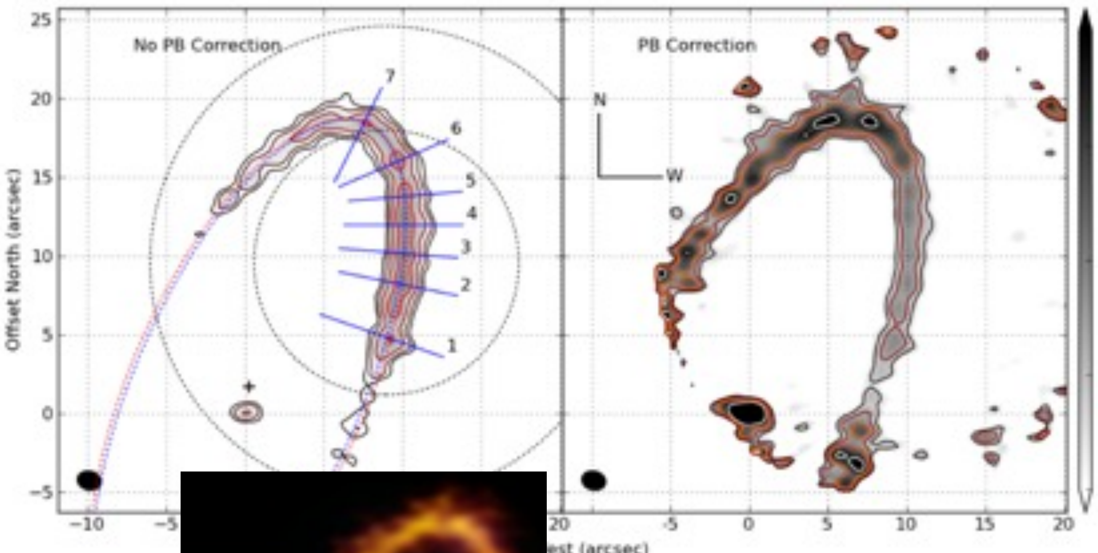


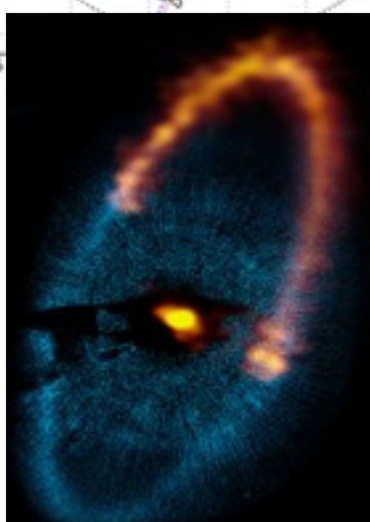


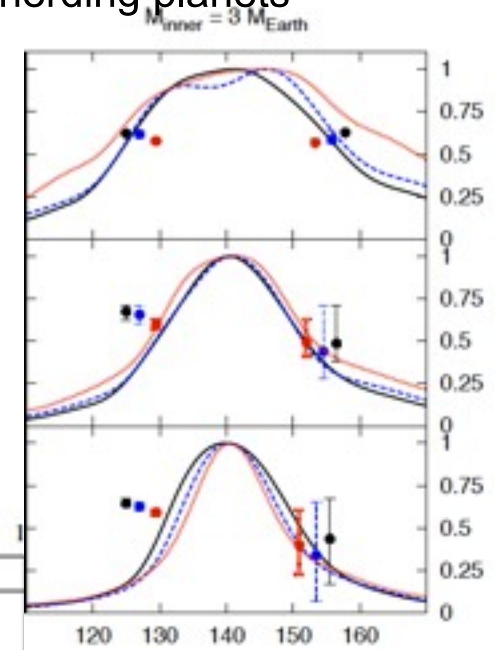
Leonardo Testi:

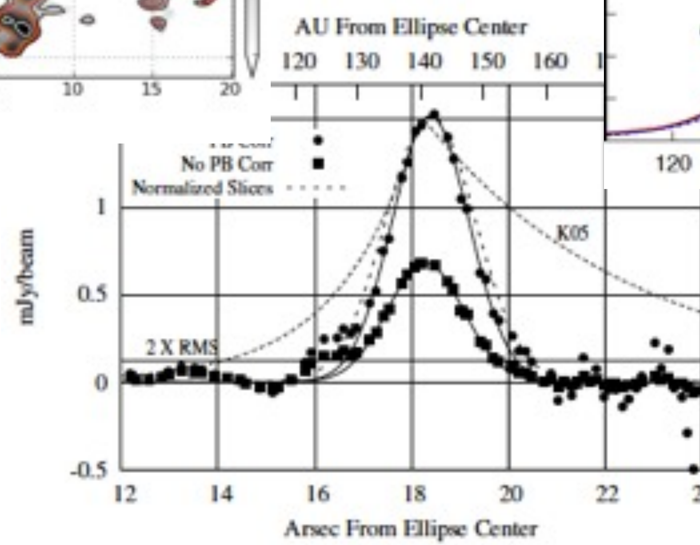
ALMA ES Science Results

- ALMA Observations of the Debris Disk around Fomalhaut
  - Boley et al. 2012, ApJL, in press (see PR in April)
  - Sharp ring in mm-size grains, indirect evidence for shepherding planets









ALMA

The First Year of ALMA Science

Puerto Varas, Chile
December 12-15, 2012

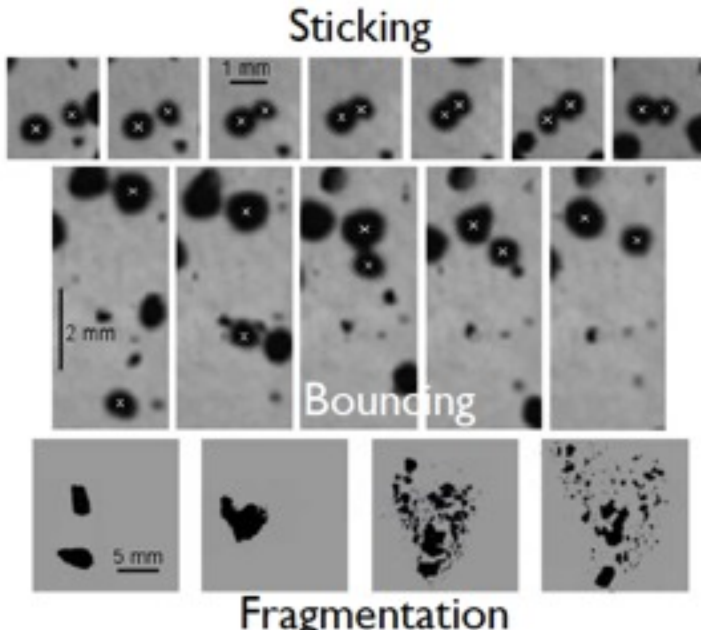
Exciting results from ALMA Early Science observations,
from the Solar System to the high-redshift Universe,
with an outlook to the future

Scientific Organising Committee

Leonardo Testi (ESO, Chair)
Paola Andreani (ESO)
Lewis Ball (JAO)

Grain Growth the Dawn of Planets

- The core-accretion scenario
  - Dust growth and planetesimals formation
  - Formation of rocky cores
  - Gas accretion from disk



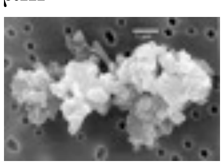
Directly observable through IR and mm observations

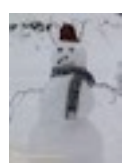
hic sunt dracones (models)

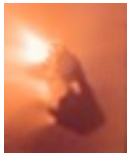
End State Exo-planets

Solar system constraints (but only 1 object! Snapshot 4.5 billion years after the fact!)

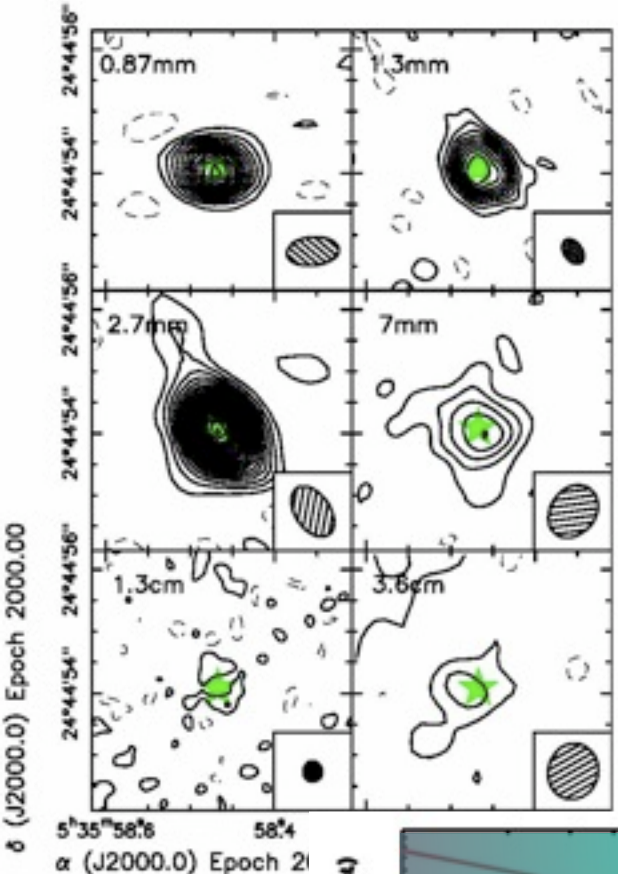
1μm | 1mm | 1m | 1km | 1000km

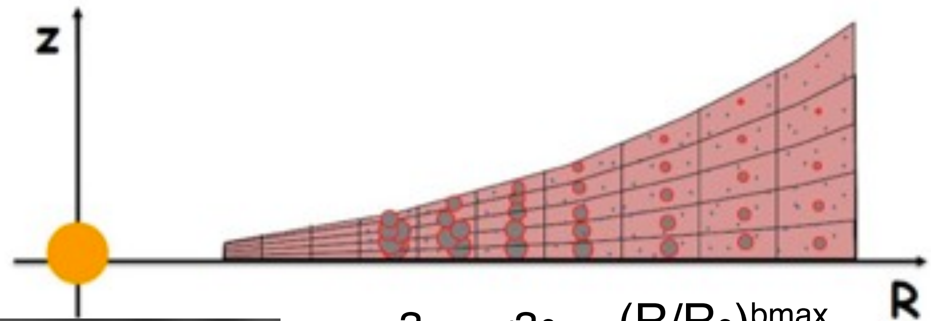


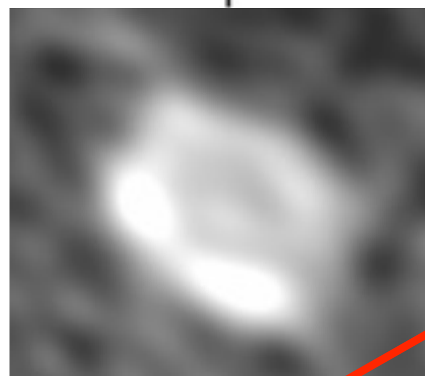



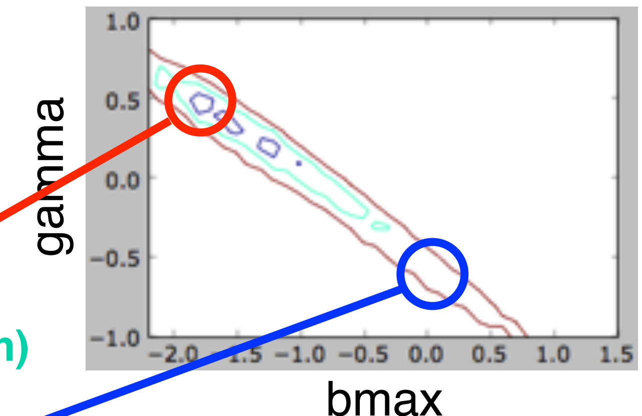


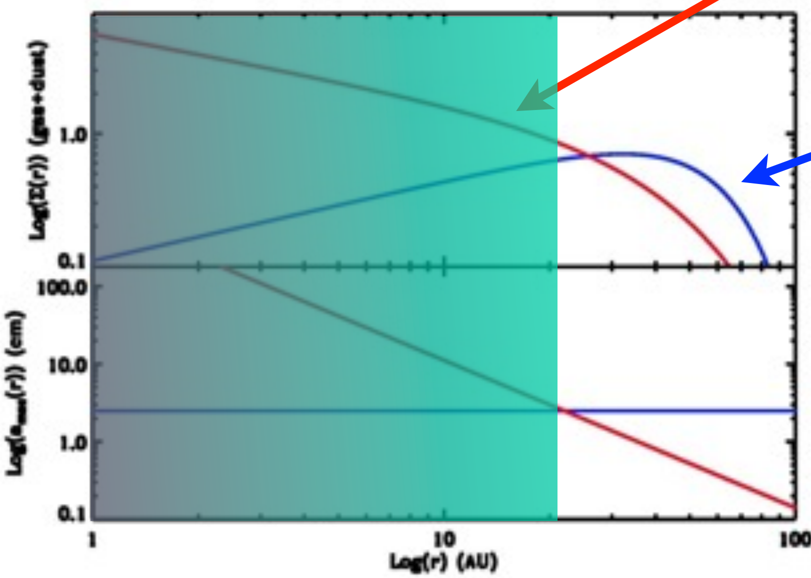
The case of the CQ Tau disk

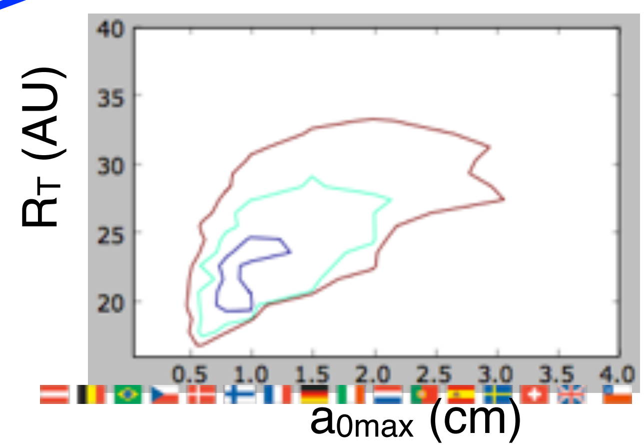












n)

- Dusty disk
- Possible ev
  properties v
- Analysis lin
- New EVLA

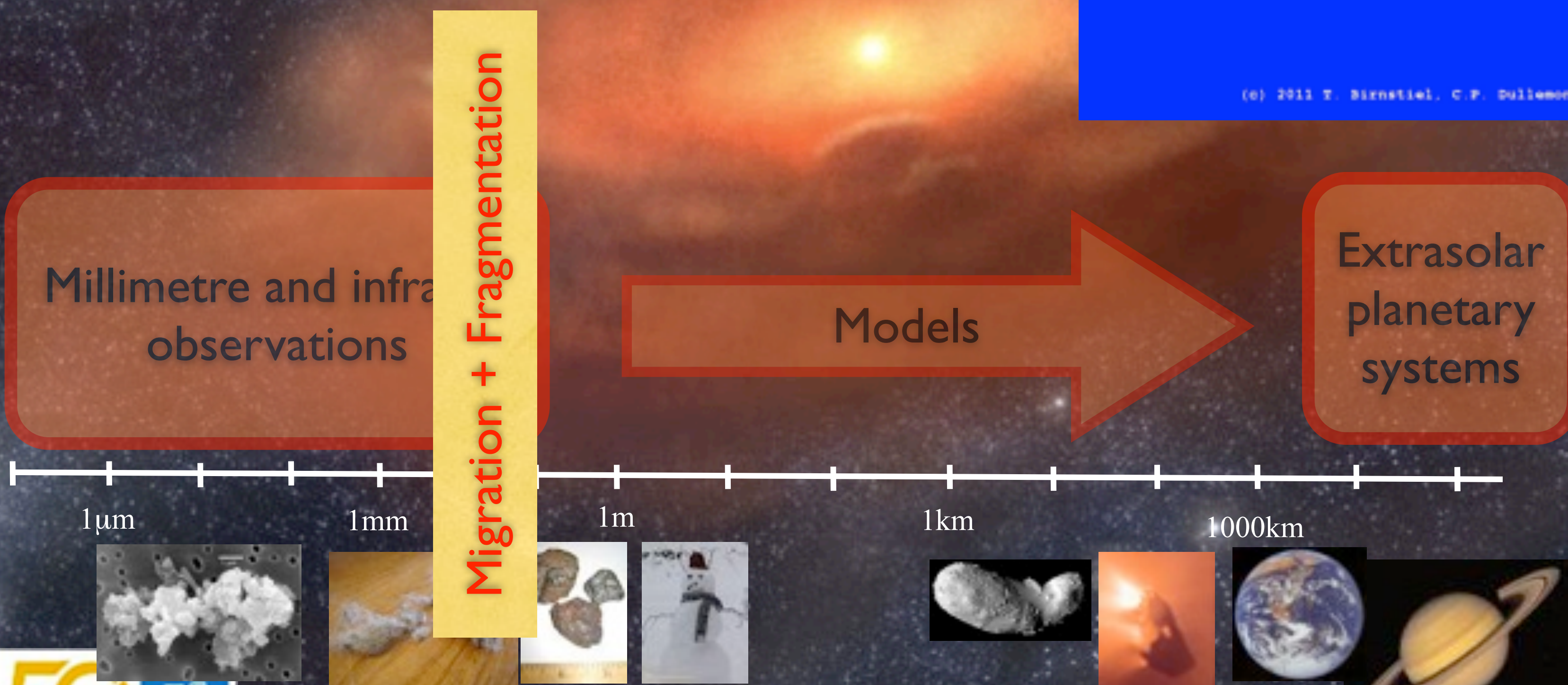
Le

(Banzatti, LT, et al. 2011; Trotta, LT, et al. 2012
Isella et al. 2010; Guilloteau et al. 2011; Perez et al. 2012)

Dust trapping in pressure maxima

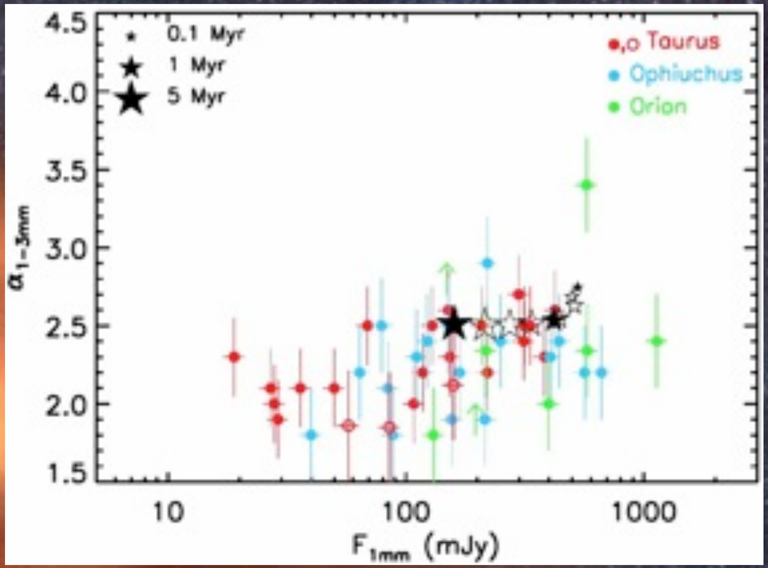
- Pressure maxima in disks (arms, vortices...) can efficiently trap large particles allowing grains to growth and stay in the disk for long times

(Pinilla, Birnstiel, Ricci et al. 11, Ricci et al. 11)

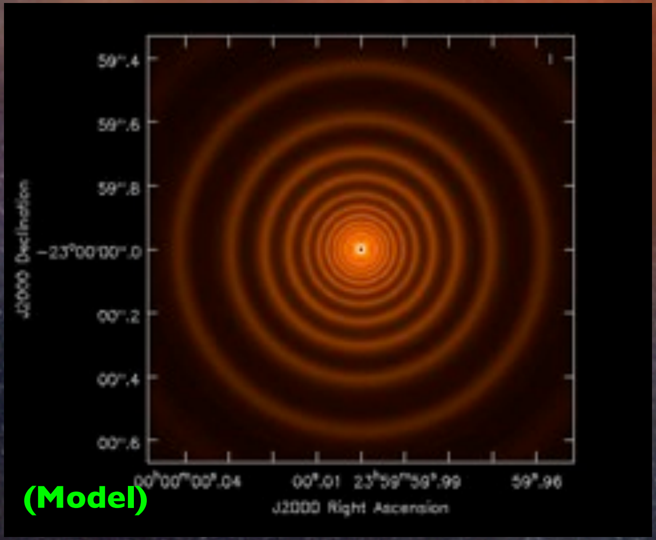


Dust trapping in pressure maxima

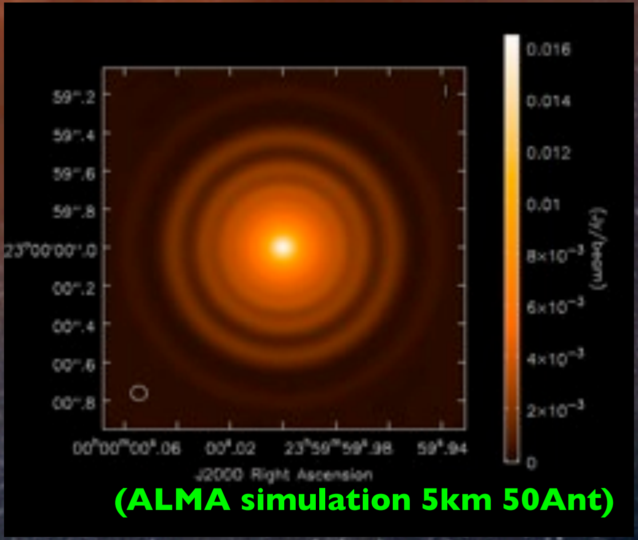
- Pressure maxima in disks (arms, vortices...) can efficiently trap large particles allowing grains to growth and stay in the disk for long times
- Observable with ALMA!



(Pinilla, Birnstiel, Ricci et al. 11, Ricci et al. 11)

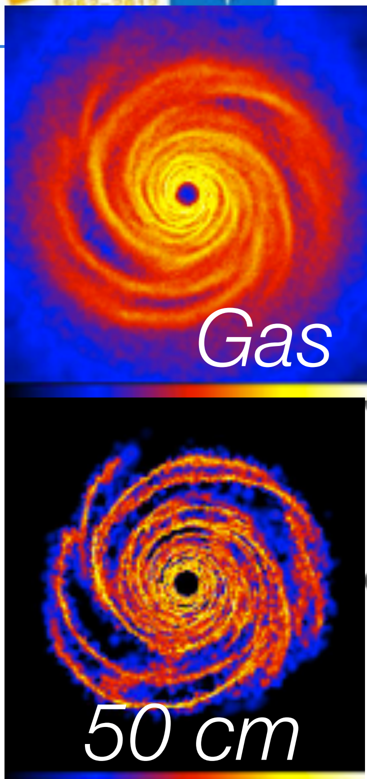


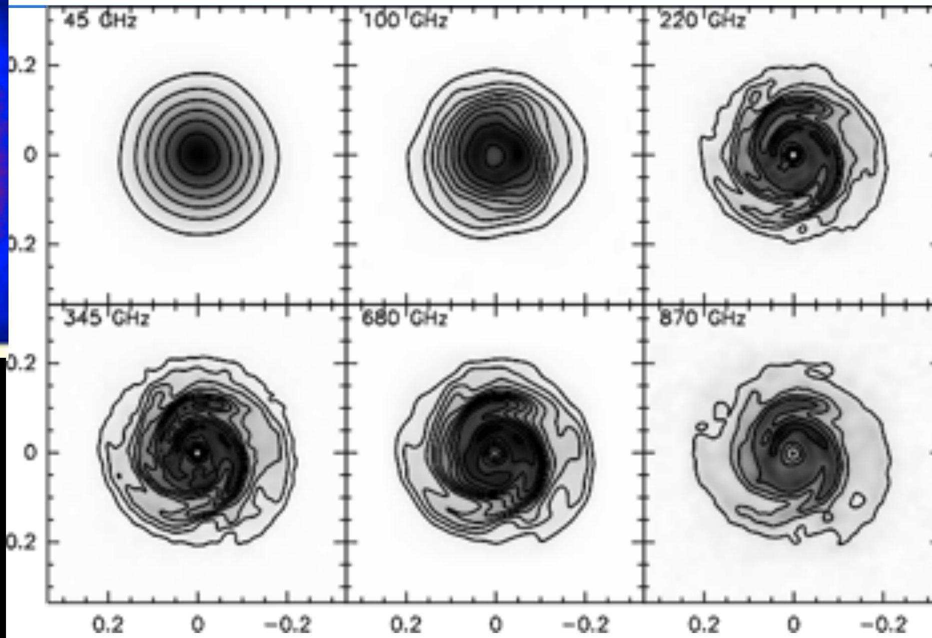
(Model)



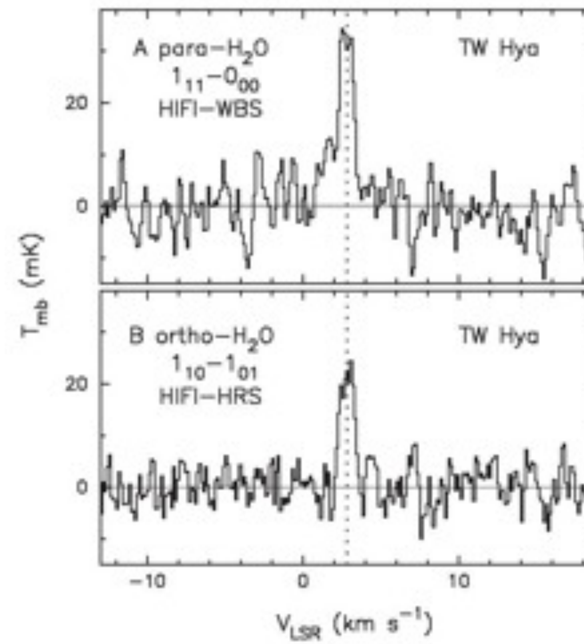
(ALMA simulation 5km 50Ant)

Dust evolution in disks





(Cossins, Lodato & Testi 2010)



(Hogerheijde et al. 2011)

- Dust evolution in the inner disk with ALMA:
  - Band 1&2, high angular resolution
- Water vapour emission:
  - Band 5

State of the Art & Future Directions

- Grains grow and settle in disks around all type of PMS objects
- Grain evolution can be very fast as we see highly processed grains around objects of all ages between 1 and 10 Myr
- Plausible physical structures in the disk can stop migration

- **Key predictions and tests:**
  - Grain growth in Class 0 and I
  - Radial gradient of dust properties (Guilloteau et al. 2011; Trotta et al. 2012)
  - Small-scale segregation of large grains (sub-AU resolution needed)
  - Disks need high gas densities for grains to grow: faint disks should be a late evolutionary stage disks around BDs should not grow grains (initial tests with ALMA)