Science with ALMA

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ESO Chili
Santiago, January 15th 2002

Main reference: "ALMA Science Case"- January 2001 http://iram.fr/ guillote
Other references are given

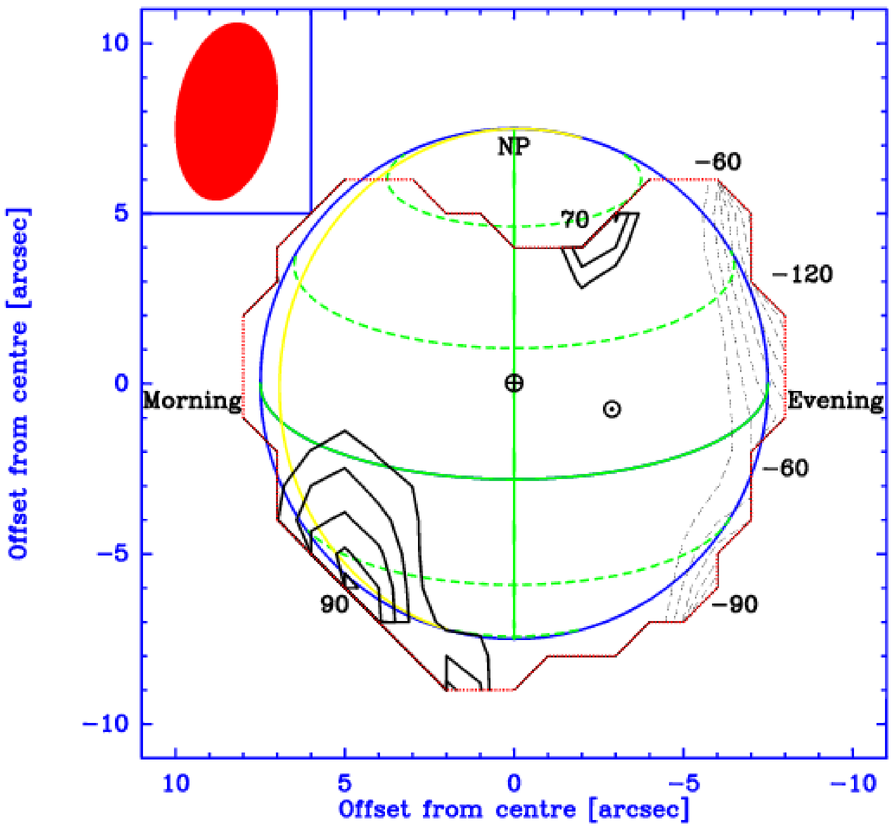
ALMA: scientific goals

- **ALMA is not a specialized telescope,**
- **but very well suited to some domains**
  - **A** High-Z universe
  - **B** Structure and evolution of galaxies
  - **C** Stellar formation and evolution
  - **D** Planetary system formation
  - **E** Solar system
  - **F** Interstellar chemistry (from galaxies to protoplanetary disks and planetology)
  - Dual Polarisation
- **One should even observe the Sun...**(if antenna surface allows...)

F - Solar System

- Intantaneous images... a major progress...
  - Winds on Mars (without smoothing due to Mars rotation...)
  - Volcanoes on Io (SO can be resolved)
  - Comets: jets better than in the optical, rates of gas evaporation.
- Atmosphere of giant planets
- Asteroids and Kuiper Belt objects

Winds on Mars

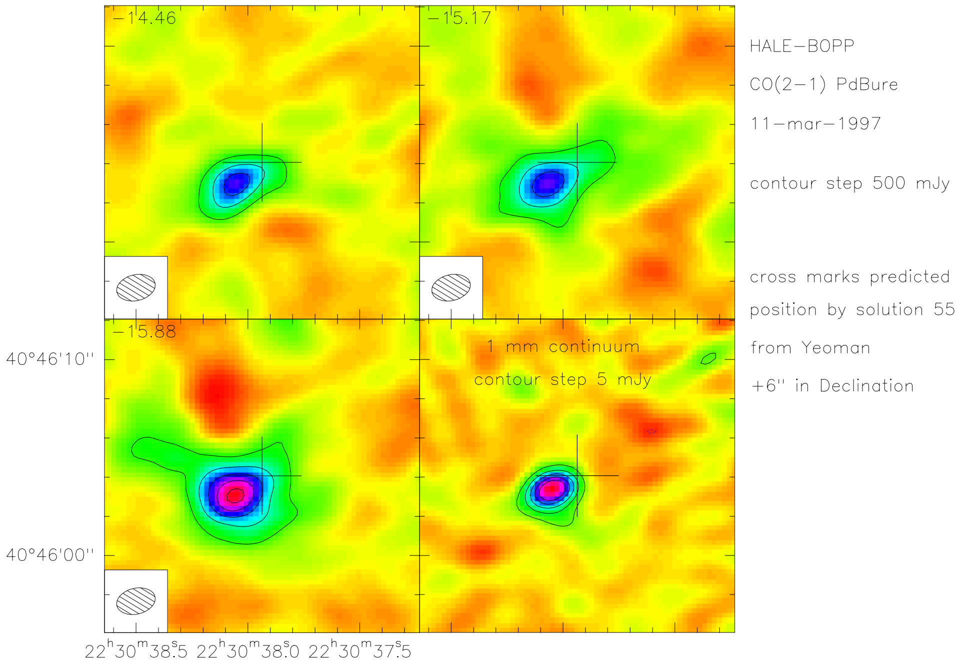


Atmospheric temperature maps will be obtained from inversion of the CO lines, providing the temperature profile from 0 to 70 km at Mars and 70 to 120 km at Venus.

+ For Mars, this is enough to resolve regional (e.g topographic) scales. The probed vertical range extends somewhat higher than in infrared sounding from martian orbiters.

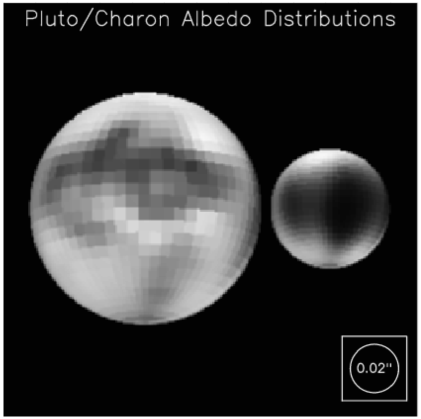
+ Figure of winds near 50 km altitude in the atmosphere of Mars (CO J=1-0, PdBI data). Positive values indicate receding winds. Contours are separated by 15 m/s (Moreno etal., 1999).

Comets



Hale-Bopp CO J=2-1 and dust continuum emission (PdBI data, Wink et al., 1997).
ALMA will allow fast imaging of coma probing *in real time* its physical and chemical evolution (dust, jets, molecule production rates). AT 1 AU, resolution will be 15 km at 1 mm. ALMA will also allow to study the CO activity of distant comets.

Albedo of small bodies and asteroids



+ B band albedo distributions of Pluto and Charon reconstructed from multiple mutual occultation events (courtesy M.W. Buie, Lowell observatory).
+ ALMA could provide a thermal map of the surfaces of both objects at 0.02″ resolution in 1 hr with 0.5 K rms noise.

Continuum observation will ALMA will allow to probe the thermal emission of Solar System small (quasi)airless bodies: asteroids, comet nuclei, Centaurs, trans-Neptunian objects as well as outer satellites (such as Triton) and Pluto and Charon separately.
Combined with data in other spectral range, this will provide information on surface properties (albedo, emissivity, thermal inertia..)
A trans-Neptunian object of 200 km diameter at 45 AU has a 1 mm flux density of $\sim 60\ \mu$ Jy detectable in 1 hr.

F - Insterstellar chemistry...

A fundamental domain linked to all others

- From galaxies to planetary atmospheres
- Molecules in star forming regions
- Chemistry in translucent / molecular clouds
- Chemistry / shocks in Jets
- Chemistry in hot cores
- Chemistry in planet forming regions (inner disks)
- Chemistry in planetary atmosphere
- **Exobiology ?**

Molecular Gas in distant galaxies

Gas content at high redshifts

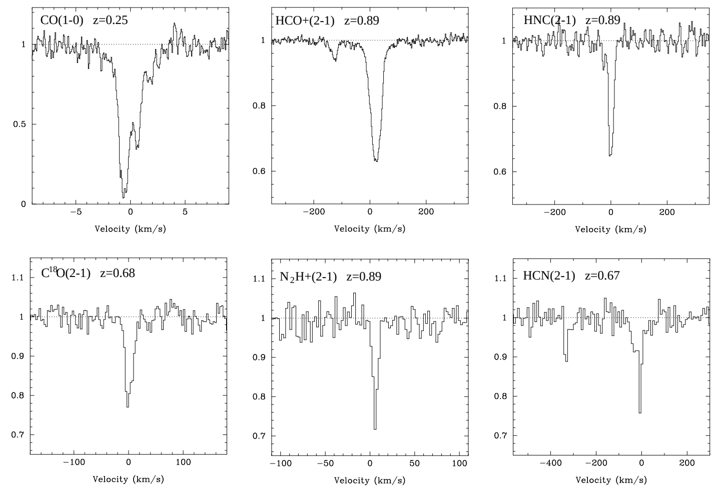
+ Mm absorption lines observed towards the quasar PKS +1830-211 (Wiklind & Combes 1998)

+ It occurs at various intermediate redshifts given in each panel

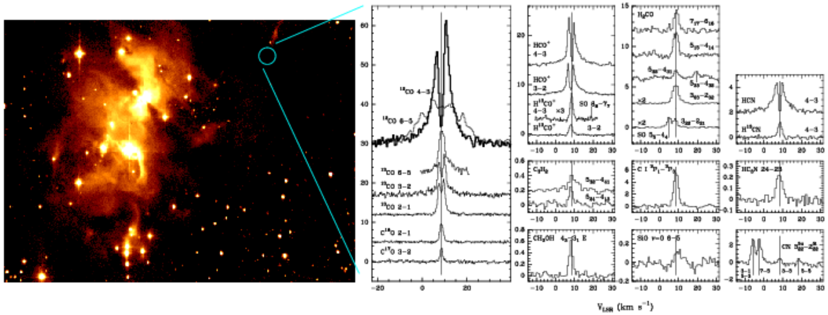
+ Derivation of physical conditions if several transitions (star formation)

+ Sensitivity limited: low continuum sources

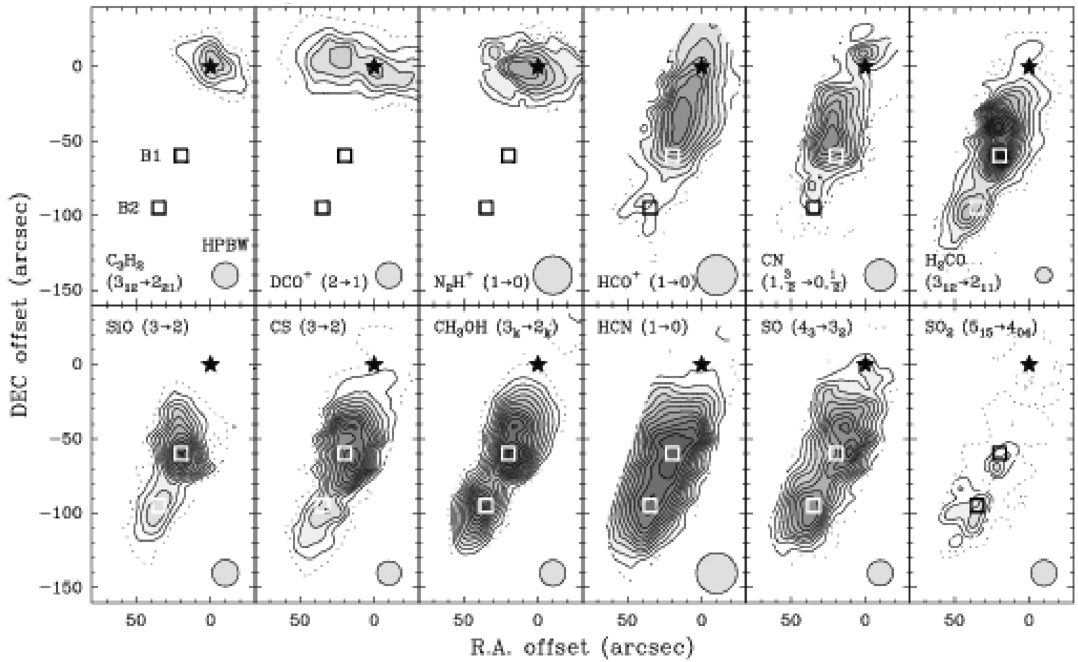
ALMA will allow systematic survey



Chemistry in molecular cores

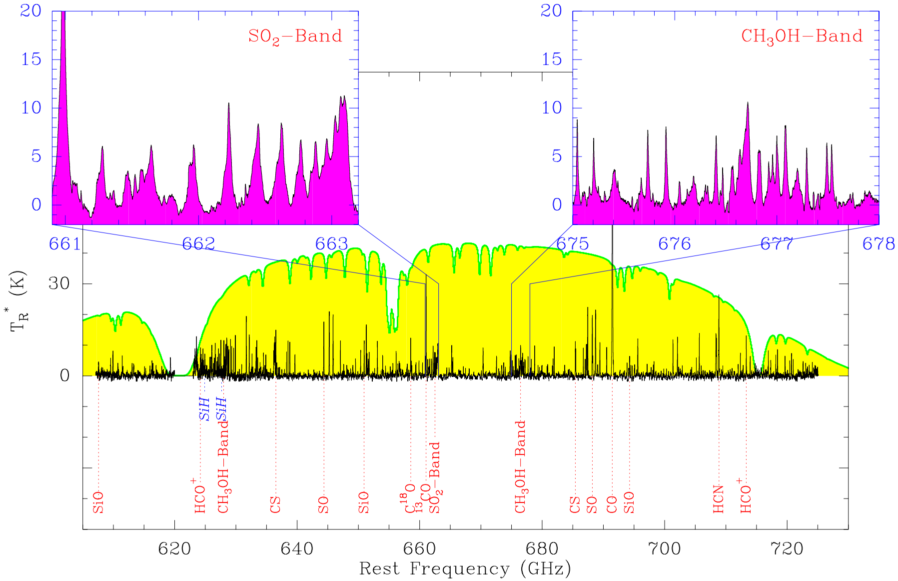


Serpens molecular cloud at 300 pc
LEFT: 2 μ m image (Hodapp 1994) - an YSO cluster
RIGHT: Mm observations from the JCMT (Hogerheijde et al., 1999)
Only ALMA will be able to image the spatial distribution of molecules on scales $\sim$ 50 AU or less



Chemistry in YSO jets Maps of the molecular emission towards the outflow in L1157 (Bachiller et al., 2000). Some molecular species such as C_3H_2 and the ions DCO^+ and N_2H^+ are excellent tracers of the circumstellar envelope around the "Class 0" protostar L1157-mm (marked with a star). A striking chemical stratification is observed along the outflow, with the different molecular species tracing different regions of the shocked gas. ALMA will directly image these chemical changes, which occur on scales of $\sim10^{15}$ cm in most known chemically-active outflows.

Chemistry in high-mass star forming regions



610-725 GHz spectra obtained with the CSO telescope, towards Orion IrC2 hot core (Schilke et al., 2000)

Bottom spectrum: whole spectral range covered with atm transmission (yellow) for comparison.

Top spectra: (mainly) series of methanol (right) and sulfur dioxide (left) transitions.

ALMA will provide imaging data for regions similar to Orion throughout the Galaxy

Molecules in protoplanetary disks

Today only a few detections around sources free of confusion

- **CTTs: DM Tau + GG Tau (binary)** Dutrey et al. 1997, A&A, 317
  $\rightarrow$ **Mean H_2 density in DM Tau + Molecular abundances $X(mol)/H_2$**
- **Detected molecules & depletion factor with respect to $X(mol)_{TMC1}$**

CO	CN	HCO^+	($H^{13}CO^+$, DCO^+)	C_2H	CS	HCN	HNC	H_2CO
∼5	∼10	∼10	(not yet measured)	∼10	∼40	∼100	∼100	∼100

- **ALMA = physico-chemistry by multi-trans./multi-isotope analyses in the inner disk ($R \leq 50 - 30$ AU) at resolution $\sim 5 - 10$ AU Comparison of these chemical gradients with the abundances found in comets should yield estimates of the locations in the solar nebula where comets were formed.**
- **LIMITATION: calibration + collision rates**

Prebiotic molecules in space (exobiology?)

Today strongly sensitivity limited (organic molecules)

Thanks to ALMA sensitivity

- **Prebiotic molecules in circumstellar envelopes (IRC+10216)**
- **Prebiotic molecules in star forming regions (Orion A)**
- **Prebiotic molecules in protoplanetary disks**
- **Prebiotic molecules in comets**
- **Prebiotic molecules in solar system (Titan)**
- **Exo-planets not detectable...**

Probing Physical/Chemical conditions with ALMA

- **Require multi-transitions and multi-isotopes analysis (several band-widths)**

- **ALMA: high precision calibration, high fidelity imaging**
  - **current status of absolute calibration**
  - 3-0.8mm band-widths: 1%
  - $\lambda \leq 0.8$ mm 3% (5%)

- **Therefore main limitations should come from**
  - Source geometry ... not a problem in simple sources (e.g. disks)
  - Molecular parameters ... not accurate enough in some cases
  - Collision rates ... a real problem (even for CO)
  - Chemical reaction rates ... poorly known ...

- **Preparatory work required ...**

ALMA: conclusions

- **Instantaneous imaging capability**
- **ALMA is not a specialized telescope**
- **but very well suited to some domains**
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  - Structure and evolution of galaxies
  - Stellar formation and evolution
  - Planetary system formation
  - Solar system
  - Interstellar chemistry (from galaxies to protoplanetary disks)
- **One should even observe the Sun...**(if antenna surface allows...)