Solar System with ALMA

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Solar System bodies with ALMA

- ✓What are they made of ?
- ✓How do they work ?
- ✓How did they evolve ?
- ✓What they tell us about the formation of the Solar System ?

Mm/submm wavelengths: a lot of observations already, a lot of unique measurements

ALMA

- ✓High spatial resolution/high sensitivity
- ✓Will do unique measurements
- ✓Will complement telescopic observations at other λ
- ✓Will complement space missions

Apparent diameters

Mercury	5-12’’
Venus	10-65
Mars	4-26
Jupiter	30-50
Saturn	15-21
Uranus	3-4
Neptune	2

Ceres	0.4-0.7’’
Io	0.8-1.3
Titan	0.6-0.9
Pluto	0.1
TNO	0.04
Comet nucleus	0.001-0.01
Comet Coma	60

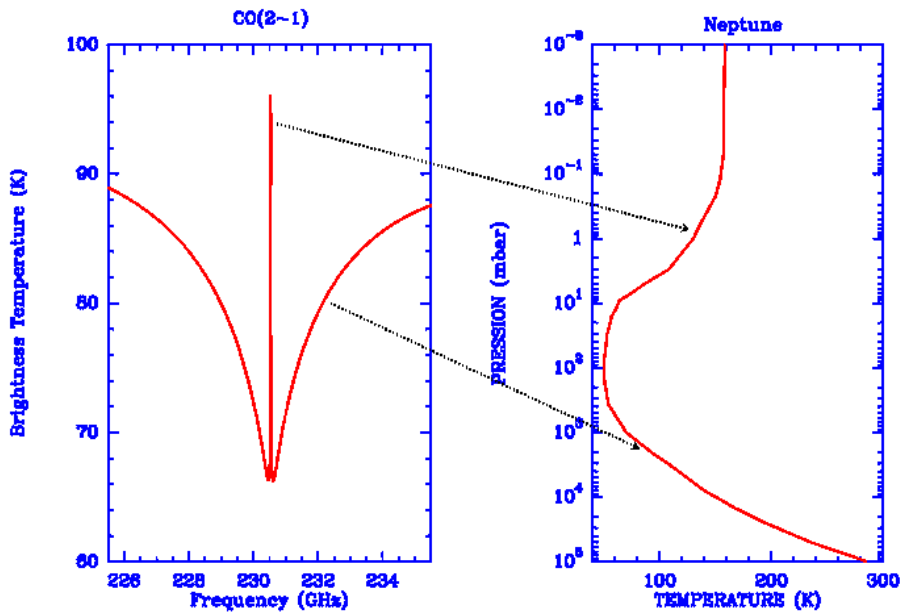
Resolution of 25 mas: 10 km@0.5 UA to 900 km@50 AU

Solar System: DRSP Themes

- Planetary and satellite atmospheres (4.1)
- Solid surfaces of planets, rings, KBOs and other minor bodies (4.2)
- Cometary comae and nuclei (4.3)

Planetary and satellites atmospheres

- Vertical distribution of species
- Thermal structure
- Dynamics (wind measurements)
- 3D mapping and monitoring
  (seasonal variations)
- Search for new species



Mars: key measurements

Tenuous atmosphere: CO_2, N_2 + traces of CO, H_2O, O_2, O_3 ….

Mm/submm: CO, ^{13}CO, H_2O, $H_2{}^{18}O$, HDO, H_2O_2
in the lower and middle atmosphere (10 to 100 km)

Line profiles: abundances and vertical distribution
thermal stucture, winds
☛all three are coupled

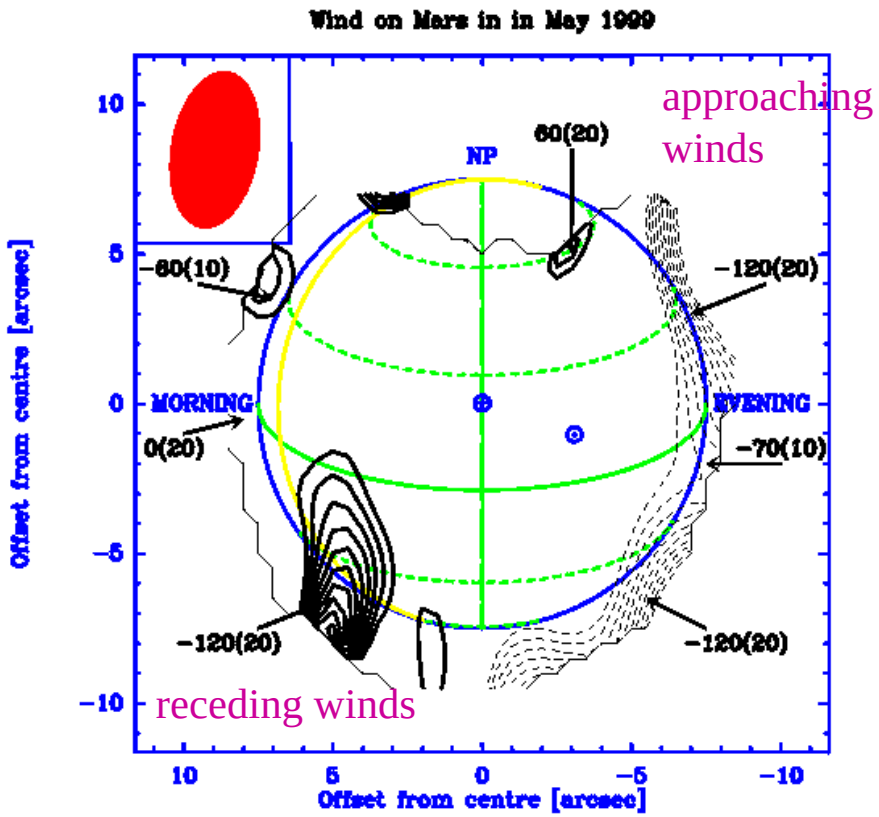
ALMA: A 3D dynamical picture of Mars middle atmosphere
not accessible from space

- 3-D wind measurements of middle atmosphere
- The cycle of water on Mars
- Search for new species

3D wind measurements on Mars

Strong (100 m/s) retrograde winds are observed whatever the season.

<u>Global circulation models:</u>
Prograde winds are expected at some seasons

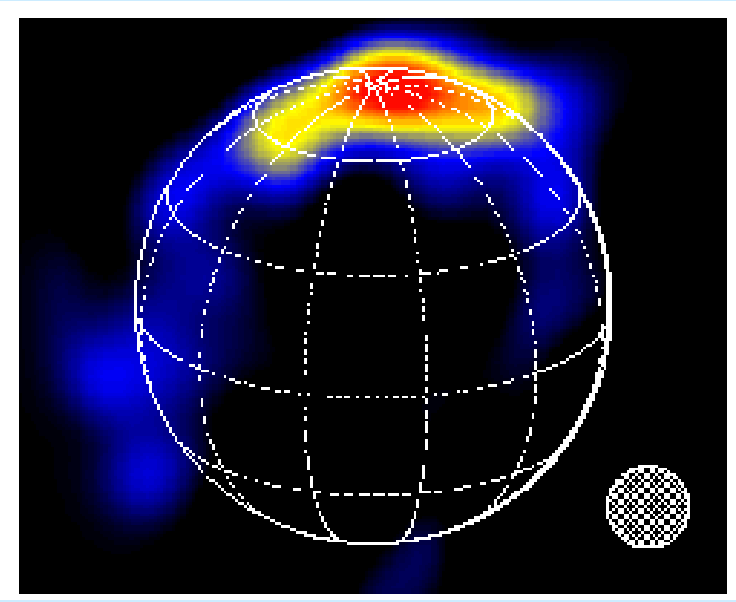


<u>May 1999</u>
Late Summer
For Northern Hemisphere

IRAM PdB CO(2-1) Moreno et al.

The cycle of water on Mars

H_2O gas and ice as a function of latitude, longitude season: key for understanding global climate and polar caps.



OVRO HDO (Gurwell/Muhlman)

<u>HDO mm observations:</u>
Water wapor content near the surface and level of condensation (~5-10 km).

Seasonal, interannual(?) variations and N/S asymmetries observed.

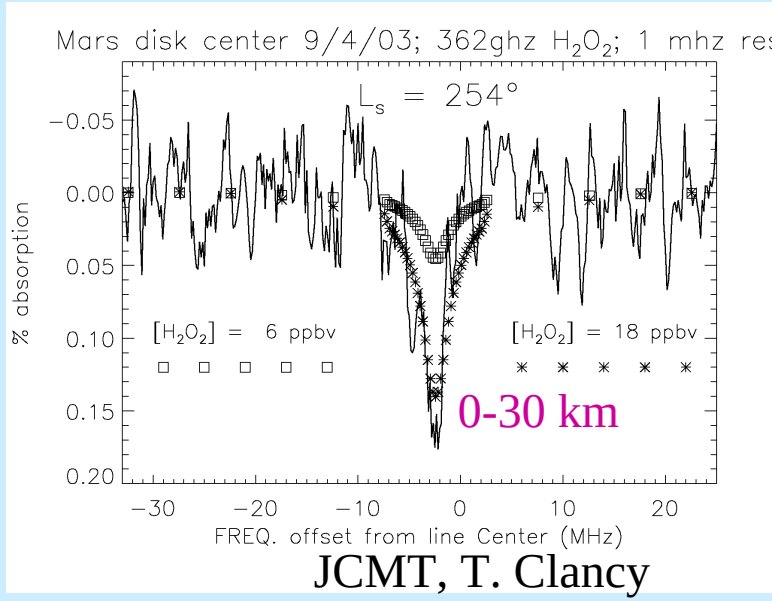
3D maps of HDO (with T(z)) needed

Minor species in Mars

- H_2O_2, recently detected in mm/IR, 10^{-5} ppm

$H+O_2+CO_2 \Rightarrow HO_2+CO_2$; $HO_2+ HO_2 \Rightarrow H_2O_2$

- An important molecule in studying Mars photochemistry
- Oxidizer of martian regolith
- Strong seasonal and spatial variations observed



JCMT, T. Clancy

- Search for key constituents of Mars photochemistry:

HO_2, H_2CO, NO ..

- Search for sulfur species in vents from possible hot spots:

H_2S, SO, SO_2, OCS

Venus: key measurements

Dense atmosphere, dominated by CO_2
Mm/submm: H_2O, HDO, CO (mesosphere 80-100 km)

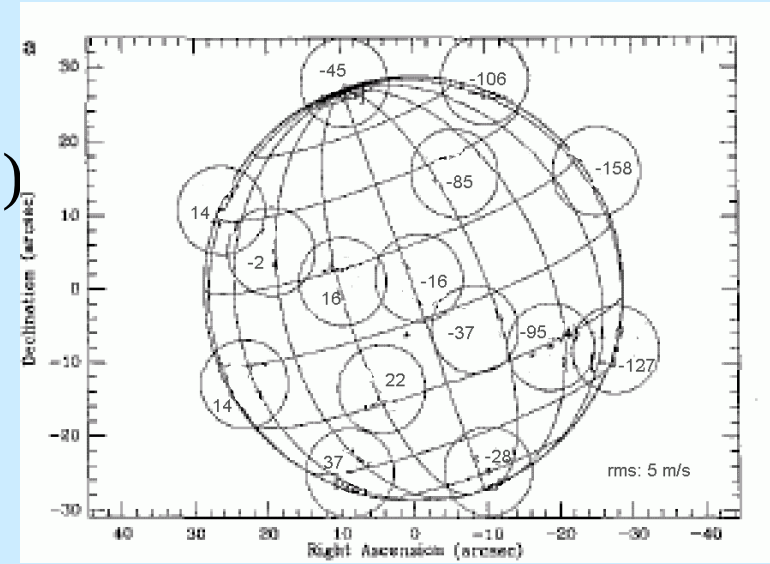
ALMA

- 3D-maps of mesospheric winds (CO)

☛Not accessible by other means

☛To understand zonal super-rotation and interannual variations

☛To understand global atmospheric circulation



Lellouch et al. 1994

- 3-D maps of $H_2{}^{18}O$, HDO☛ H_2O above the clouds, D/H
- Search for sulfur species in the mesosphere (H_2S, SO_2 ….)

Giant Planets Stratospheres

Mainly H_2, He and CH_4
Hydrocarbons from CH_4 photolysis
Stratospheric species in mm/submm: CO (J,N), HCN (J,N), H_2O (J,S,N,U) and several species in Jupiter following SL9 impacts

ALMA

- 3D vertical profiles of CO and HCN in Neptune
  - ☛ origin: internal or external ?
  - ☛ 3D thermal structure
- Search for CO (detected in IR) and HCN in Uranus
- Search for photochemical products in Neptune (nitriles)
- Observation of HDO in Jupiter, Saturn, Neptune, Uranus
  - ☛ D/H: origin of stratospheric water ? IDP, rings, icy moons ?

Interferometric observations of Jupiter and Saturn will be difficult and limited to low frequencies (because of their large size)

Giant planets tropospheres

Chemical abundances controlled mainly by thermal equilibrium

NH_3, CH_4, H_2S,…+disequilibrium species PH_3

A key to investigate the origin of stratospheric species, and vertical transport

Abundances: constraints on Solar Nebula models and planet formation

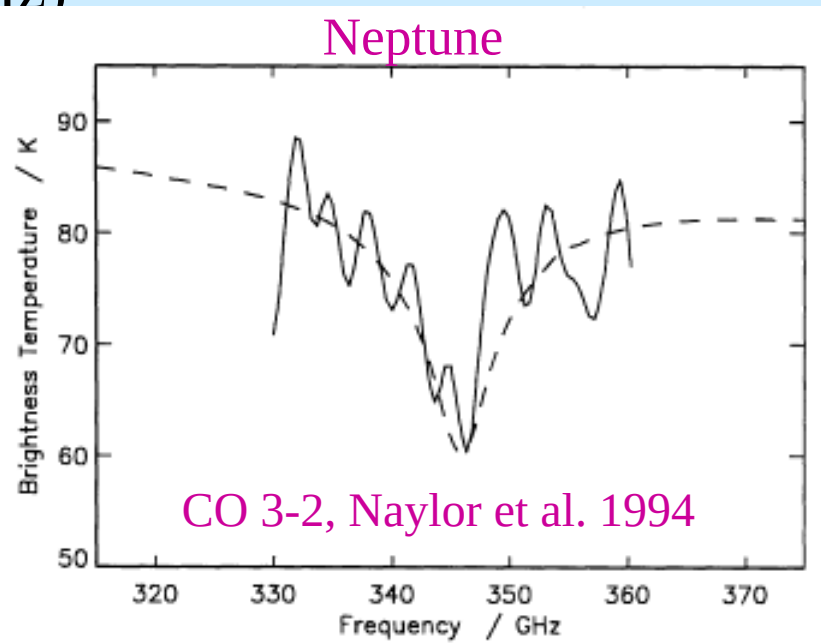
Detected tropospheric species in mm/submm: CO (N), PH_3 (J, S)

Tropospheric lines are broad (a few GHz)

ALMA

- PH_3 search in Uranus and Neptune
- H_2S search in Uranus, Neptune
- CO in Uranus
- Continuum maps of Jupiter/Saturn

☛ T, NH_3 tropospheric distribution



Planetary Satellites Atmospheres

Io: stable, tenuous atmosphere dominated by SO_2

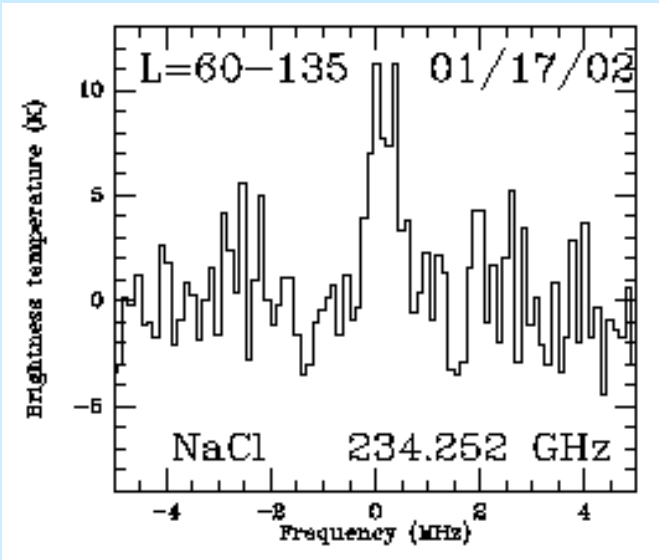
Species detected in mm: SO_2, SO, NaCl

Thermal structure, vertical distributions ill-characterized

Debate on SO_2 origin: volcanism, sublimation ?

ALMA:

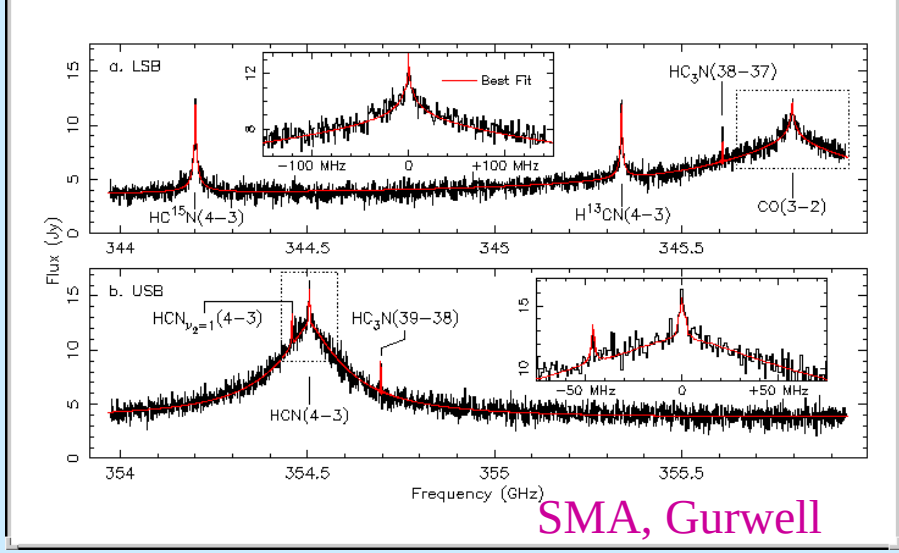
- 3D-maps of SO_2, SO and NaCl
- search for new species (S_2O, H_2S, KCl, SiO)



IRAM 30m, Lellouch et al. 2003

Titan atmosphere

Dense and cool, N_2 dominated, CH_4
Rich photochemistry in stratosphere:
hydrocarbons,nitriles, H_2O, CO, CO_2



SMA, Gurwell

MM/Submm: CO, HCN, HC_3N, CH_3CN and isotopes

ALMA:

- 3D-maps of nitriles: dynamics/photochemistry coupling
- Mesospheric (500 km) winds, complementary to deeper Cassini-Huyghens measurements.
- Search for complex species
- Isotopic ratios, e.g. D/H

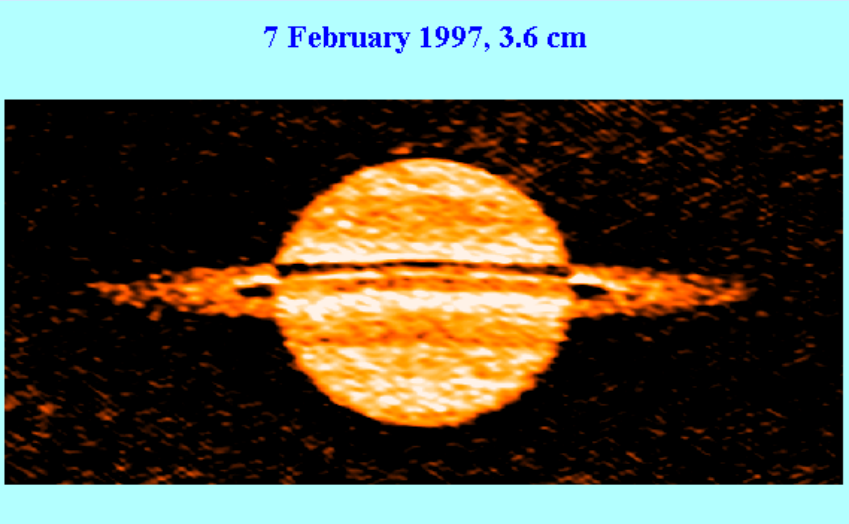
Planetary Surfaces

ALMA will map the continuum emission of the surfaces/subsurfaces of terrestrial planets, planetary satellites, large asteroids, Pluto ….

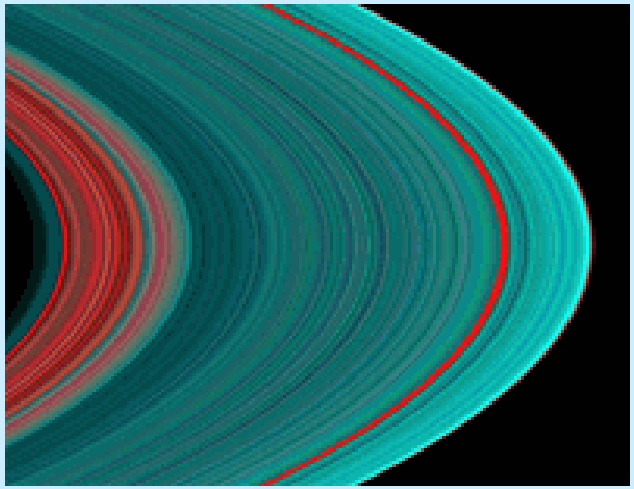
ALMA will obtain sensitive lightcurves

- ☛thermal and electrical properties of the surfaces
- ☛surfaces inhomogeneities
- ☛constraints on surface composition

Saturn's rings



VLA image 0.5'' (Molnar&Dunn, 1997)



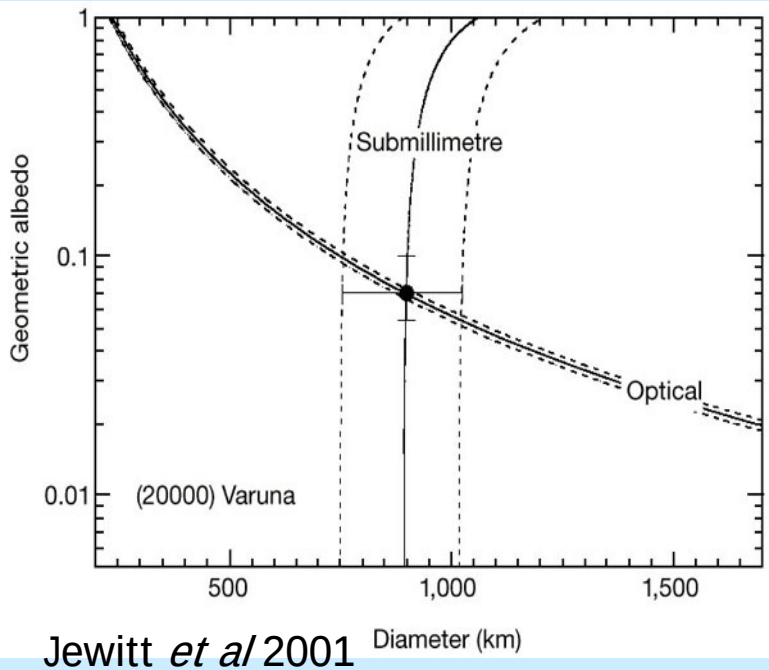
Cassini image in UV

ALMA will help in constraining the size distribution and properties of Saturn's rings

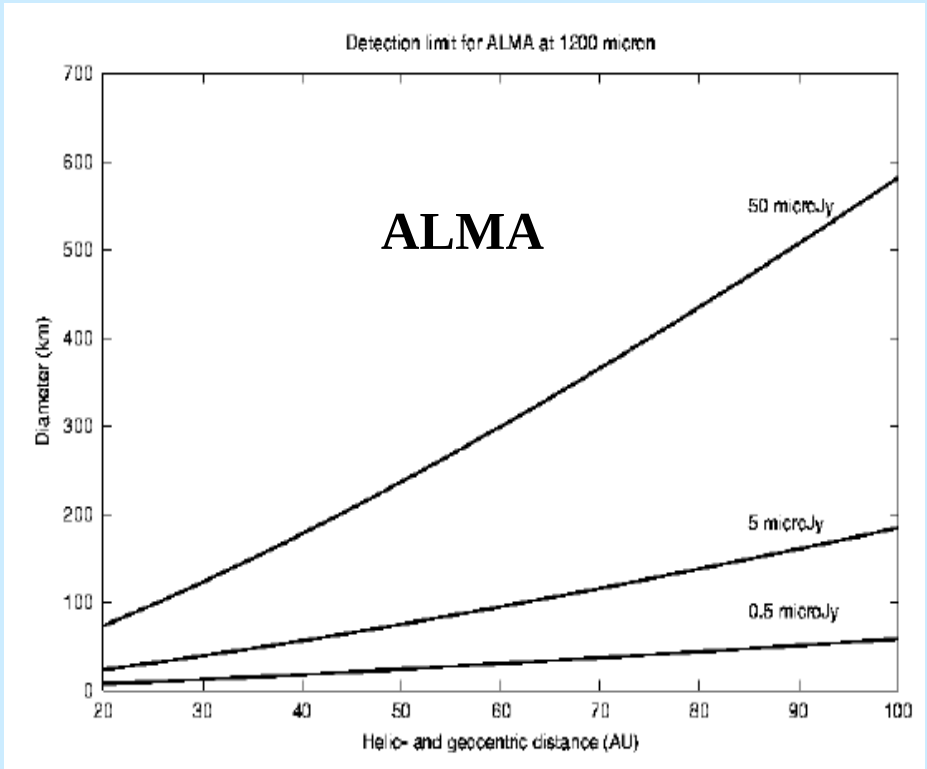
Trans-Neptunian Objects

ALMA : albedo, albedo variations, emissivity, thermal inertia

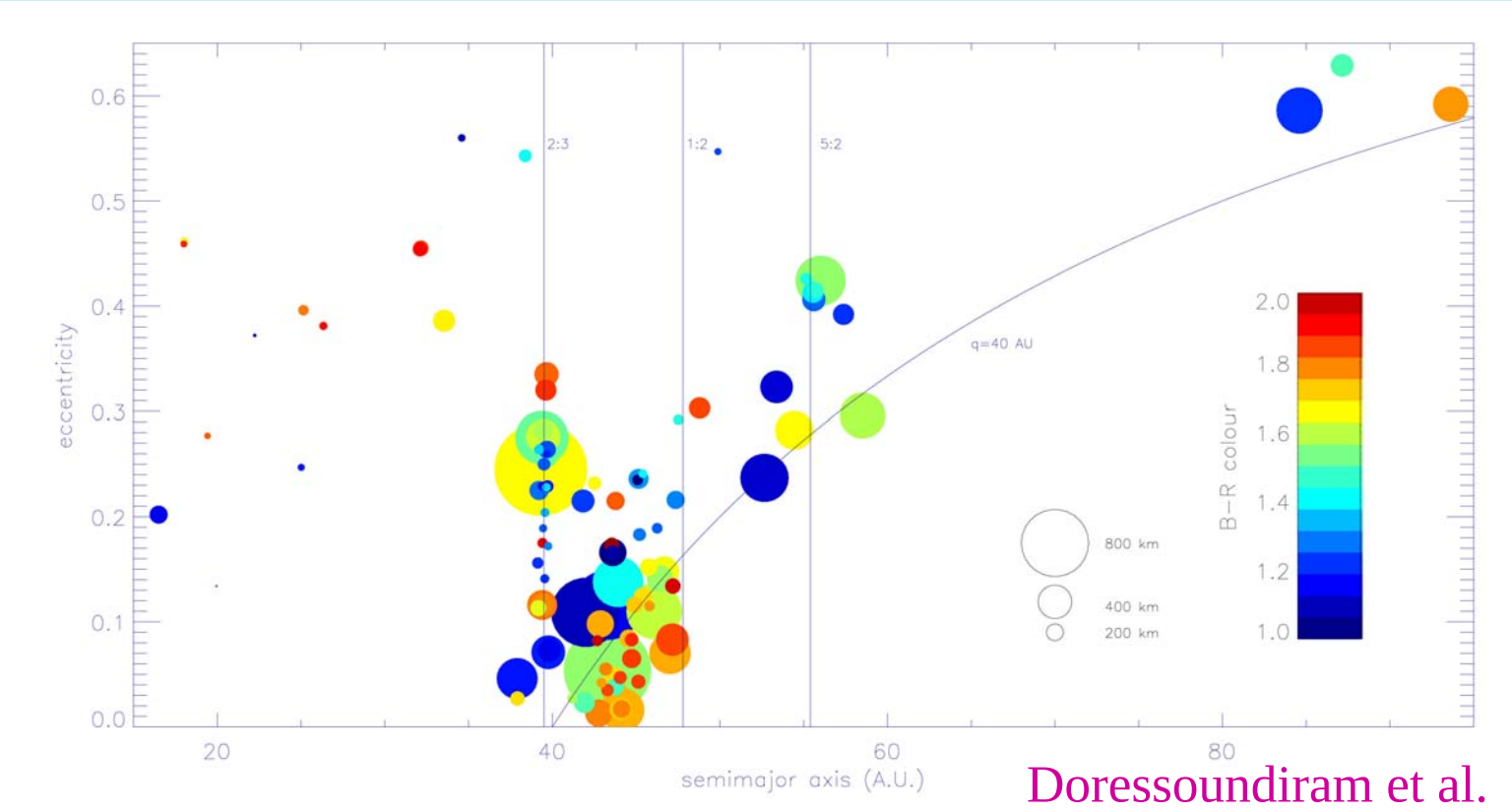
- Albedo measurements, critical for
  - size estimates,
  - interpretation of visible/IR spectra in terms of composition
- complementary to Spitzer, Herschel



Jewitt *et al* 2001



Sensitivity (1σ -1h)=15 μJy



Doressoundiram et al.

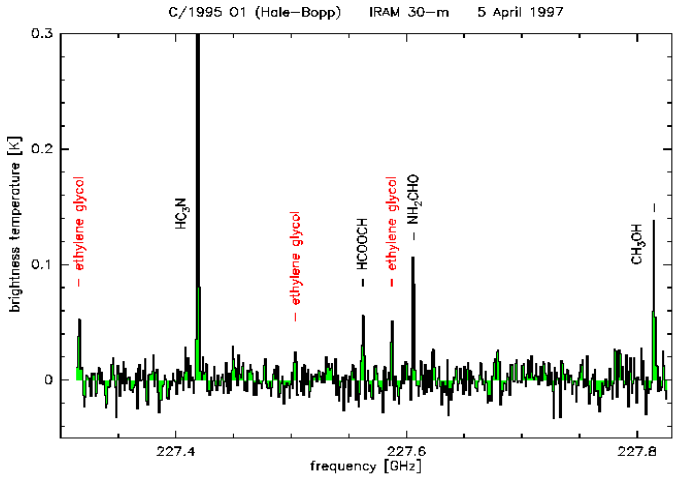
Are there correlations between albedo/color, albedo/TNO families, albedo/size ?

☛ origin, evolution of the TNO population

Other ALMA Science: search for CO gas around TNO

Chemical investigation of Comets

2 dozens of molecules detected
in mm/submm
Analogies with star-forming regions

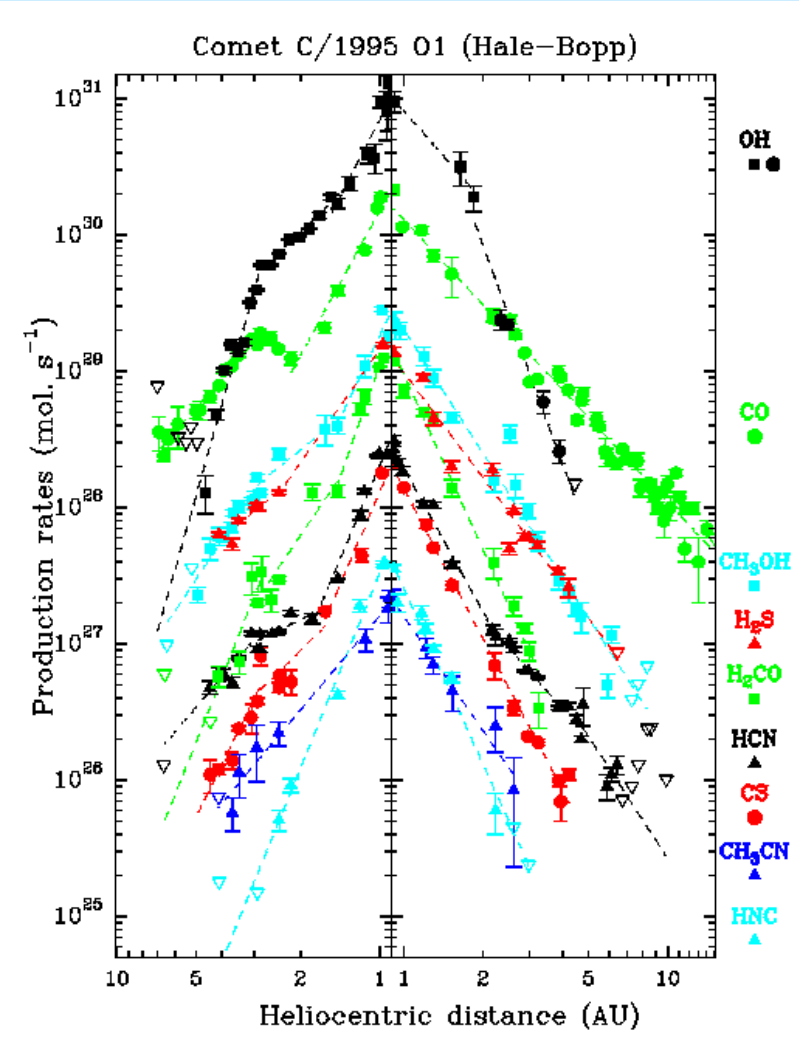


Ethylene glycol in Hale-Bopp Crovisier et al. 2004

ALMA

- Search for new species
- Isotopic ratios: deuterated species, C, N, S isotopes
- Study of chemical diversity among comets
- Radial distribution of molecules in the coma
  origin of molecules: nucleus or organic grains?

Long term monitoring of gas and dust production rates



Biver et al. 2002

Easier with **ALMA**

Sublimation processes inside comet nuclei

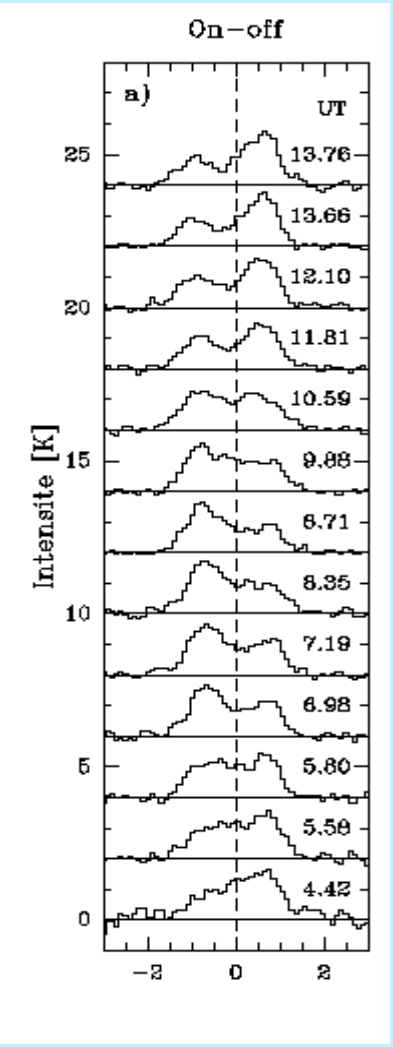
Physical properties of cometary ices

Seasonal effects

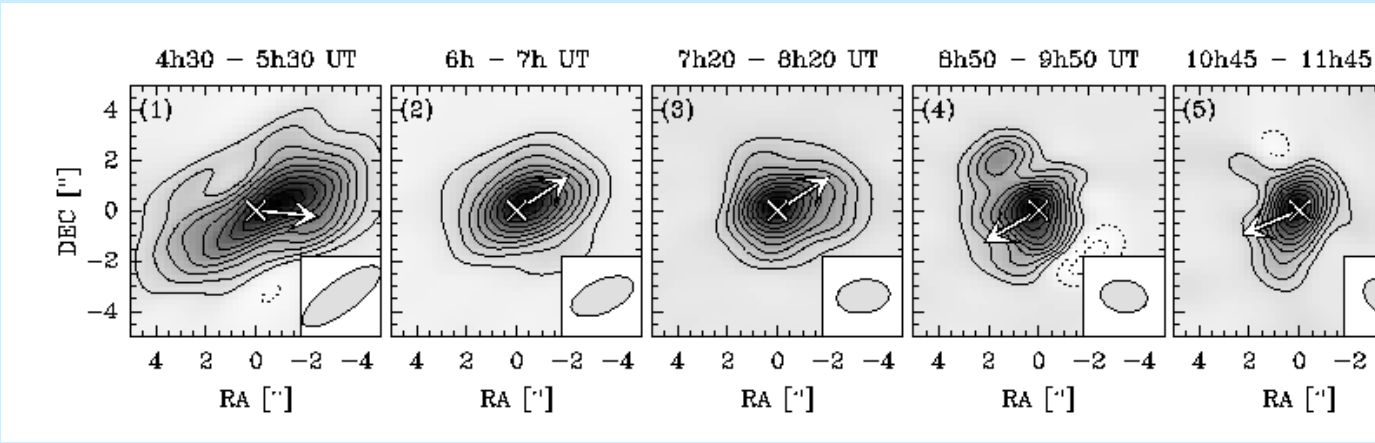
Species origin in the coma

Dust/gas ratio heliocentric evolution

Mapping cometary atmospheres



Henry 2003



CO 230 GHz/Hale-Bopp with IRAM PdB

ALMA

Instantaneous 3-D maps of gaseous and dust (thermal) emissions

☛Coma morphology, spiral gaseous jets, nucleus outgassing, rotation properties, dust/gas links

☛Gas temperature and velocity maps

☛Nucleus thermal emission on long baselines: size, albedo

Specific requirements for planetology with ALMA

☛Position and velocity tracking of Solar System Bodies, including planet moons and comets **IS NEEDED**

☛Make possible autocorrelation (on-off) observations

• More sensitive for composition measurements in comets

• Allow to make observations of newly discovered comets in any ALMA configuration

Early Science with ALMA

- Io volcanic atmosphere
- Mars dynamics
- CO in Pluto and Kuiper Belt Objects
- Comets observed with Herschel
- Targets of cometary missions (Rosetta, Stardust, New Contour)
- Periodic comets making close approaches to Earth (~ 0.1 AU)