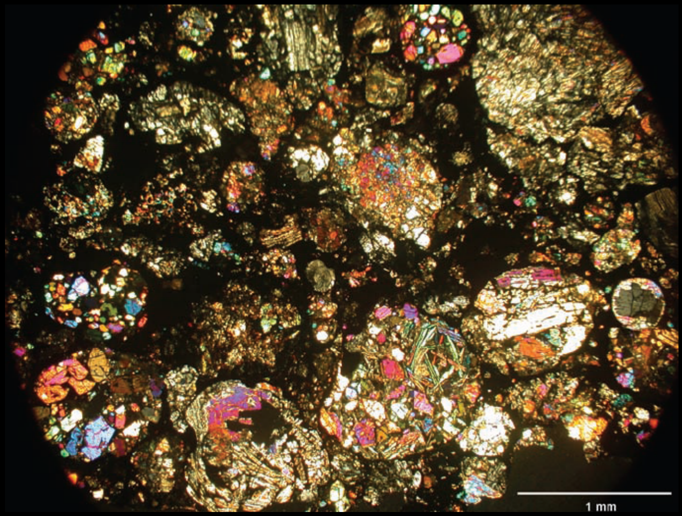
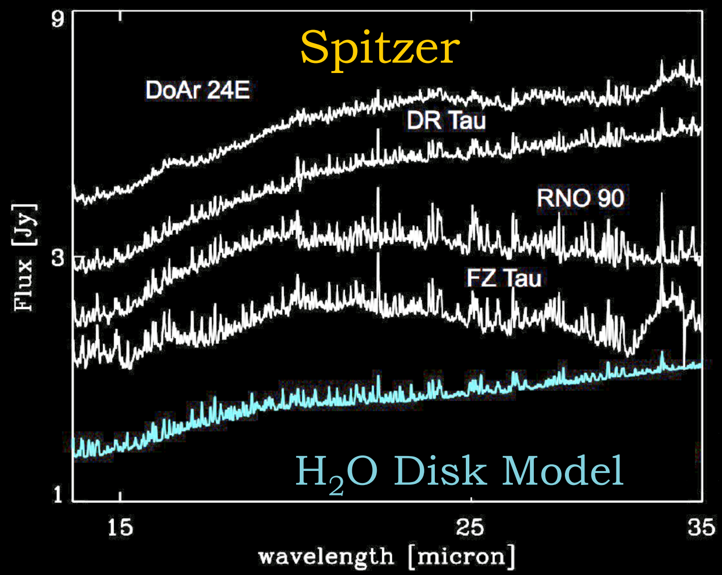
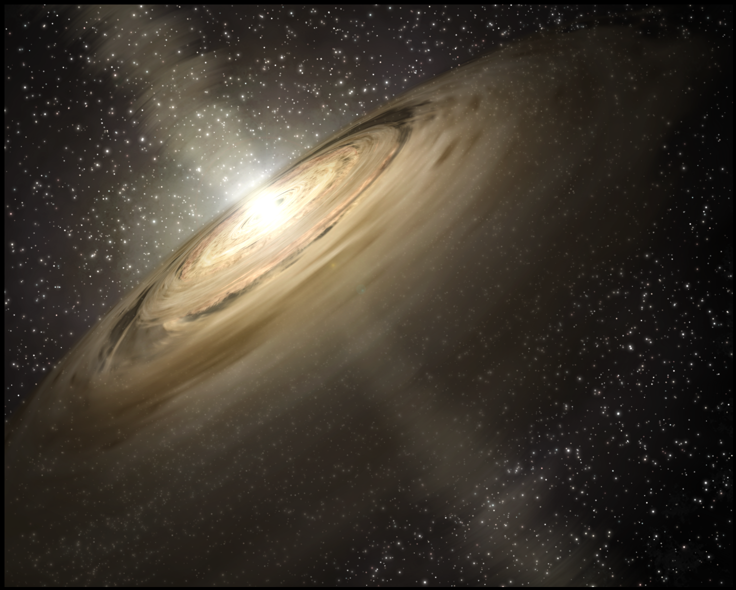
D/H & Volatiles in Primitive Bodies



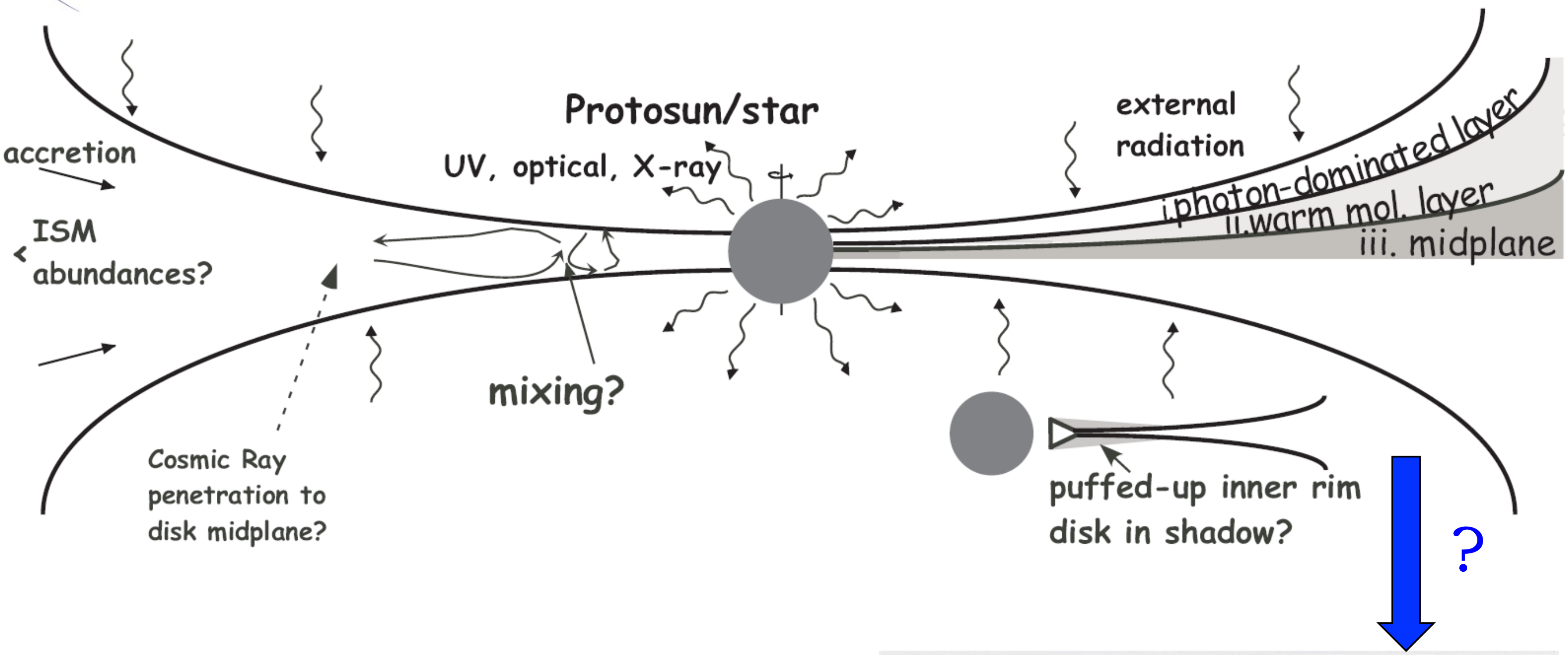


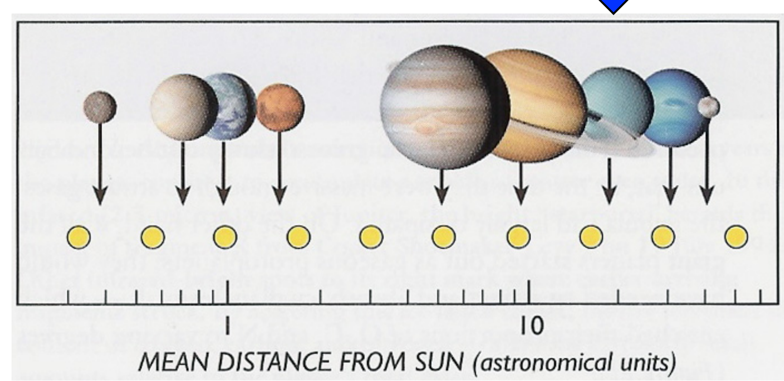


Geoffrey A. Blake, Div. of GPS, Caltech

KISS Workshop, 01 May 2011

A recipe to build a planet: Start with a disk of gas/dust...

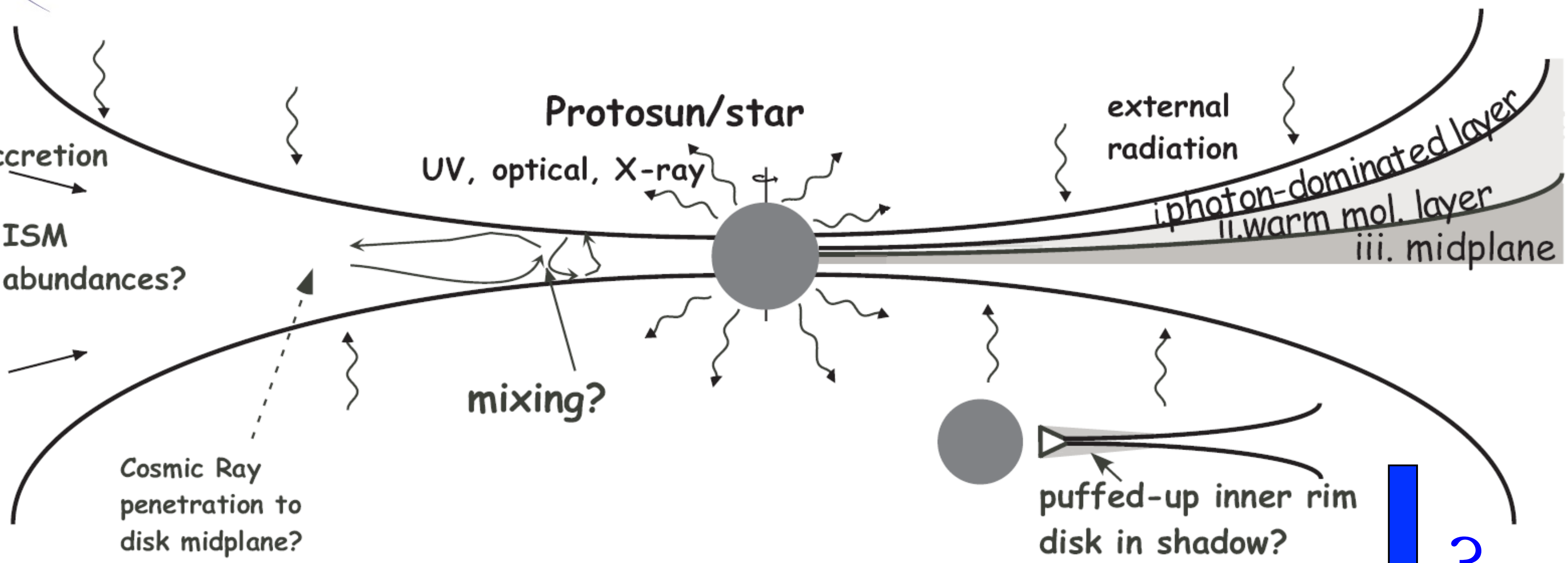




Strong gradients in T, P, and with time also.

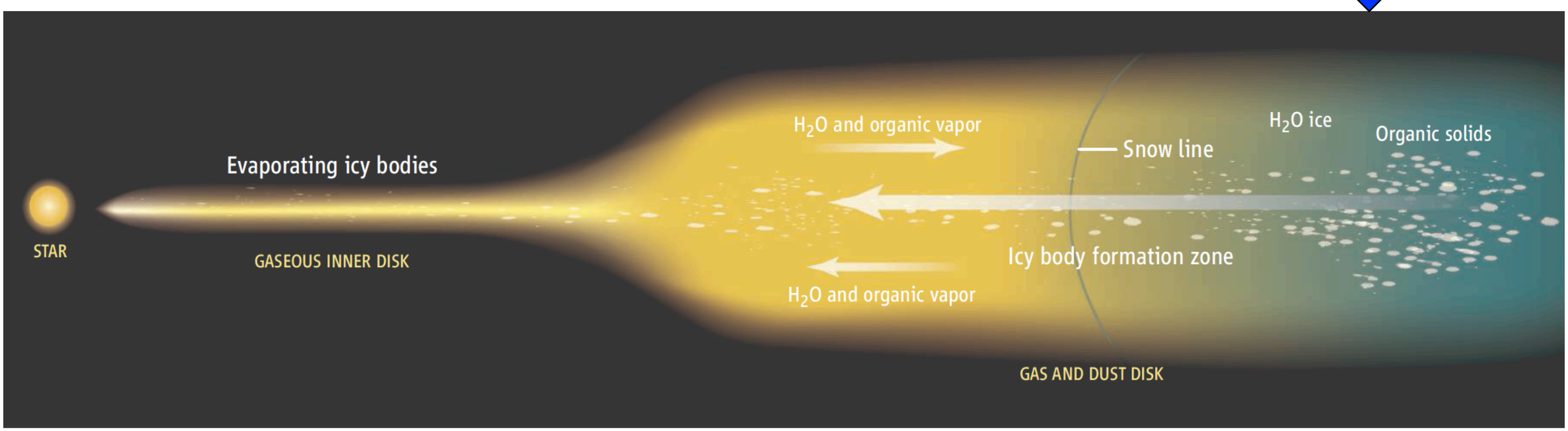
Remember that disk observations largely sense the surface, but the bulk of the (planetary) action is near the mid-plane. Bias?

Might water, a condensable, move?

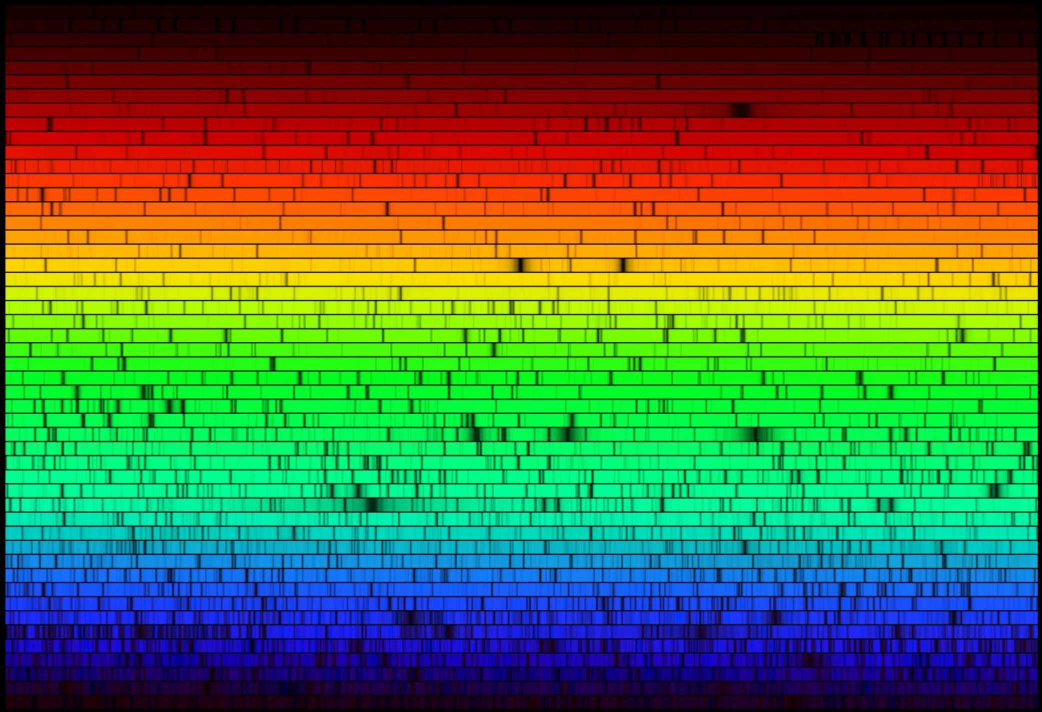


?

The “snow line”:



How do we derive chemistry at a distance?



Photons have come a long way, don't lose them!

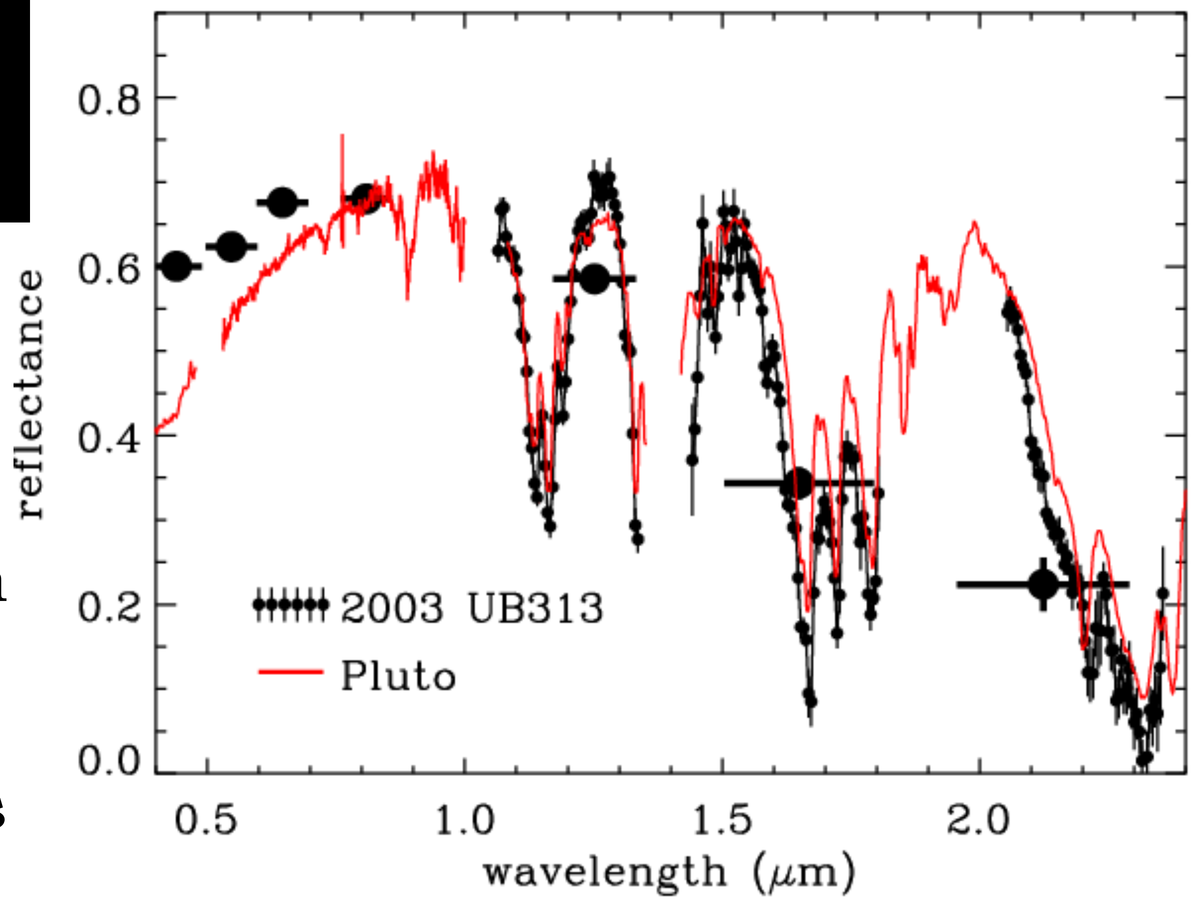
Echelle spectrometers in conjunction with large format CCDs can provide spectra across the entire visible or near-IR range.

One application uses such instruments to detect the presence of molecular ices on the surfaces of KBOs…

Near-IR spectroscopy of volatile ices in the outer S.S.:

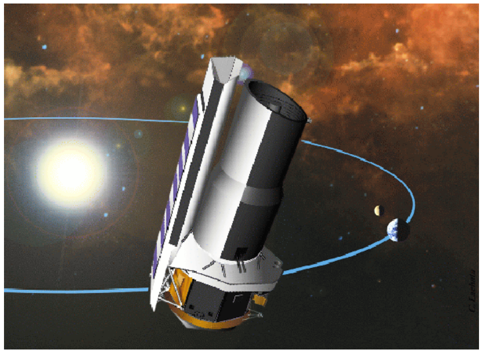
Pluto/Charon (ESO)

For the Kuiper Belt, studying even the largest objects from the ground requires 10m-class telescopes…



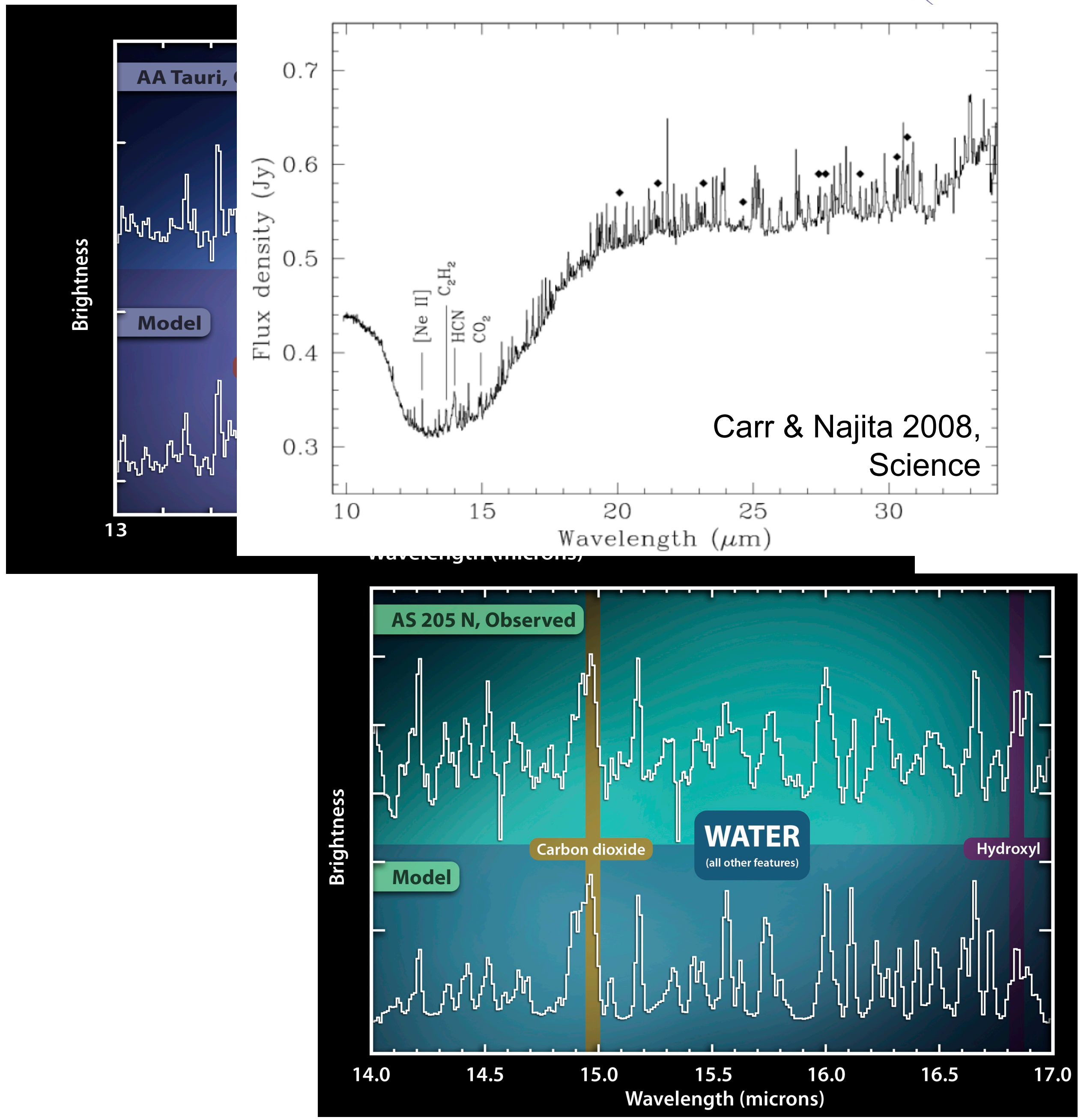
Find interesting trends of *surface* ice composition w/size, location (Schaller & Brown 2007)

Water & organics in disks?



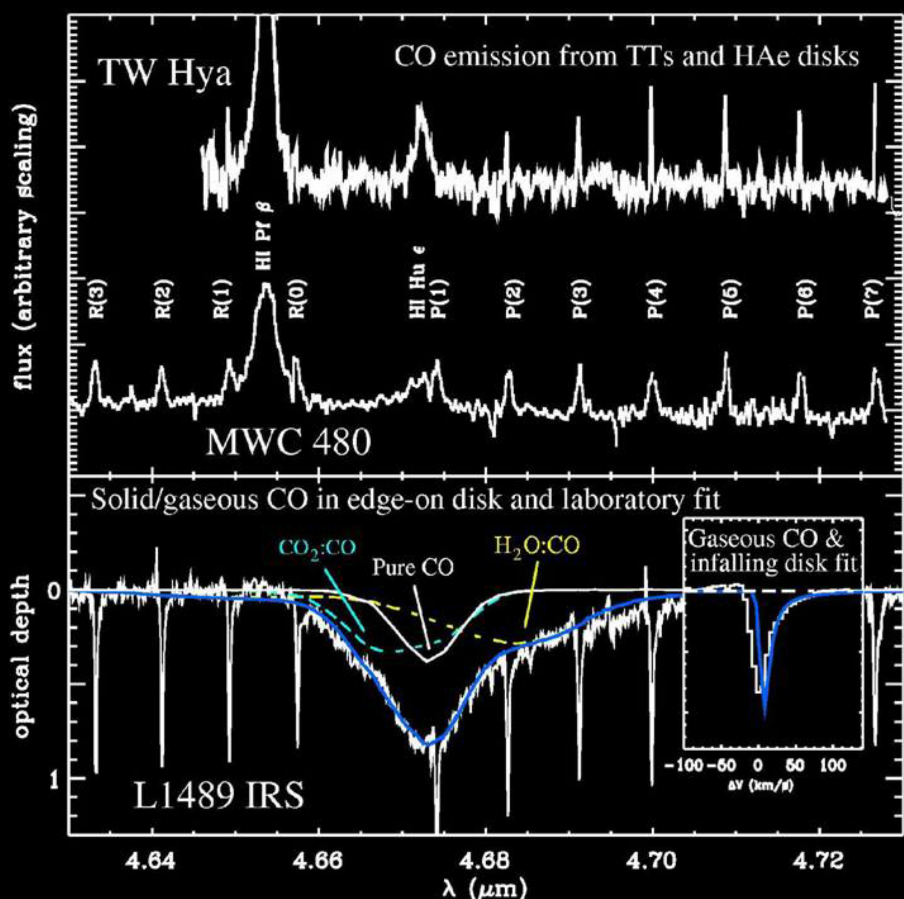
The first extensive studies opened with the beautiful emission lines & bands seen with Spitzer (R=600) toward AA Tau (right, Carr & Najita 2008, *Science* **319**, 1504), and AS 205/DR Tau (Salyk et al. 2008).

Now >100 objects.

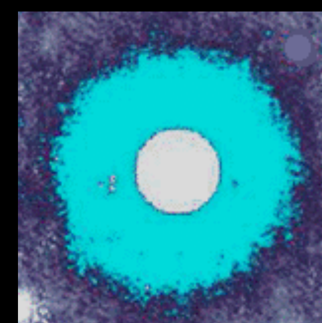


CO: High Resolution IR Spectra & Disks

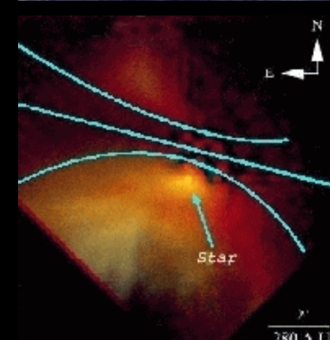
Echelles on 8-10 m telescopes can now Probe "typical" T Tauri/Herbig Ae stars:



CO M-band



TW Hya

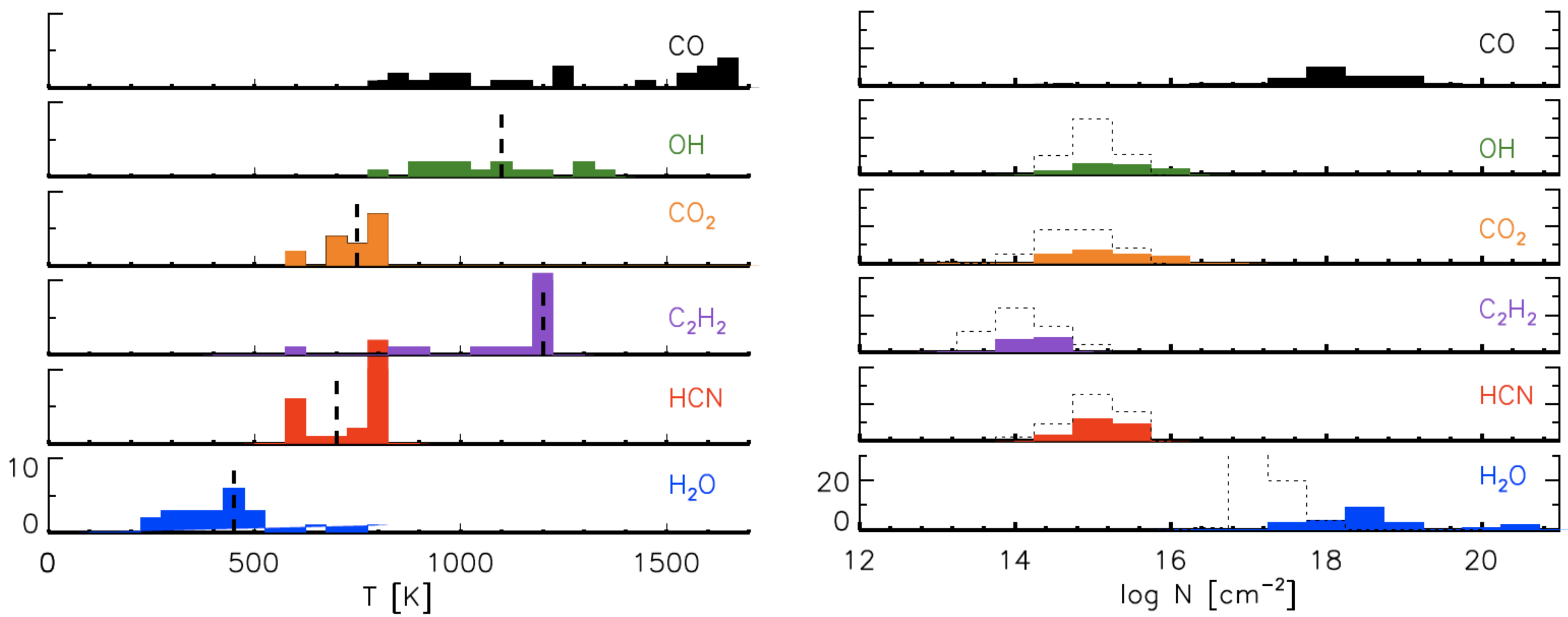


L1489 IRS

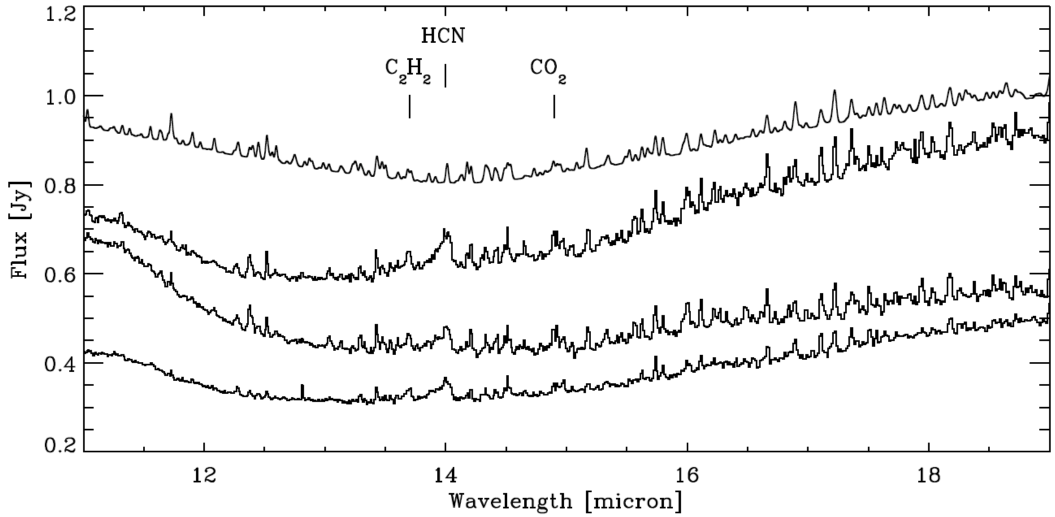
Simple Slab/LTE Models Results:

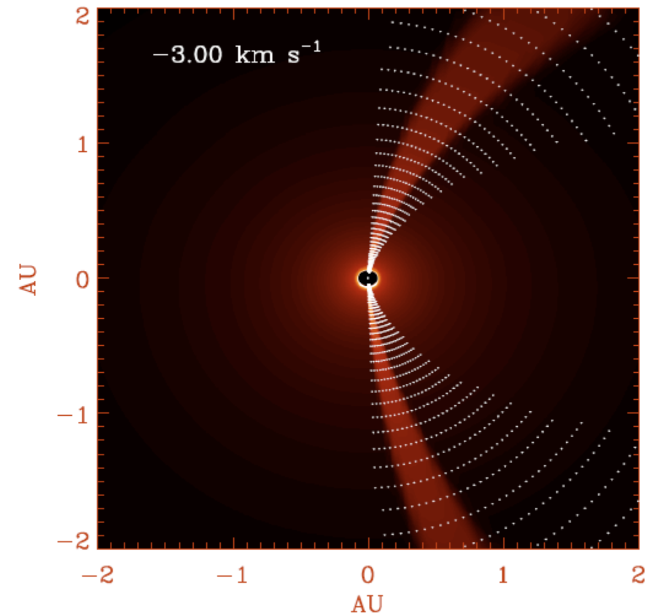
As expected, temperatures are high, and so the lines arise from the inner disk.

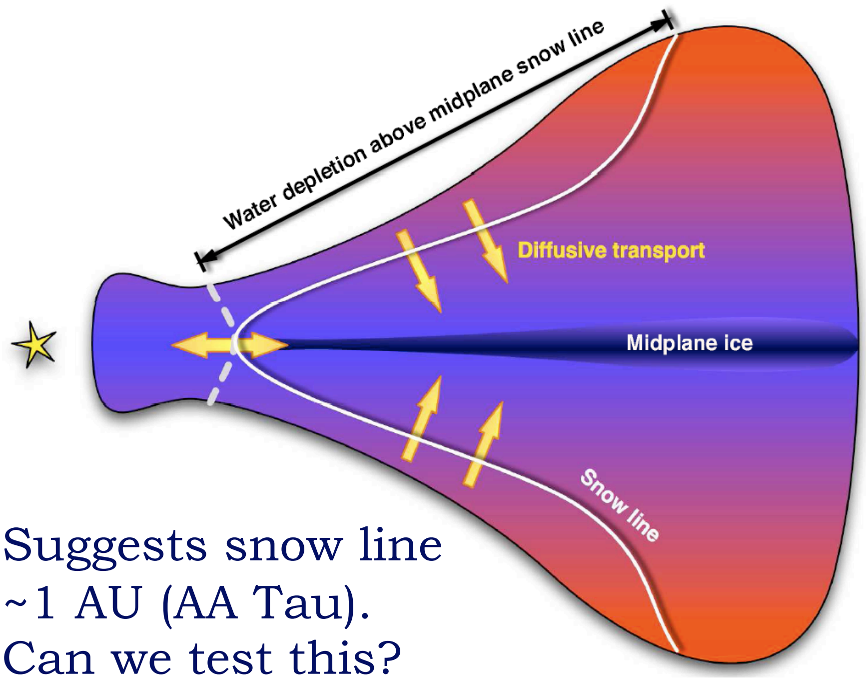
Only a tiny fraction of the cosmically available N is seen.



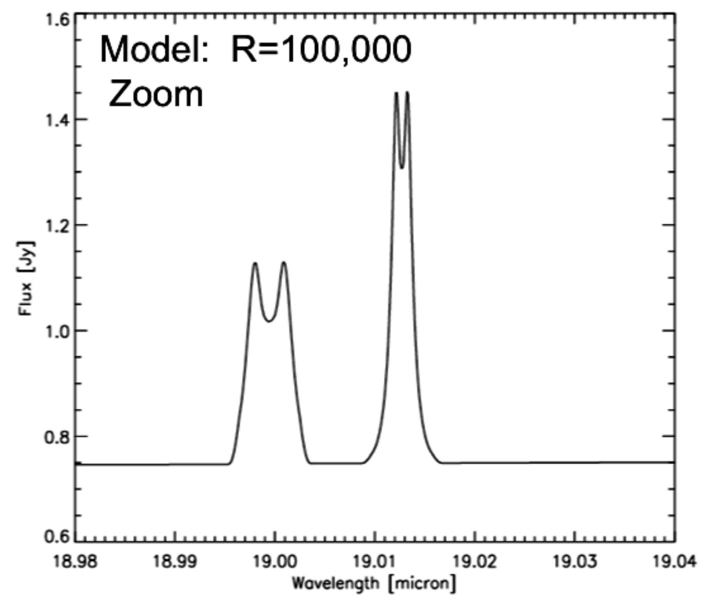
Modeling the water emission:





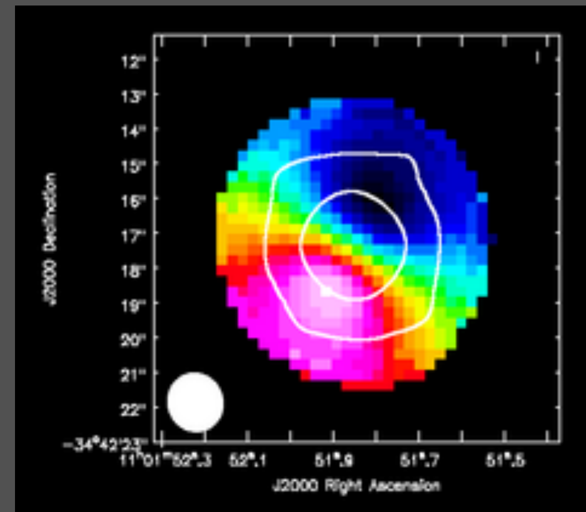


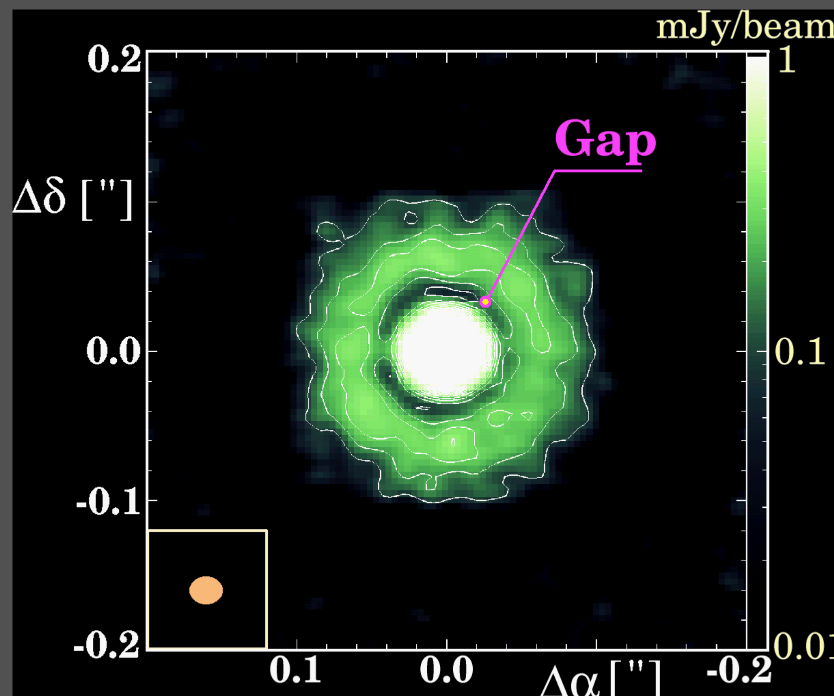
Suggests snow line ~1 AU (AA Tau). Can we test this?



ALMA will help, but…

TW Hya





Wolf et al. 2002, ApJ 566, L97.

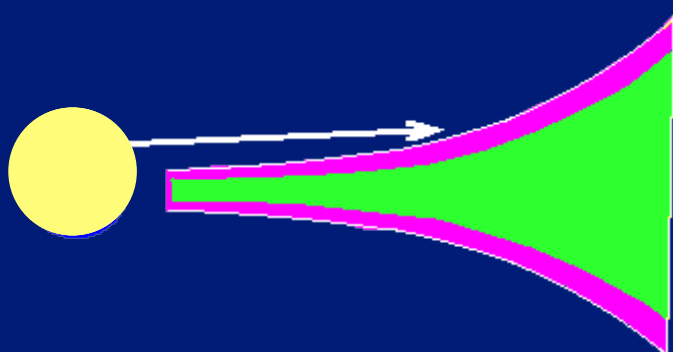
ALMA should detect 1 AU wide gaps in its largest configurations via dust imaging, but for 3 AU pixels at 140 pc,

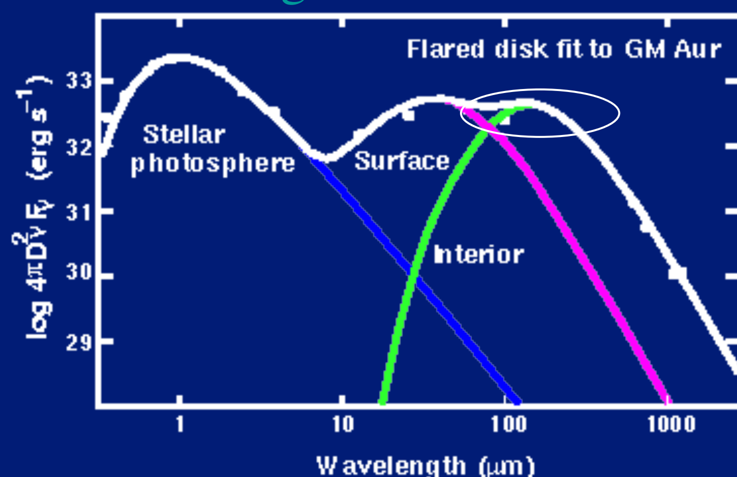
1 km/s in CO 3-2 = 100 K rms in 8 hr

Very difficult to see lines, does the grain emissivity change across the snow line? (Cold) Water will be nearly impossible, other polar species (HCN, HCO^+) OK.

Tests? Water/Ice/Organics at large(r) R?

Tera incognita. Launched 14May2009.

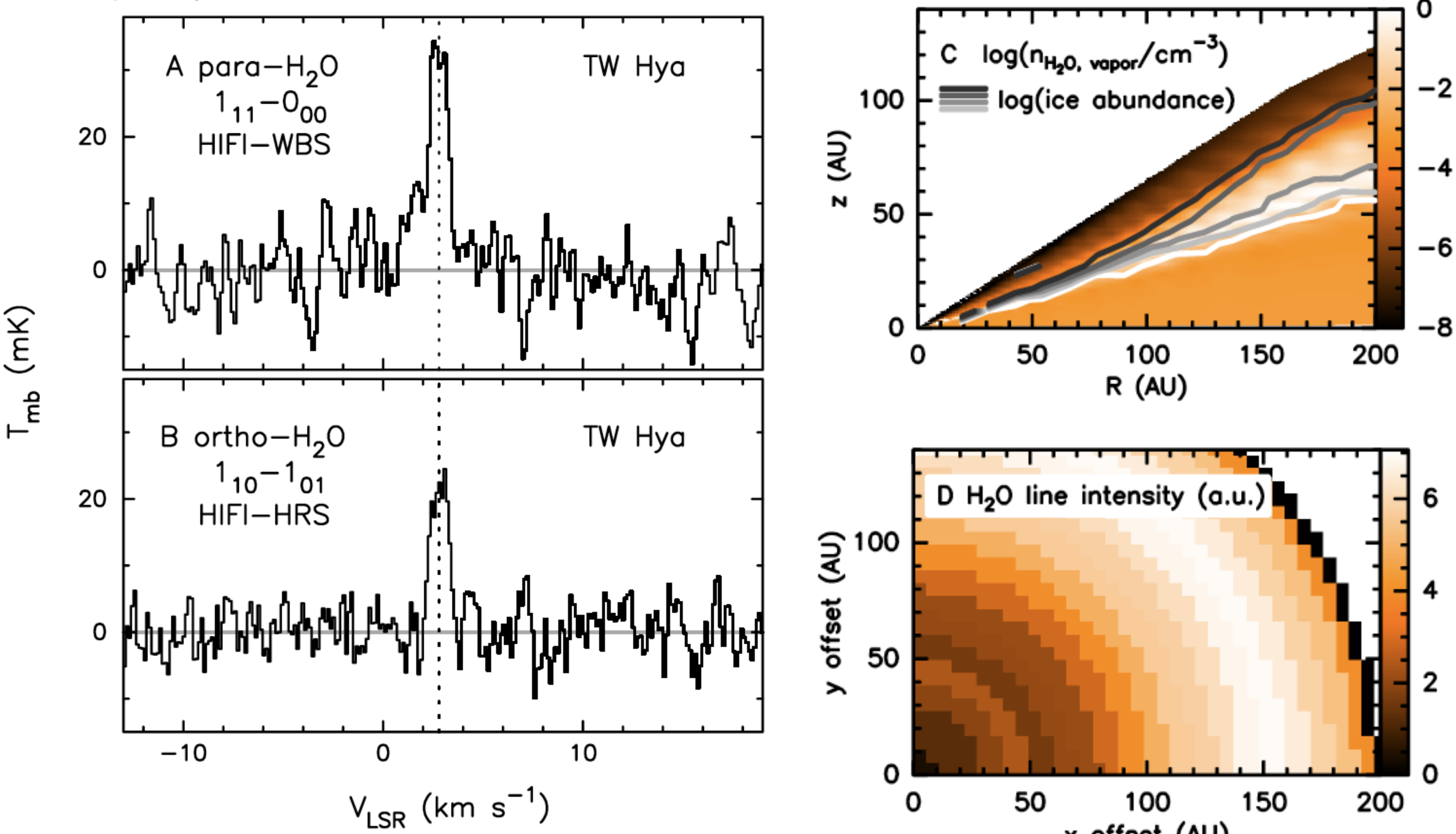




THz → Extremely strong transitions of hydrides, incl H_2O.

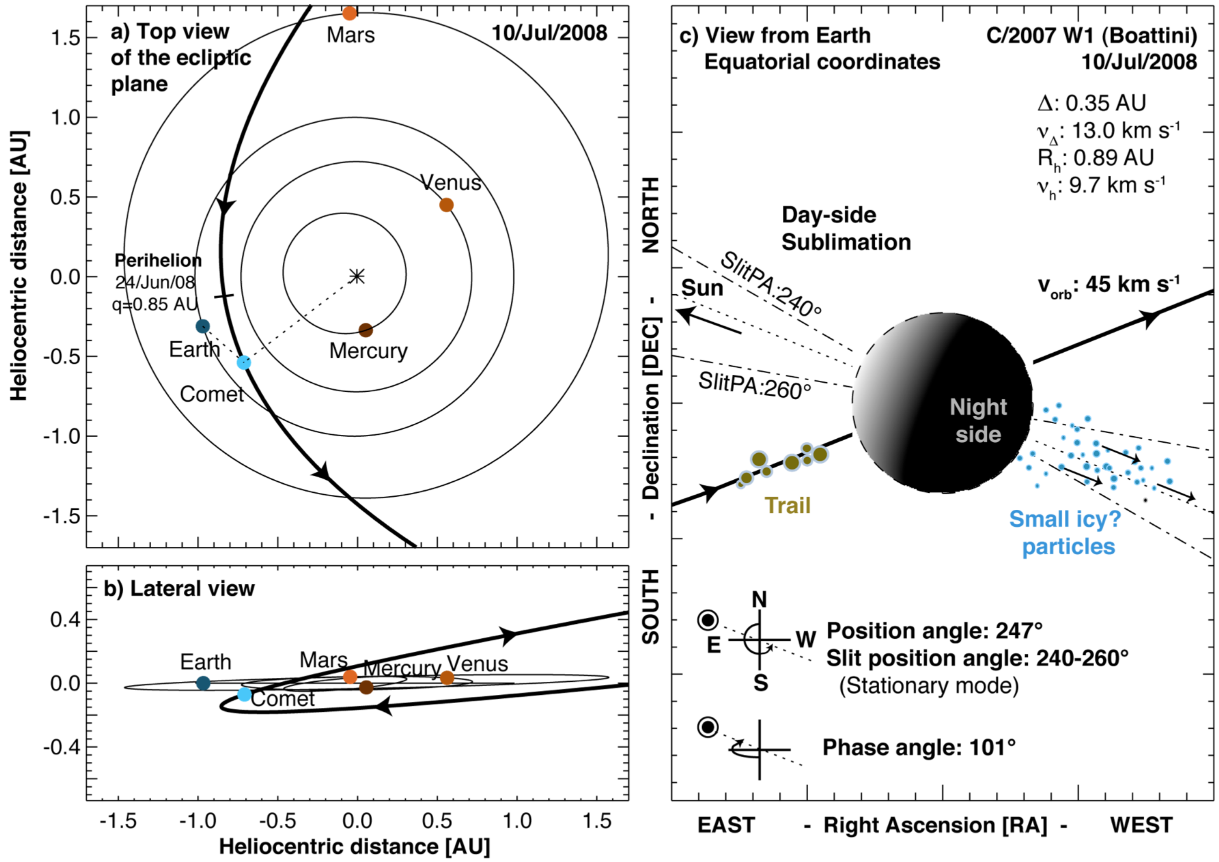
Herschel HIFI has detected water in one disk, arises from region of photo-desorption:

Hogerheijde et al. 2011, *Science*.



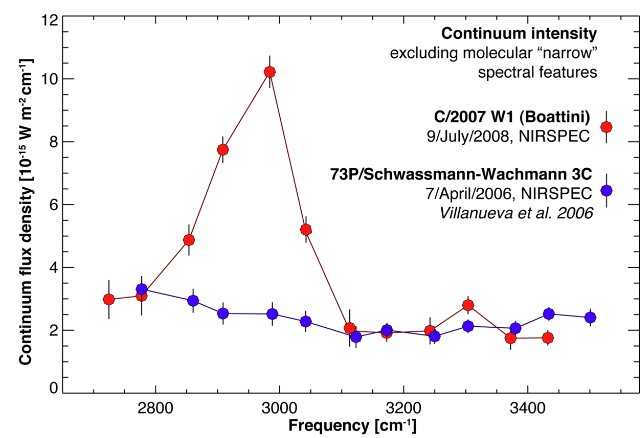
Access to volatiles at large distances?

Bring samples in? Comets in the IR.



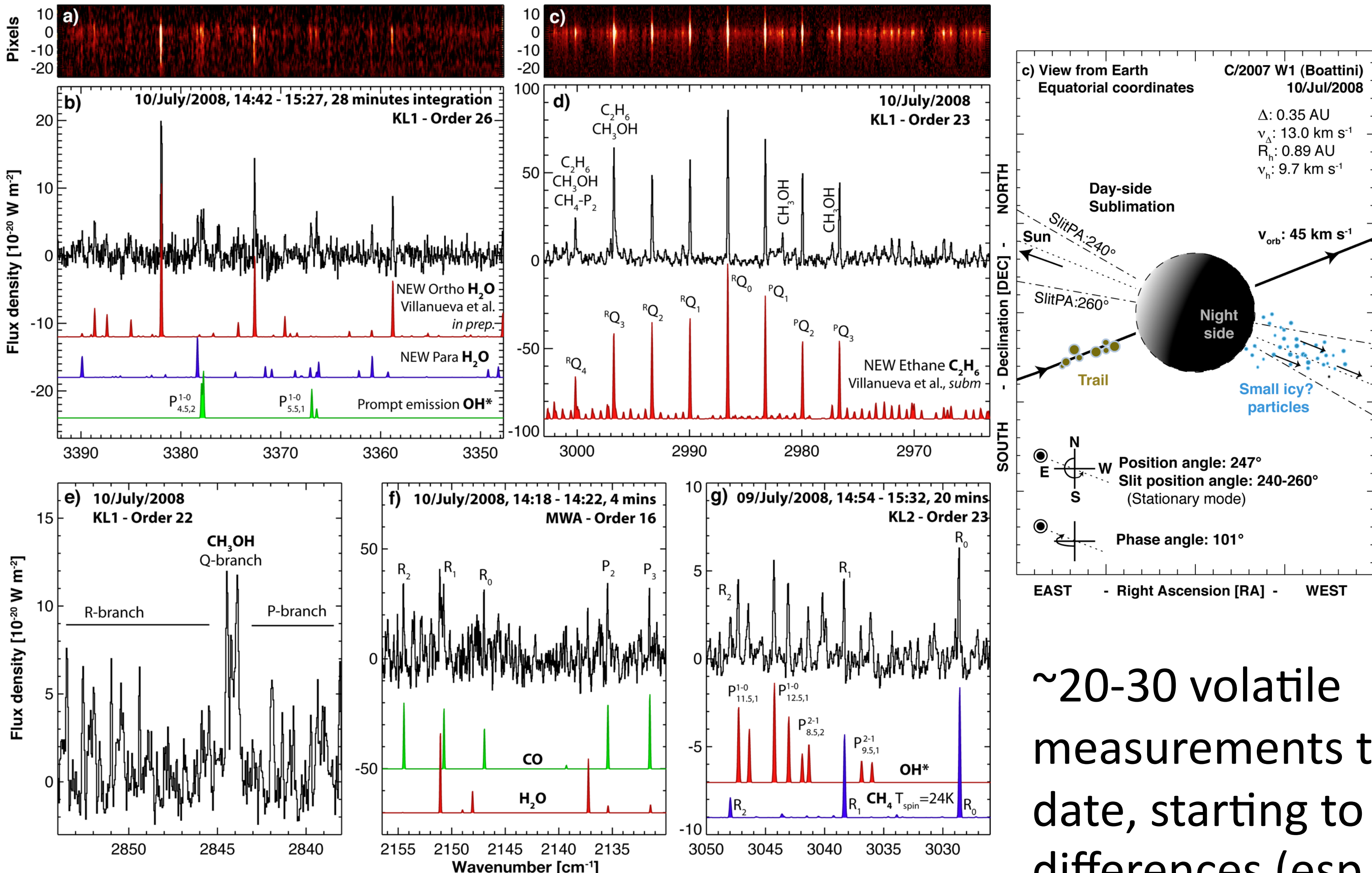
Viewing geometry dictated by orbit, use high dispersion for gas, low/moderate resolution for dust.

Organic/icy dust (3.3 µm)



Comet Boattini, Villanueva et al. (2011)

Bring samples in? Comets in the IR.



Comet Boattini, Villanueva et al. (2011)

~20-30 volatile measurements to date, starting to see differences (esp. in "hypervolatiles").

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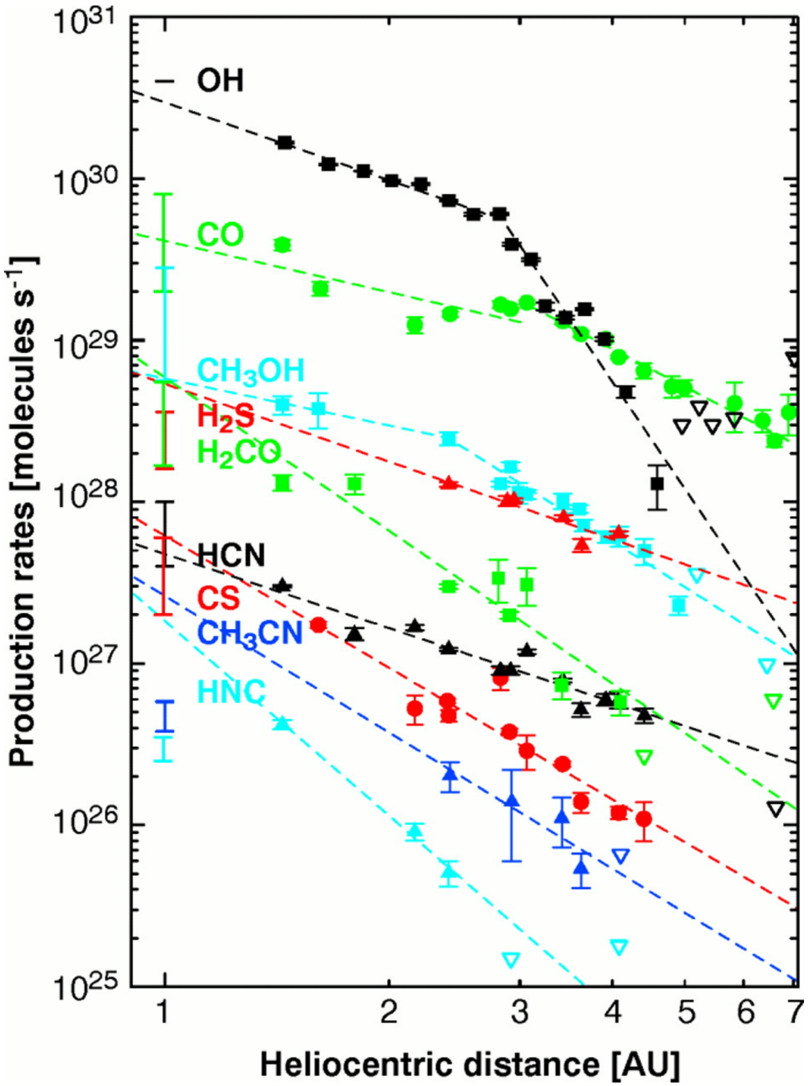
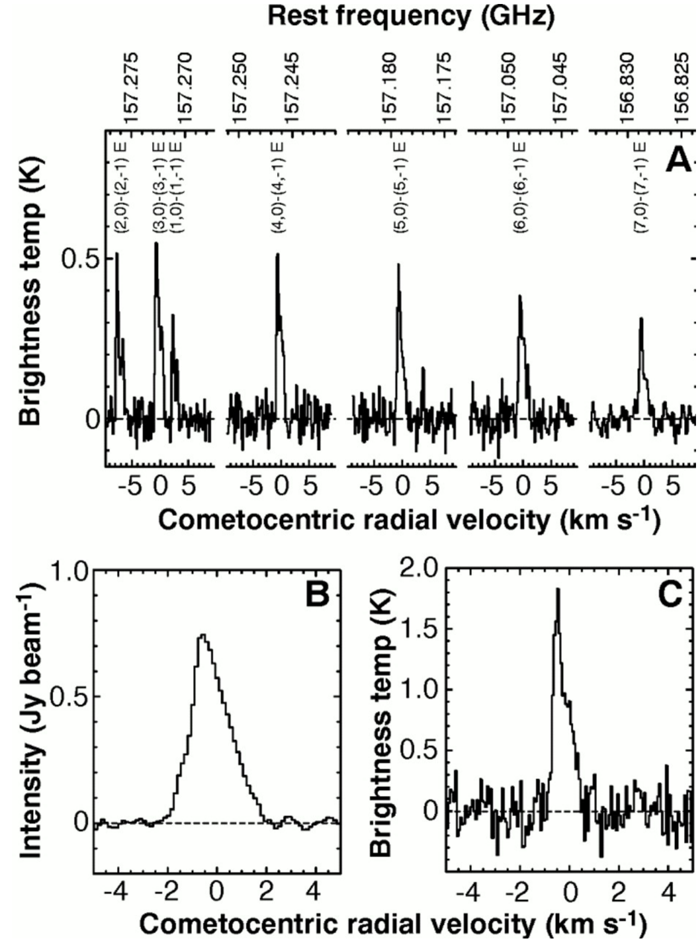
For species with dipole moments, use rotational spectra:



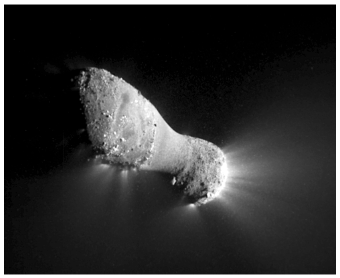
Biver et al.



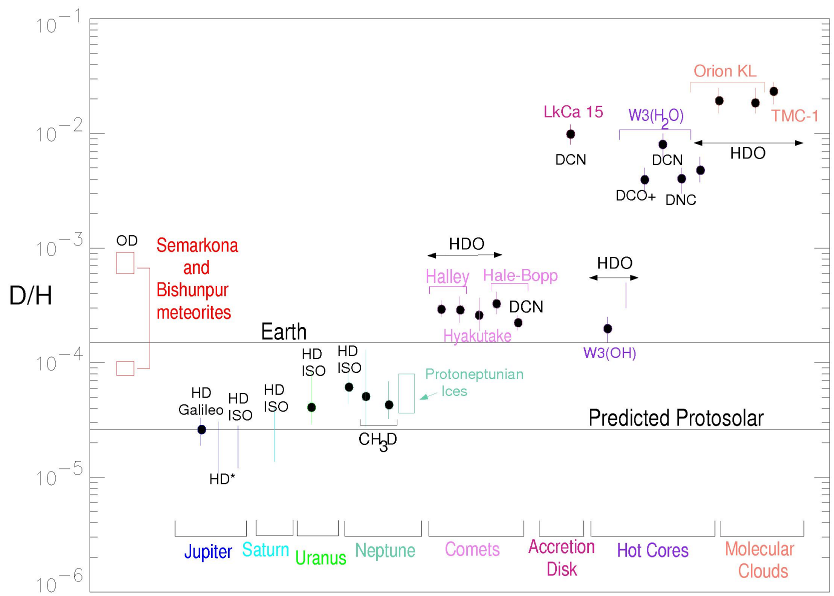
Collisionally excited, can see to large distances (Centaurs?).

No noble gases (nor for IR) .

Isotopic data & volatiles?



Produces enhanced D/H in water formed and stored at low temperature!

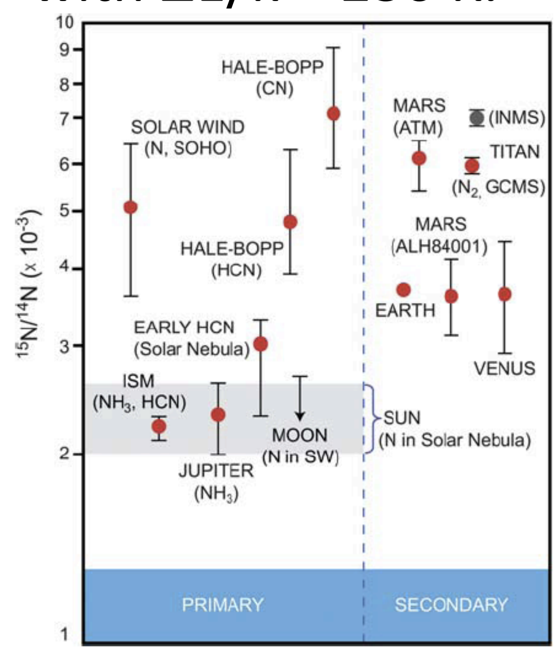


Works for many species because H_3^+ is a good proton donor, and low/no barrier to reaction…

Thermodynamics measured from vibrational zero point level. Thus,

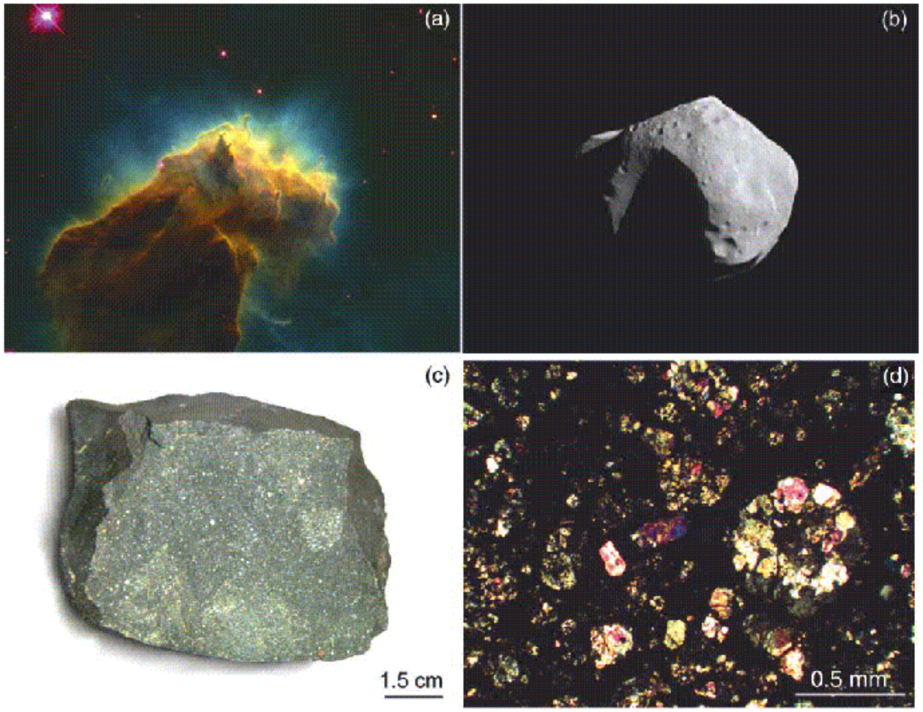
$$HD + H_3^+ \rightleftarrows H_2 + H_2D^+$$

is exothermic to the right, with ΔE/k ~ 230 K.

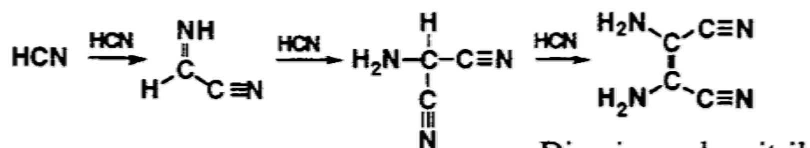


^{15}N

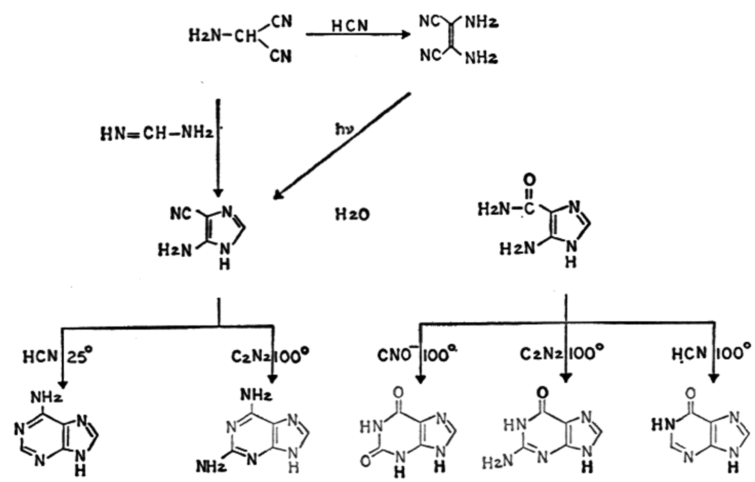
From whence the complex nebular organics?



An amazing variety of organics are found in chondrite matrices, esp. a wide variety of aliphatic and aromatic hydrocarbons, carboxylic acids, amino acids, purines, pyrimidines, and sugars. Synthesis?

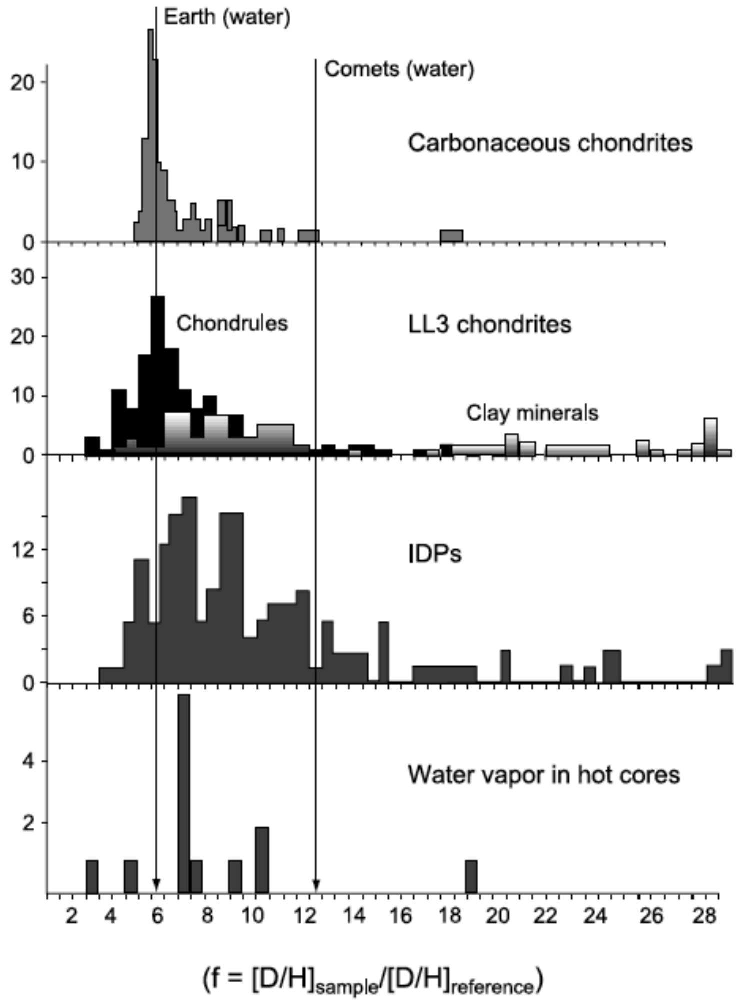


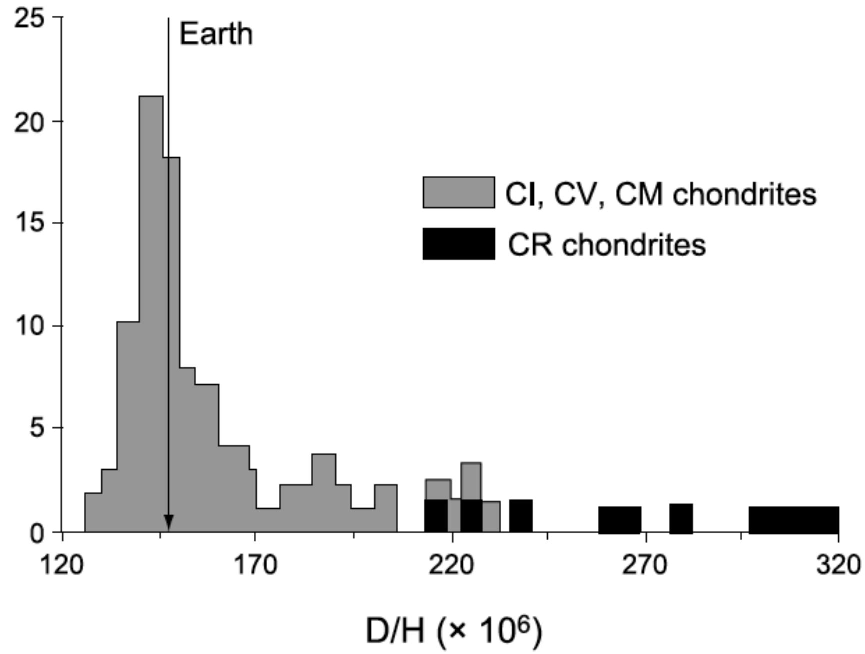
Diaminomaleonitrile (DAMN)



δD values can be large, structural diversity ~complete. Supposedly formed by aqueous alteration of ISM precursors on parent bodies, but organic and silicate aqueous signatures can be contradictory.

D/H in solar system materials:

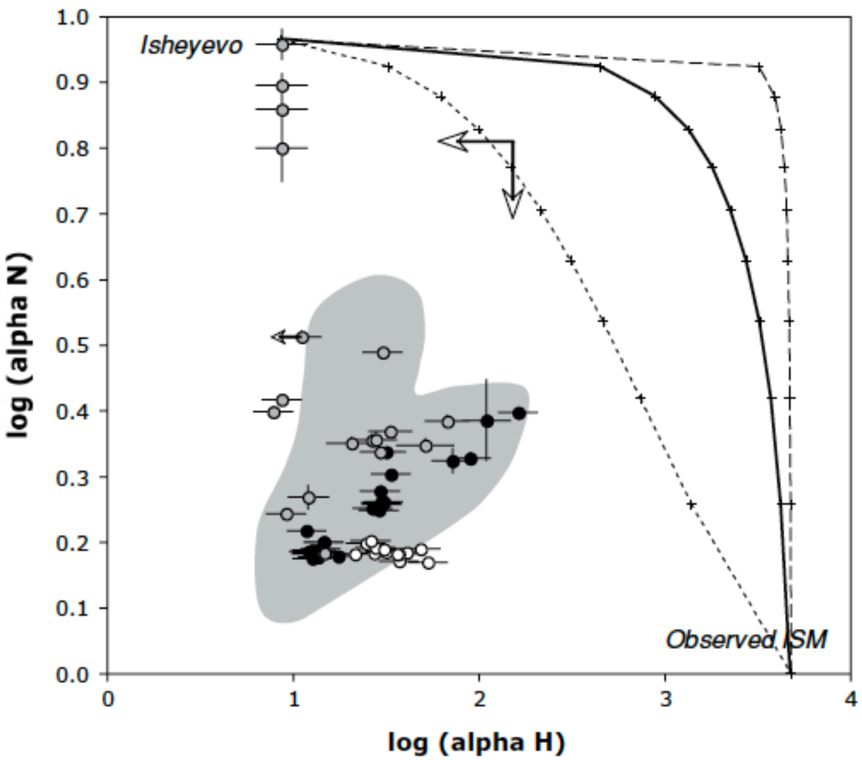




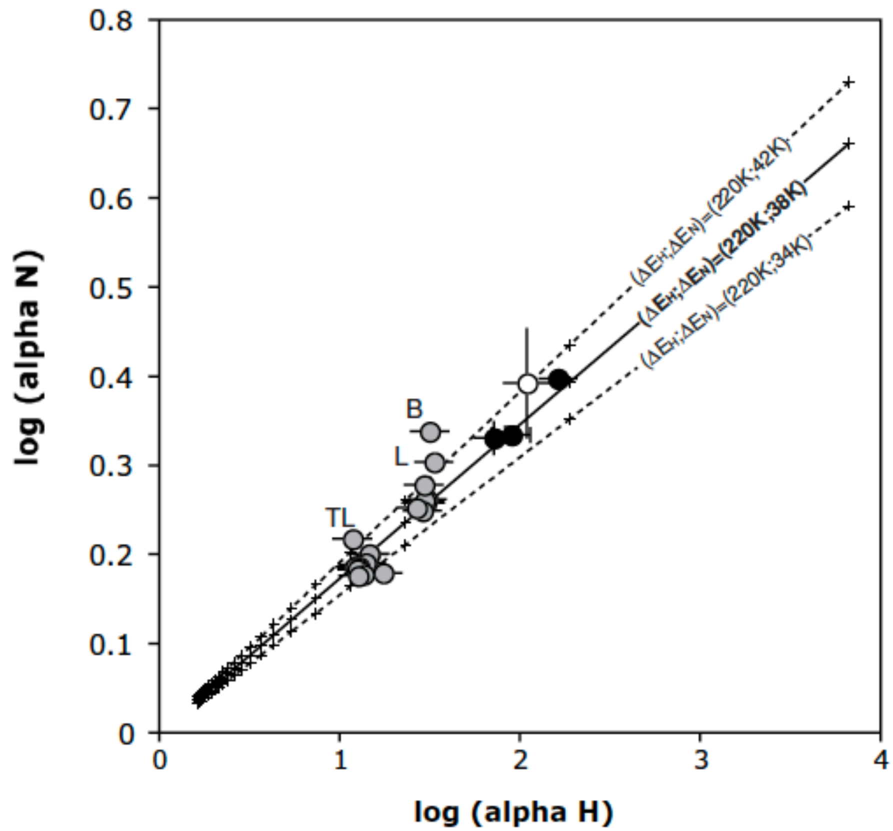
Bulk D/H in chondrites, note the significant distribution…

Robert, *Meteorites & the Early Solar System II.*

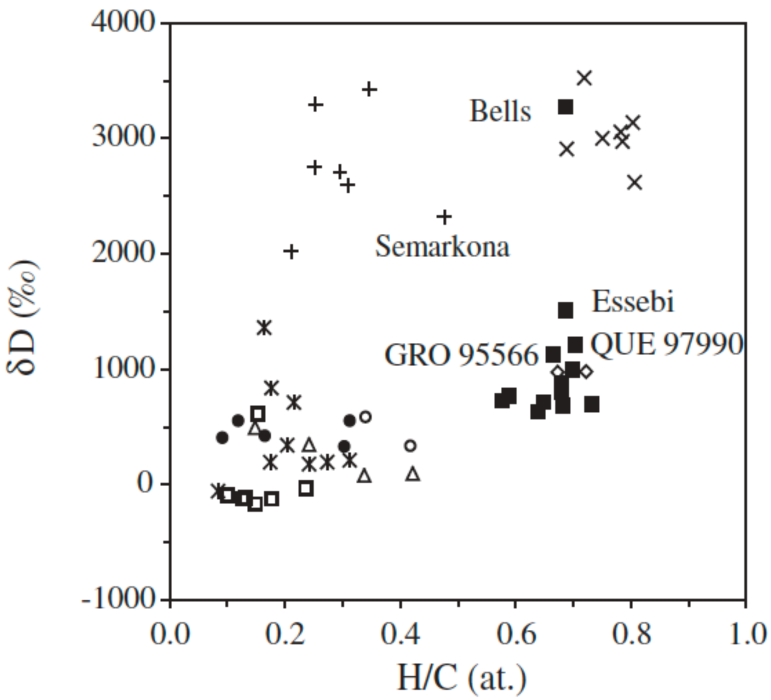
Correlated D/H and $^{15}N/^{14}N$ in meteorites:

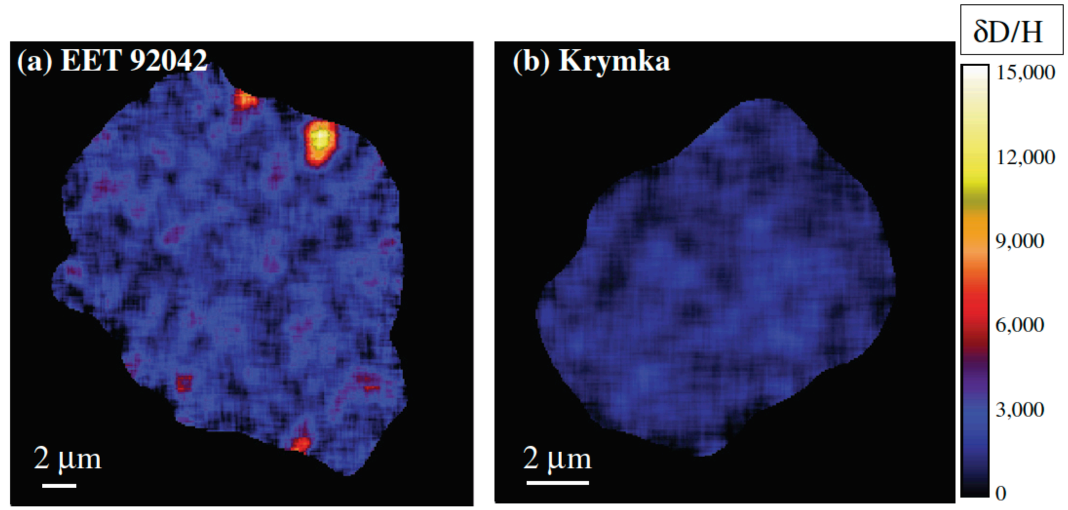


Aléon 2010, *Ap. J.*

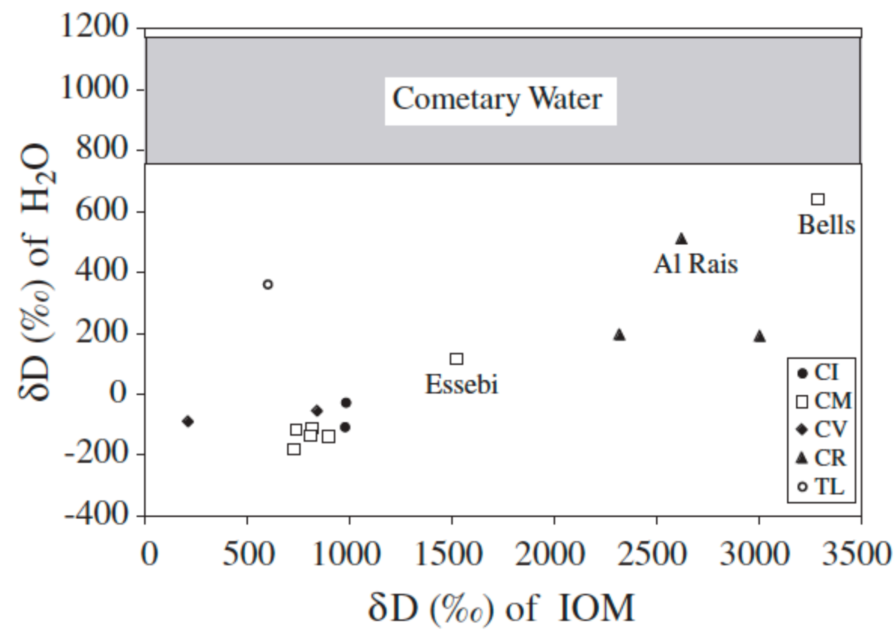


Do we need to carry out microscopic measurements *in situ*?



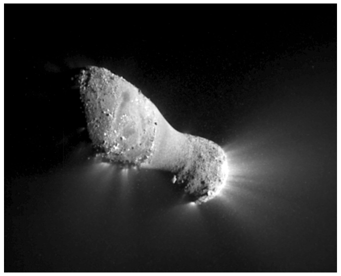


Alexander et al. 2010, *G.C.A.*

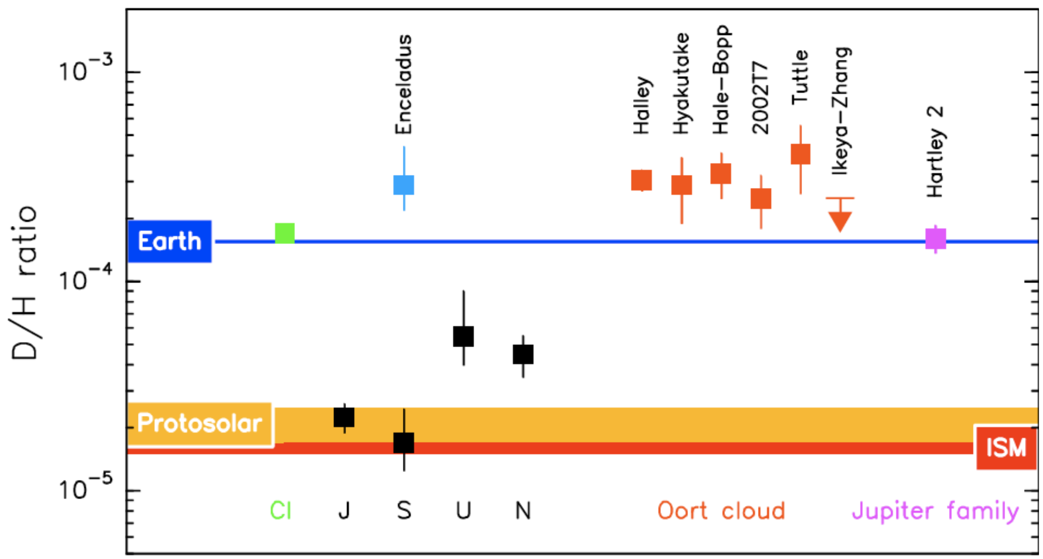


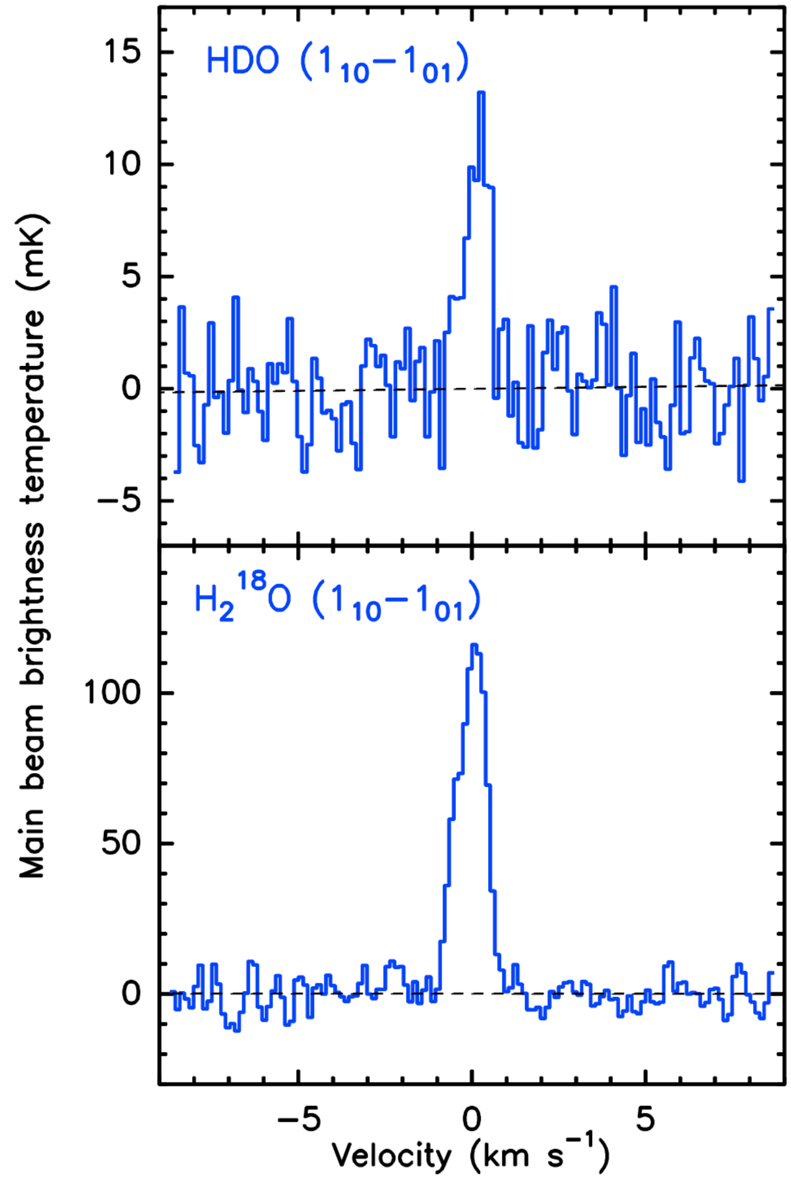
Similar bulk D/H compositions, but very different spatial distributions…

Hartley 2 w/Herschel



Use optically thin water tracers, takes a few hours per comet...





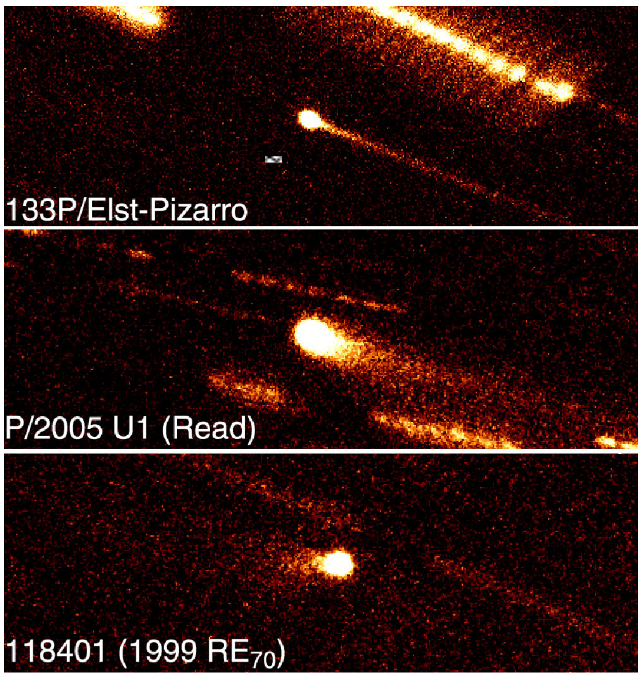
Two additional JFC's in hand with Herschel data, along with Garradd.

Other bodies to look at?

A Population of Comets in the Main Asteroid Belt

Henry H. Hsieh* and David Jewitt

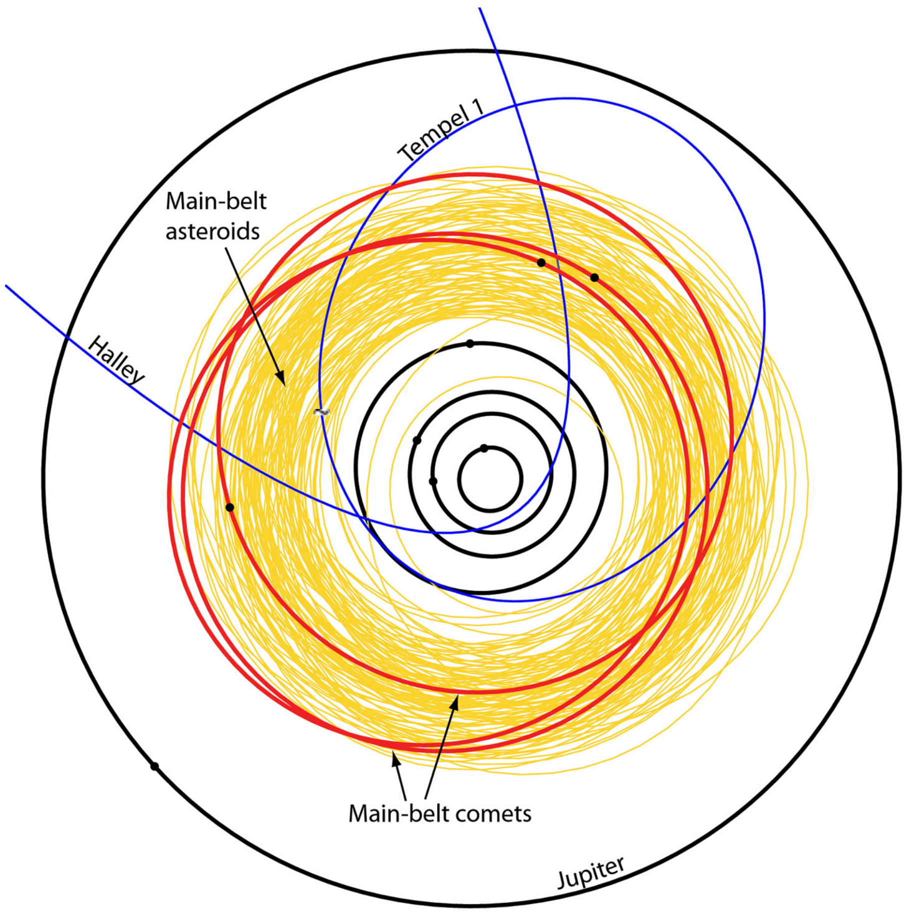
SCIENCE VOL 312 28 APRIL 2006

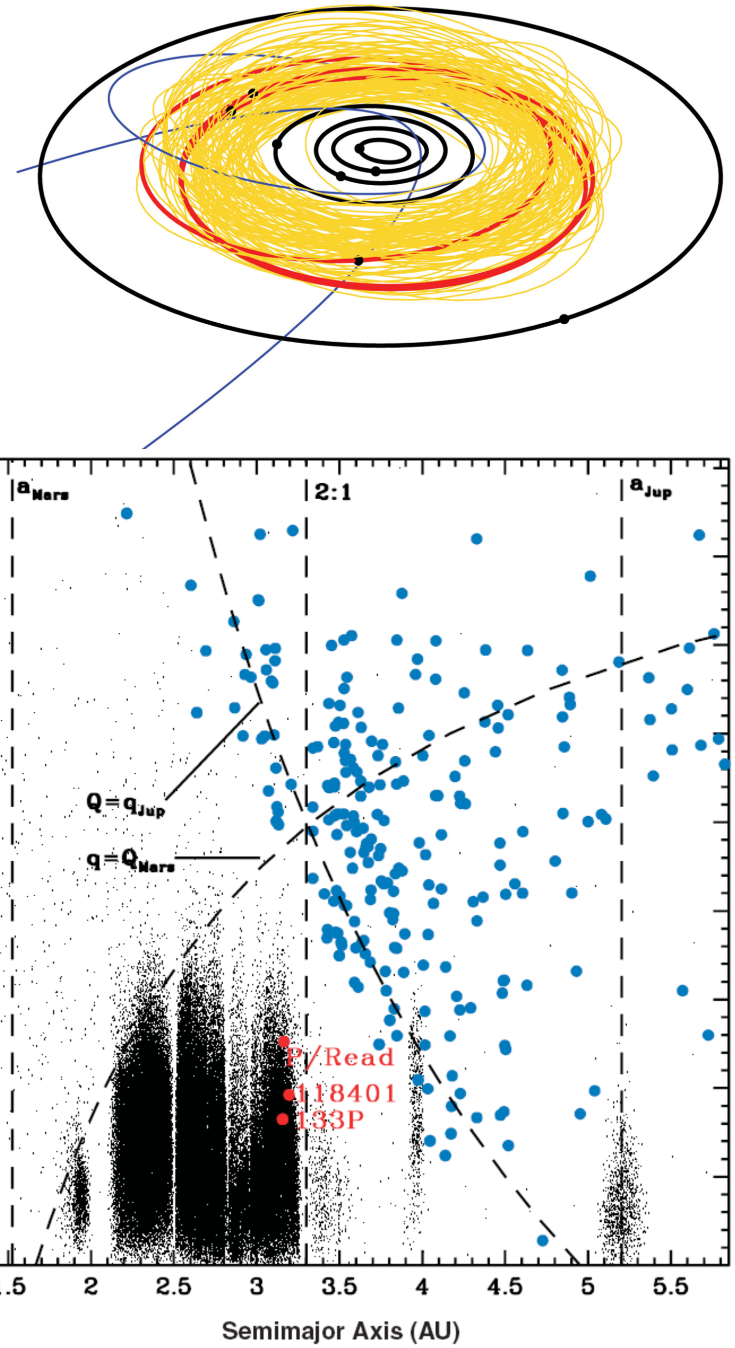


Comets are icy bodies that sublimate and become active when close to the Sun. They are believed to originate in two cold reservoirs beyond the orbit of Neptune: the Kuiper Belt (equilibrium temperatures of ~40 kelvin) and the Oort Cloud (~10 kelvin). We present optical data showing the existence of a population of comets originating in a third reservoir: the main asteroid belt. The main-belt comets are unlike the Kuiper Belt and Oort Cloud comets in that they likely formed where they currently reside and may be collisionally activated. The existence of the main-belt comets lends new support to the idea that main-belt objects could be a major source of terrestrial water.

See also http://www.ifa.hawaii.edu/~hsieh/mbcs.html

A Population of Comets in the Main Asteroid Belt





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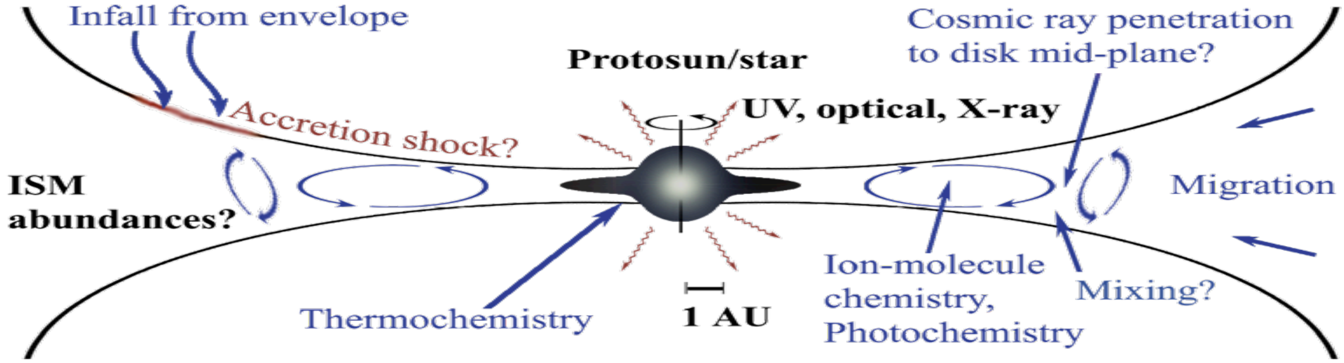
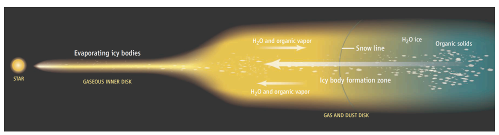
D/H & Volatiles - Questions





- What volatiles are key to measure?
- What isotopic systems are most useful?
- Are there key bodies we have not studied?
- How do we deal with distributions?

- Suppose we could measure volatiles and stable isotope systematics for many bodies across the solar system. What would this tell us about the origin of the solar system?