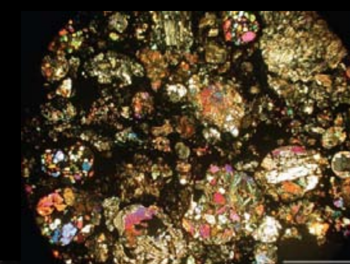
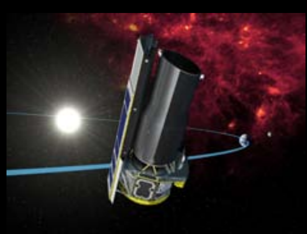
Key Science Opportunities from Airships in Planetary & Small Bodies Science





Spitzer

Keck

Herschel

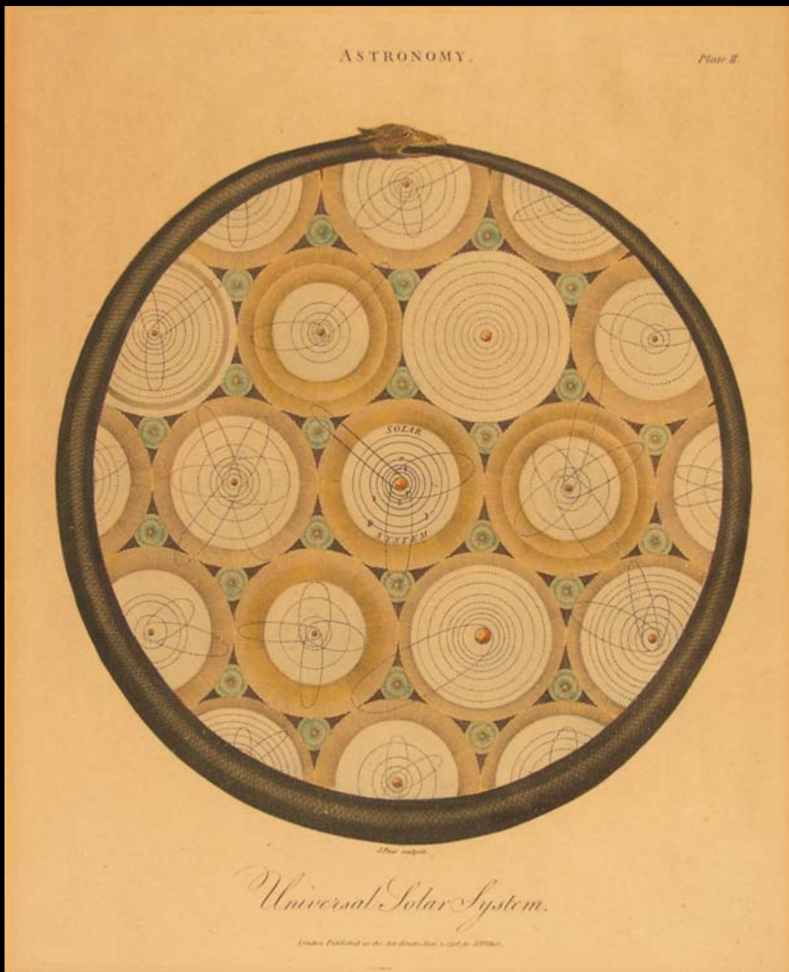
Geoffrey A. Blake, Div. of GPS, Caltech
Airships: A New Horizon for Science,
KISS Worskhop, 30 April 2013

Laplace 1796 – What can the solar system tell us about The formation & evolution of planetary systems?

Key insights:

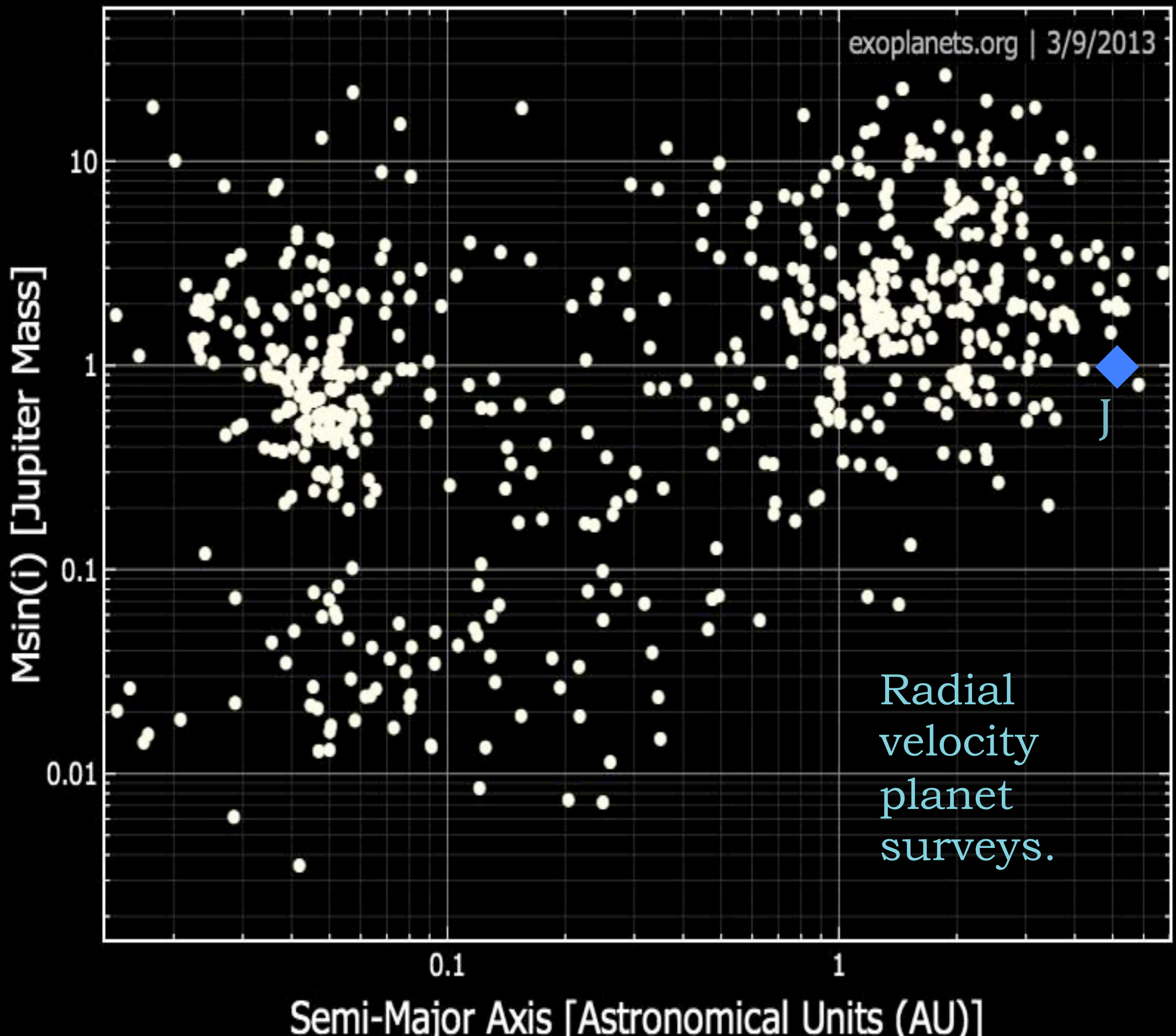
1. Most of the mass is in the sun.
2. The “major planets” all orbit in the same sense.
3. Small bodies, especially comets, are very different (eccentric, not in one plane).

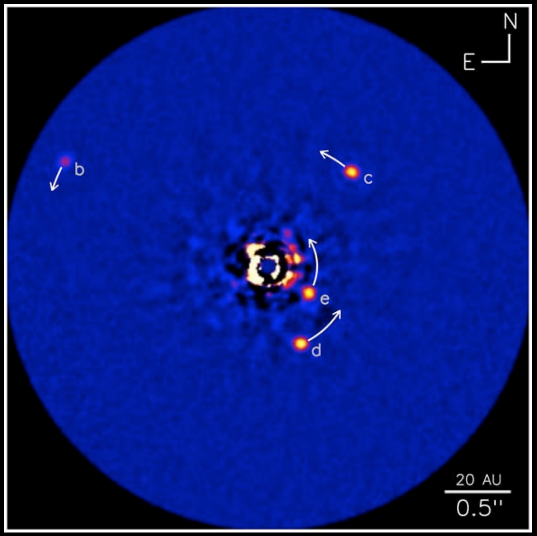
We have dreamed of extrasolar planets for a long time, ...



English engraving 1798
(and Physics Today 4/2004).

Now can detect them!

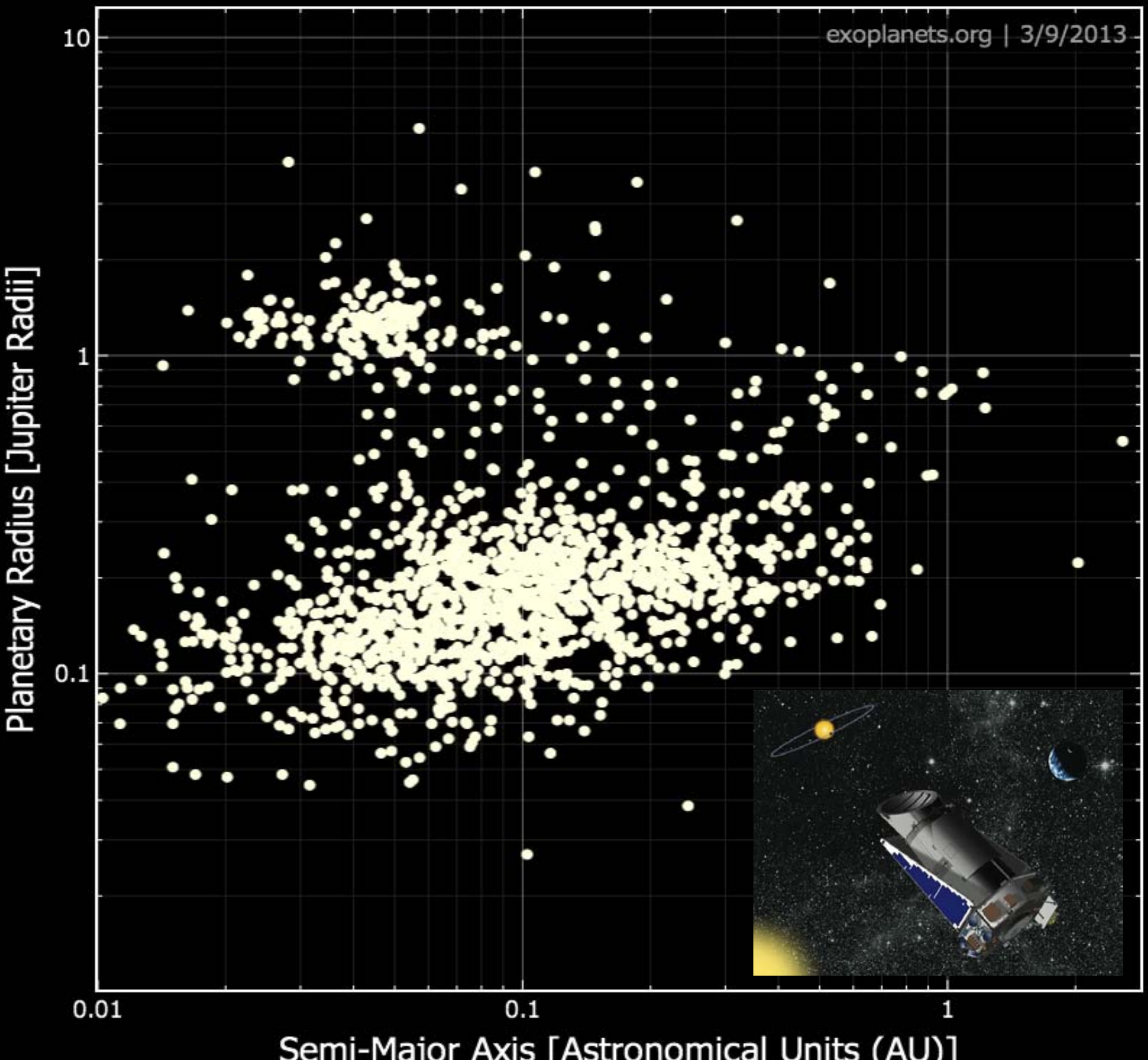


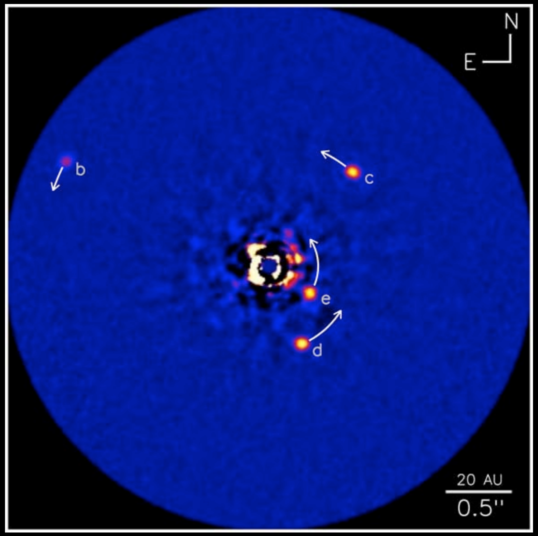


C. Marois (2010)

Jupiter mass planets from <0.05 to >50 astronomical units!

Now we can detect them!

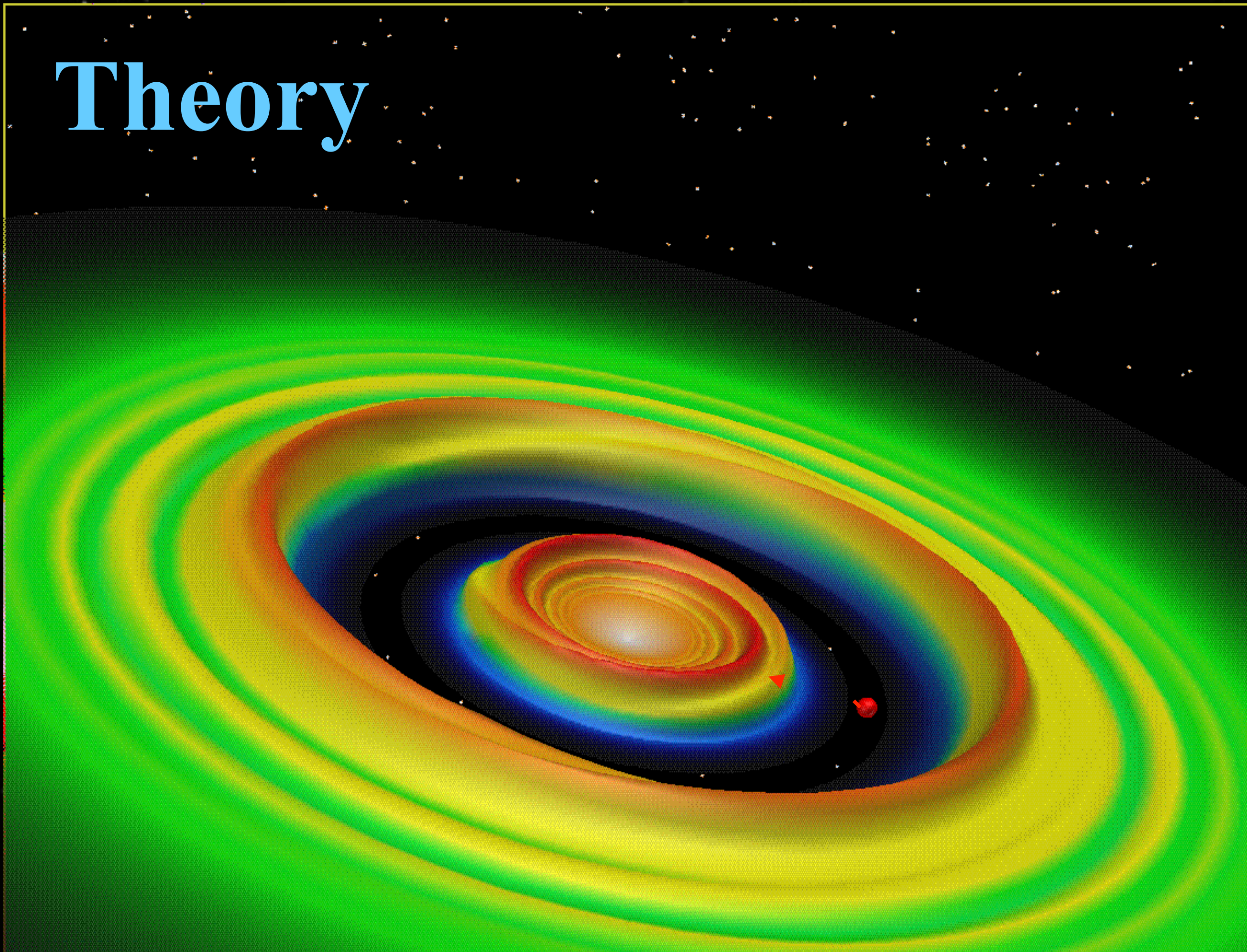




C. Marois (2010)

Kepler is pushing well into the hot Neptune & super-Earth regime.

How can we explain Neptune/Jupiter-mass planets over such wide distances?



Simulations G. Bryden (JPL), T. Pyle (SSC)

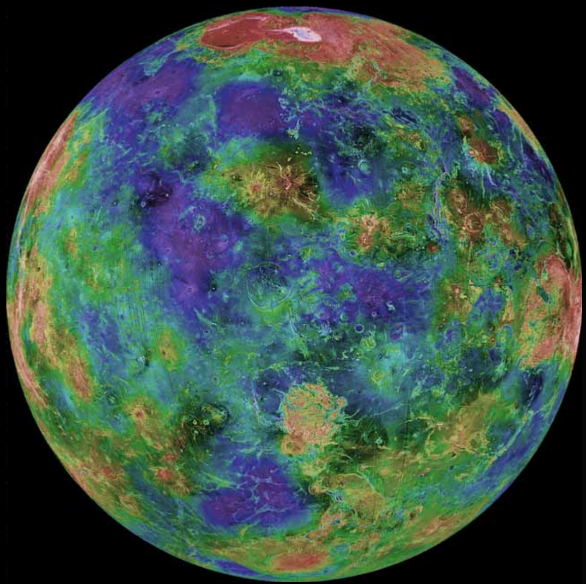
Disk-star-and protoplanet interactions can lead to migration *while the gas is present*. How does this work?

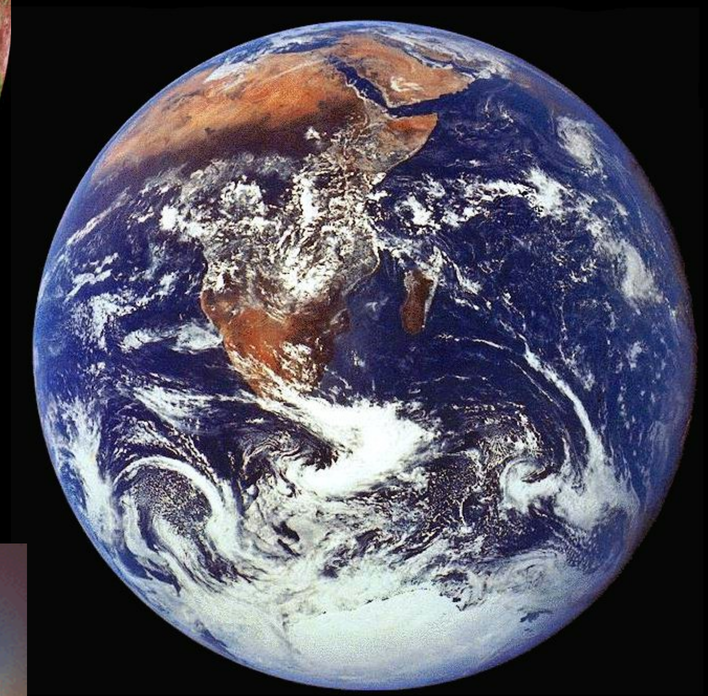
Jupiter (5 AU):
$V_{doppler}$ = 13 m/s
V_{orbit} = 13 km/s

Observation?

Central Question: Building a habitable planet, or

From whence water and organics?

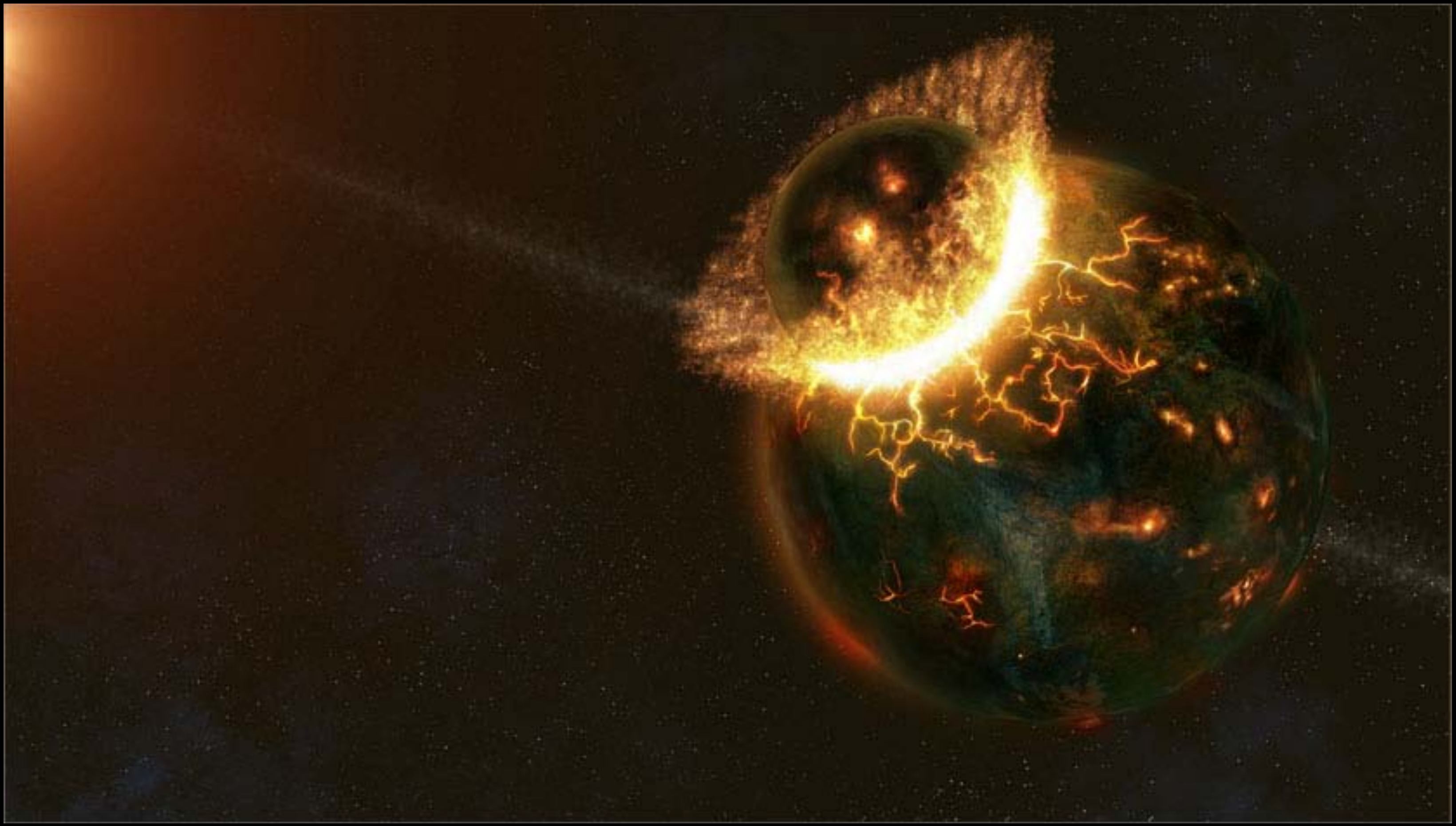




Planetesimal accretion from the outer solar nebula?

Early solar system dynamics?

Why should we consider volatiles from the outer solar system as the source of terrestrial water?

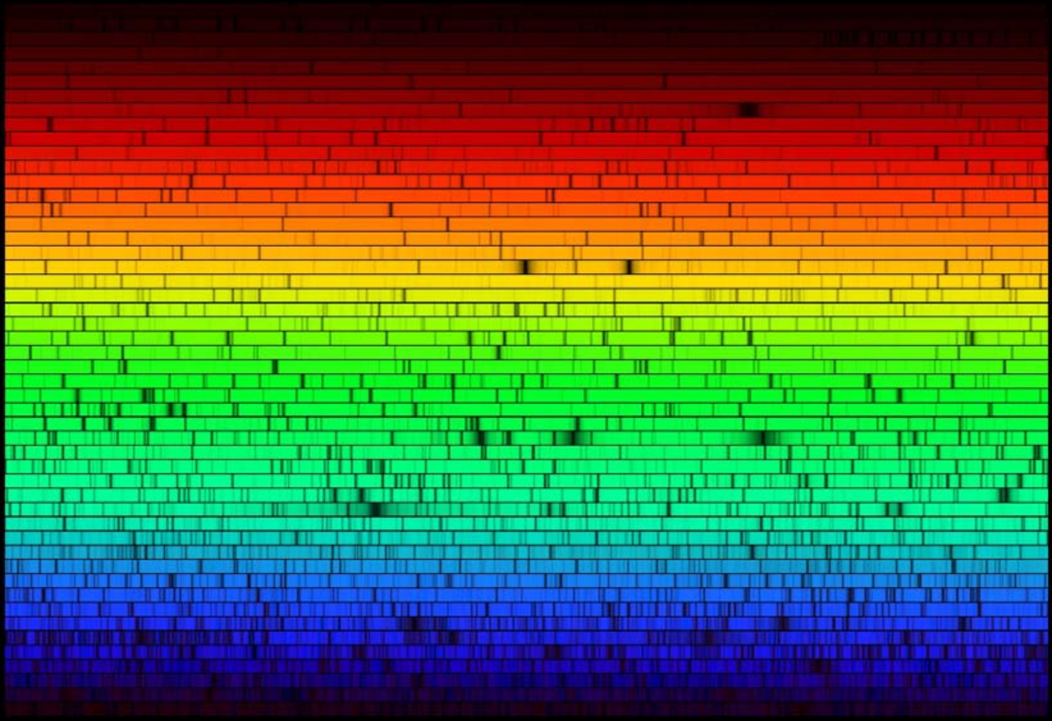


"Earth 4.5 AE B.C. – Fishing is extremely poor, especially in August."

Cliff Hauptman, *The Complete History of Fishing*

Impacts!

How do we sense objects/derive chemistry at a distance?



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

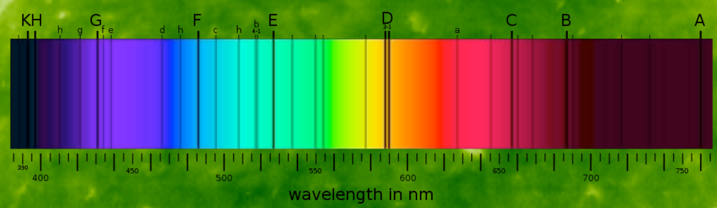
Echelle spectrometers in conjunction with large format CCDs can provide spectra across the entire visible or near-IR range.

One application uses such instruments to detect the presence of extrasolar planets via the Doppler effect.

The photospheres of stars tell us what they are made of…

The Astronomer's Periodic Table

H



[O,C] ~10^{-4}[H]
[N] ~10^{-5}[H]
[Si,Fe]~10^{-6}[H]

H, H_2, He very hard to see.

Dust+Ice/Gas~1%

He

O

C

N

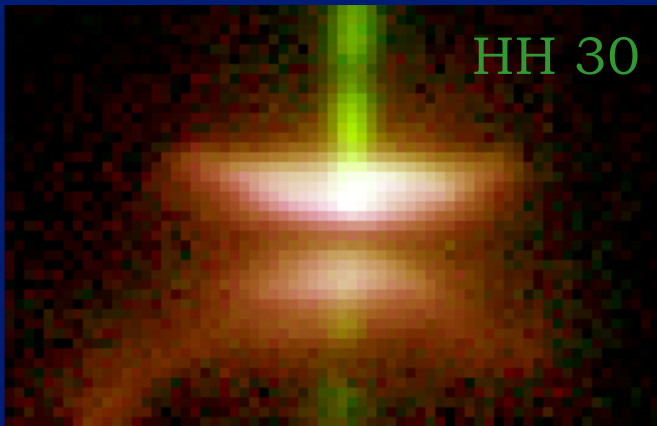
Si

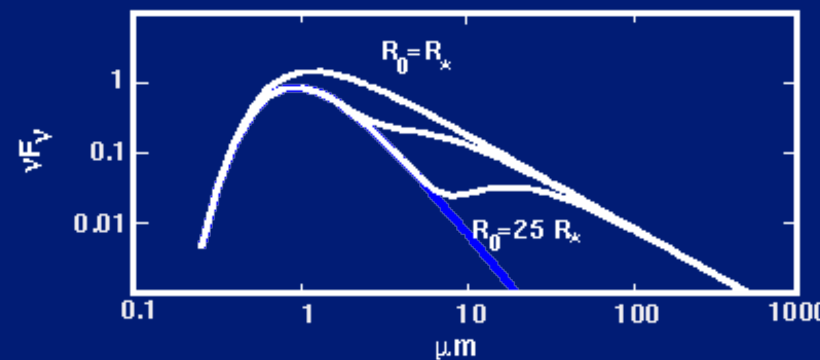
Fe

All Else

… and serve as beacons for exoplanet searches.

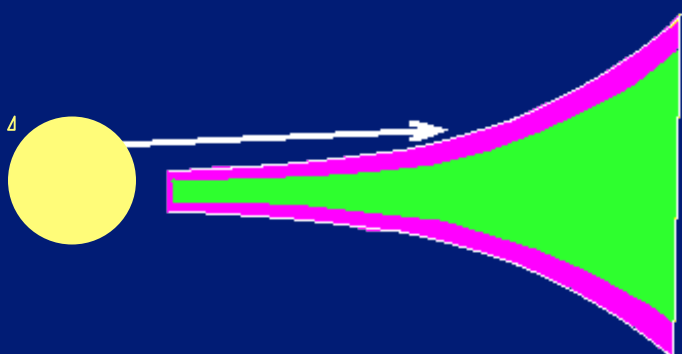
Are there optimal λ to study disks/protoplanets?

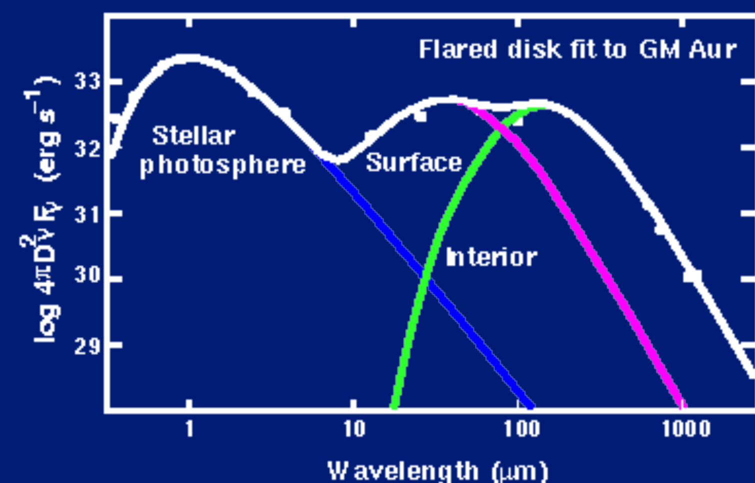




G.J. van Zadelhoff (2002)

← Hotter Colder →





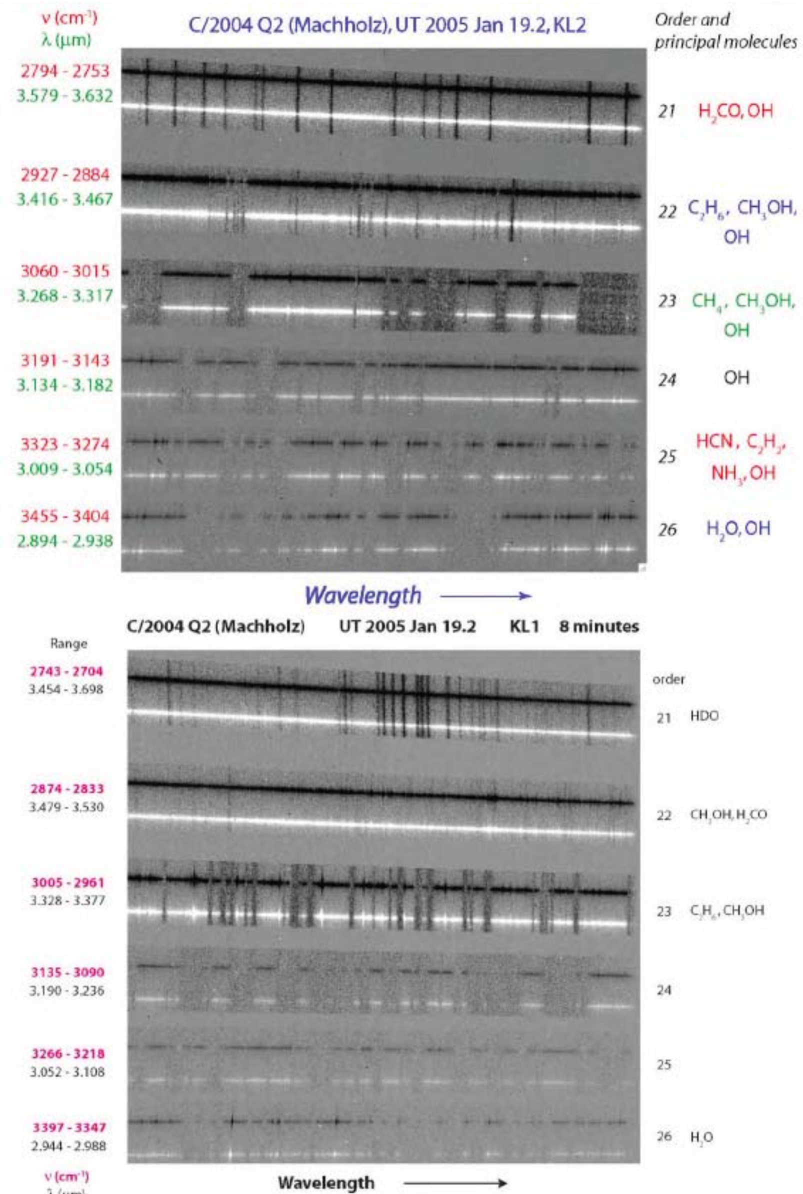
Chiang & Goldreich (1997)

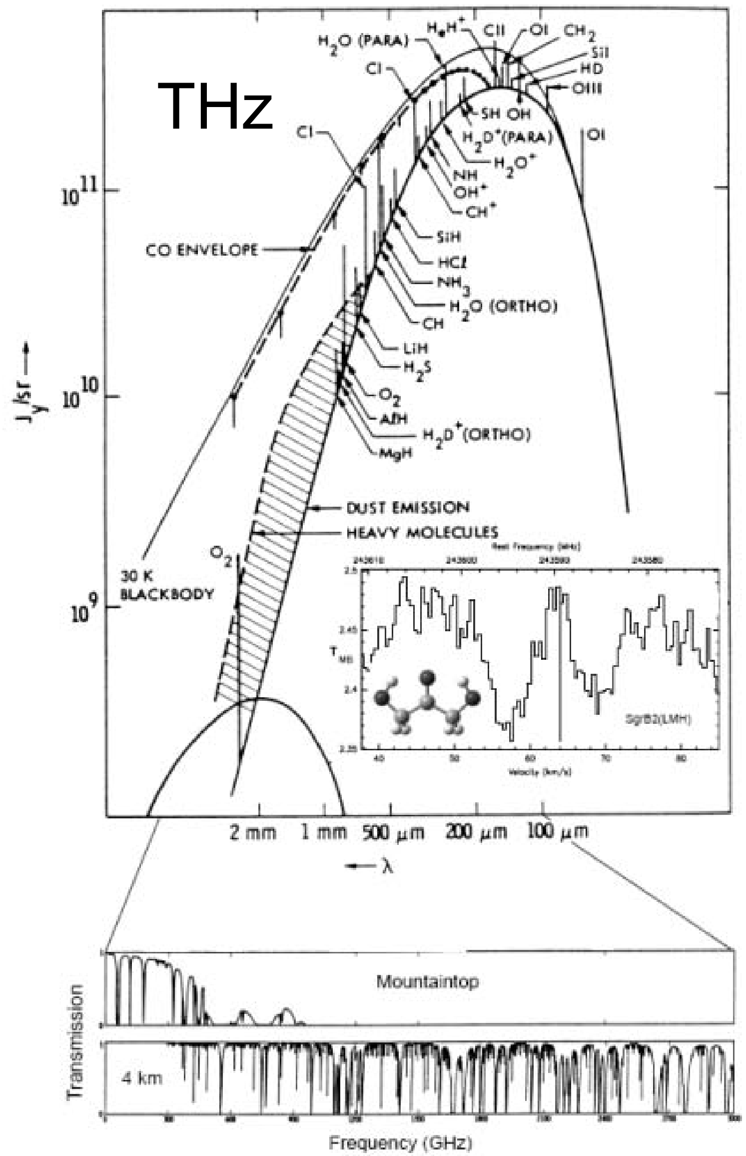
IR ➡ disk *surface* within several 0.1 – several tens of AU.

(sub)mm ➡ disk surface at large radii, disk *interior* also, results highly model dependent/degenerate (another talk!).

The Spectroscopic Challenge: Fighting Through the Earth's Atmosphere

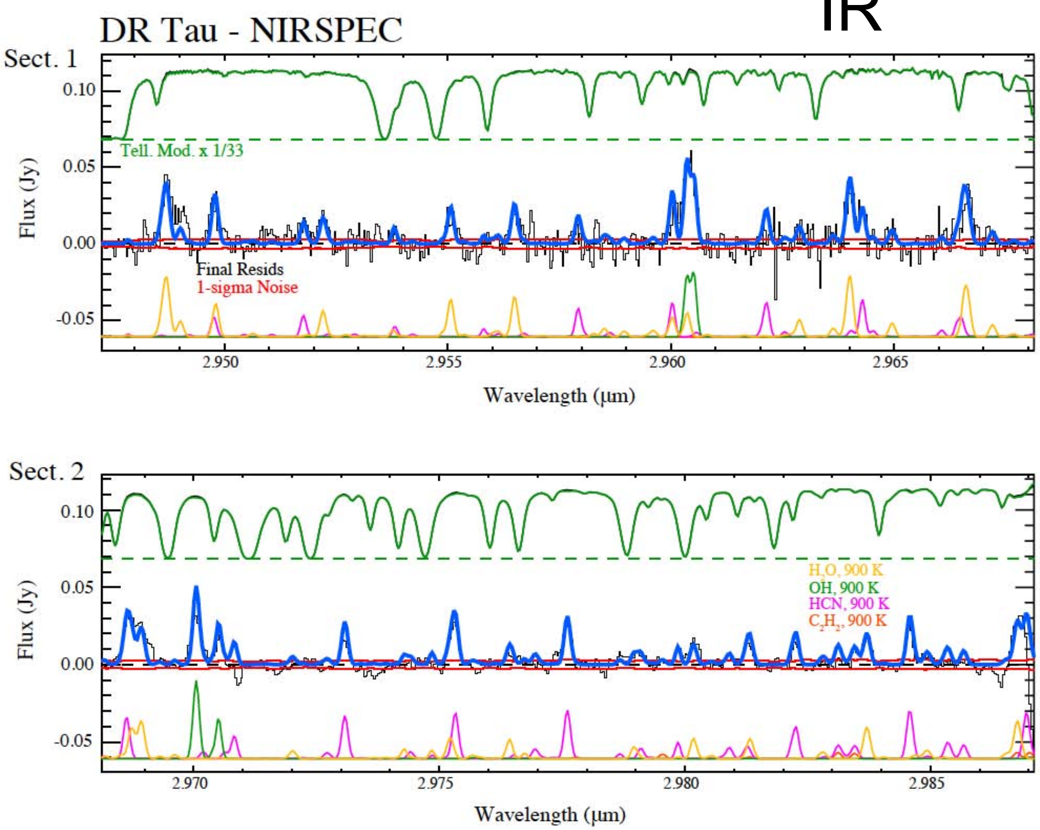
IR

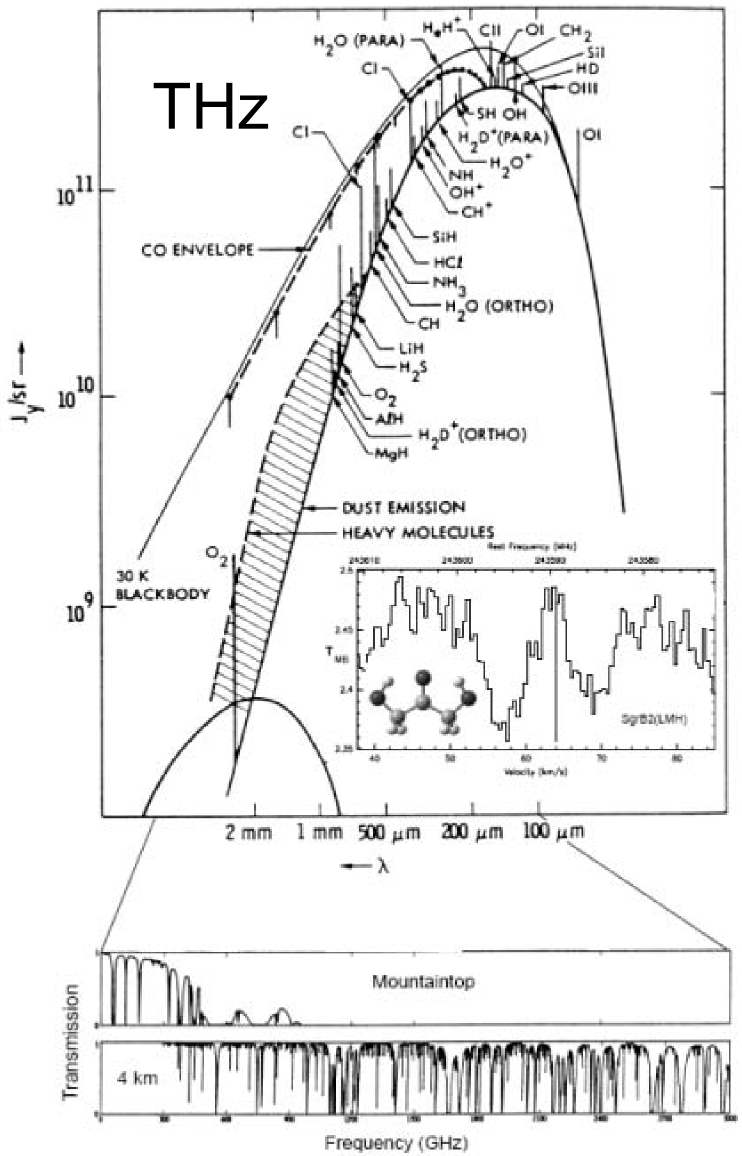




The Spectroscopic Challenge: Fighting Through the Earth’s Atmosphere

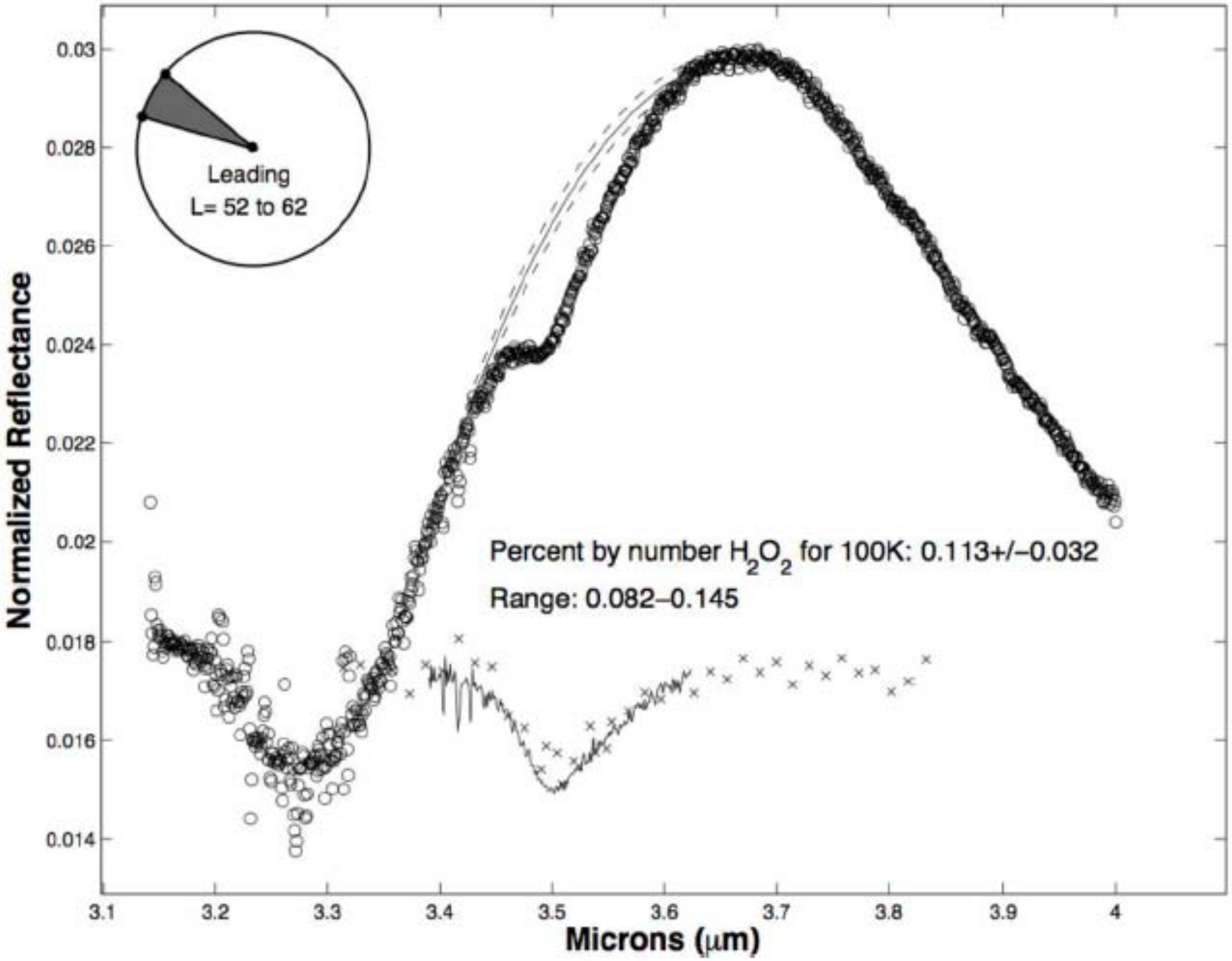
IR





Several key species (esp. water, methane, oxgen, carbon dioxide) are optically thick even atop Mauna Kea, the ALMA site, etc.

The Spectroscopic Challenge: Fighting Through the Earth's Atmosphere



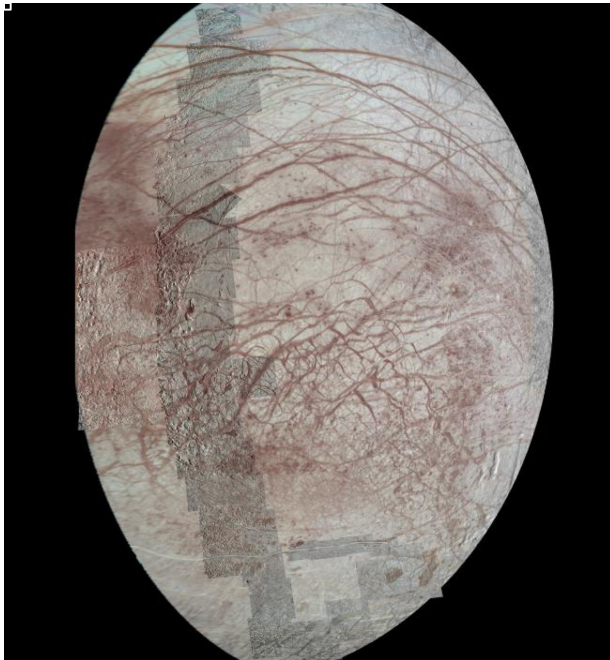
For ices and solids, good data can be acquired in atmospheric windows…

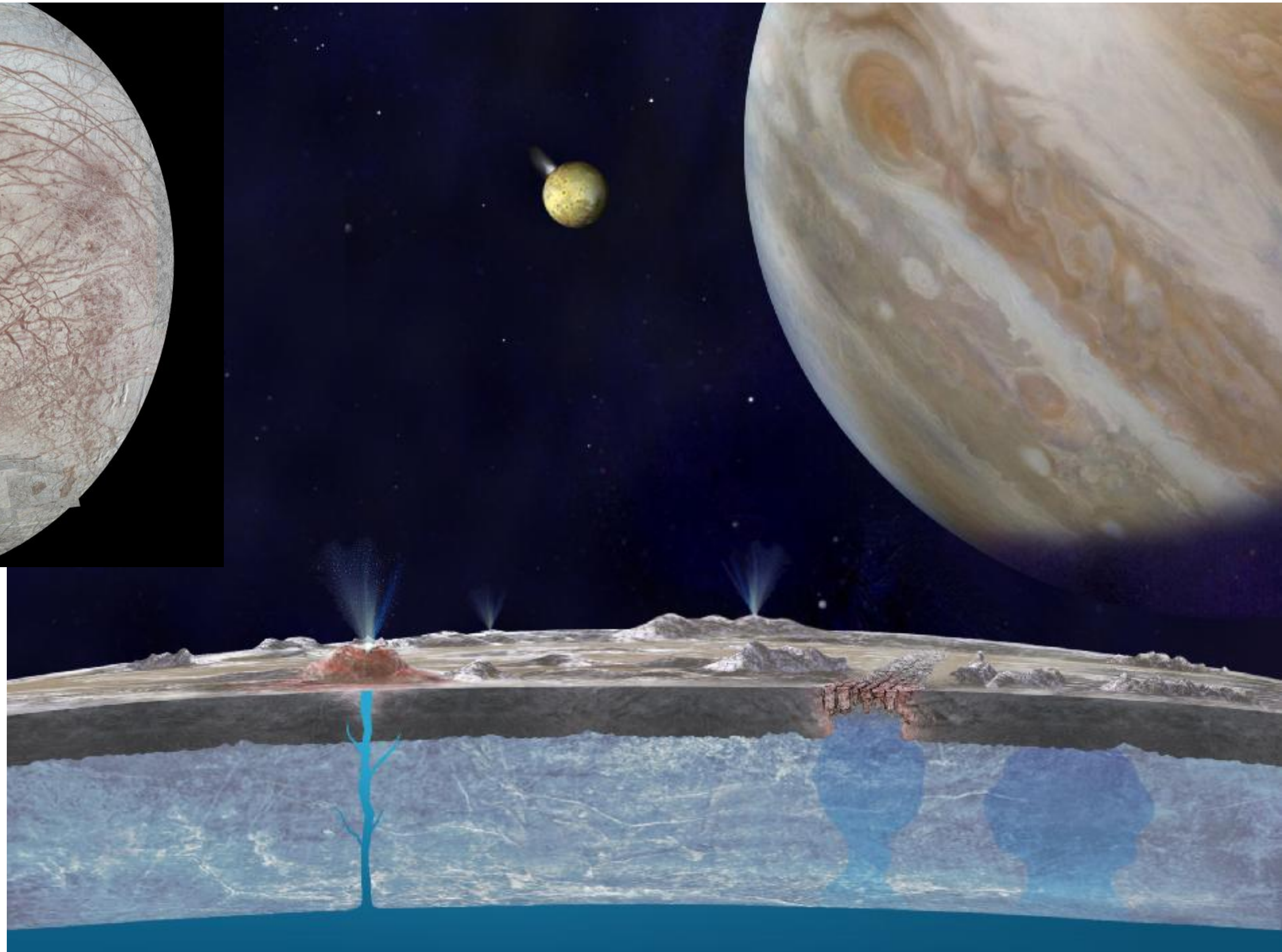
Europa,
Hand & Brown 2013

Such studies have led to extensive discoveries about the nature of small bodies and satellites…

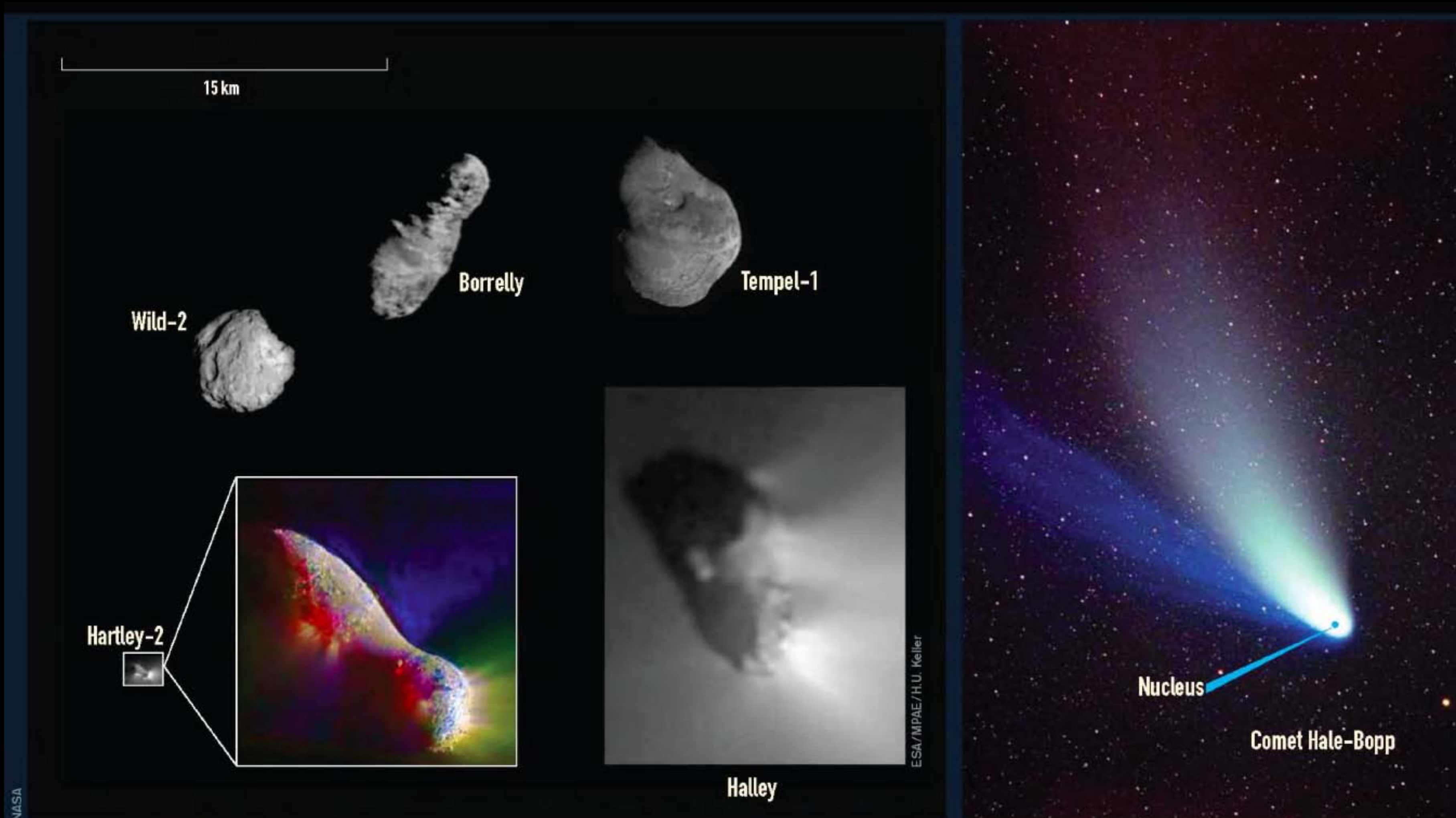
…such as salts and hydrogen peroxide on the surface of Europa. Hard to compete w/small, cold telescopes in space, orbiters.

Brown & Hand 2013



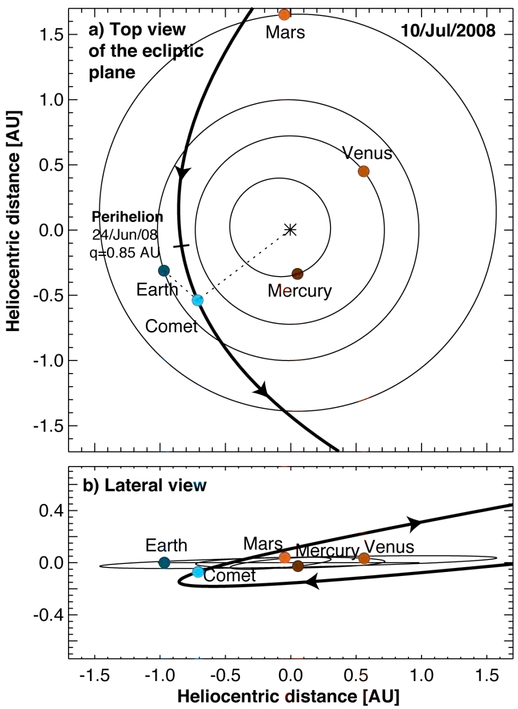


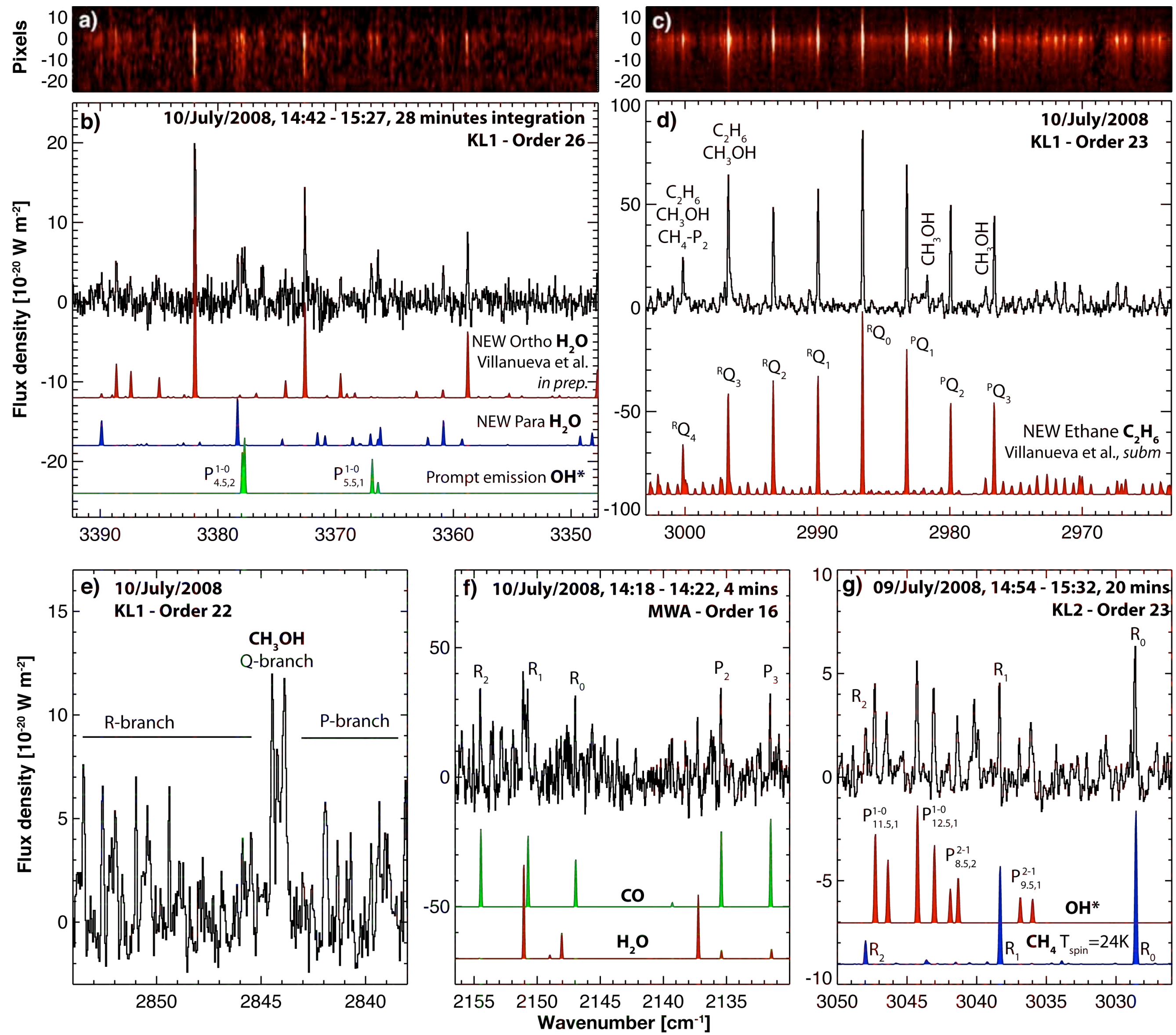
As they enter the inner solar system, the gas and dust of comets can be studied in great detail.



FIVE COMET NUCLEI IMAGED BY SPACECRAFT: Active vents of comet Halley (lower middle) release jets of gas and dust that are seen as white streaks in reflected sunlight. The largest nucleus measured was of Hale-Bopp (70 kilometers; about 6 times larger than Halley's nucleus).

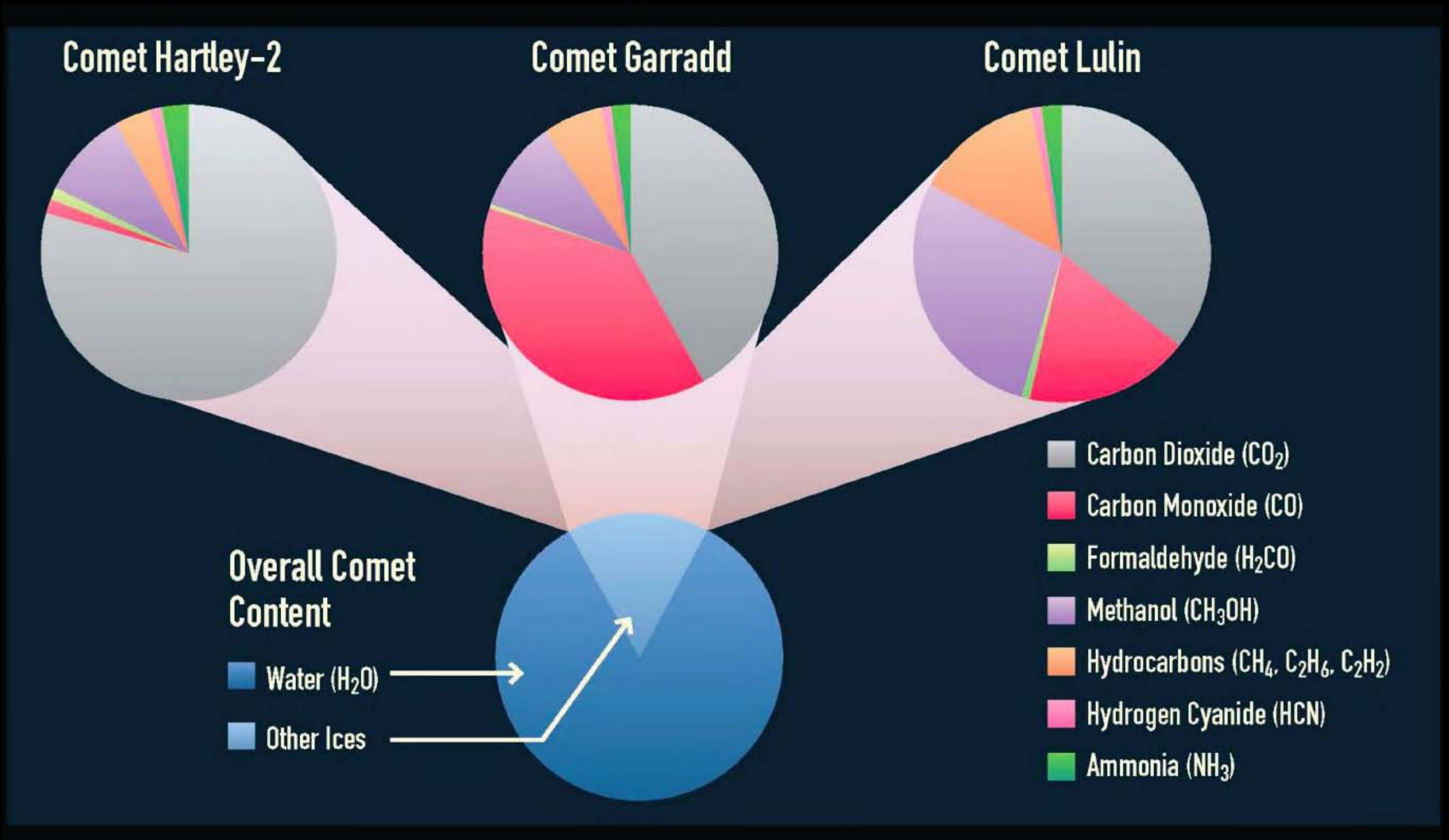
Here are high resolution infrared specetroscopy results for one such object:





Keck NIRSPEC spectra of Comet Boattini

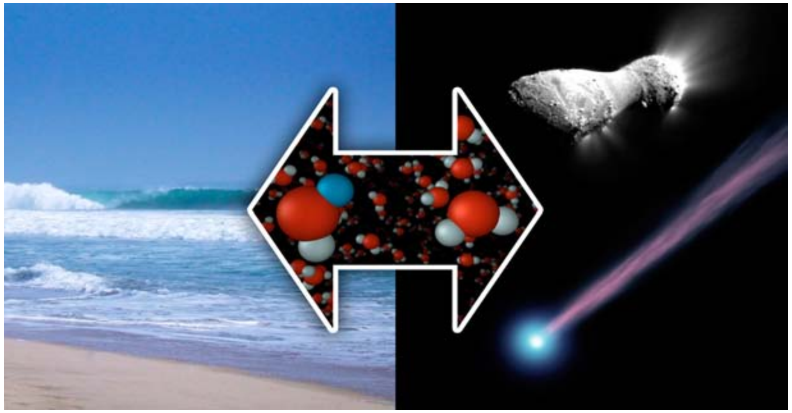
Comets are chemically diverse:

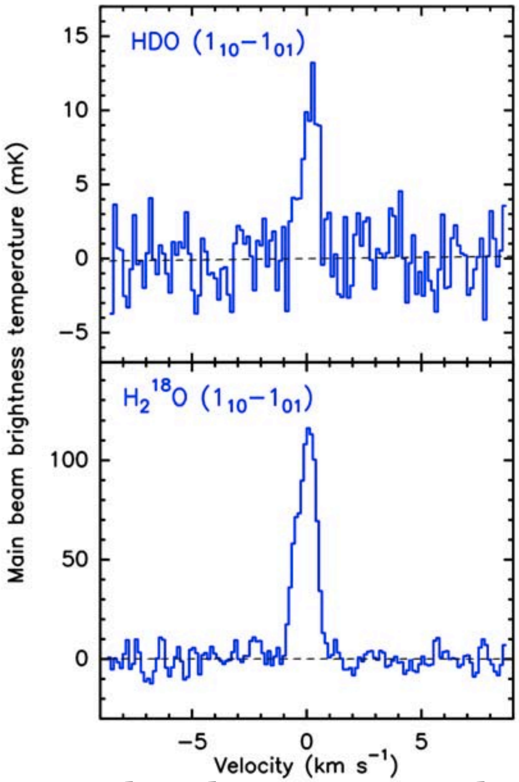


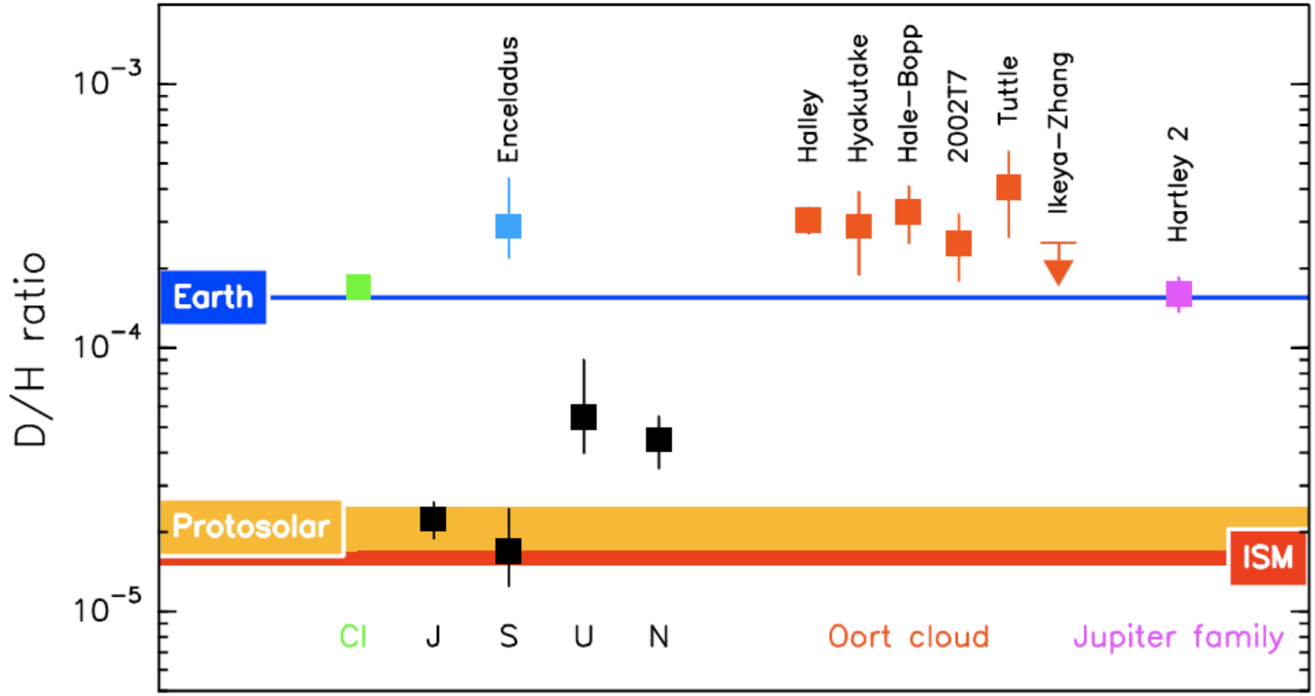
Need significant samples to make further progress.

What about THz studies of comets/satellites?

103P Hartley 2,
5 hrs Herschel



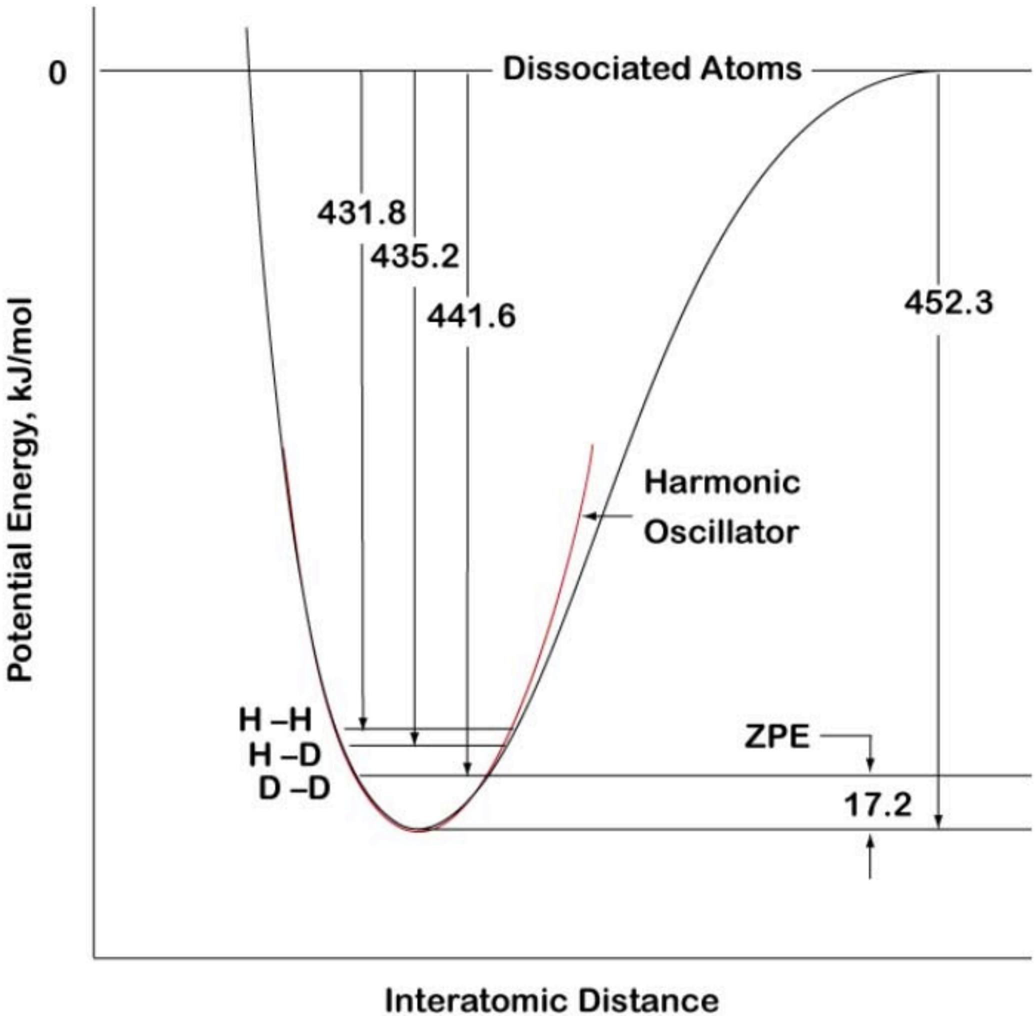




Why do we care about isotopes?

Hartogh et al. 2011, *Nature* **478**, 7367.

Low T Chemistry & Deuterium Fractionation



Thermodynamics measured from vibrational zero point level. Thus,

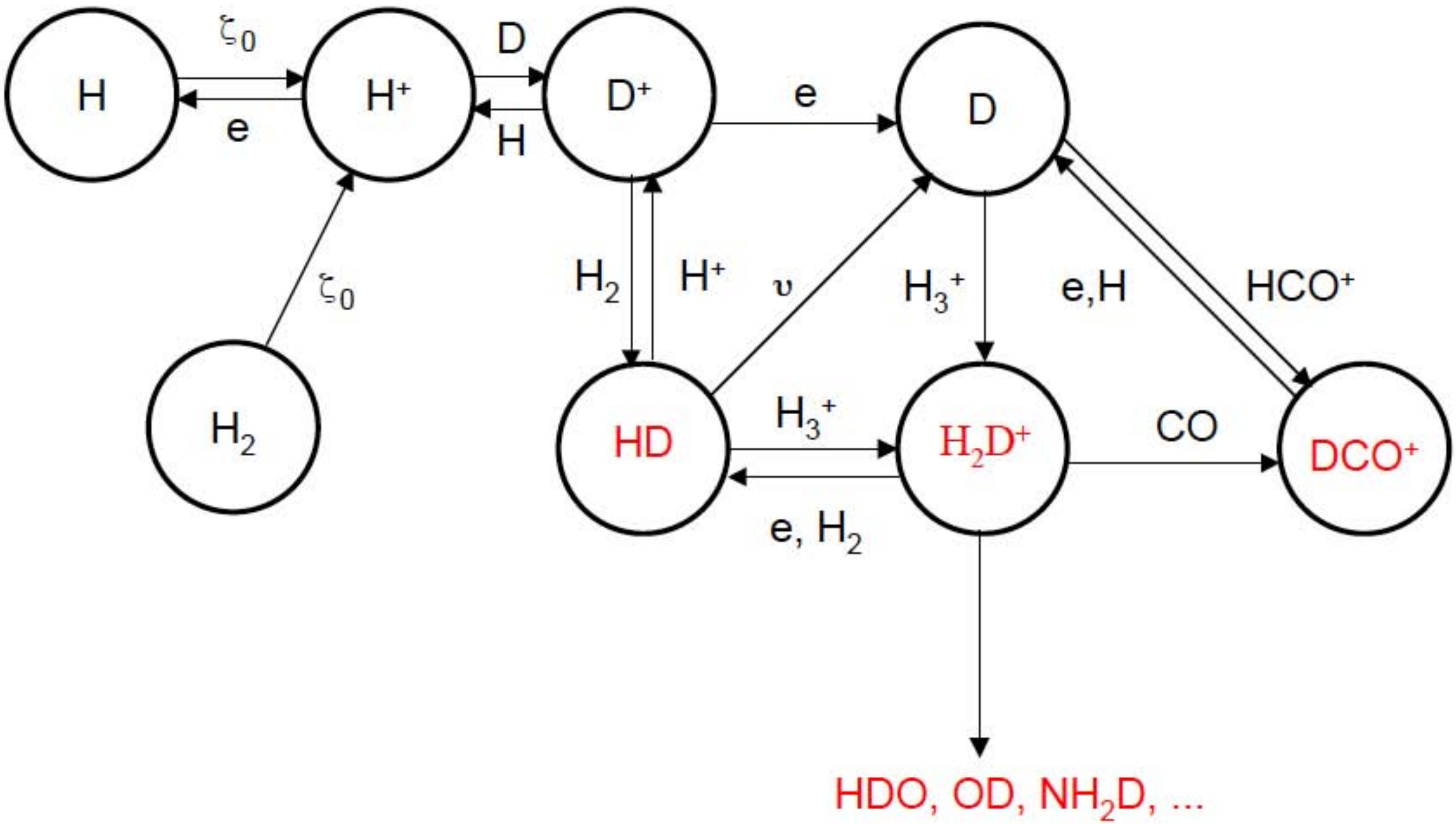
$HD + H_3^+ \rightleftharpoons H_2 + H_2D^+$

is exothermic to the right, with $\Delta E/k \sim 230$ K.

And, the backward reaction rate becomes very sensitive to T below 100 K.

Deuterium chemistry

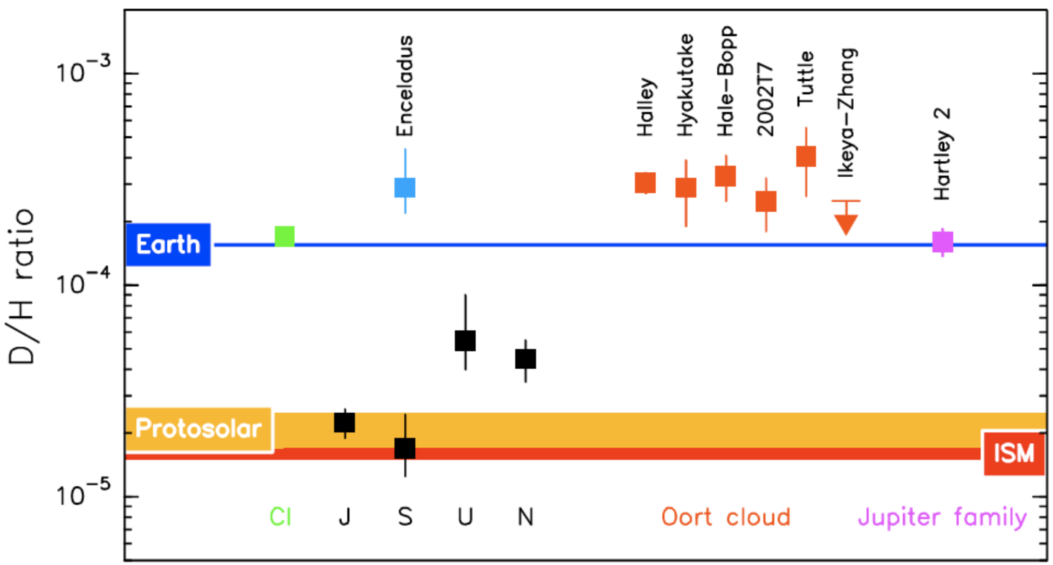
GREAT



R. Stark

Deuterium Fractionation & Water

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

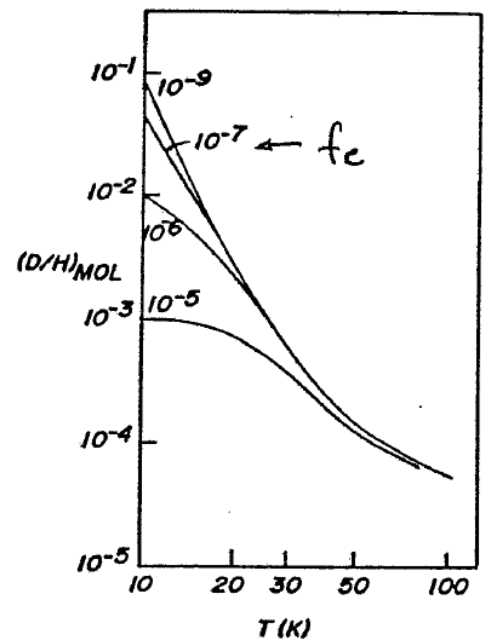


Works for many species because H_3^+ is a good proton donor…

Thermodynamics measured from vibrational zero point level. Thus,

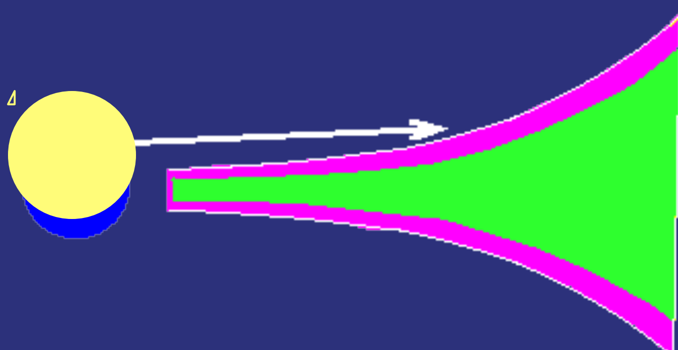
$$HD + H_3^+ \rightleftharpoons H_2 + H_2D^+$$

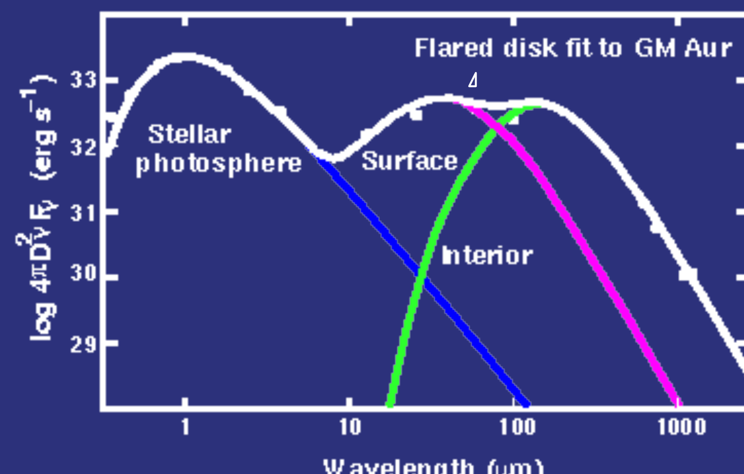
is exothermic to the right, with $\Delta E/k \sim 230$ K.



Water/Ice/Organics at large R (and so cold)?

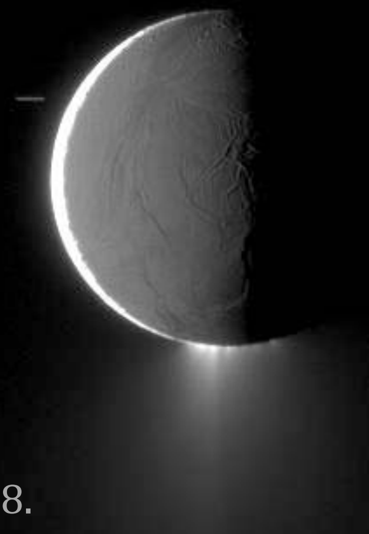
Tera incognita. Launched 14May2009. L_{He} now gone.



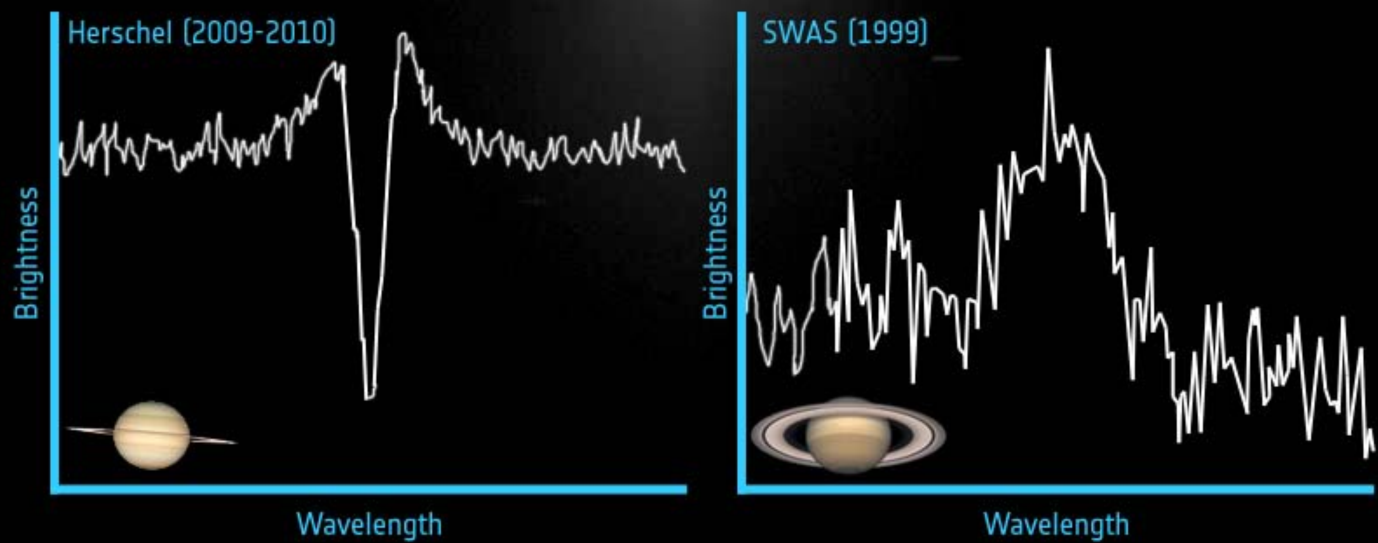


THz → Uniquely sensitive to first row atoms, hydrides.

Herschel studies of water at Enceladus (and Saturn/Titan)



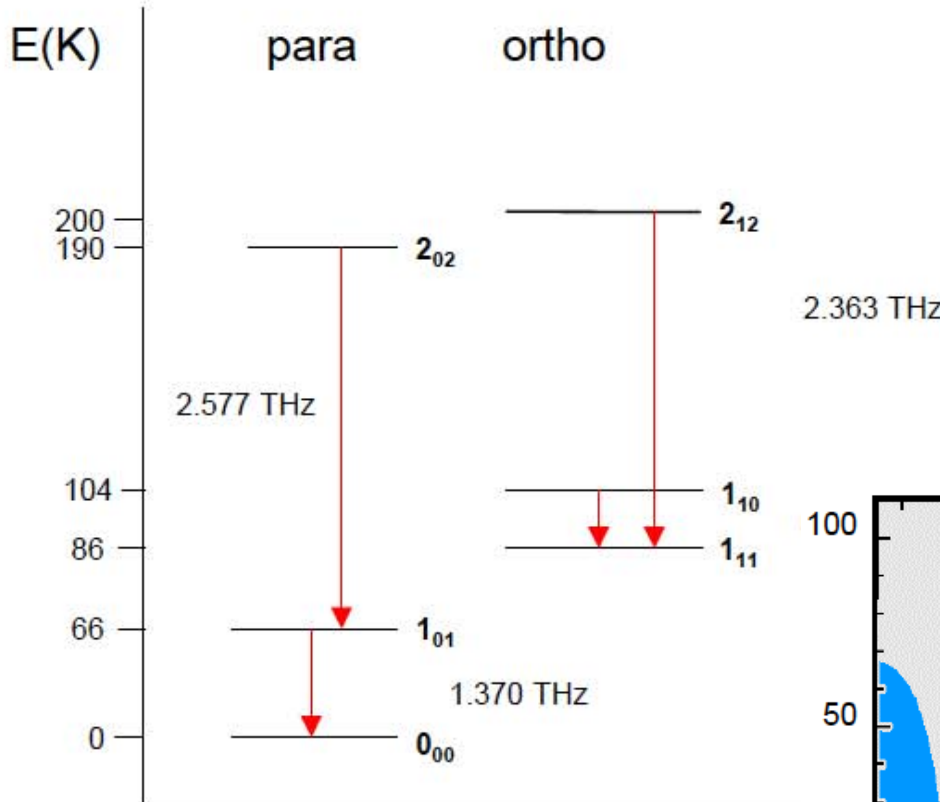
Dip has a line/
continuum of 0.8.



THz emission can probe to large distances. D/H ratio? Organics?

H_2D^+ rotational energy levels

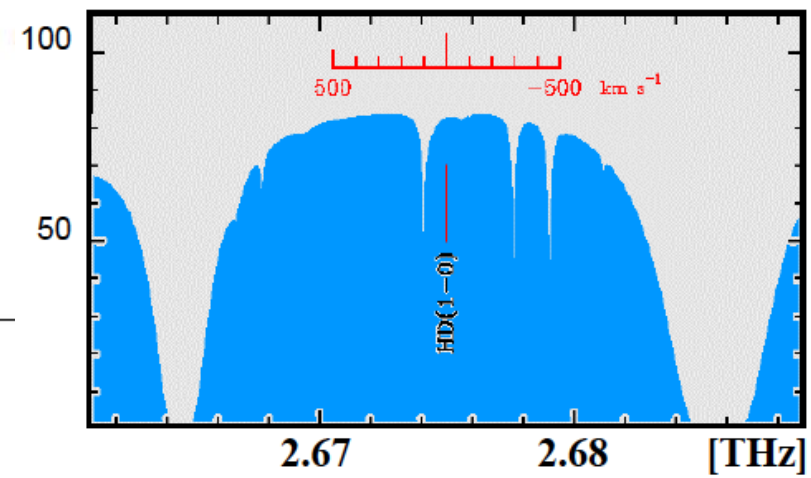
GREAT



Other species?

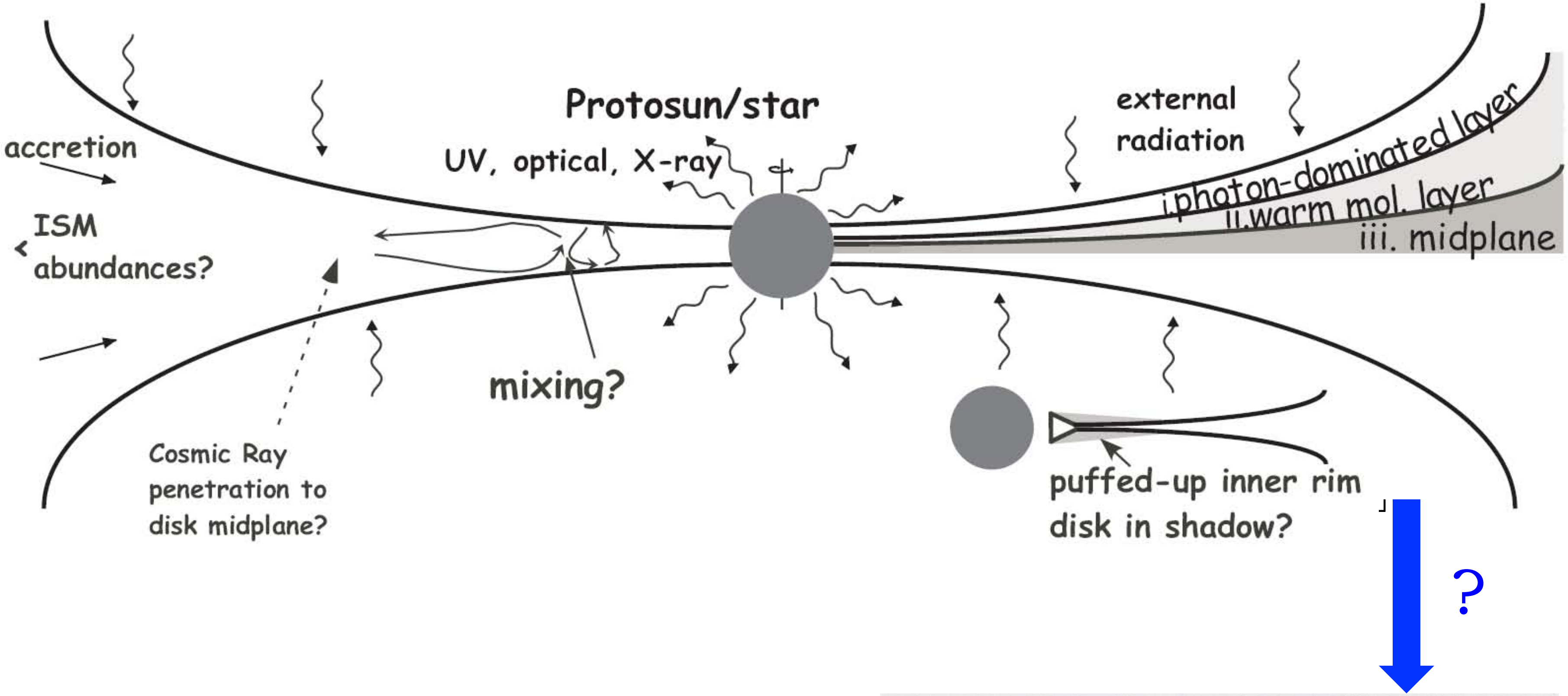
D_2H^+ $1_{11} - 0_{00}$
@ 1476.6 GHz;

HD 1 – 0:



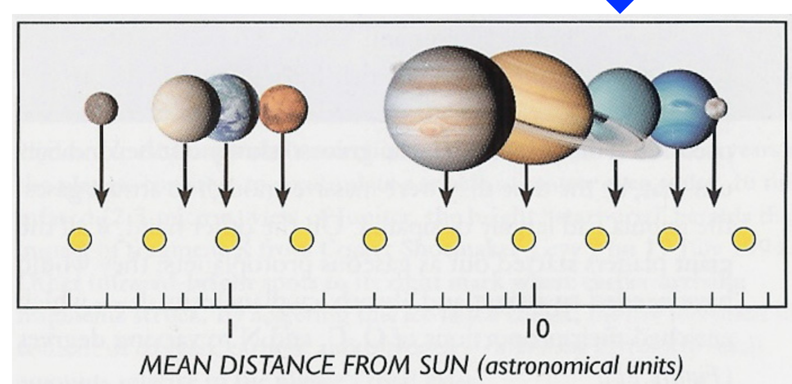
R. Stark

A core-accretion recipe to build a planet:



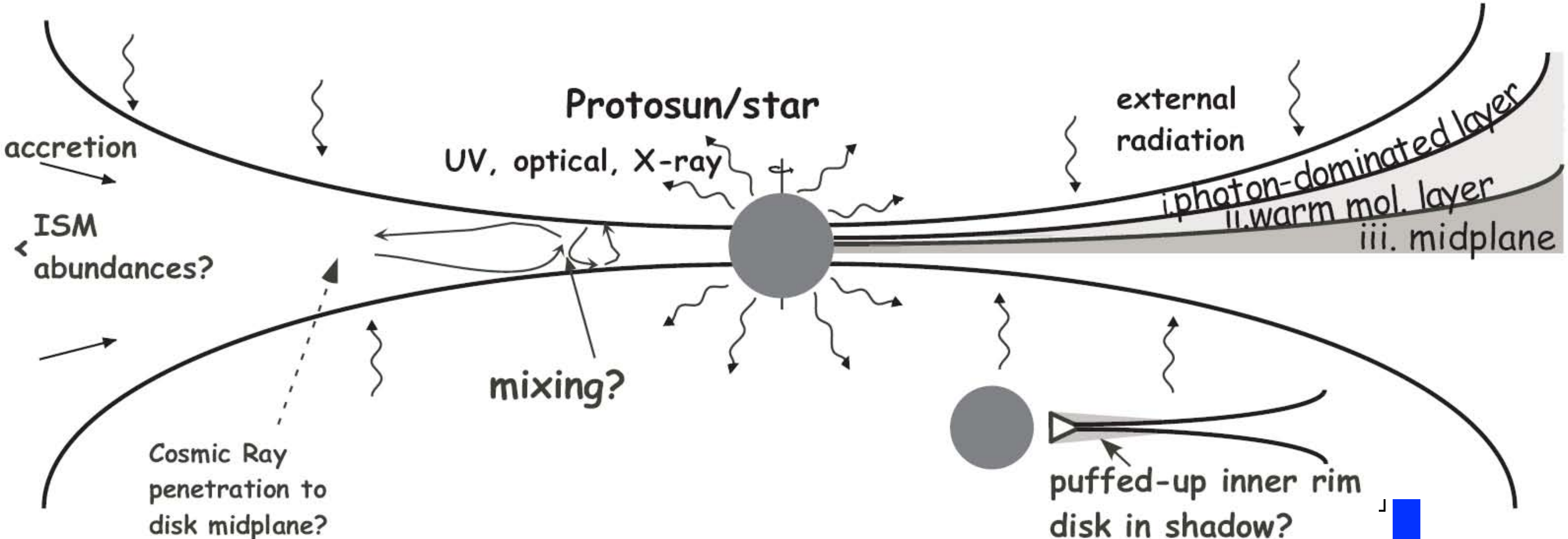
Step #1:

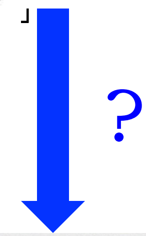
Dust (talcum powder	→	Dust bunnies marbles/ billard balls)



Dust grains stick, grow, and *settle* toward the midplane.

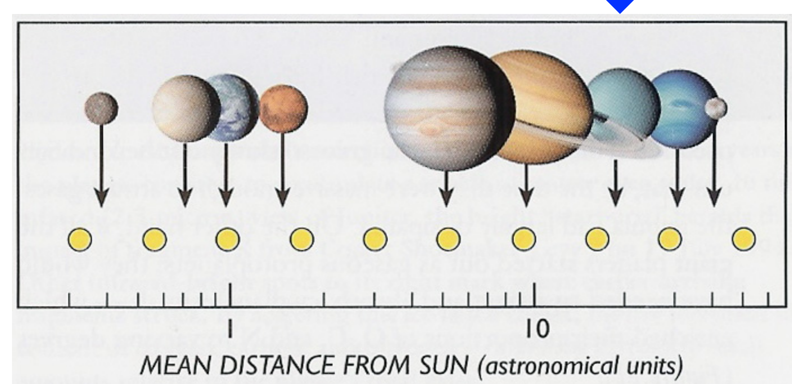
A core-accretion recipe to build a planet:





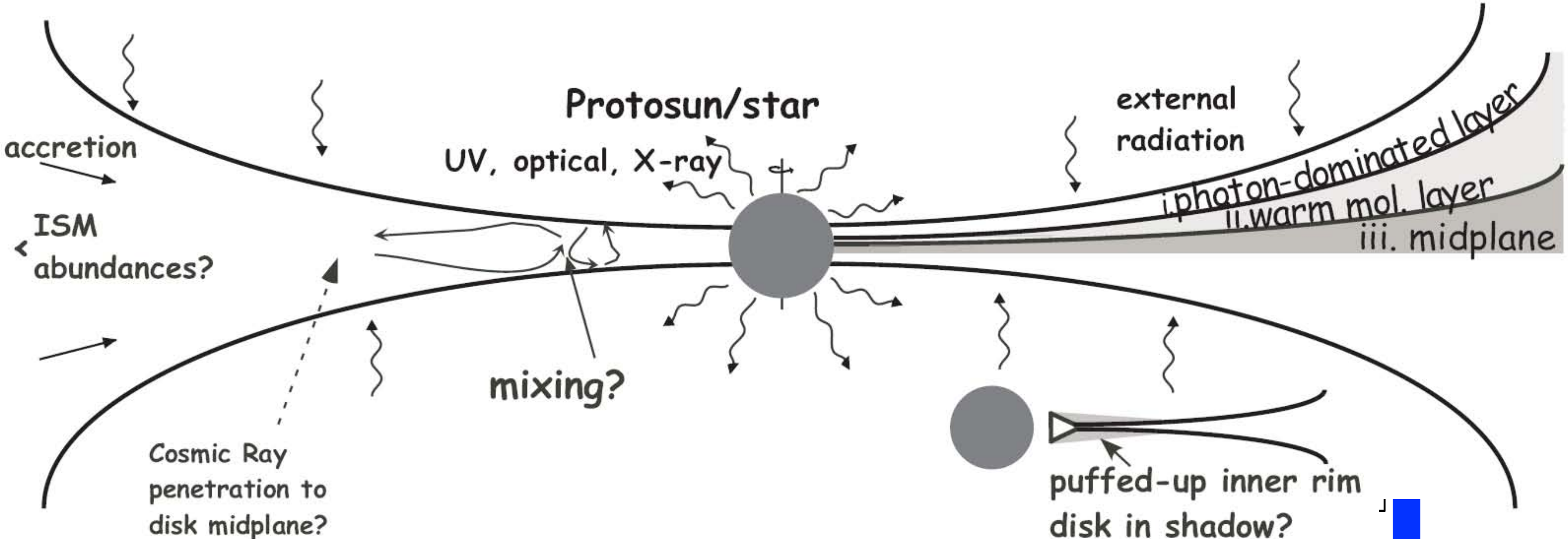
Step #2:

Dust bunnies (billard balls) → Planetesimals asteroids/ comets)



Magic happens. No, really. We have ideas…

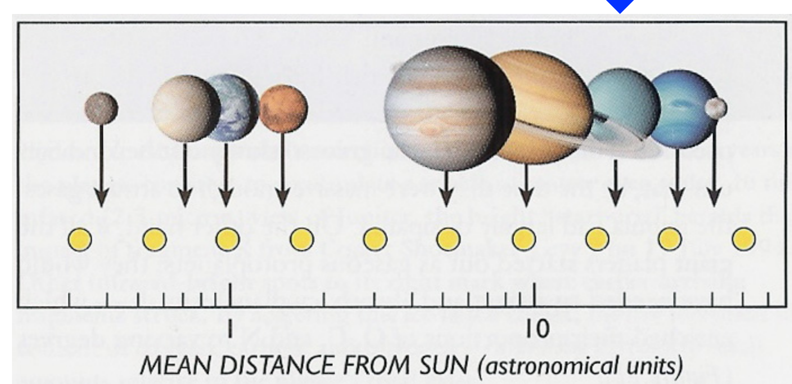
A core-accretion recipe to build a planet:



?

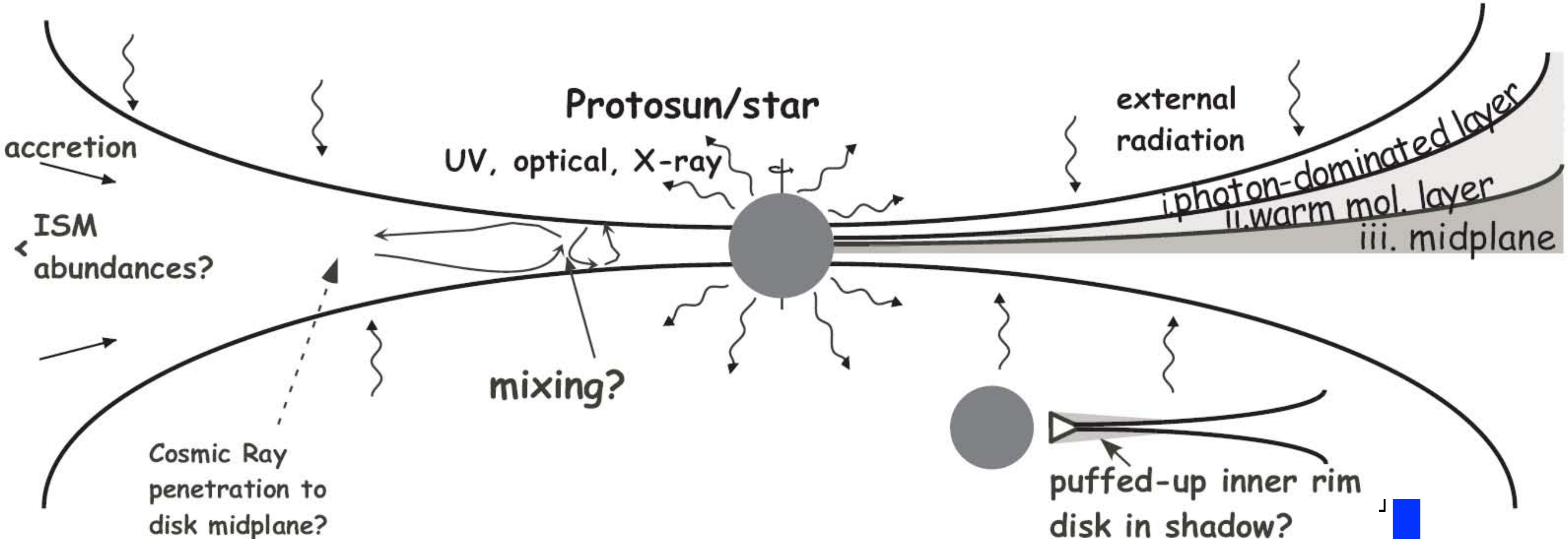
Step #3:

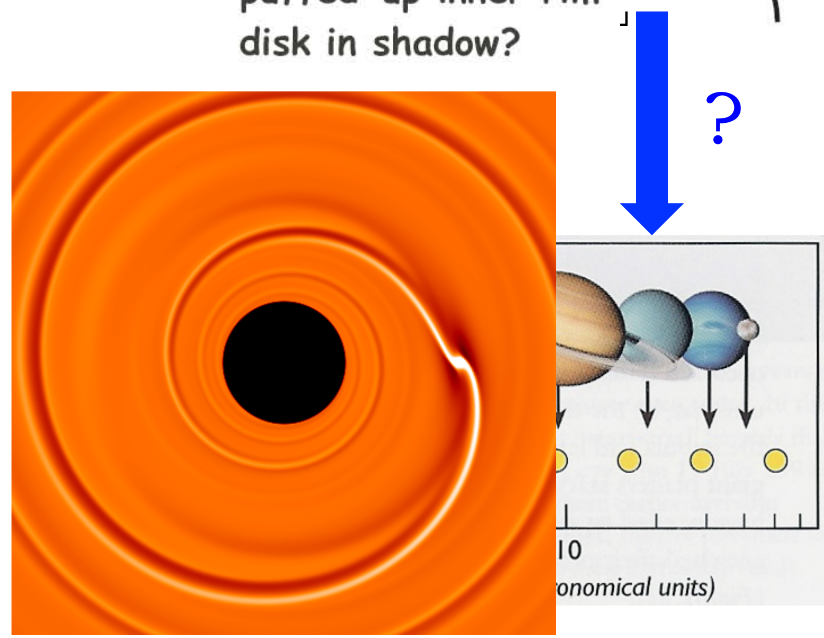
Asteroids/ Comets (km → Oligarchs 0.1-10 M_{earth})



Gravity is good!

A core-accretion recipe to build a planet:





Step #4: (For Jupiters, etc.)

Add gas from the disk.

Can take time, the disk must survive! Strong disk-planet interactions.

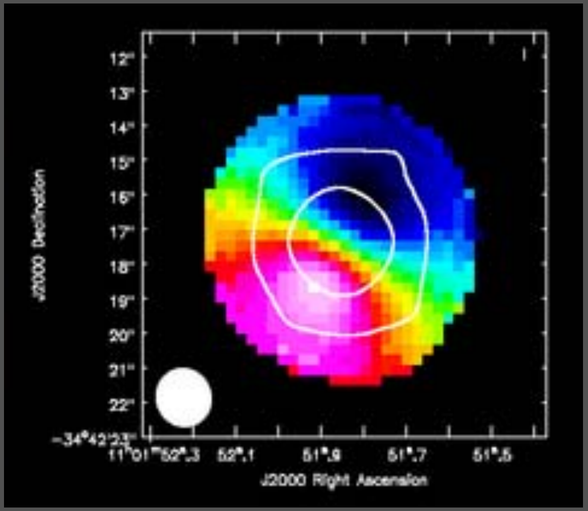
Arrays at long wavelengths, esp. ALMA:

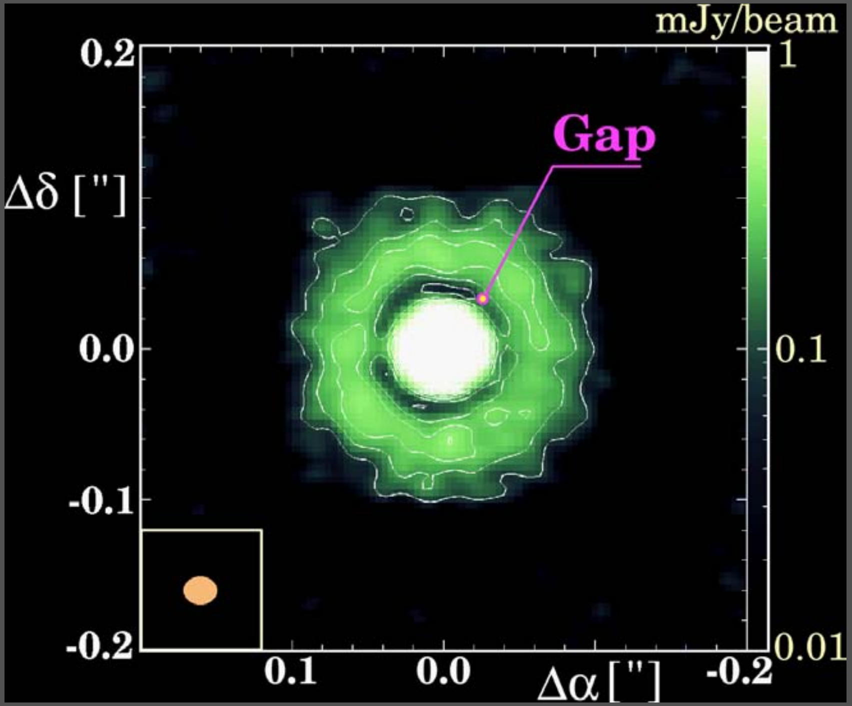
Once completed, ALMA should be able to detect 1 AU wide gaps in its largest configurations via dust imaging, but for 3 AU pixels at 140 pc,

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

Very difficult to see lines at <5 AU, does the grain emissivity change with radius?

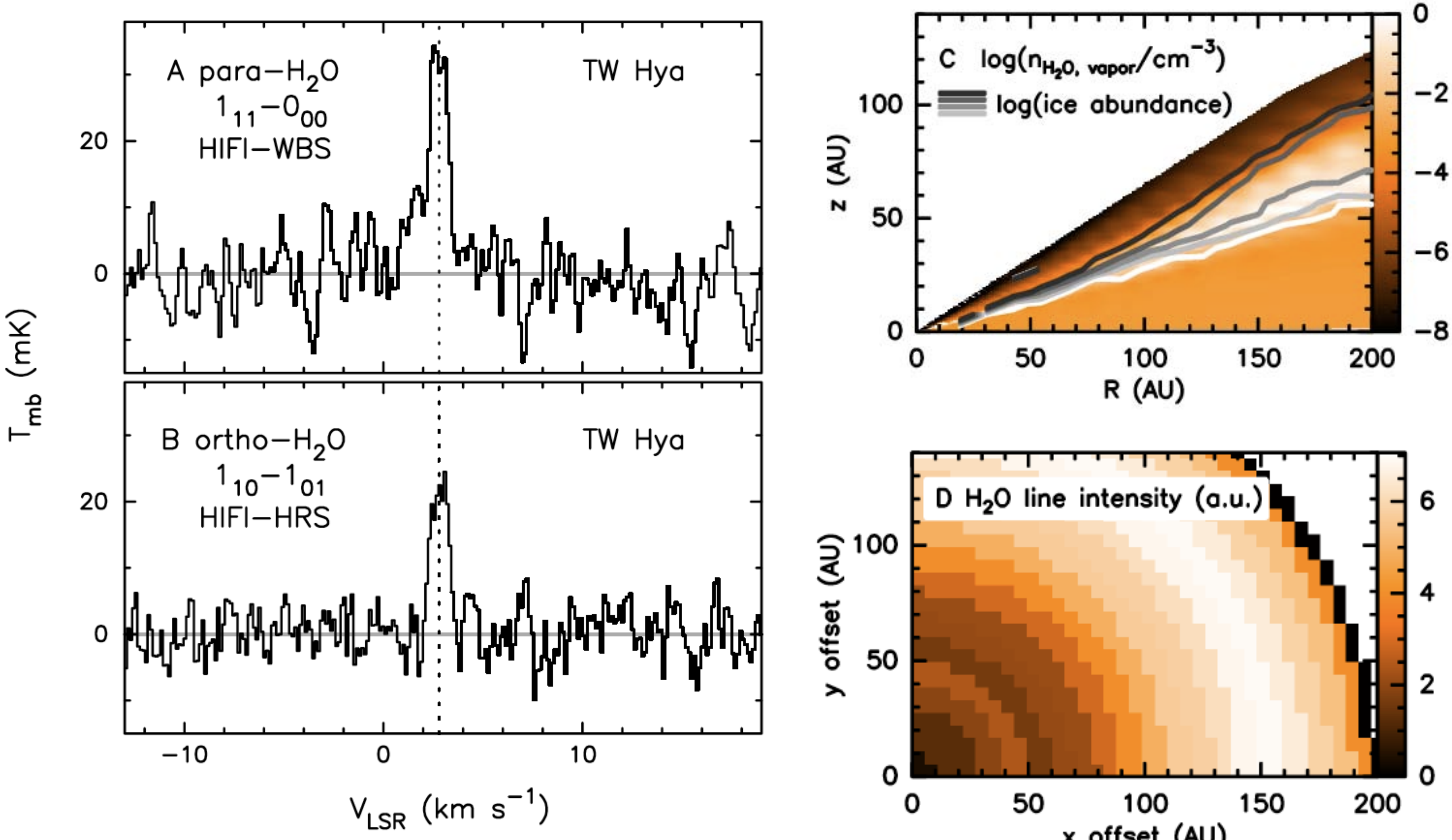
Gas in TW Hya (SV Data)





Wolf et al. 2002, ApJ 566, L97.

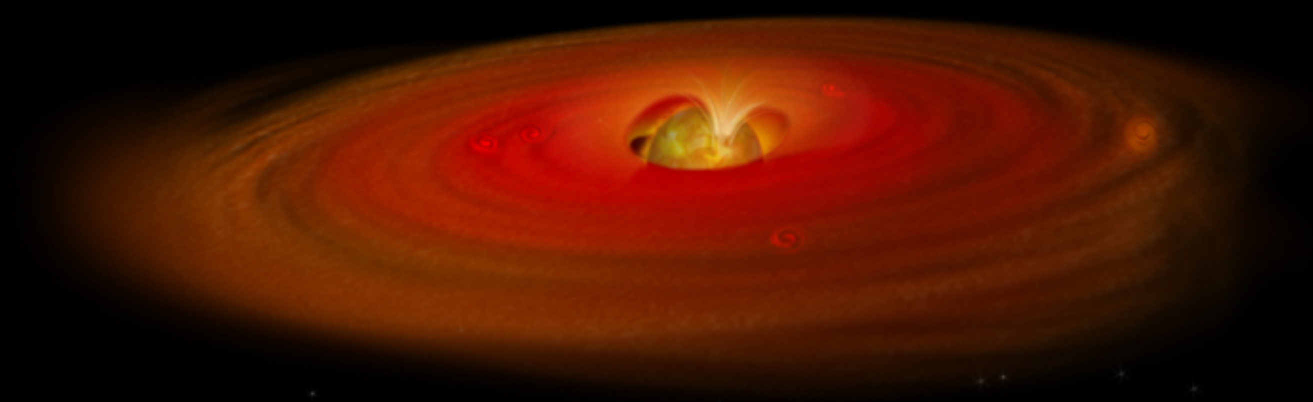
Herschel HIFI has one reported detection of water in a protoplanetary disk (PACS~10):



Hogerheijde et al. 2011, *Science* **334**, 338 (8 total hours integration)

How have IR spectra enabled tests of planet formation models @ 0.1-10 AU?

Theory



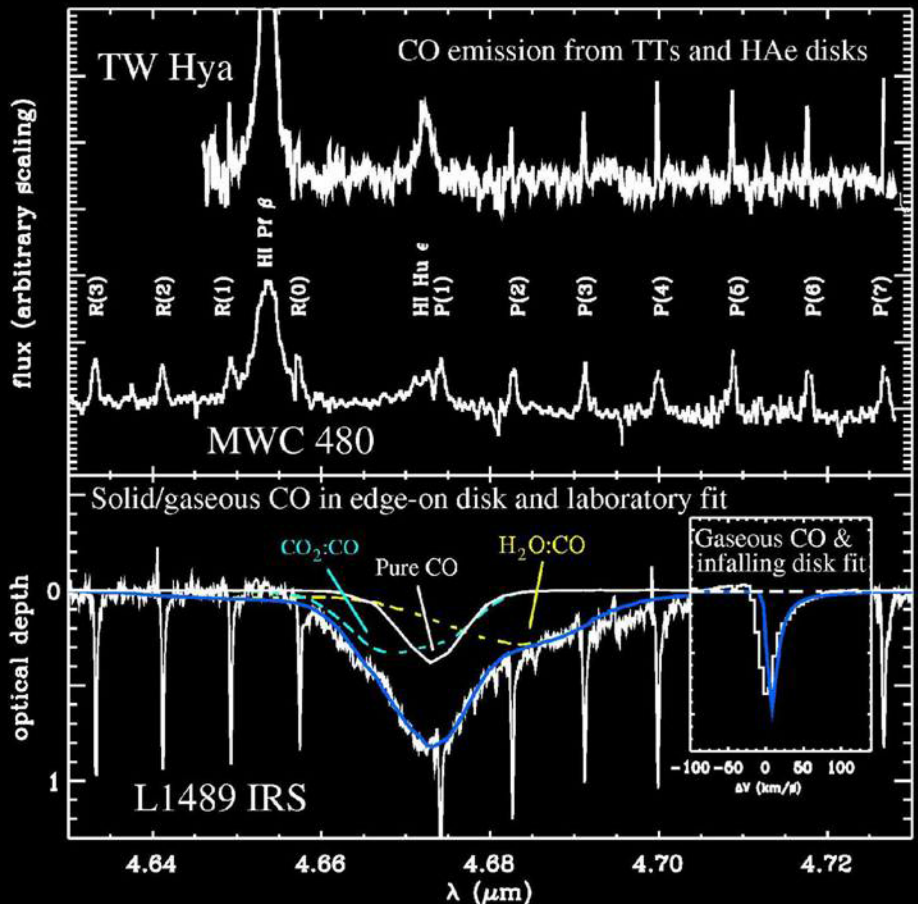
Even w/ALMA, the size scales are too small even for the largest mm-wave arrays. Look where the inner disk is self-luminous, or, IR spectroscopy to the rescue…

Jupiter (5 AU):
$V_{doppler}$ = 13 m/s
V_{orbit} = 13 km/s

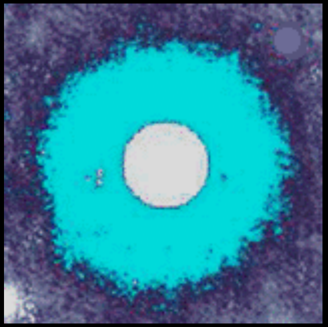
Observation?

High Resolution IR Spectroscopy & Gas in Disks

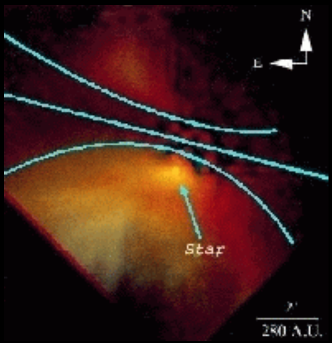
Only with Keck/NIRSPEC could the first IR *surveys* of the disk gas in “typical” T Tauri (Sun-like) stars be carried out:



CO
M-band

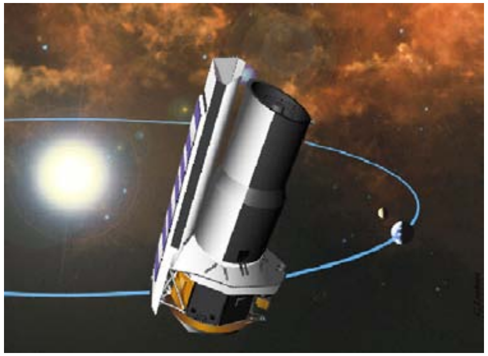


TW Hya

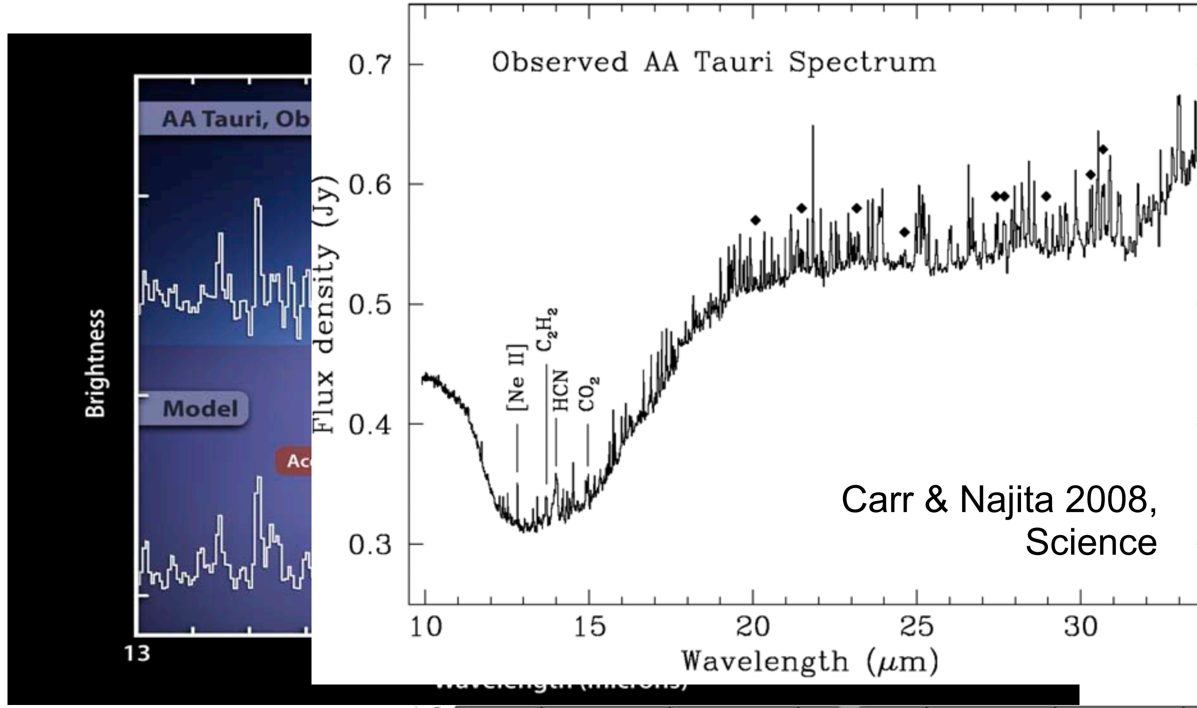


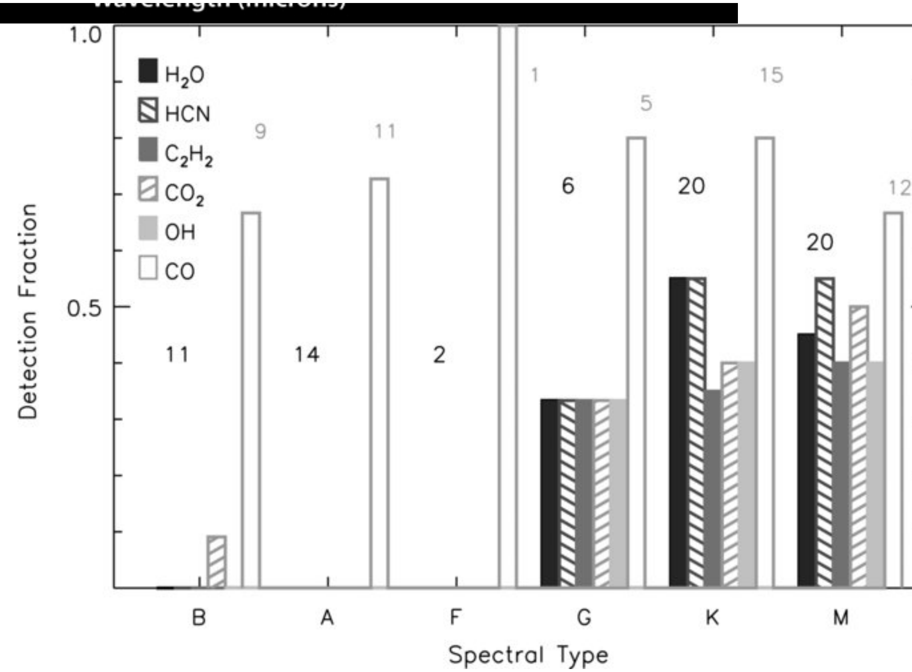
L1489
IRS

Other species?



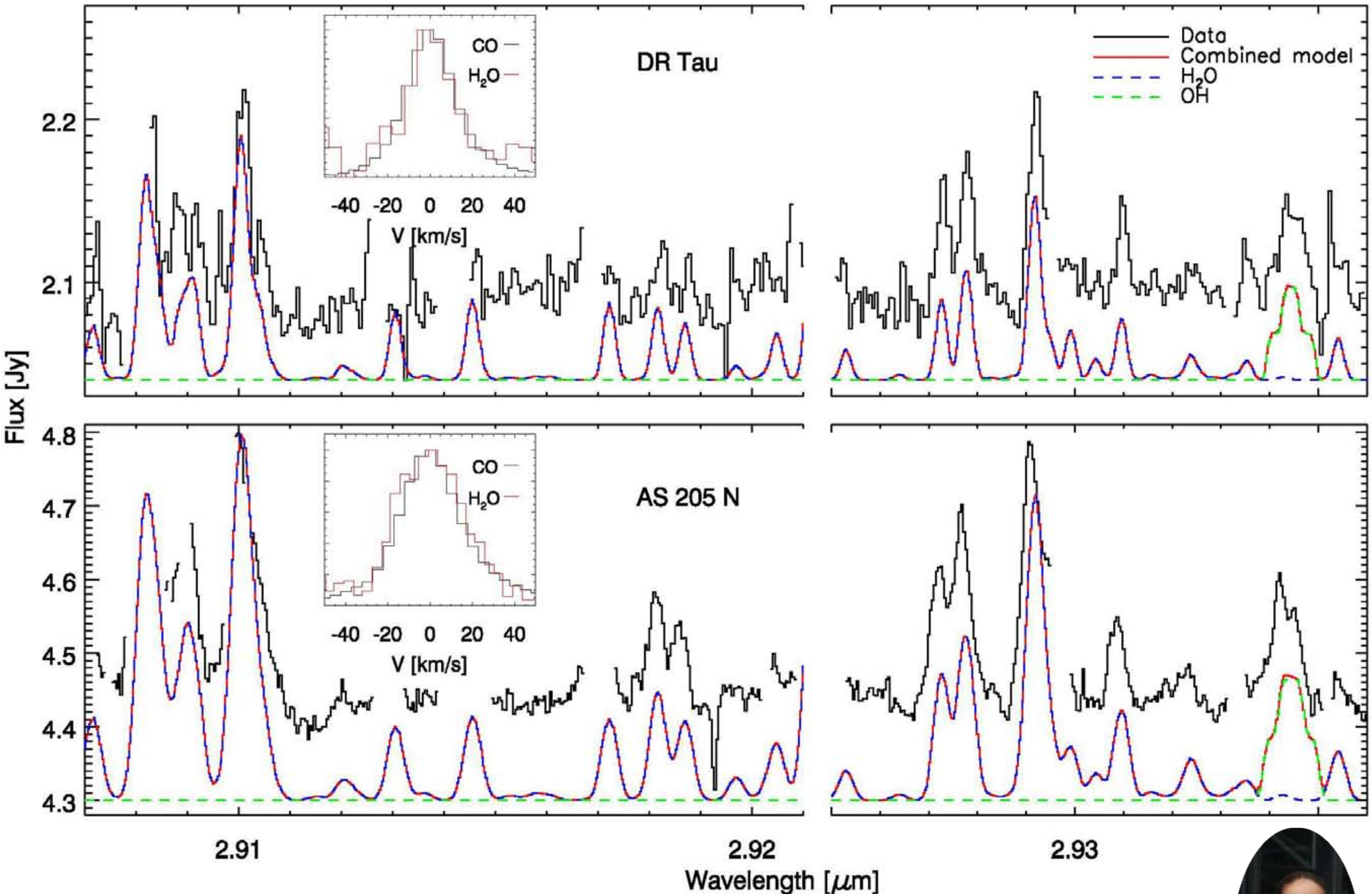
The next key step combined the beautiful emission lines & bands seen with Spitzer (R=600) toward AA Tau (right, Carr & Najita 2008, *Science* **319**, 1504), and AS 205/DR Tau (Salyk et al. 2008) with Keck/NIRSPEC data.
Now >100 objects.





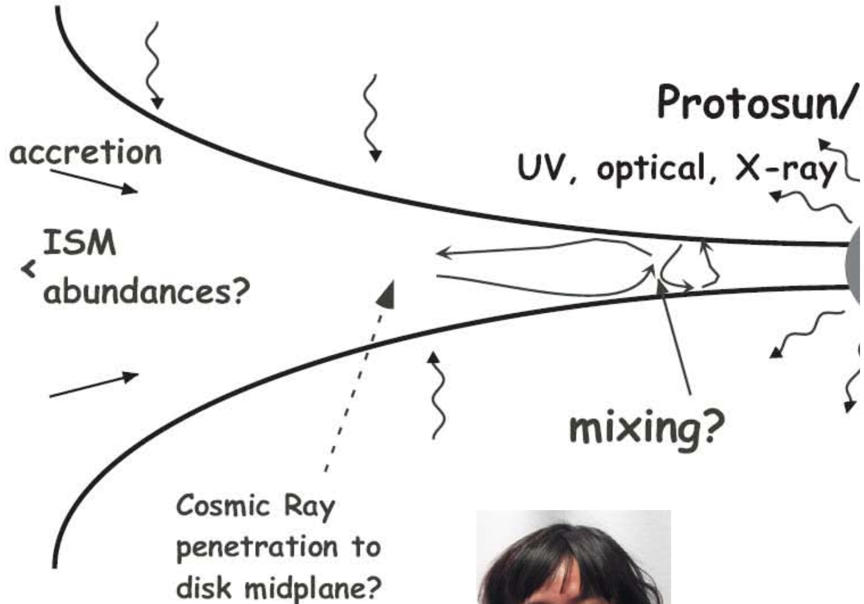
Hard from the ground, H_2O in atm!

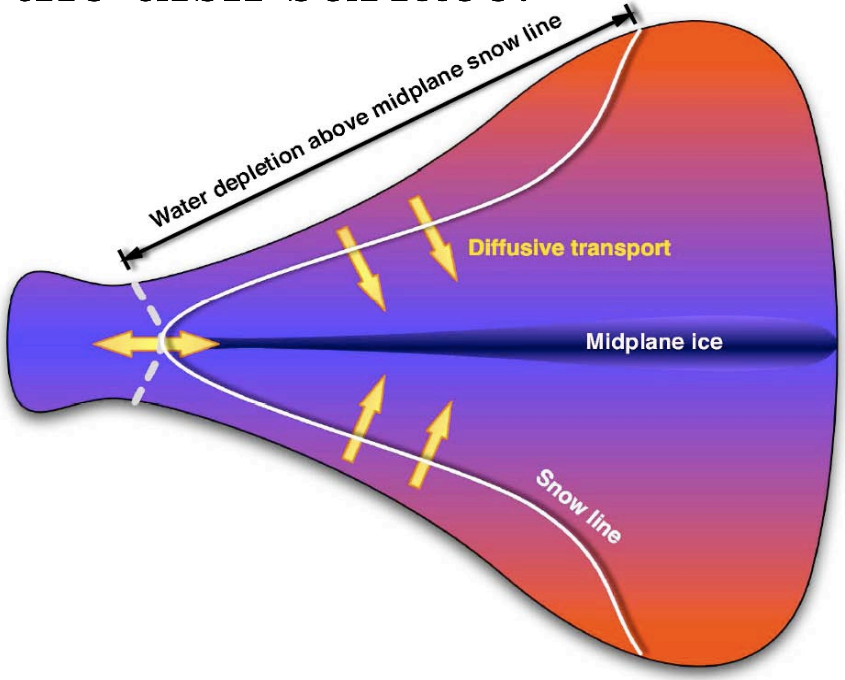
Salyk et al. 2008, ApJ **676**, L49.



Line shape ➡ distance from the star via Doppler shift. Keck confirms disk origin…

And locates the “snow line” at the disk surface:





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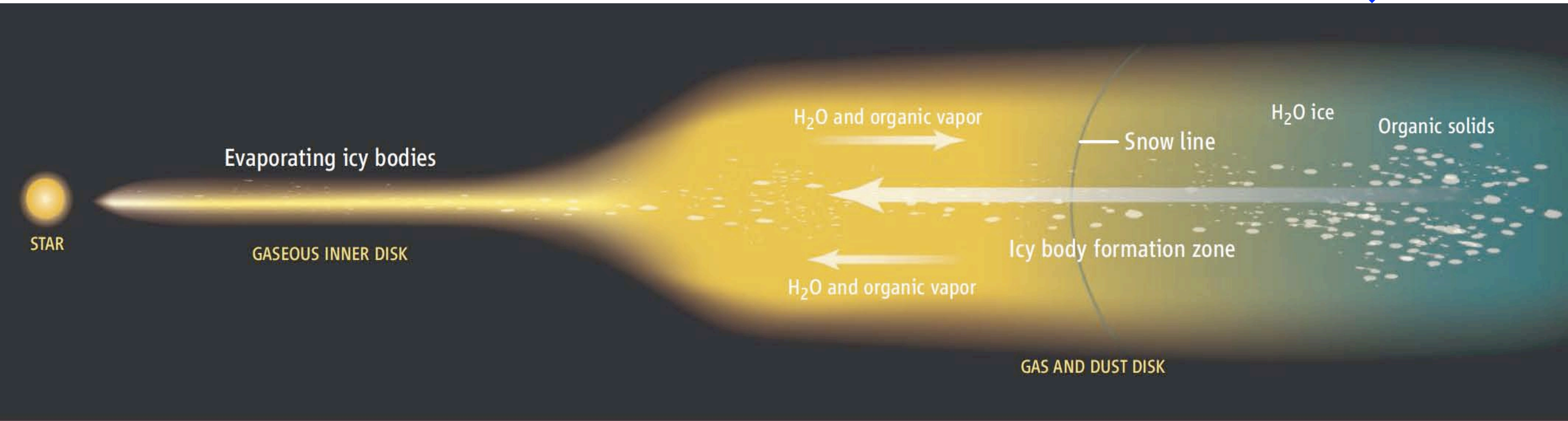
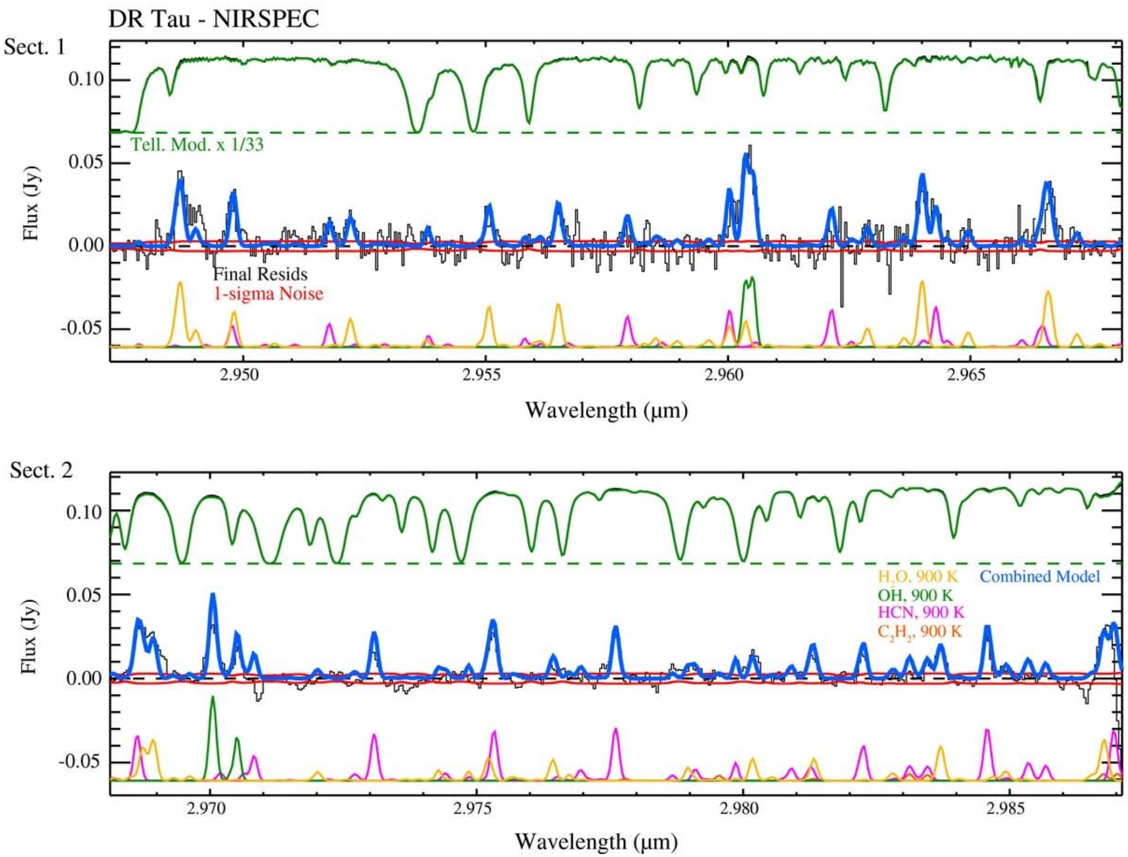
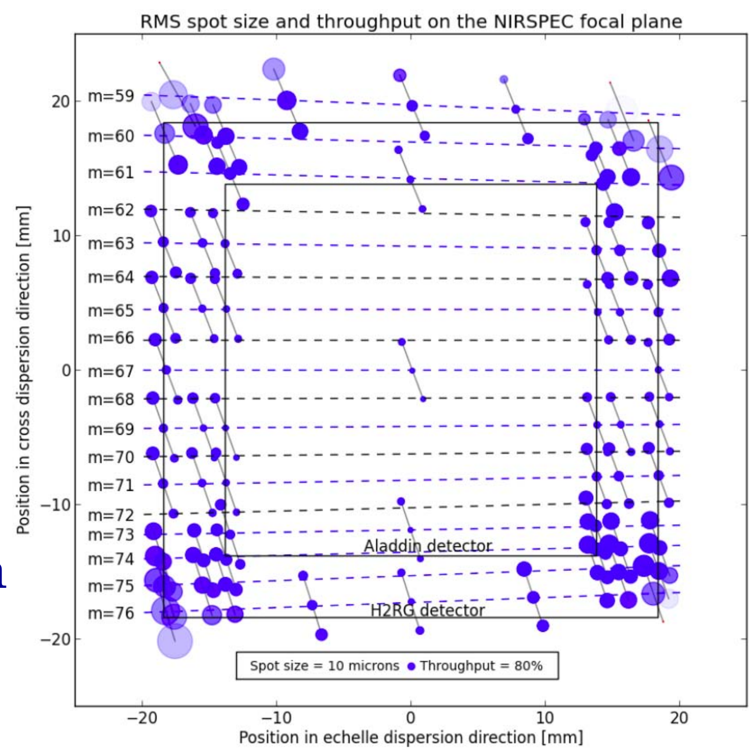


The next ground based steps?



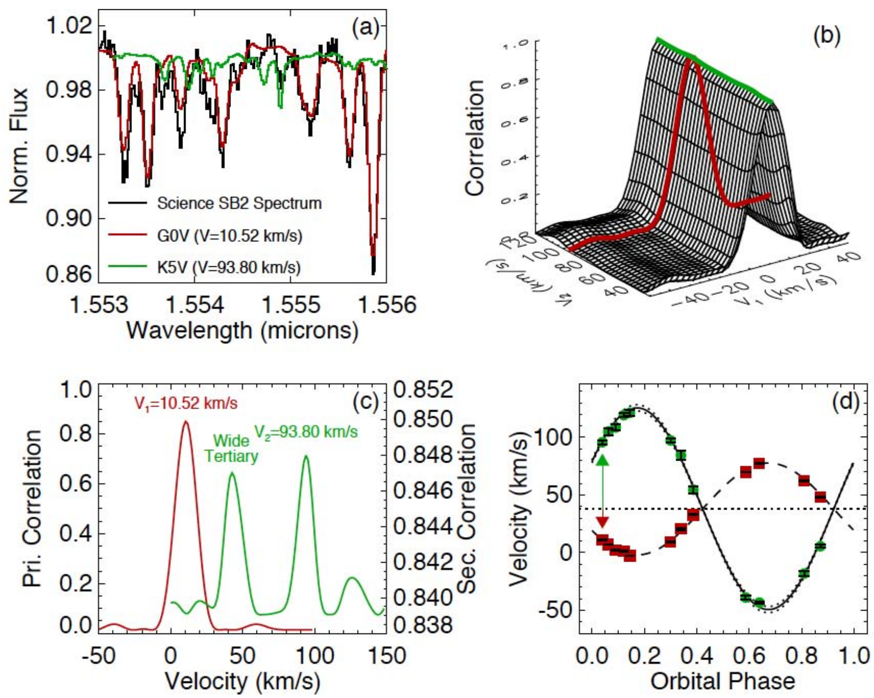
NIRSPEC can achieve a shot noise-limited dynamic range of >1000 for *bright* sources with careful data reduction (nec. for D/H and the like, see Mumma talk).

Velocity-resolved detection of organics, Mandell et al. (2012)

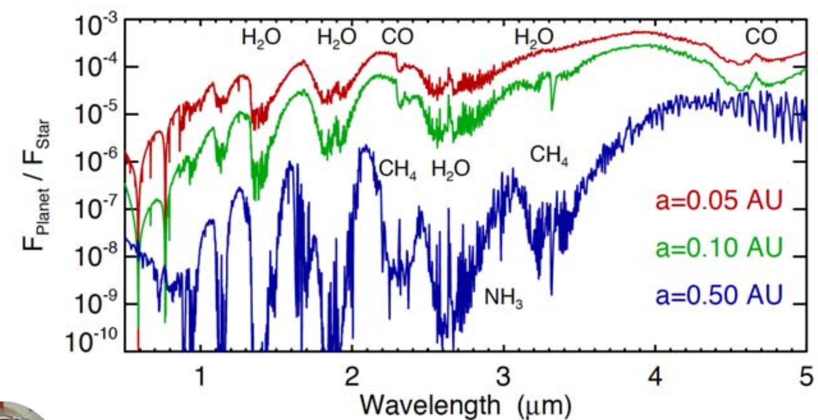


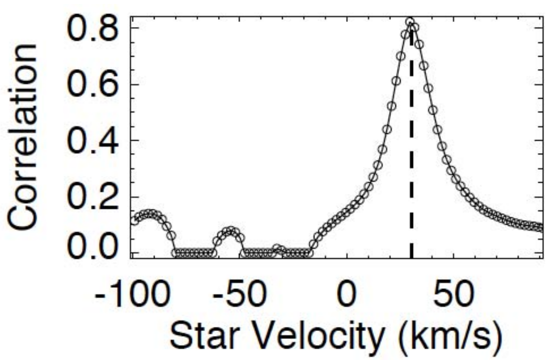
Upgrade would significantly boost spectral resolution & sensitivity, enabling precision surveys for protoplanet tracers (especially CH_4, NH_3) over a larger span of disk radii.

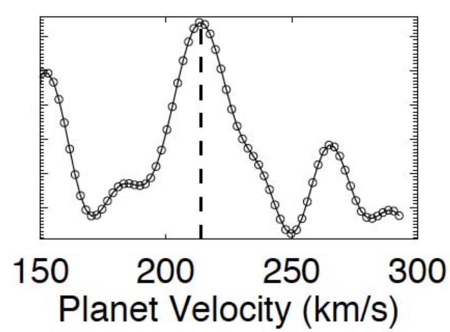
The next steps? Direct detection of exoplanets?

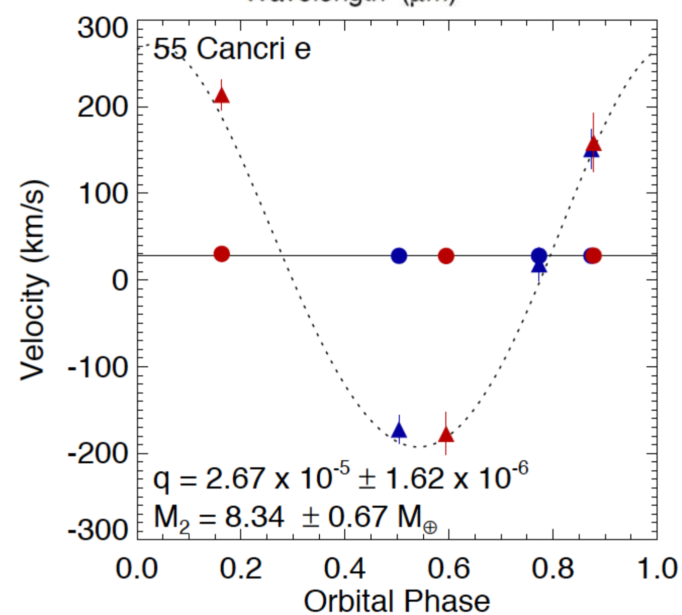


Treat as a high mass ratio spectroscopic binary, and doppler track the planet.

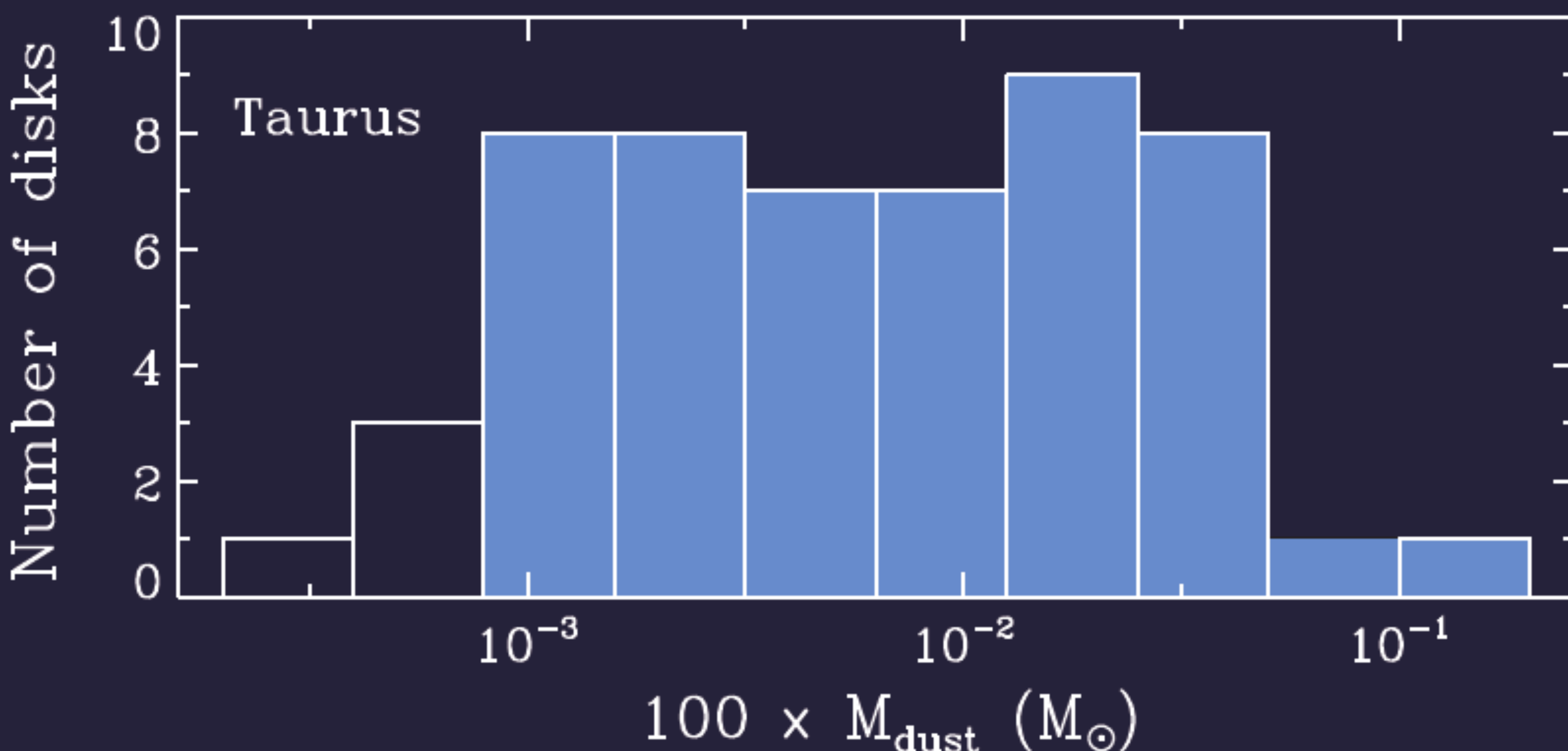






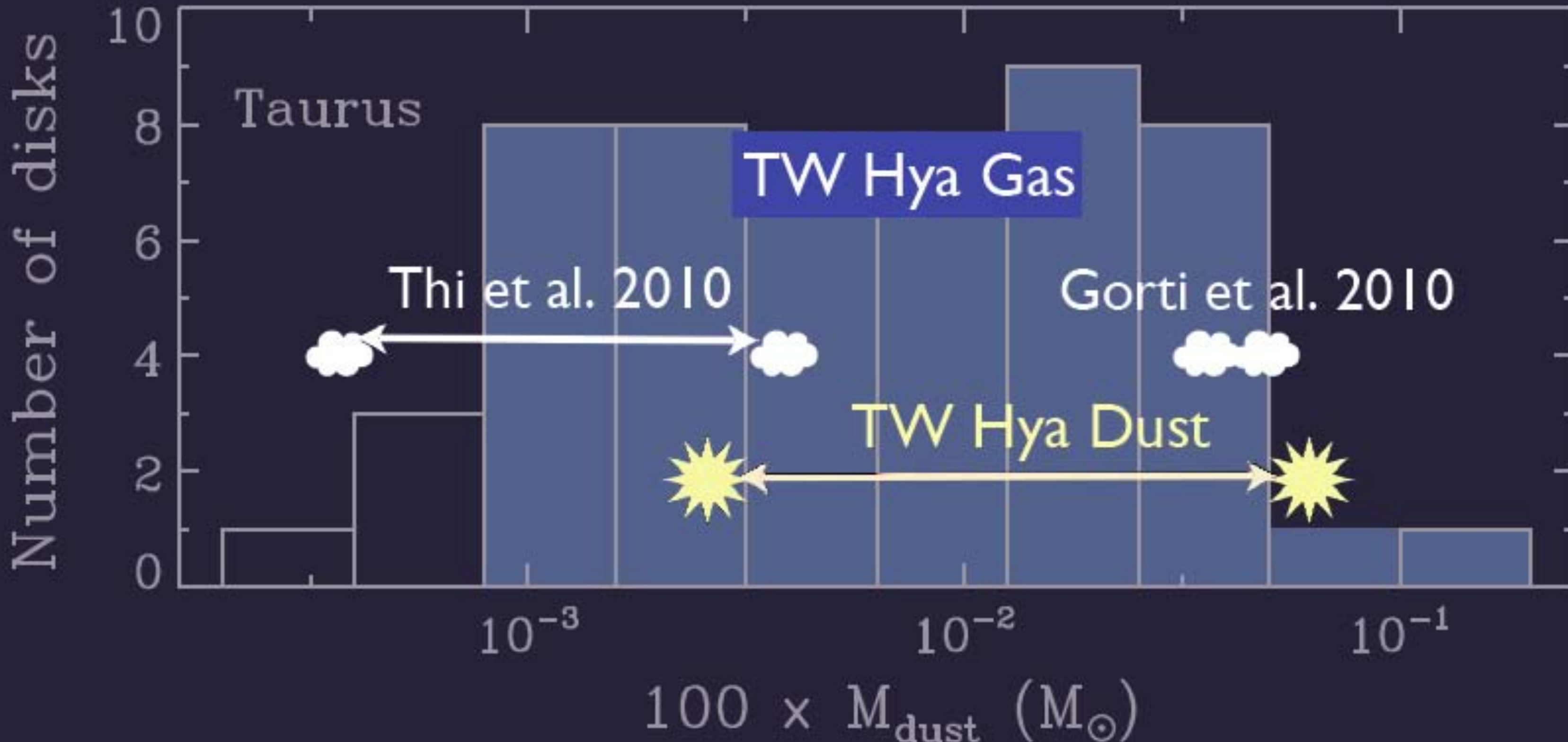


Protoplanetary Disk Gas Mass

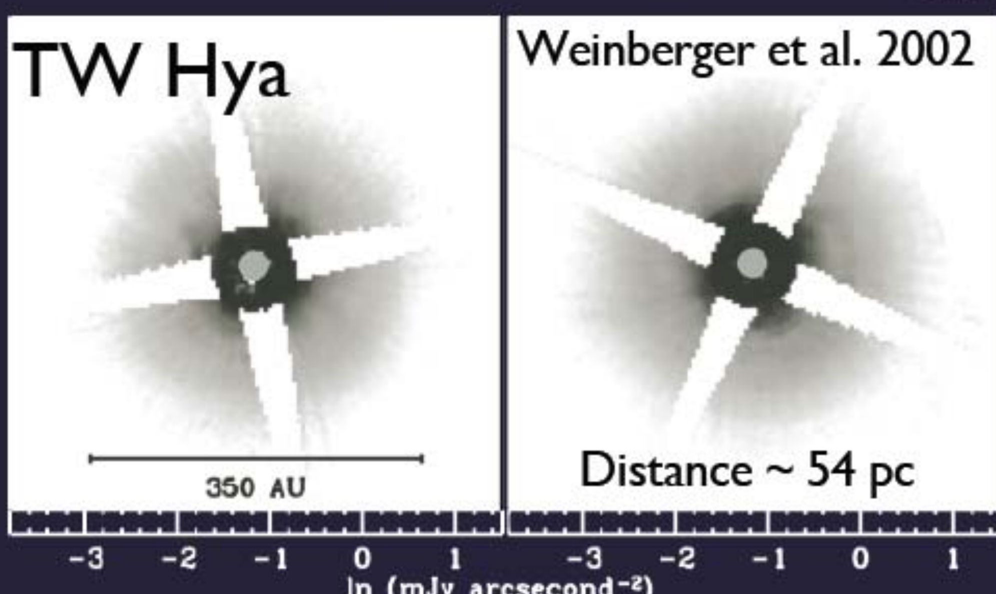


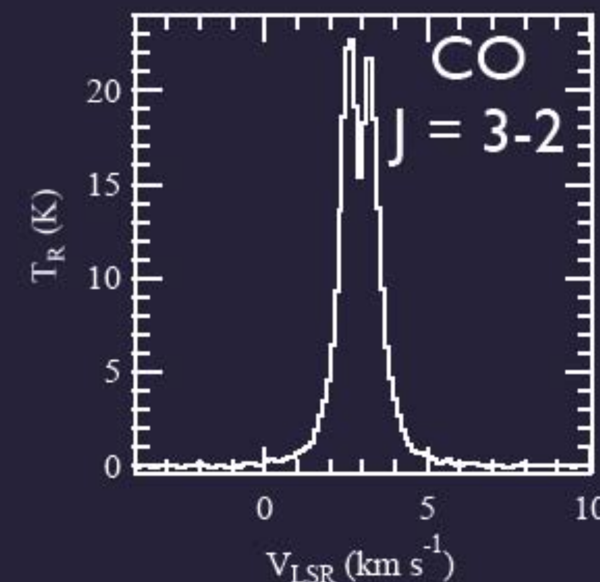
Williams and Cieza 2011

How much of this distribution is due to uncertainty?????

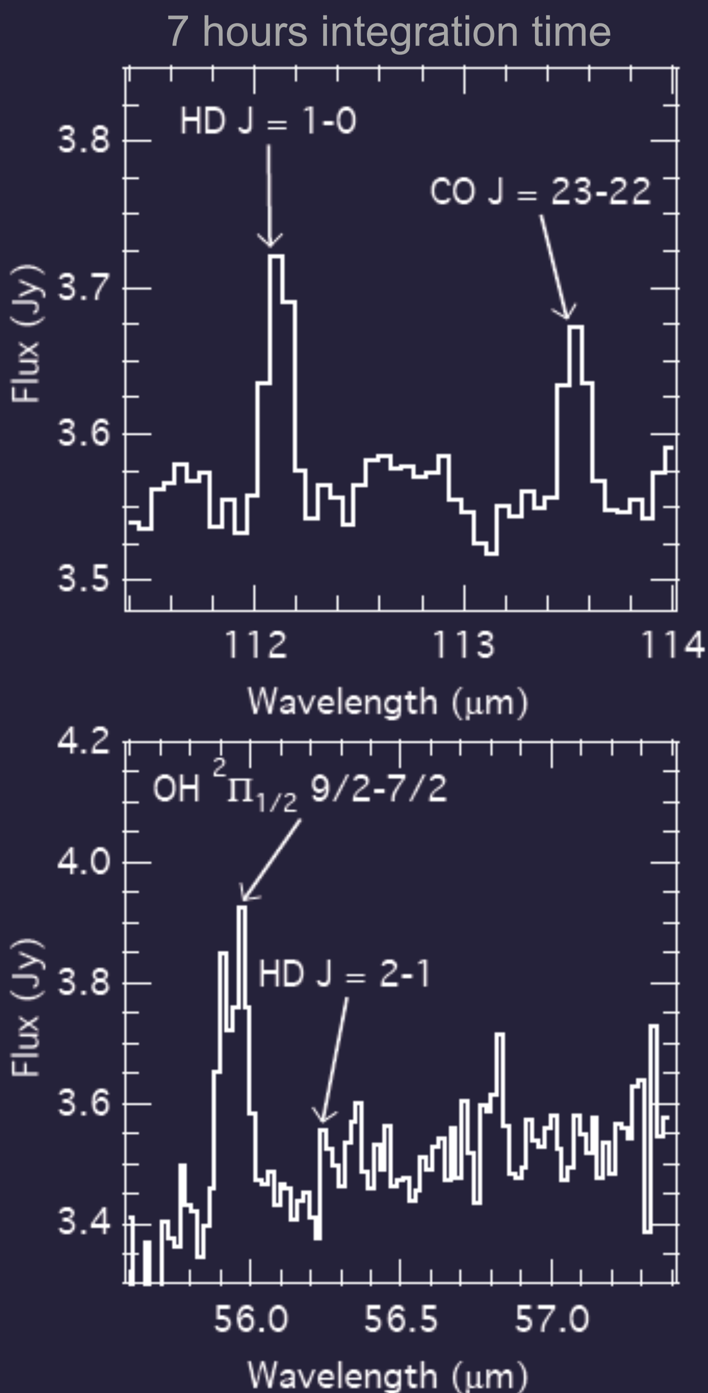


Williams and Cieza 2011





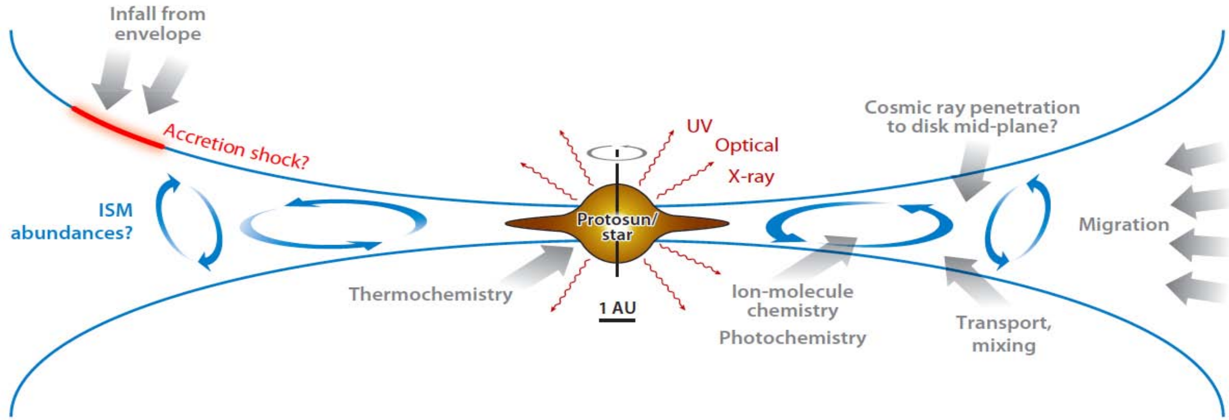
Herschel Detection of HD towards TW Hya

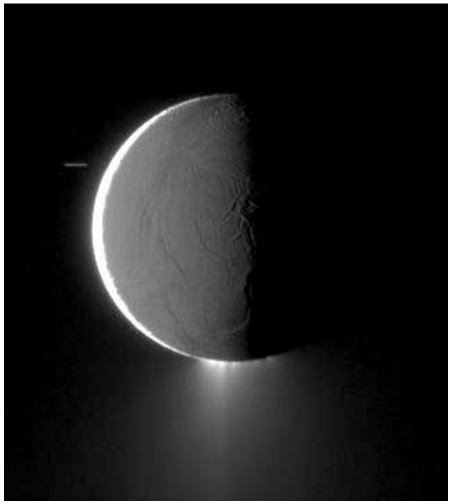


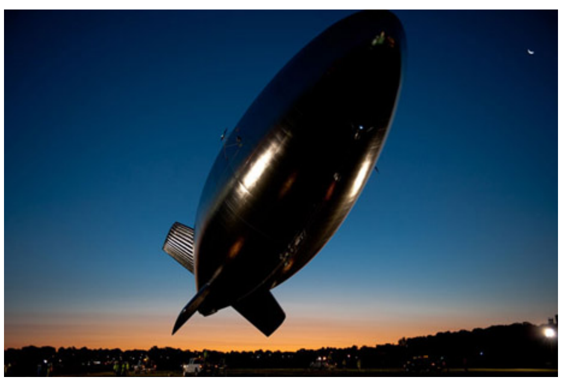
- HD is a million times more emissive than H_2 at T ~ 20 K.
- *Atomic* D/H ratio inside the local bubble is well characterized (~1.5 x 10^{-5})
- HD will follow H_2 in the gas
- New probe of gas mass

Bergin et al. 2013, Nature, 493,

Airships & IR/THz Spectroscopy for (Exo)Planetary Science







- Keck, Spitzer & Herschel have done the pioneering work of the first detections of H_2O & other compounds needed for life in the solar system and in the disks around young stars. The critical next steps involve thhe high resolution study of large samples.
- Can IR echelle format and sensitive THz spectrometers from airship platforms provide this capability?