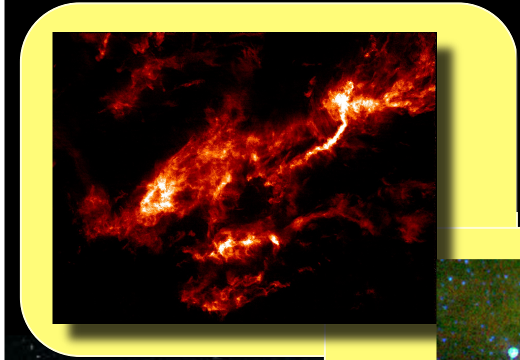
Center for Astrochemical Studies

Max-Planck-Institute for Extraterrestrial Physics

Herschel and ALMA synergy from the ISM to planet forming regions

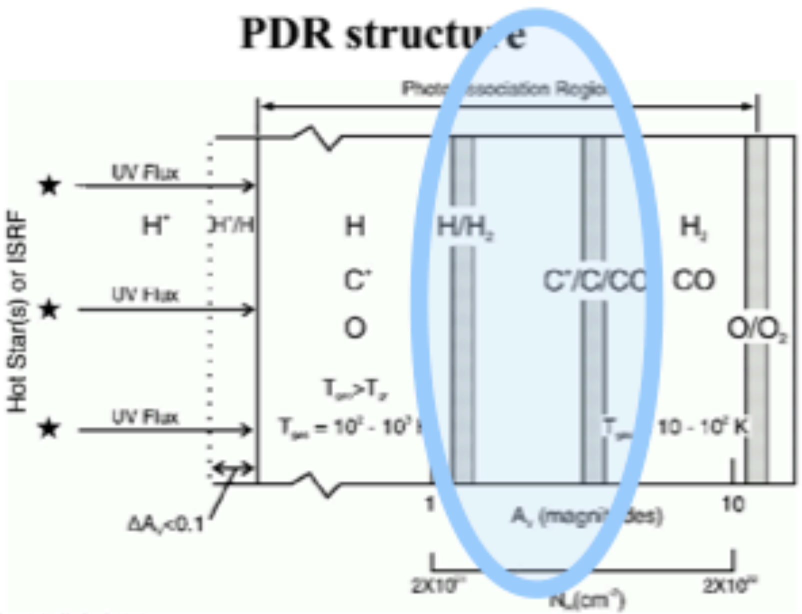


Science, 2005

Unveiling Extensive Clouds of Dark Gas in the Solar Neighborhood

Isabelle A. Grenier,[1*] Jean-Marc Casandjian,[1,2] Régis Terrier[3]

From the comparison of interstellar gas tracers in the solar neighborhood (HI and CO lines from the atomic and molecular gas, dust thermal emission, and γ rays from cosmic-ray interactions with gas), we unveil vast clouds of cold dust and dark gas, invisible in HI and CO but detected in γ rays. They surround all the nearby CO clouds and bridge the dense cores to broader atomic clouds, thus providing a key link in the evolution of interstellar clouds. The relation between the masses in the molecular, dark, and atomic phases in the local clouds implies a dark gas mass in the Milky Way comparable to the molecular one.



Tielens & Hollenbach 1985

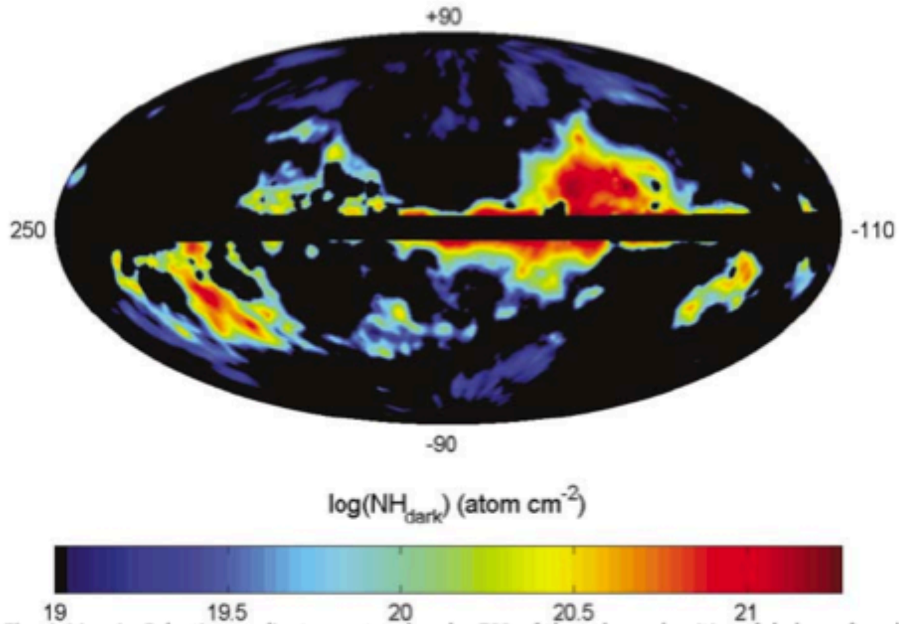
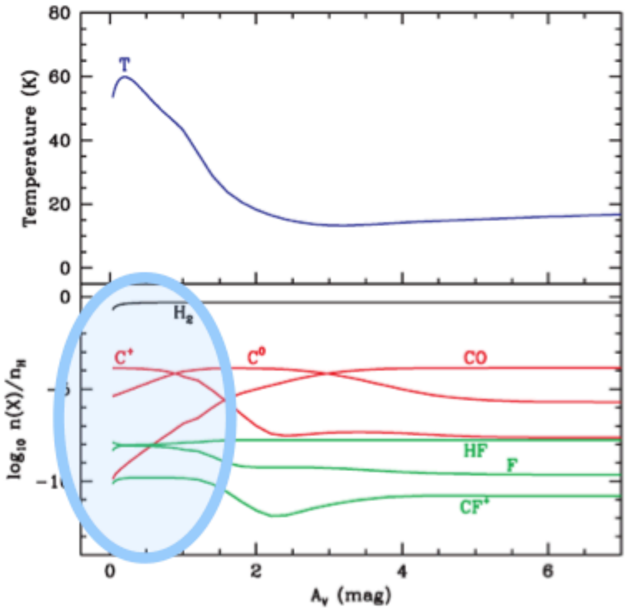
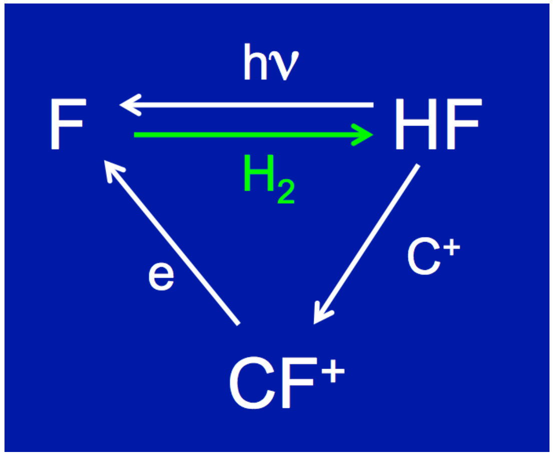


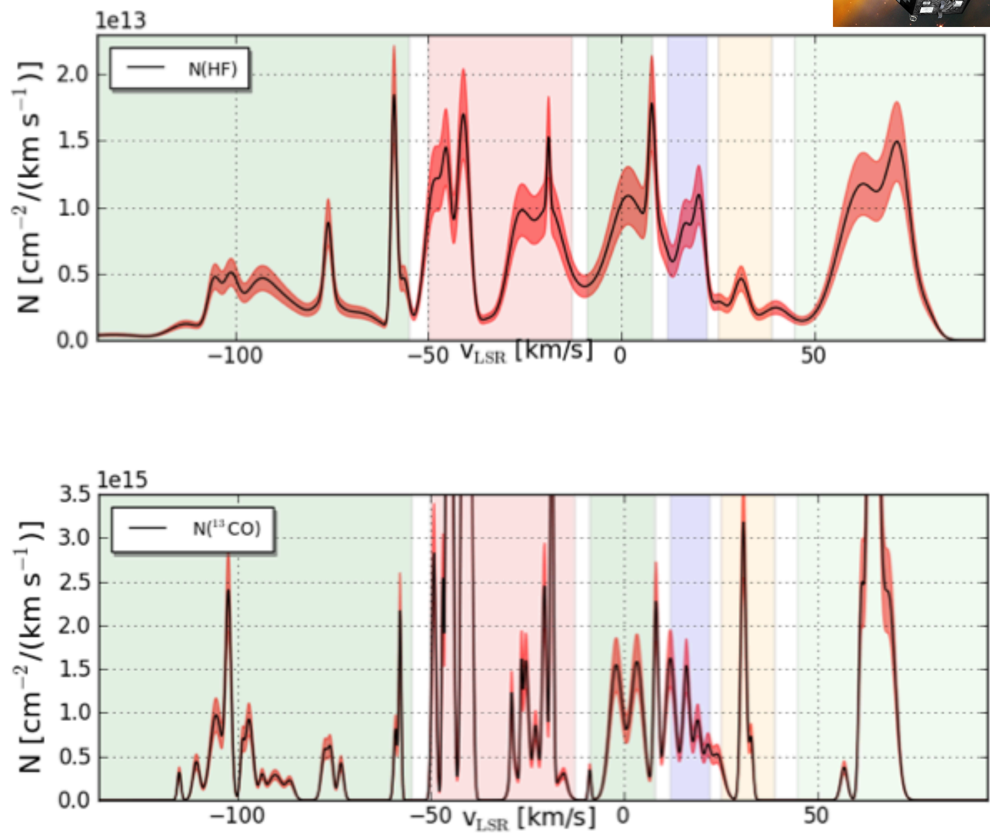
Fig. 4. Map, in Galactic coordinates centered on $l = 70°$, of the column densities of dark gas found in the dust halos, as measured from their γ-ray intensity with the reddening map. This gas complements that visible in HI and CO. The two dust tracers [E(B-V) and 94-GHz emission] yield consistent values within 30% over most regions.

Tracers other than C^+ – the Herschel legacy



Neufeld, Wolfire & Schilke 2005



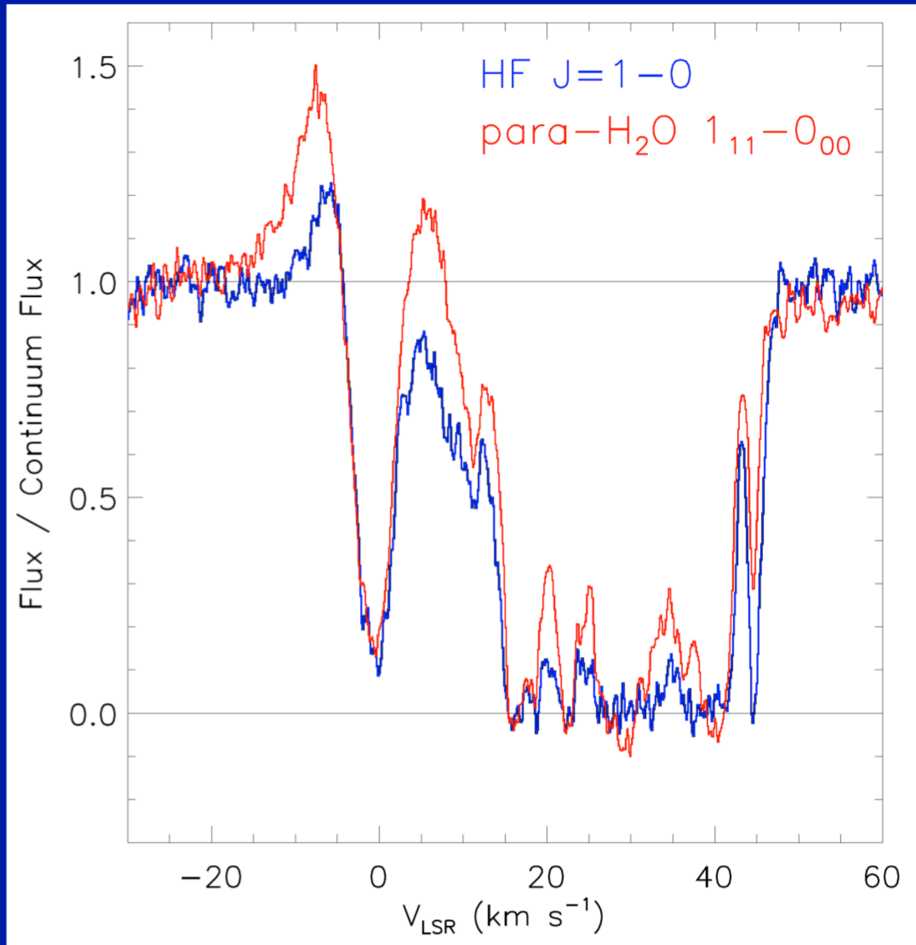


SgrB2(M) HEXOS (HF), SMA, PdB (CO)

Courtesy of Peter Schilke

Strong HF absorption observed toward G10.6 – 0.4 (W31C)

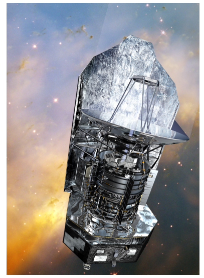
Remarkably, the optical depth for HF is larger than that for para-H_2O, even though the elemental abundance of fluorine is 10^4 times smaller than that of oxygen

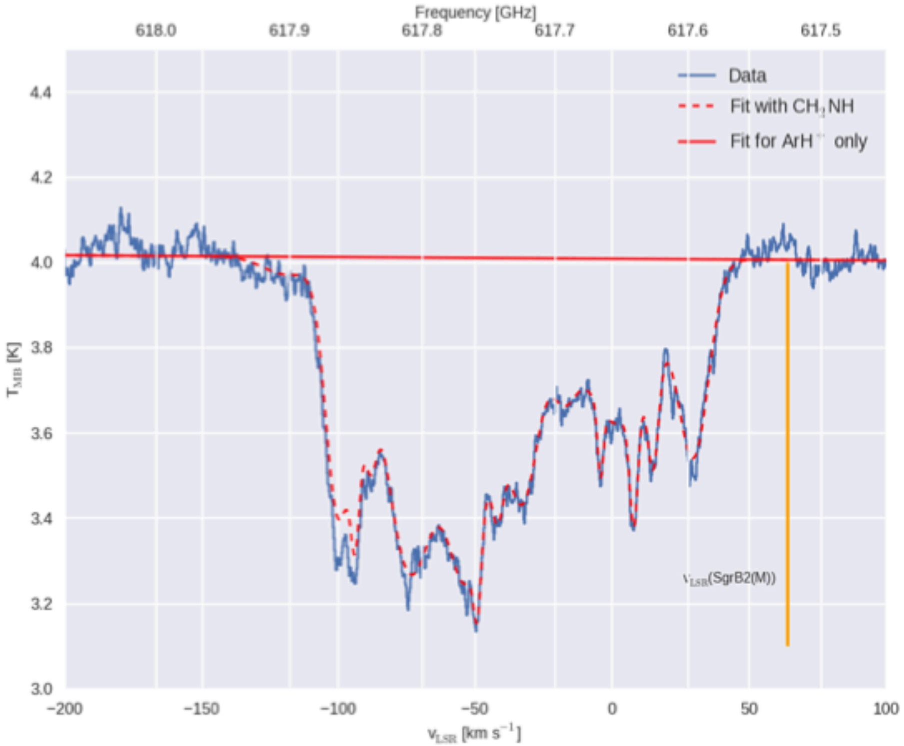


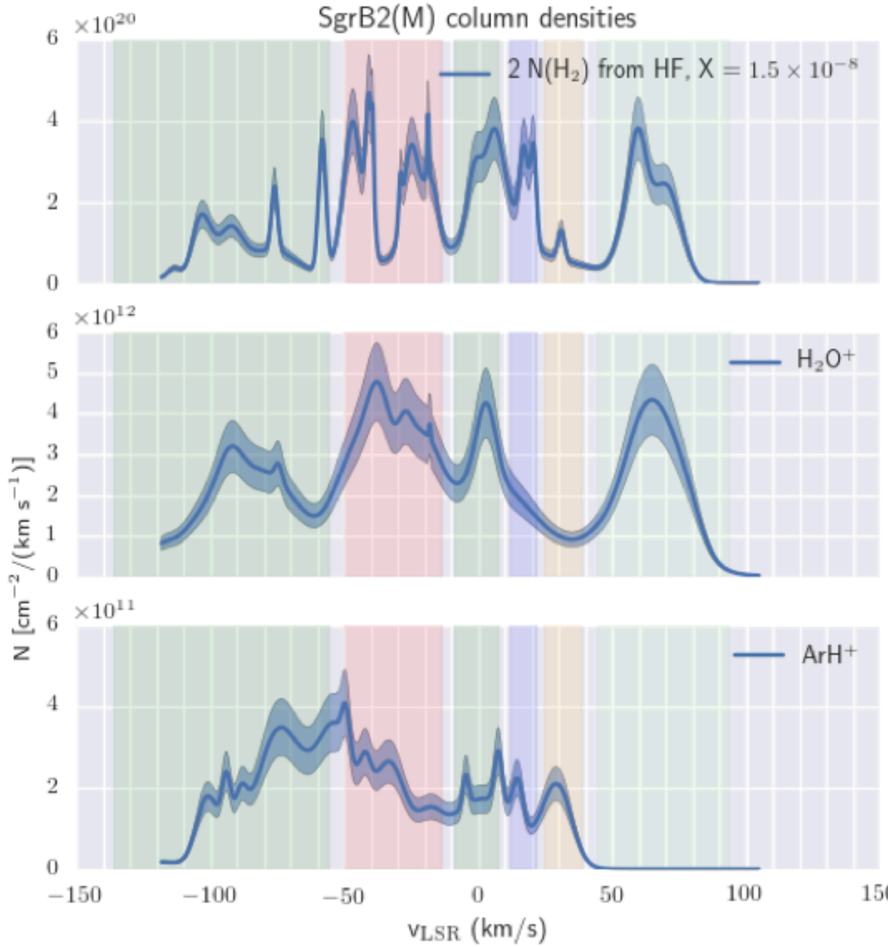
Courtesy of David Neufeld

Neufeld et al. 2010

ArH^+



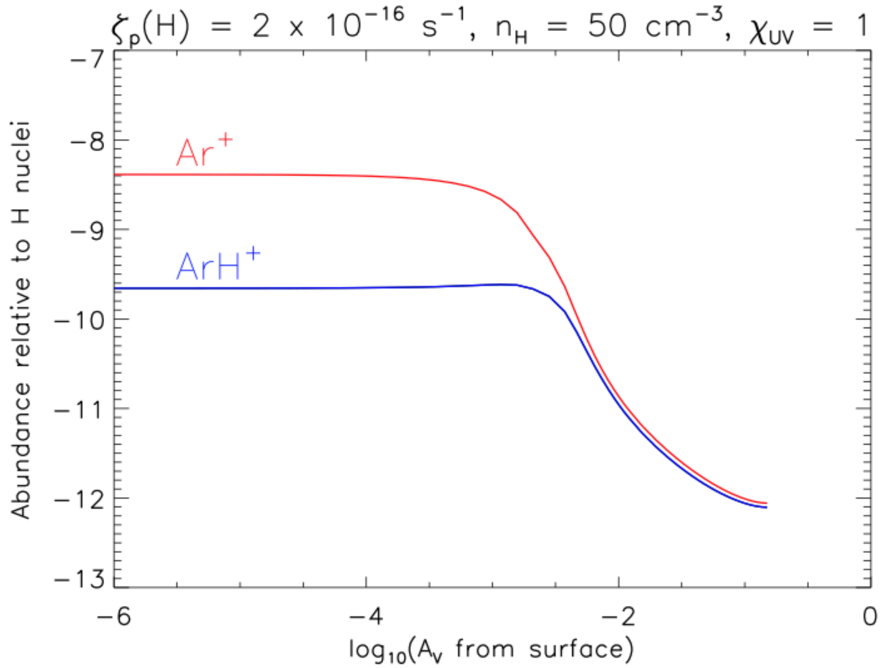


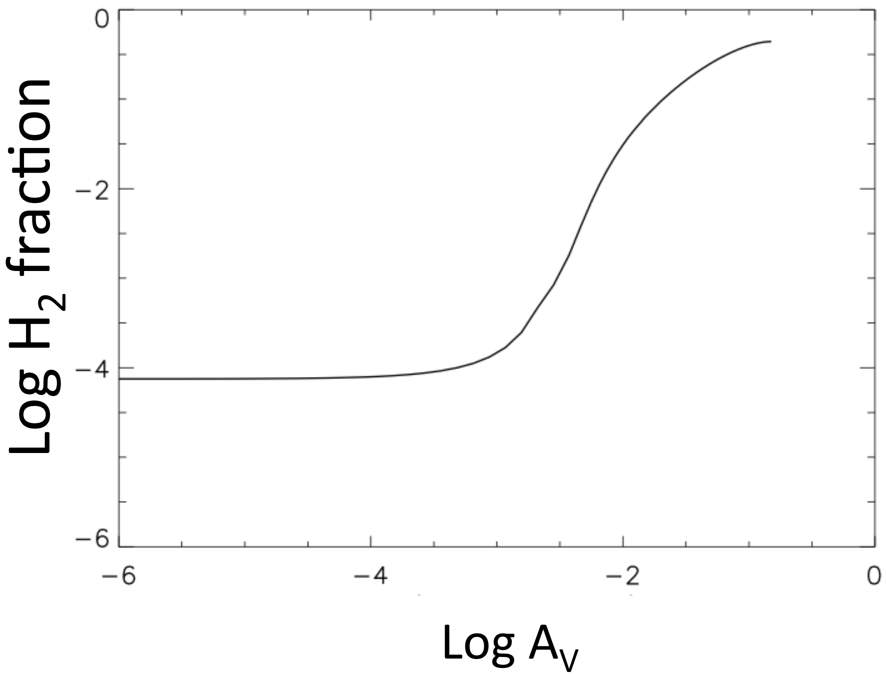


ArH^+ singles out gas that is >99.9% atomic (i.e. it is a better tracer of almost purely atomic hydrogen than HI itself!)

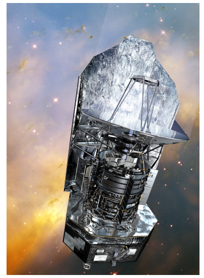
Schilke et al. 2014

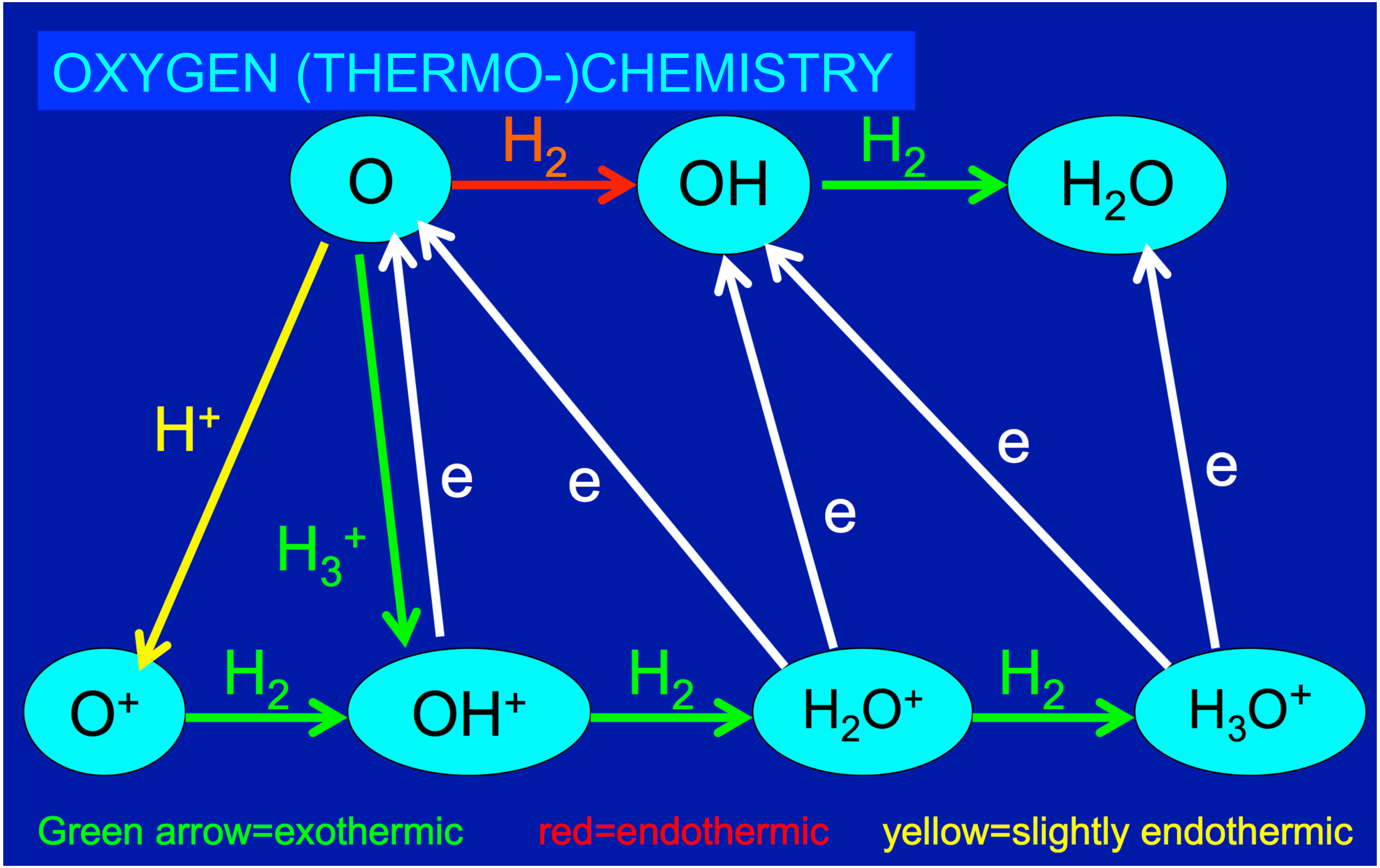
ArH^+





Schilke et al. 2014



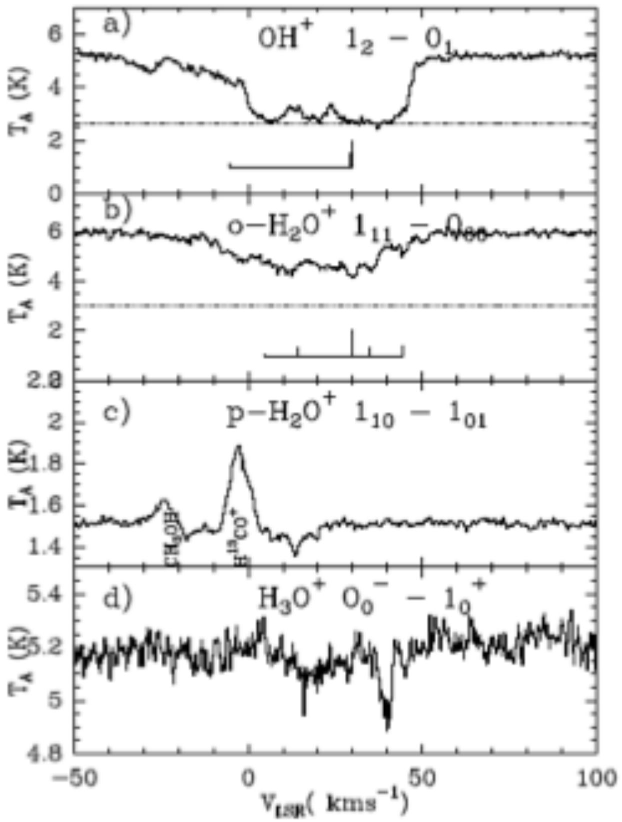


Courtesy of David Neufeld

Discovery of OH^+ & H_2O^+

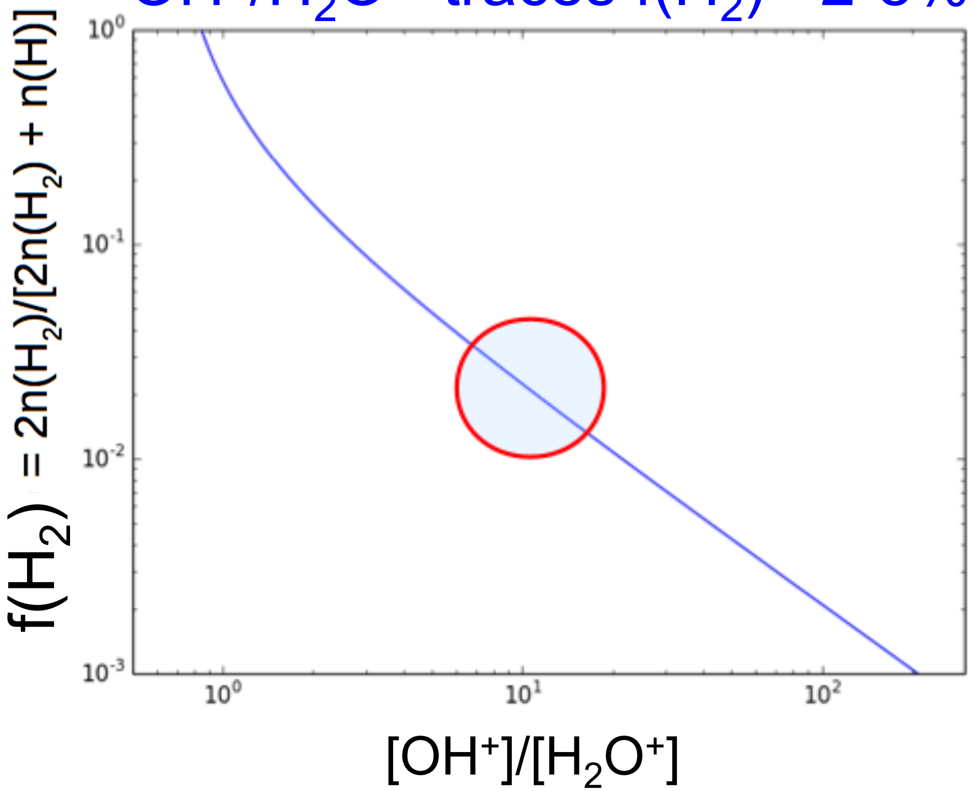
$$\frac{k(H_2|OH^+)}{k(H_2|H_2O^+)} + \frac{n(e)k(e|H^+)}{n(H_2)k(H_2|H_2O^+)} = 0.64 + 1490\,\frac{x_e T_2^{-0.5}}{f(H_2)}$$

Neufeld et al. 2010

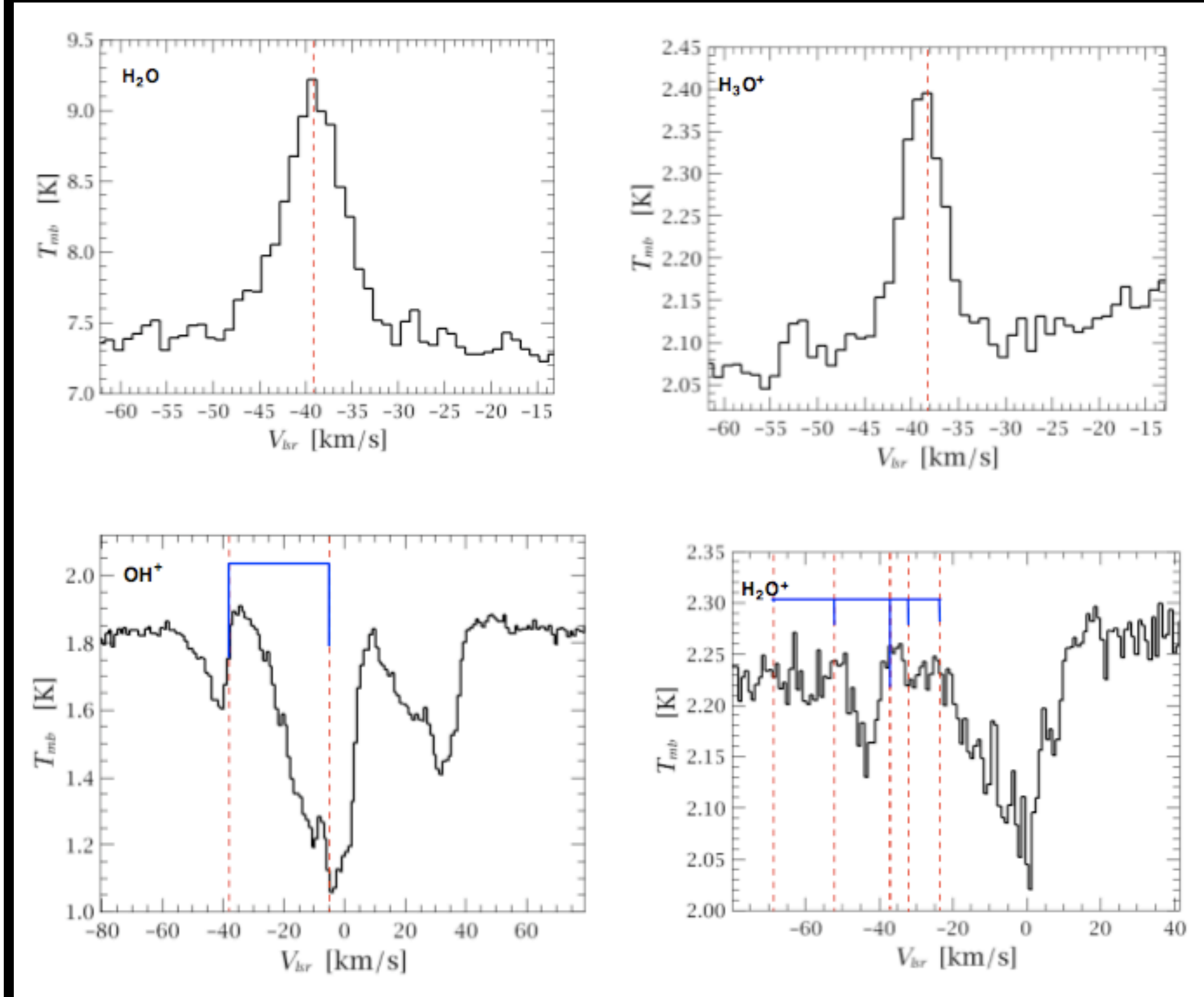


Gerin et al. 2010 (G10.6-0.4)

OH^+/H_2O+ traces $f(H_2)$ ~2-8%



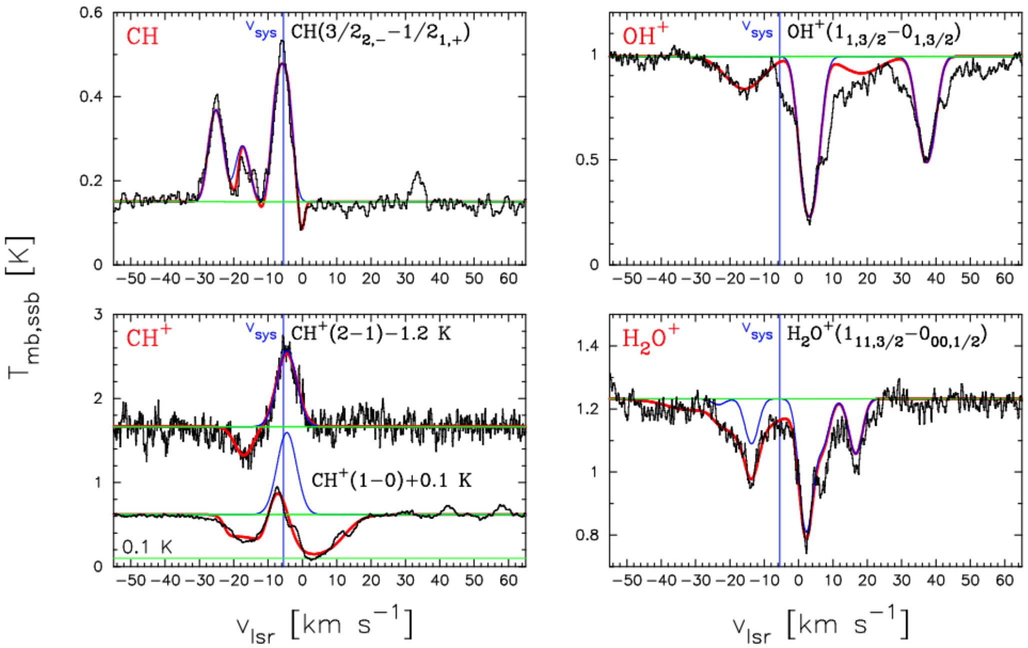
WISH: Water In Star-forming regions with Herschel

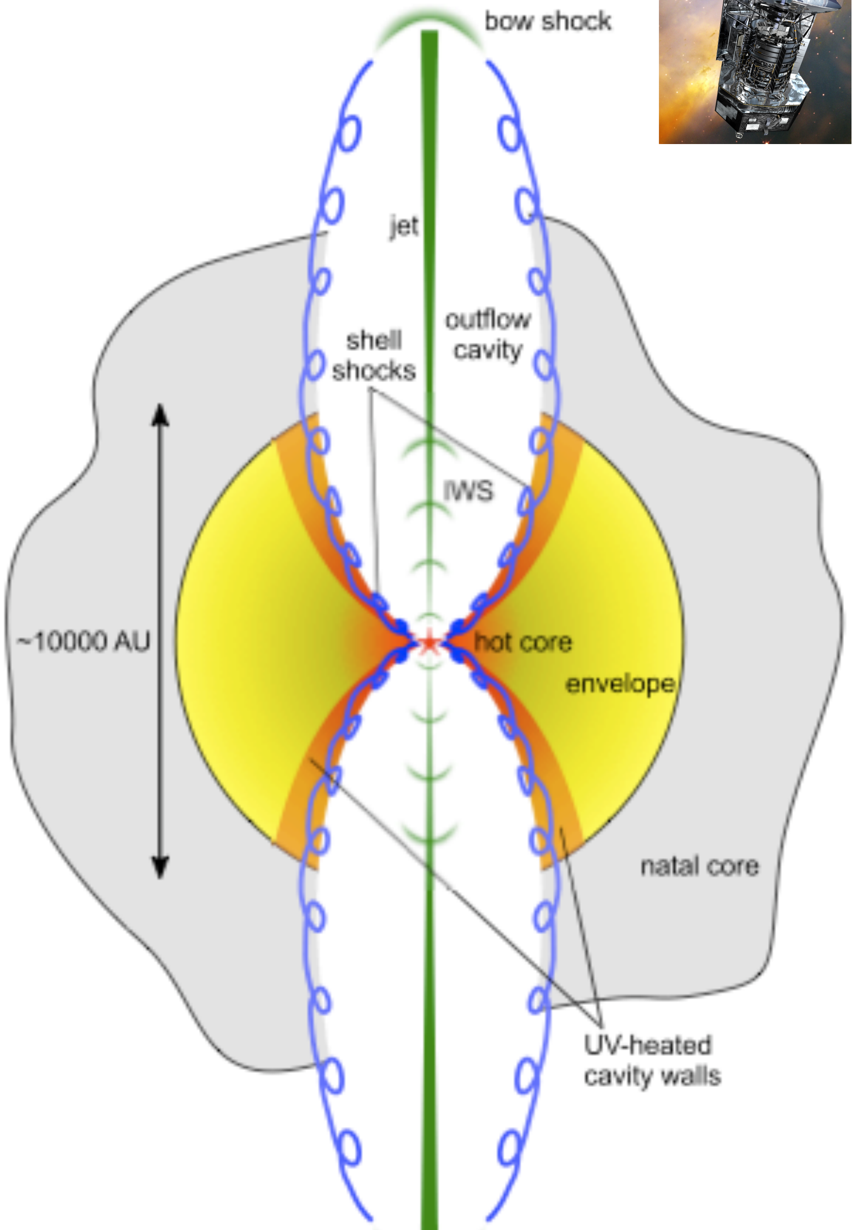


Detection of hydrides toward the high mass YSO W3 IRS 5: low density and high UV field (Benz et al. 2010)

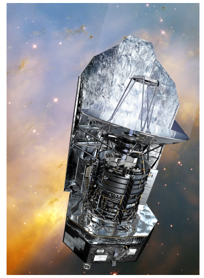
H_2O^+/H_2O from 0.01 to > 1 (Wyrowski et al. 2010)

Other hydrides, in particular CH^+, trace FUV irradiated cavity walls *(e.g. Bruderer et al. 2010)*

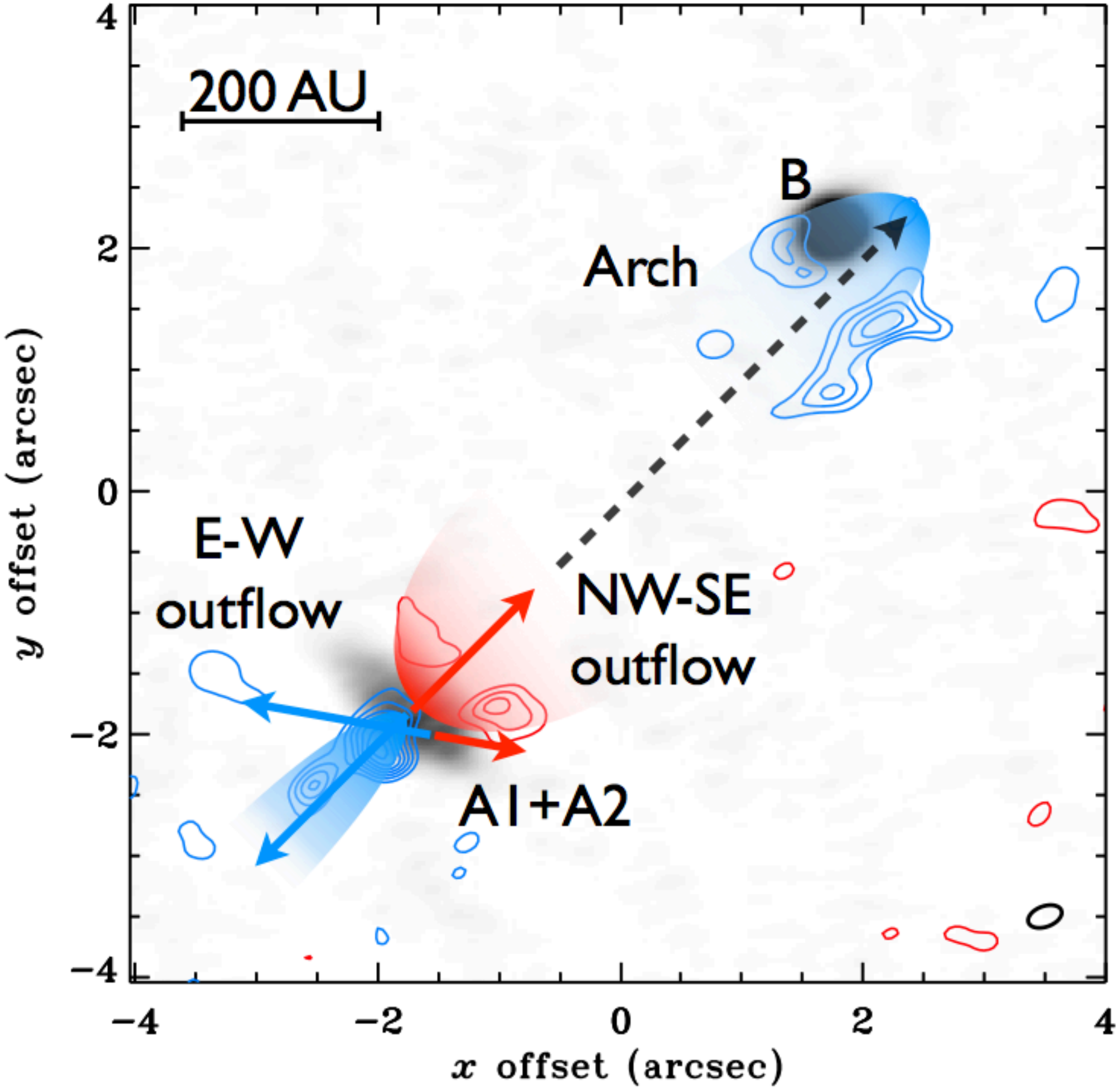




Credit: R. Visser



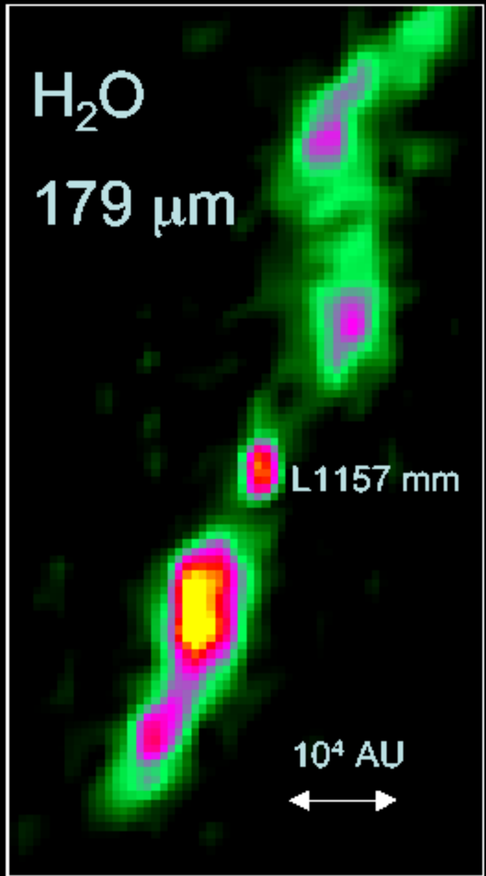
ALMA CO(6-5) toward IRAS 16293-2422



Kristensen et al. 2013

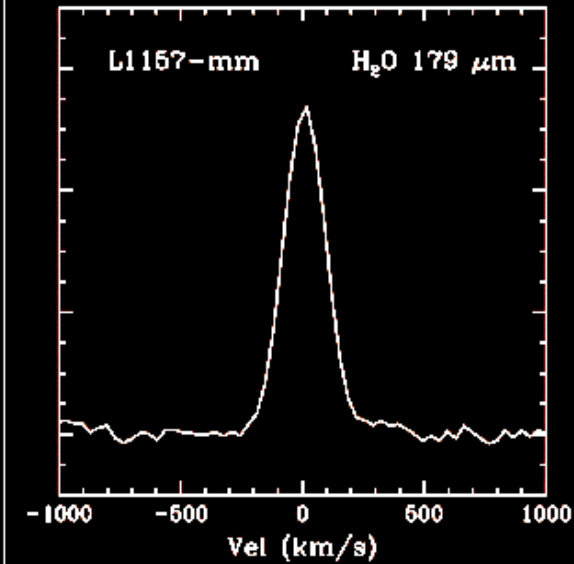
Herschel-PACS image of water in proto-stellar systems

3’



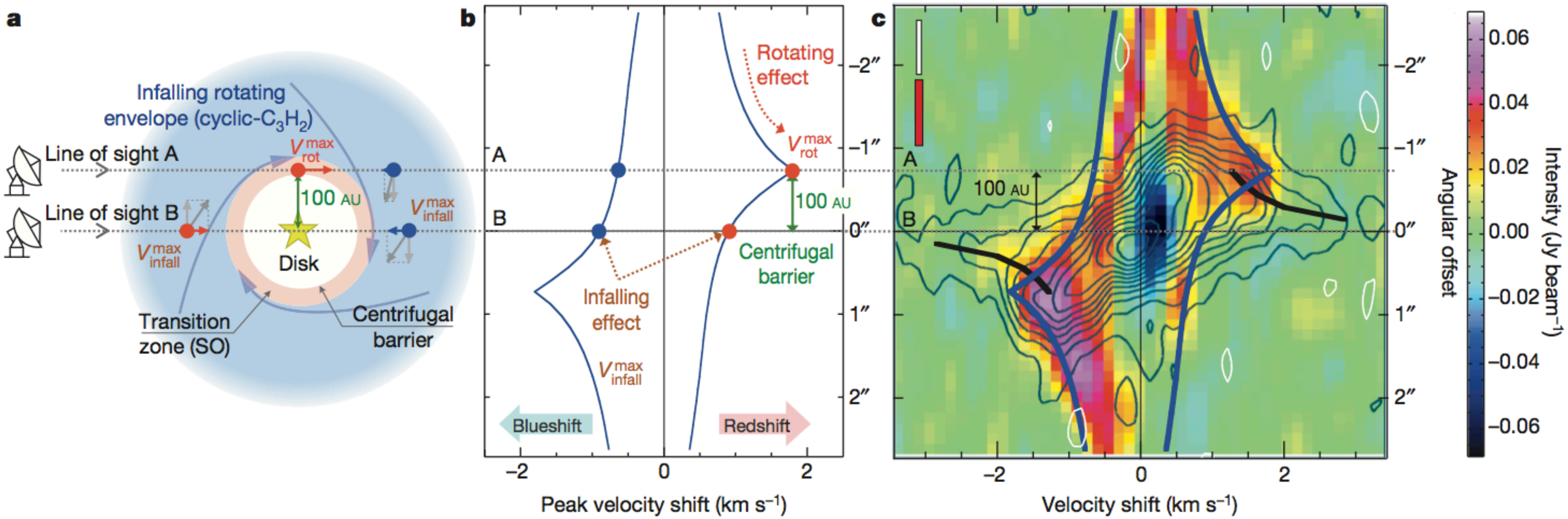
Nisini et al. 2010

L1157-mm outflow
***D* = 440 pc, L_{bol} = 8.3 L$_o$**



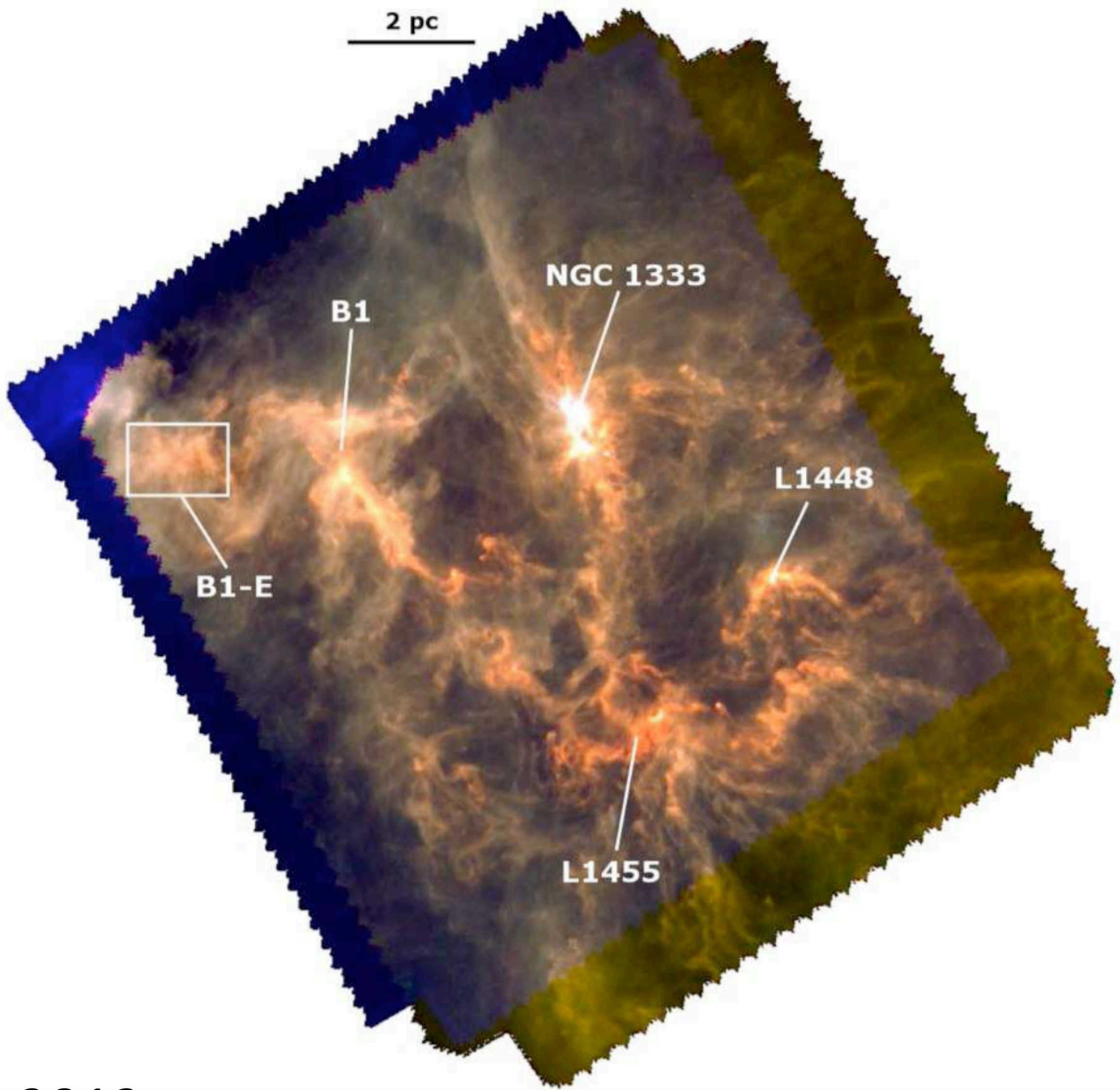
Water traces ‘hot spots’ where shocks dump energy into cloud

SO and C_3H_2 to trace the inner few hundred AU of young protostar (L1527)

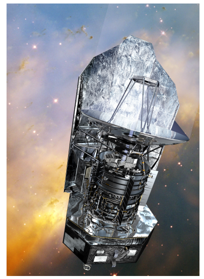


Sakai et al. 2014, Nature

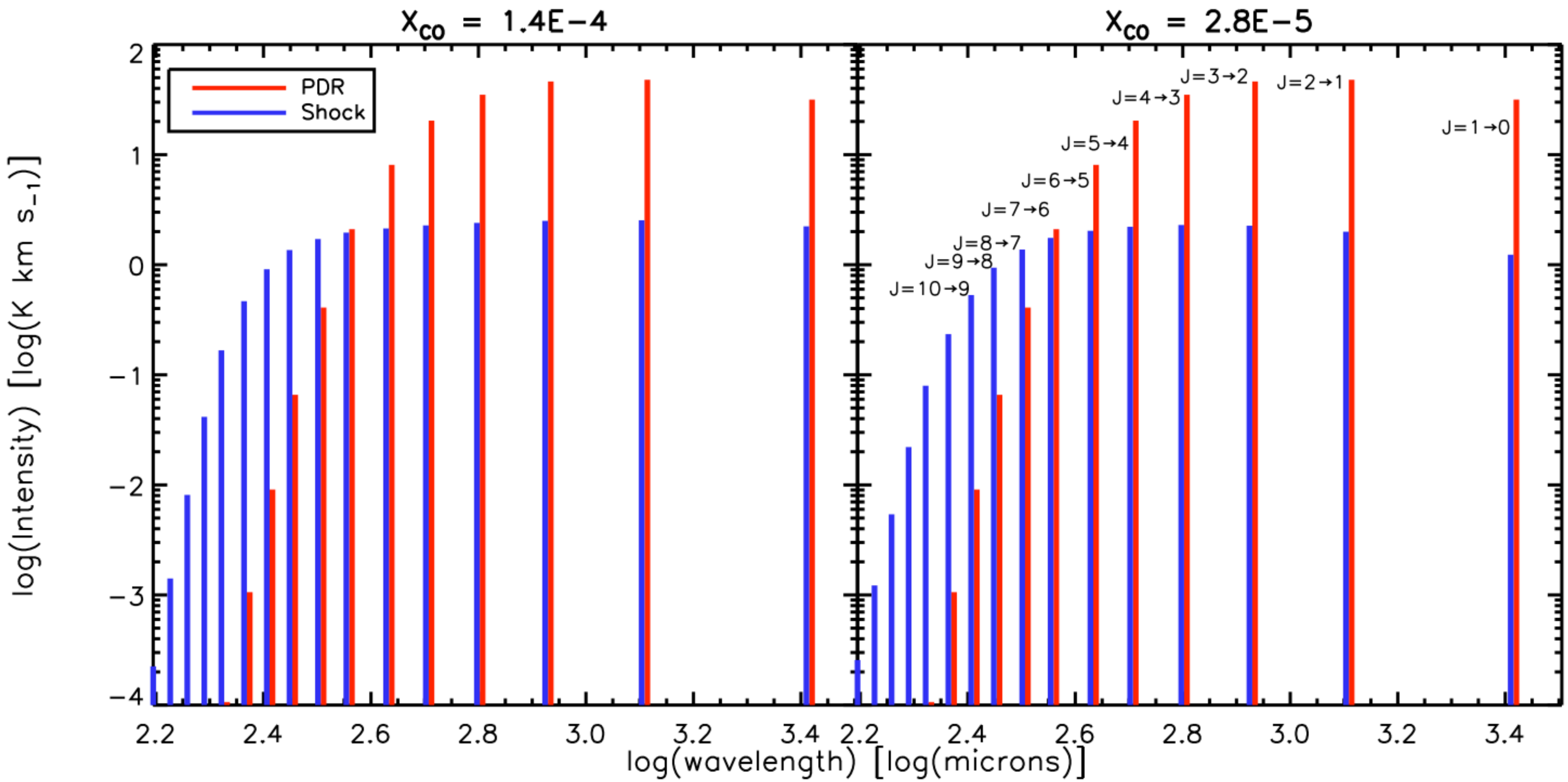
Evidence of turbulence dissipation via low-velocity shocks in Per B1E *(Pon et al. 2014)*



Sadavoy et al. 2012

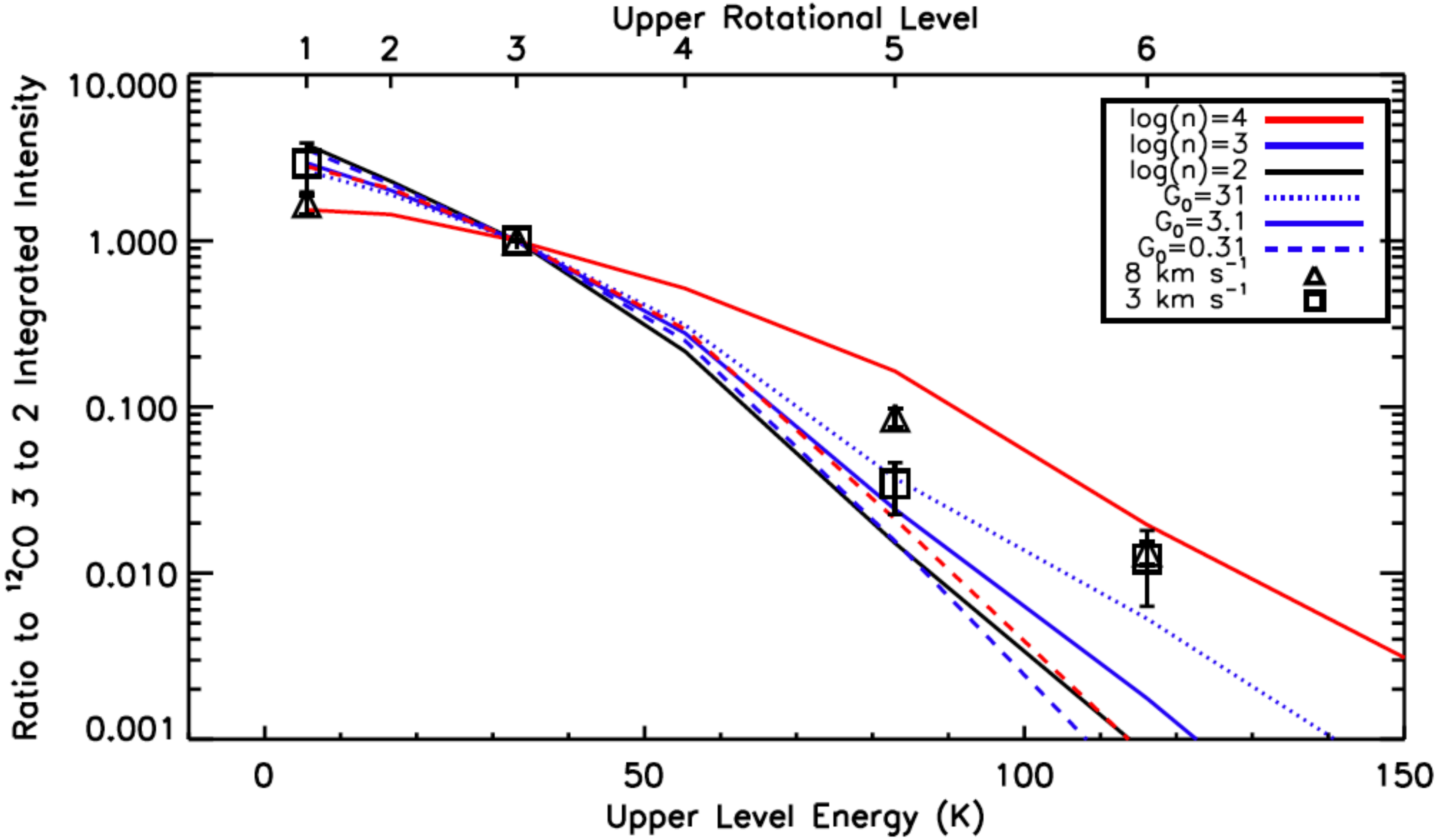


Evidence of turbulence dissipation via low-velocity shocks in Per B1E



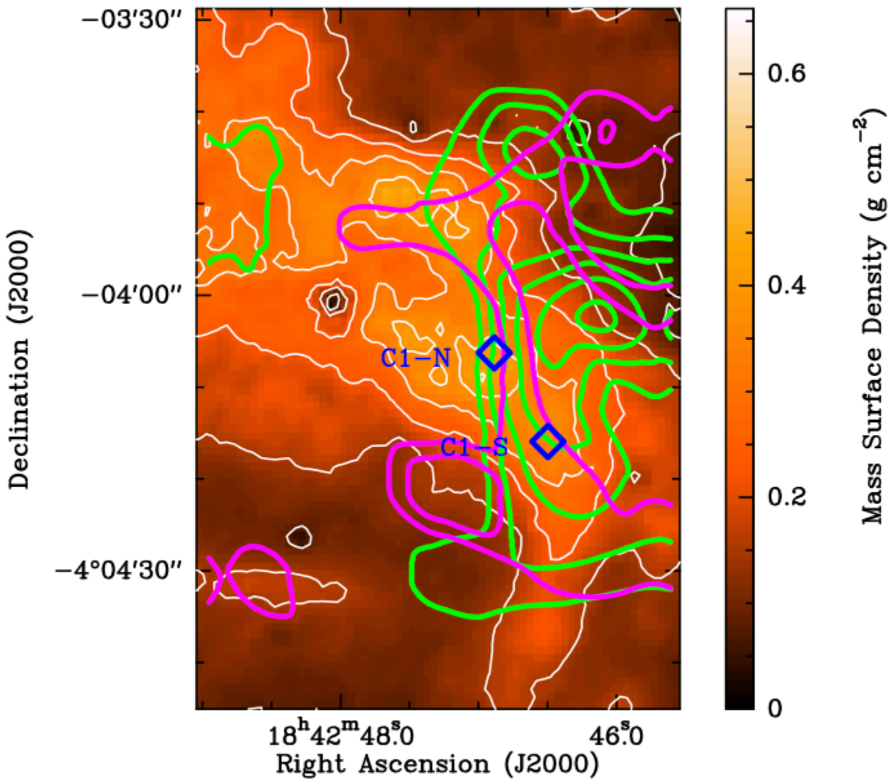
Pon et al. 2012

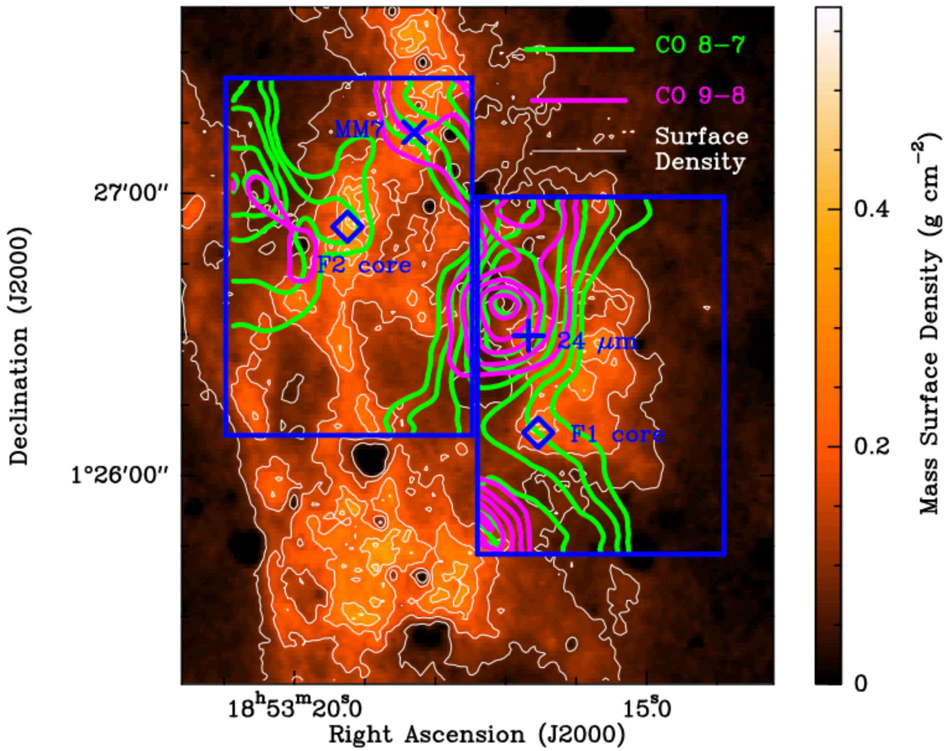
Evidence of turbulence dissipation via low-velocity shocks in Per B1E



Pon et al. 2015a

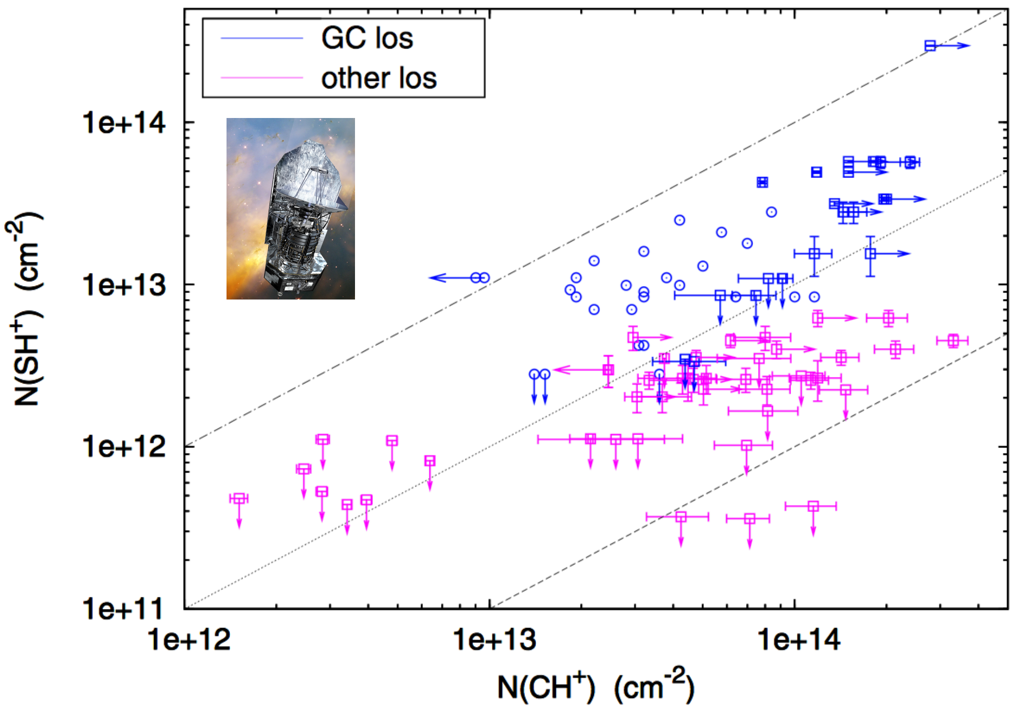
Evidence of turbulence dissipation via low-velocity shocks in quiescent Infrared Dark Clouds



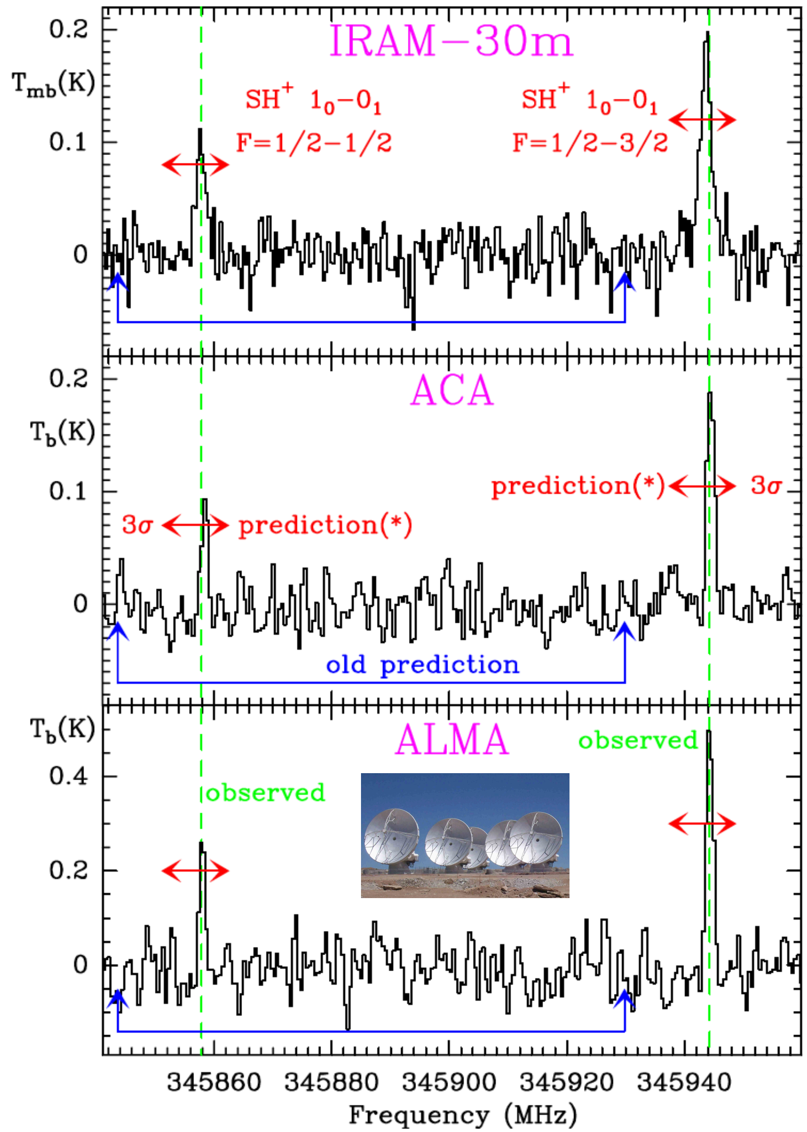


Pon et al. 2015b

SH^+ and CH^+ appear to be good tracers of turbulence dissipation in the diffuse ISM and toward the Galactic Center



Godard et al. 2012



Müller et al. 2014 (Orion Bar)

Nitrogen chemistry: NH, NH_2

Herschel/CHESS RESULTS:

<<Nitrogen hydrates in the cold envelope of IRAS16293-2422>>

$NH:NH_2:NH_3$ ~ 5:1:300

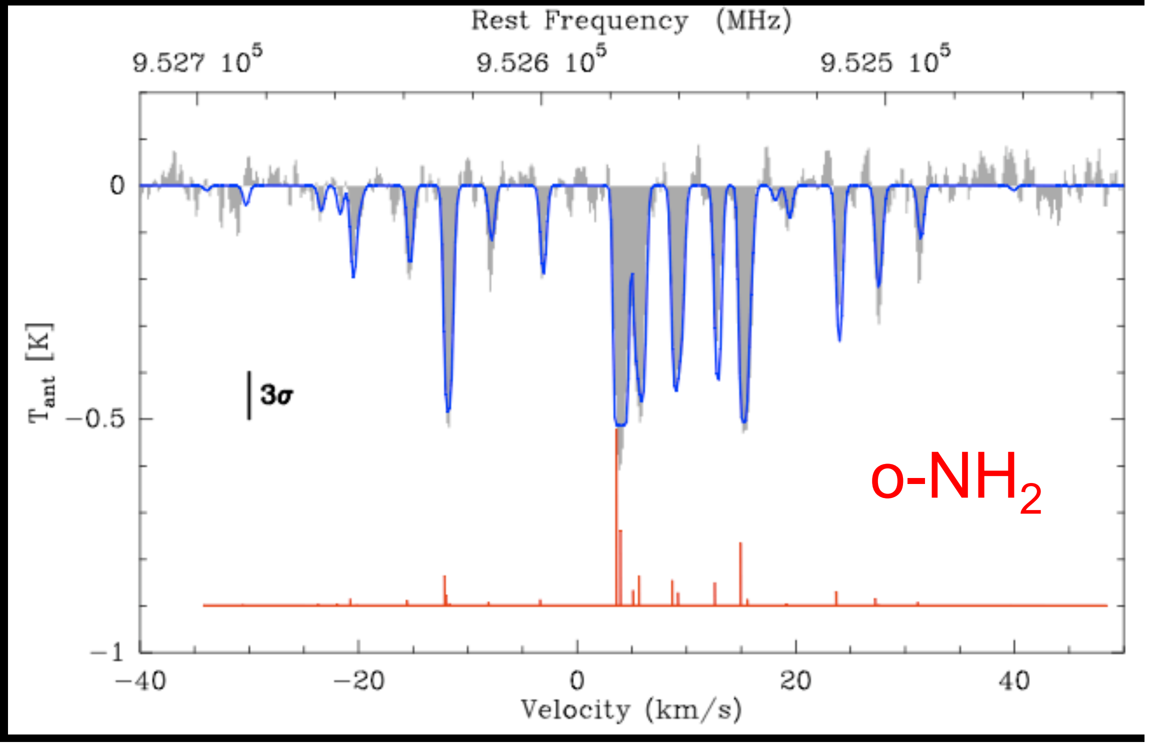
NH is under-predicted by more than an order of magnitude

Possible route:

$NH_2 + O \rightarrow OH + NH$

Unless NH can be formed by $N_2H^+ + e$ ..

Hily-Blant et al. 2010



Nitrogen chemistry: ND

Herschel/CHESS RESULTS: First detection of ND

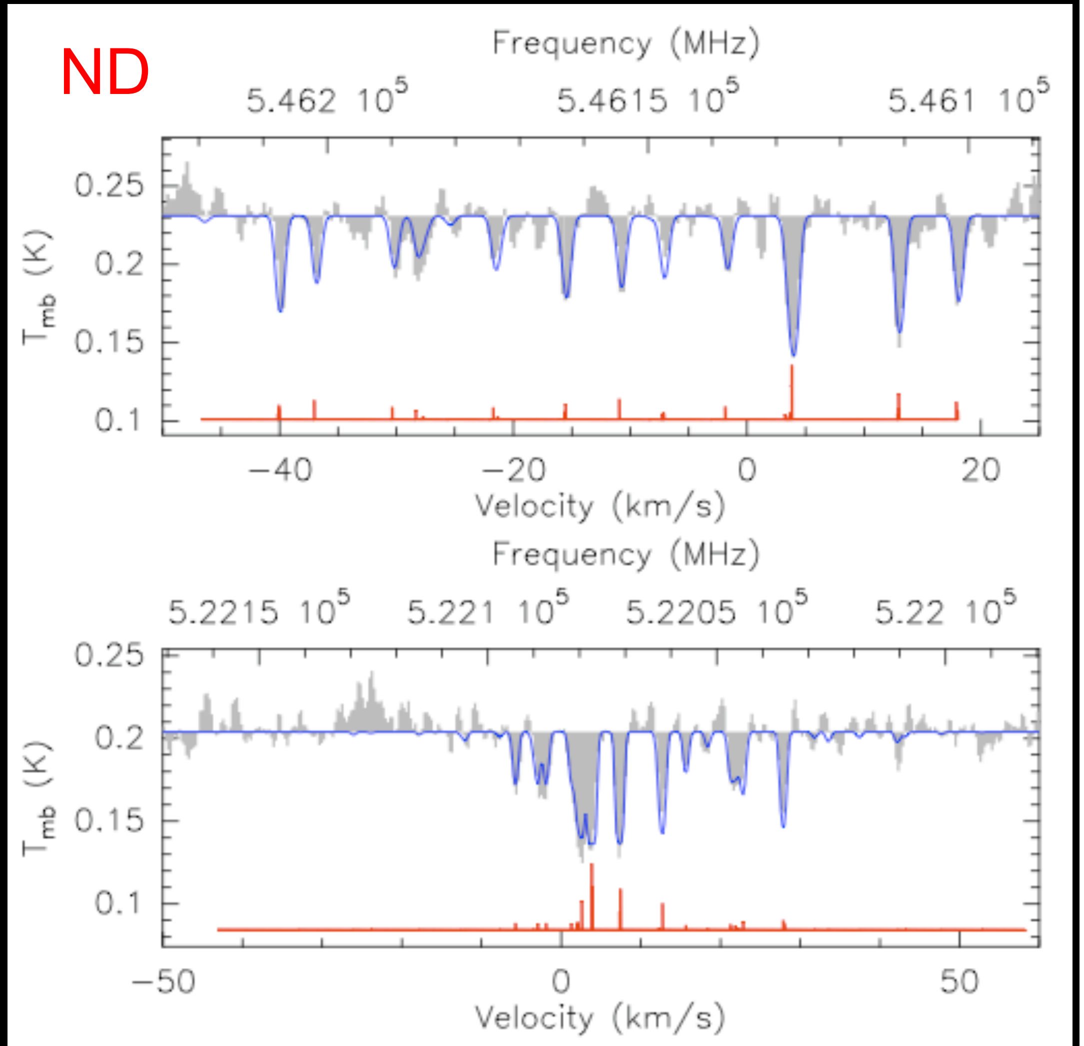
[ND]/[NH] ~ 0.3-1.0 !

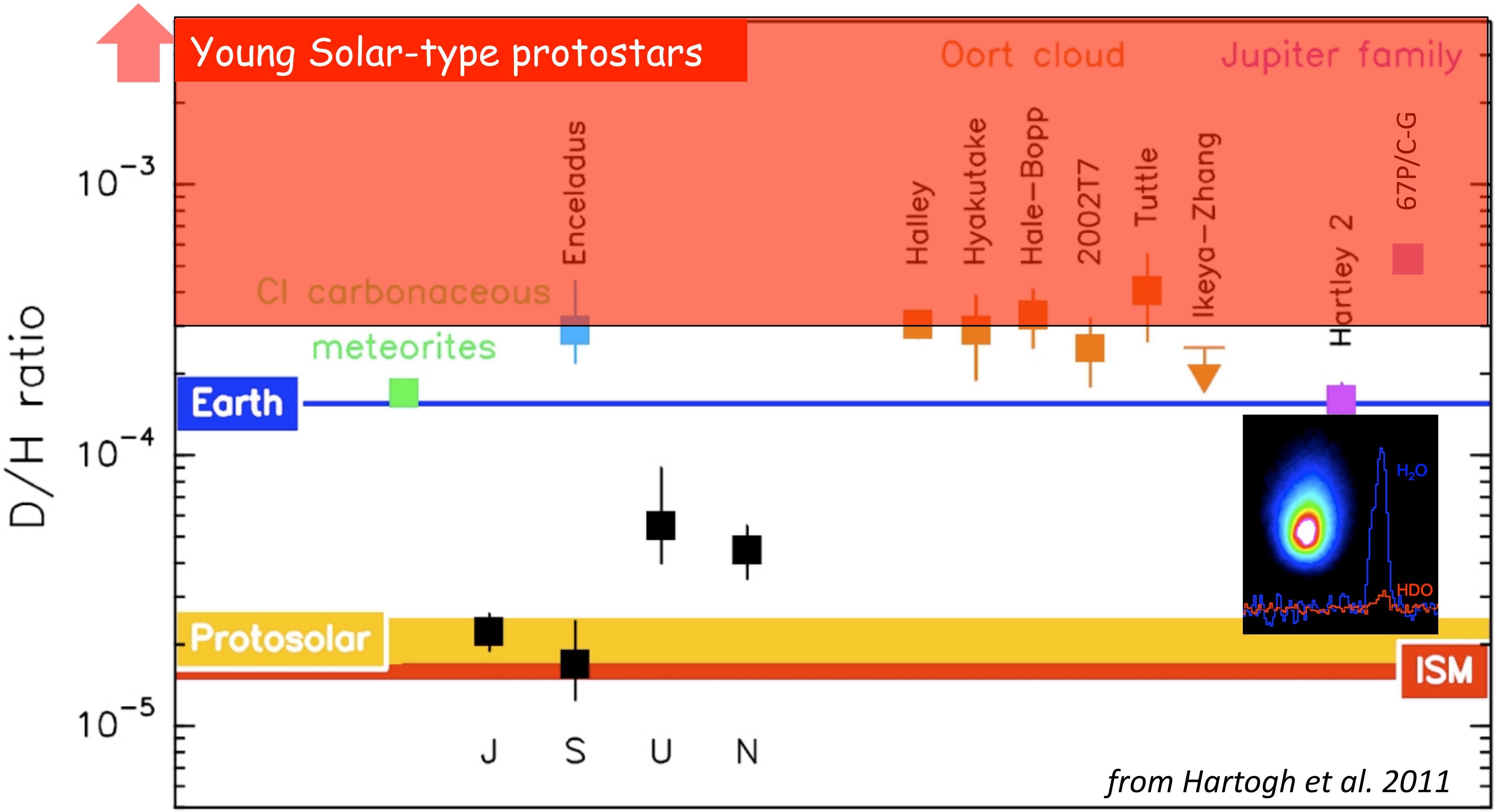
Possible routes:

$NH + H_2D^+ \rightarrow NHD^+ + H_2$

$N^+ + HD \rightarrow ND^+ + H$

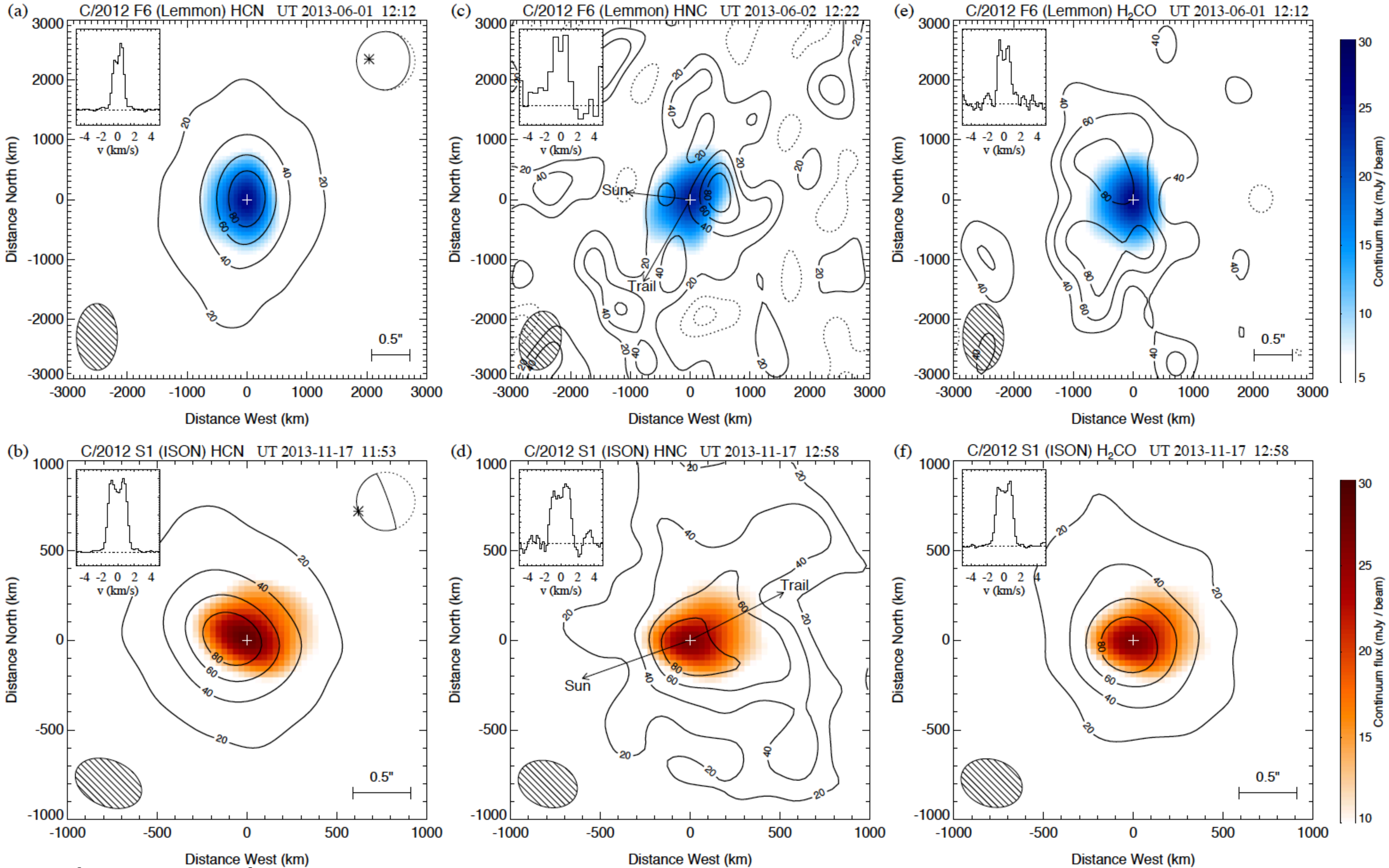
Bacmann et al. 2010





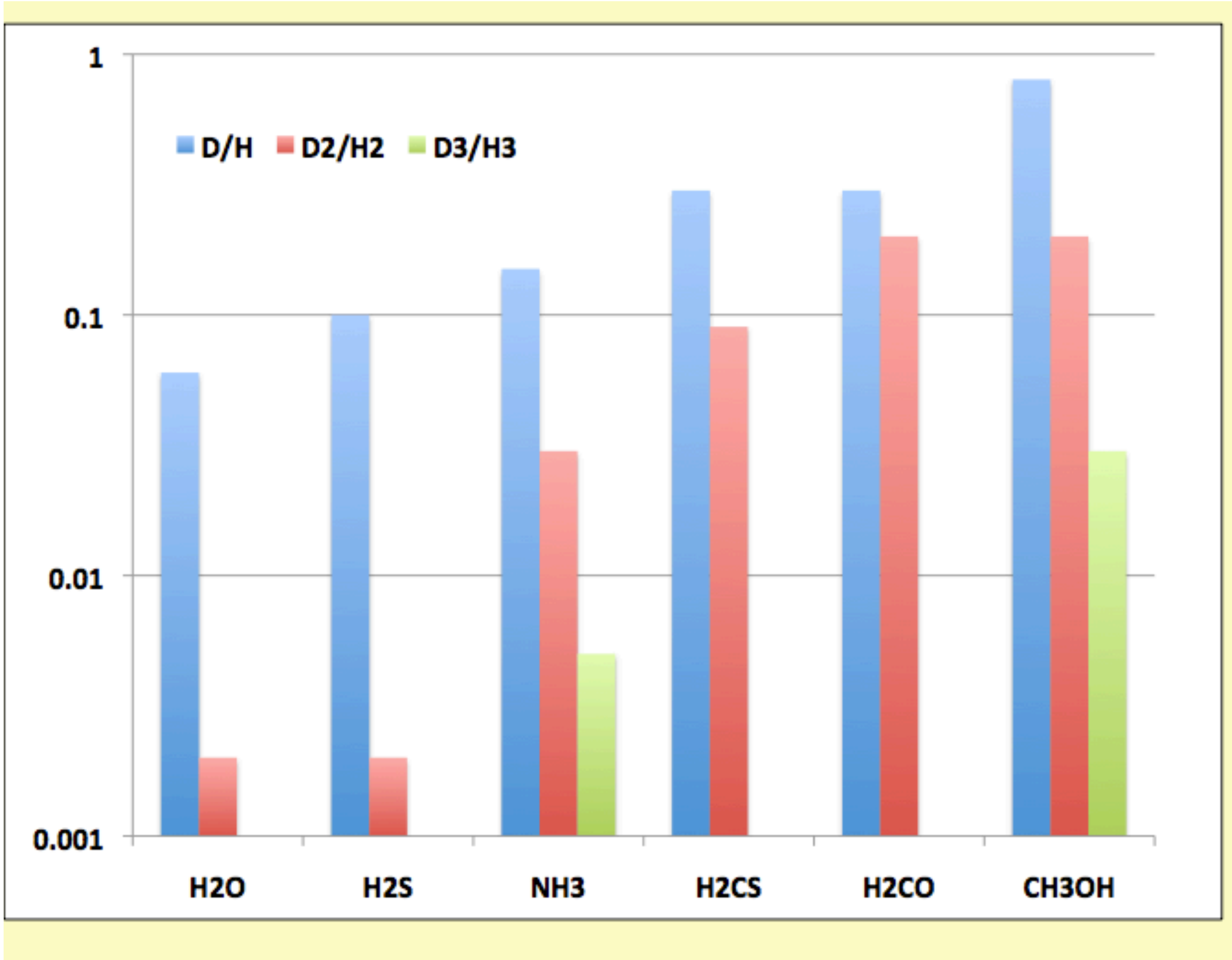
D/H in Hartley 2 = D/H in oceans (Hartogh et al. 2011);
D/H in 67P/Churyumov-Gersaimenko = $5x10^{-4}$ (Altwegg et al. 2014).
[See also Lis et al. 2013]

Mapping volatiles release in comets



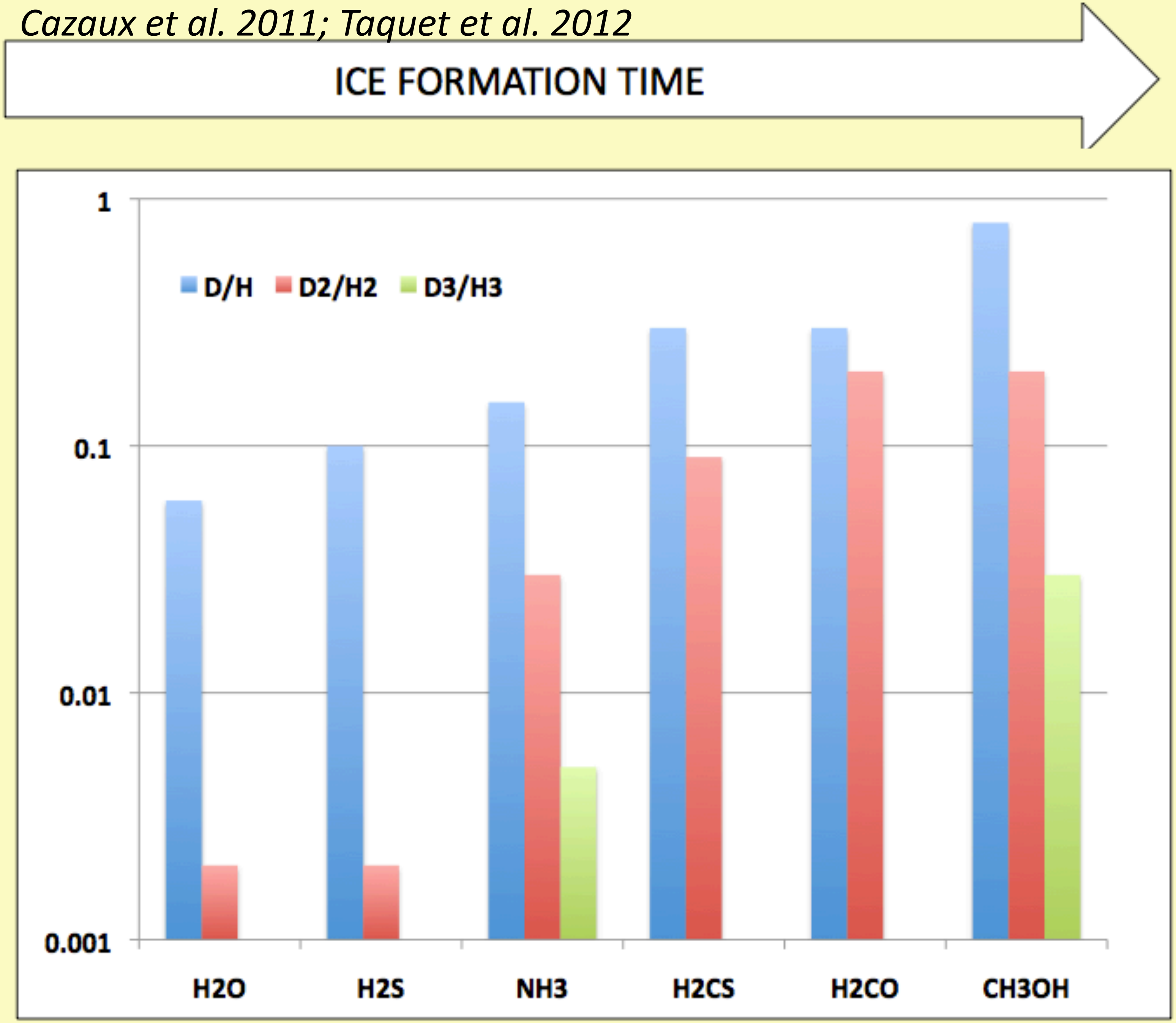
Cordiner et al. 2014

The youngest protostars show very large deuterations, especially of organic molecules

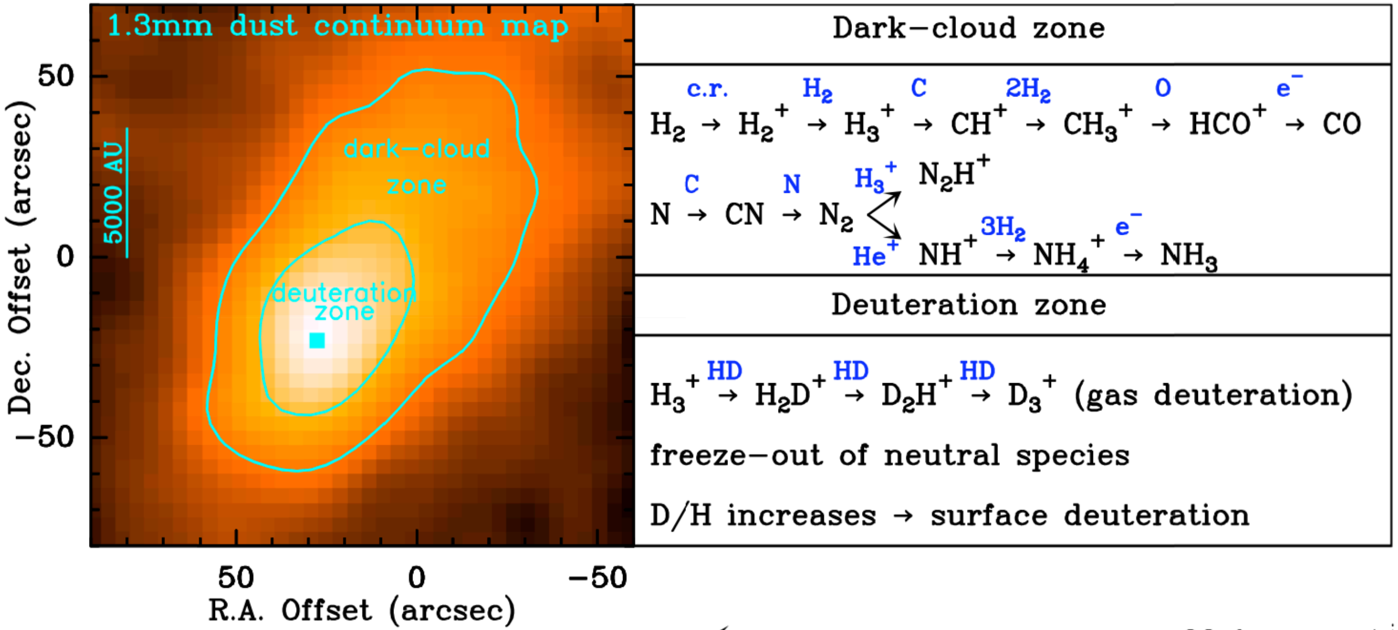


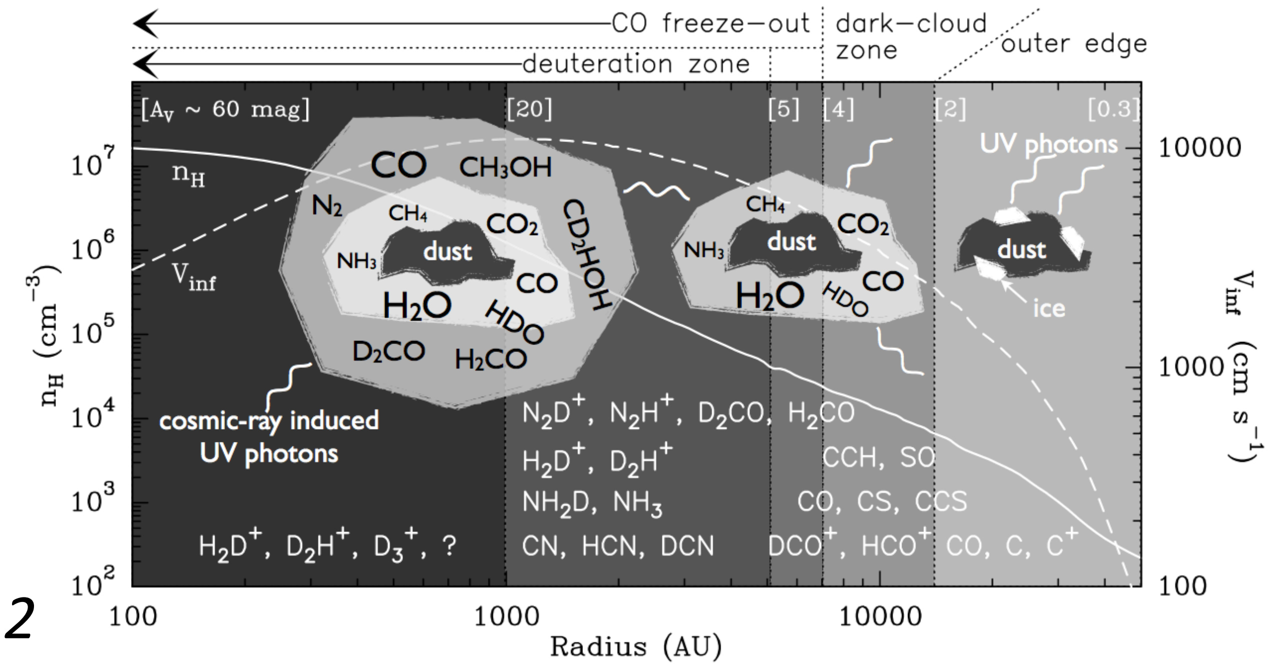
H_2O:
Coutens+ 2012,2013
Persson+ 2012
Taquet+ 2012,2013
Butner+ 2007
Vastel+ 2010
H_2S:
Vastel+ 2003
NH_3:
Loinard+ 2001
van der Tak+ 2002
H_2CS:
Marcelino+ 2005
H_2CO:
Ceccarelli+ 1998
Parise+ 2006
CH_3OH:
Parise+ 2002
Parise+ 2004
Parise+ 2006

Cazaux et al. 2011; Taquet et al. 2012



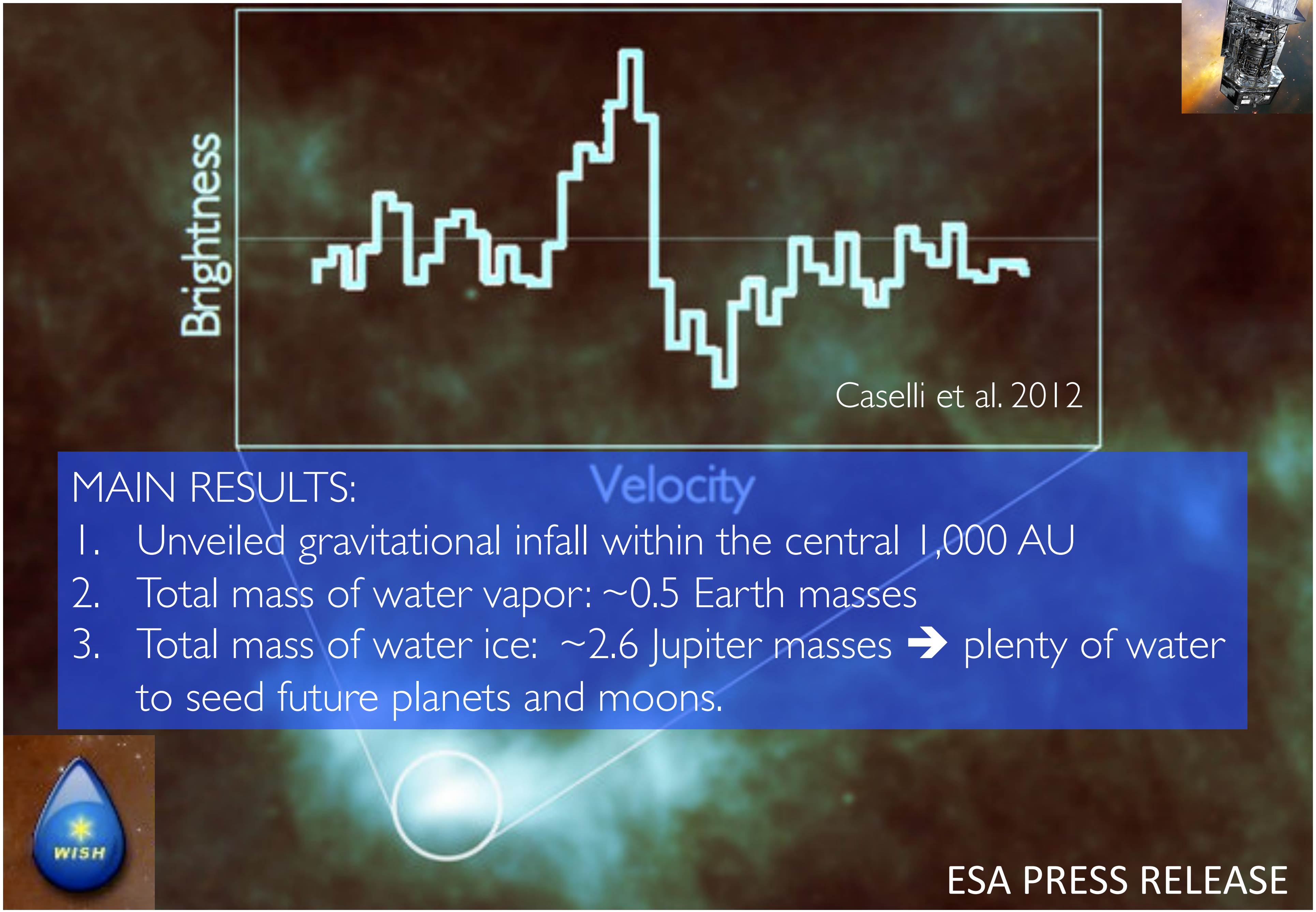
The earliest phases of star formation: pre-stellar cores





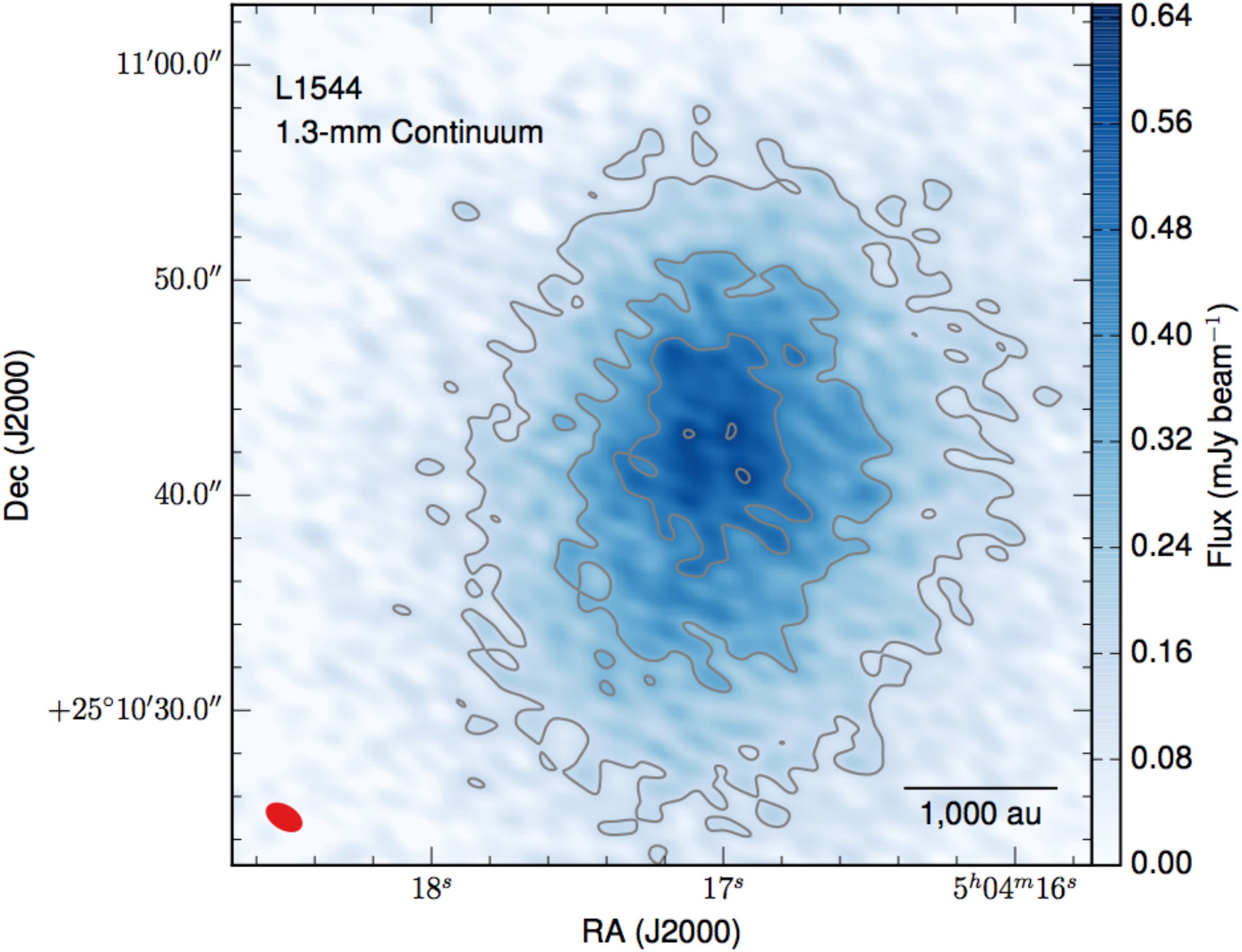
Caselli & Ceccarelli 2012

First detection of water vapor in a pre-stellar core

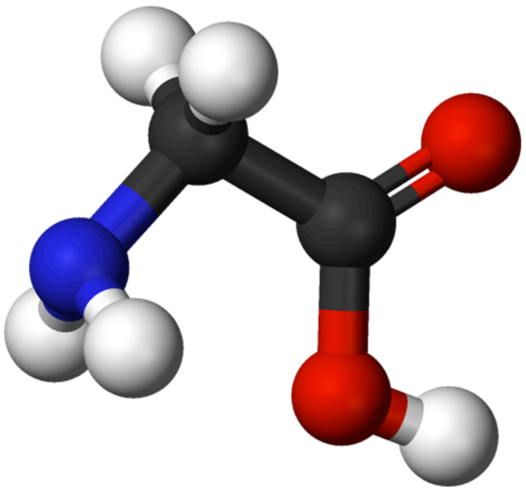


MAIN RESULTS:

1. Unveiled gravitational infall within the central 1,000 AU
2. Total mass of water vapor: ~0.5 Earth masses
3. Total mass of water ice: ~2.6 Jupiter masses ➔ plenty of water to seed future planets and moons.

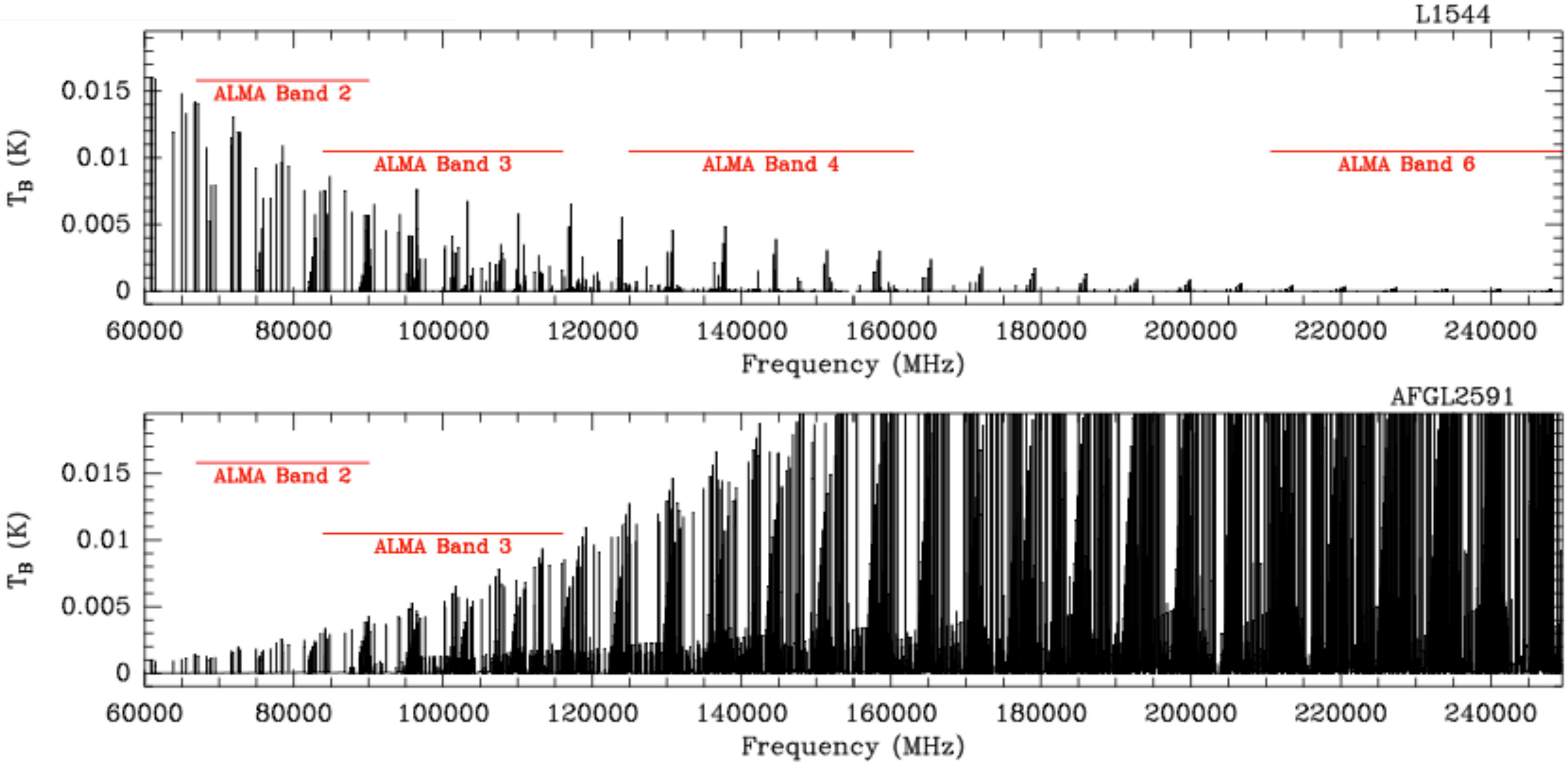


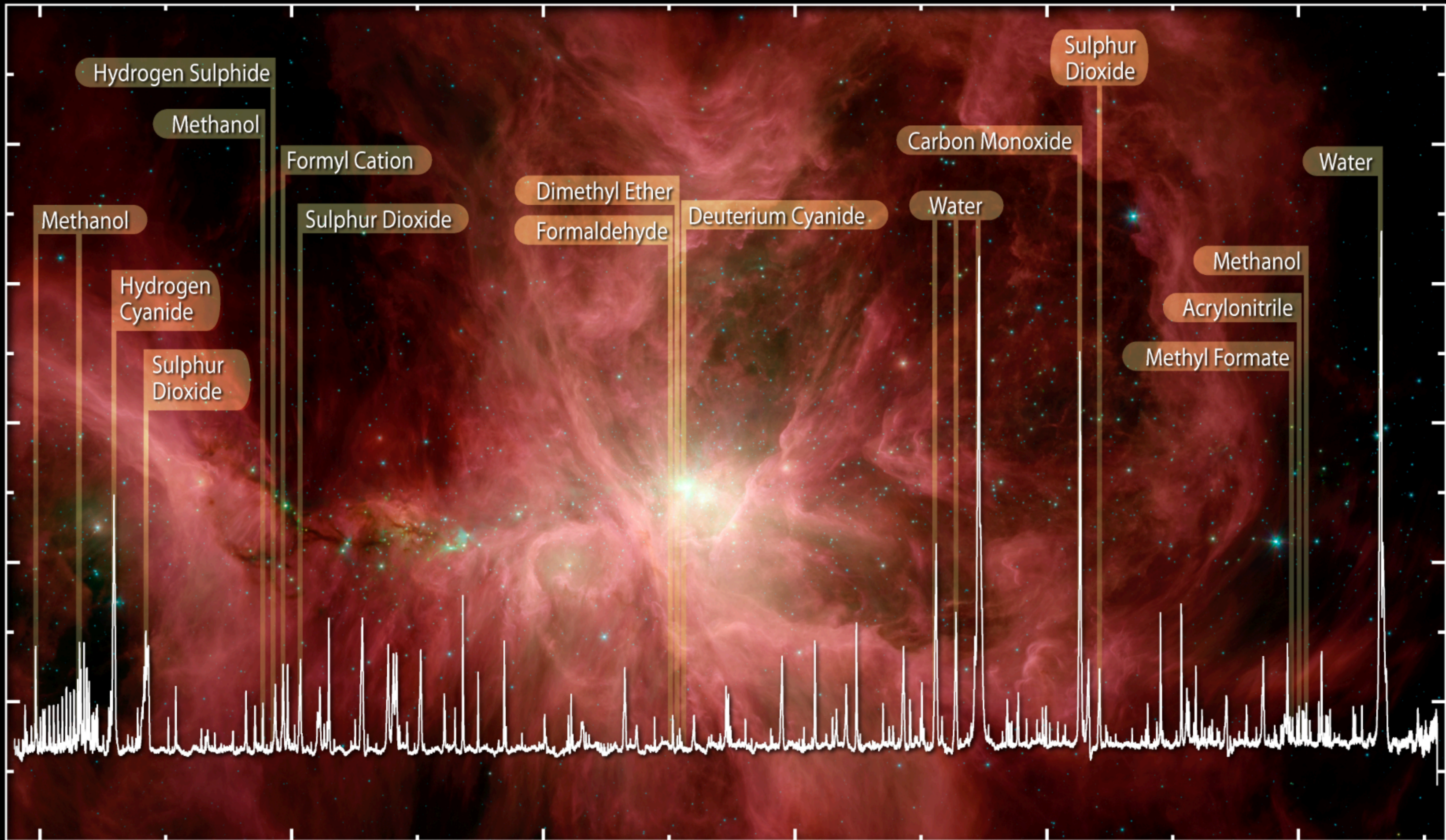
L1544
1.3-mm Continuum
11′00.0″
50.0″
40.0″
+25°10′30.0″
Dec (J2000)
18s
17s
5h04m16s
RA (J2000)
1,000 au
0.64
0.56
0.48
0.40
0.32
0.24
0.16
0.08
0.00
Flux (mJy beam−1)



Detectability of Glycine in Solar-type System Precursors –

Jiménez-Serra et al. 2014



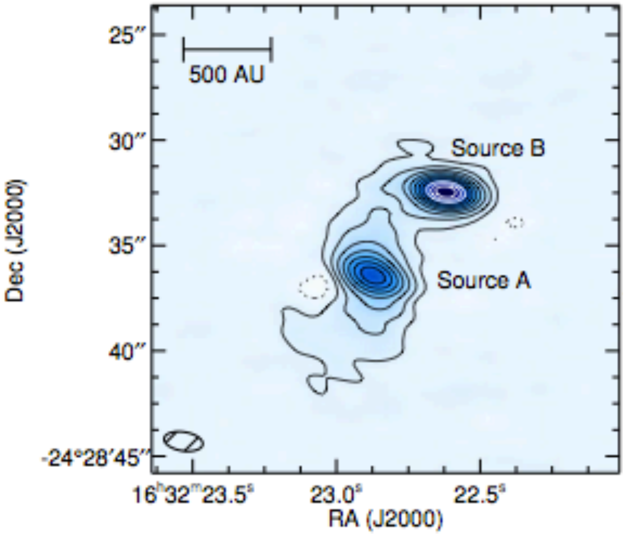


HIFI Spectrum of Water and Organics in the Orion Nebula

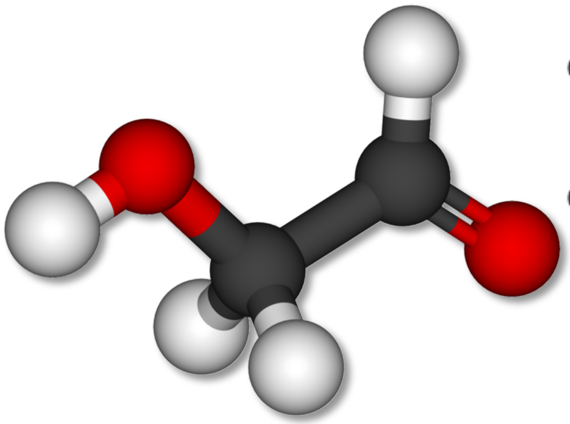
© ESA, HEXOS and the HIFI consortium
E. Bergin

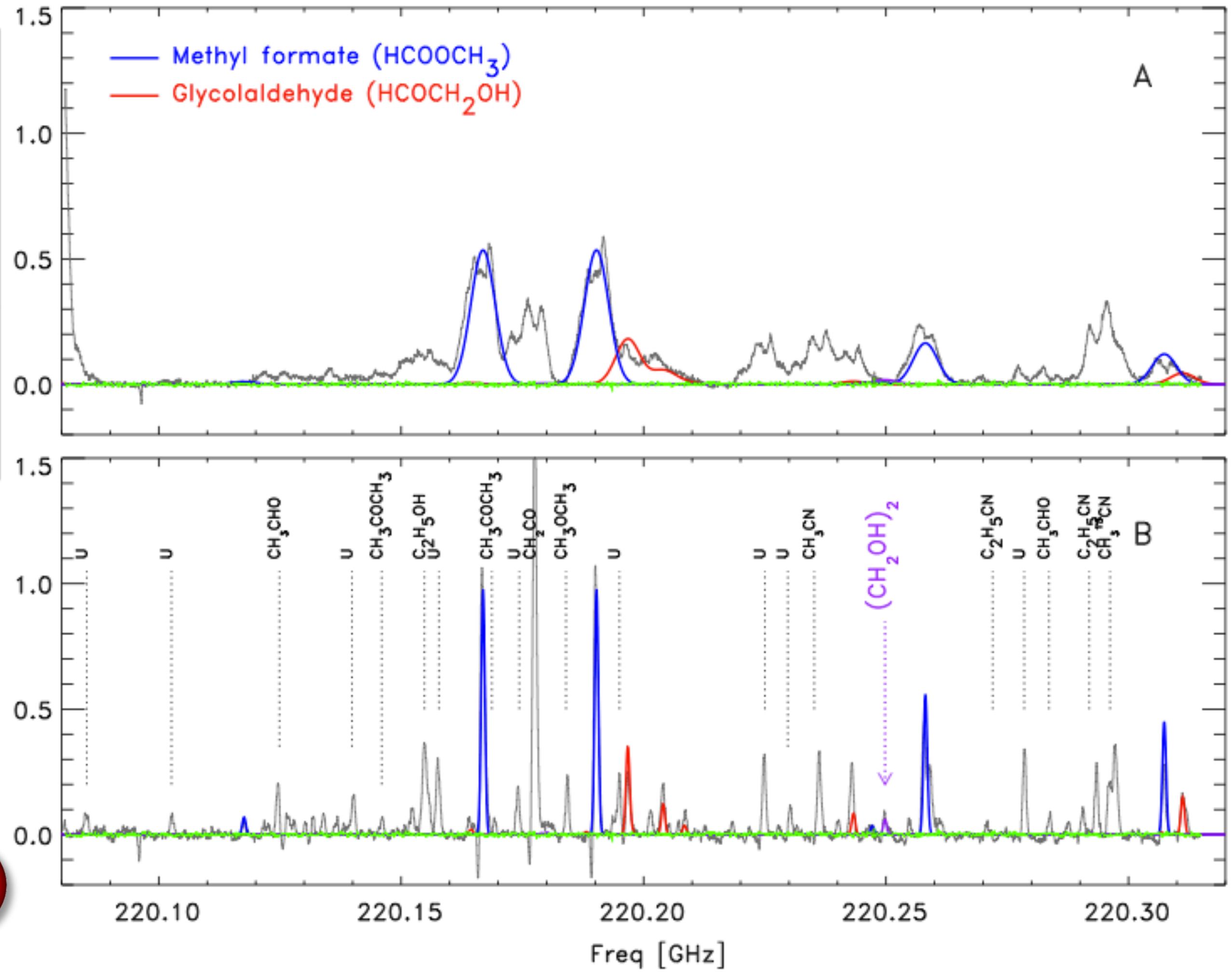
The simplest sugar detected with ALMA

1mm continuum map



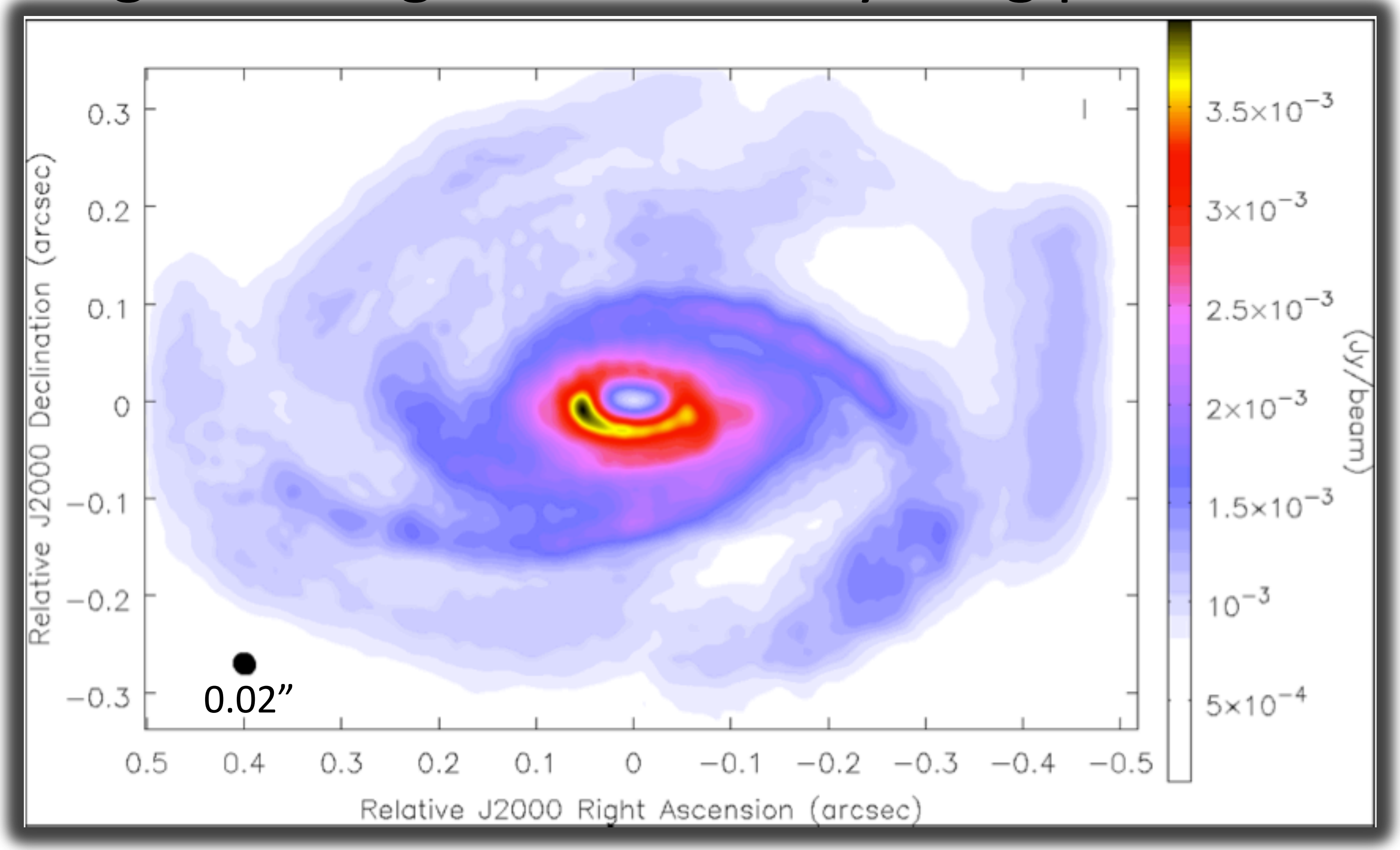
Pineda et al. 2012



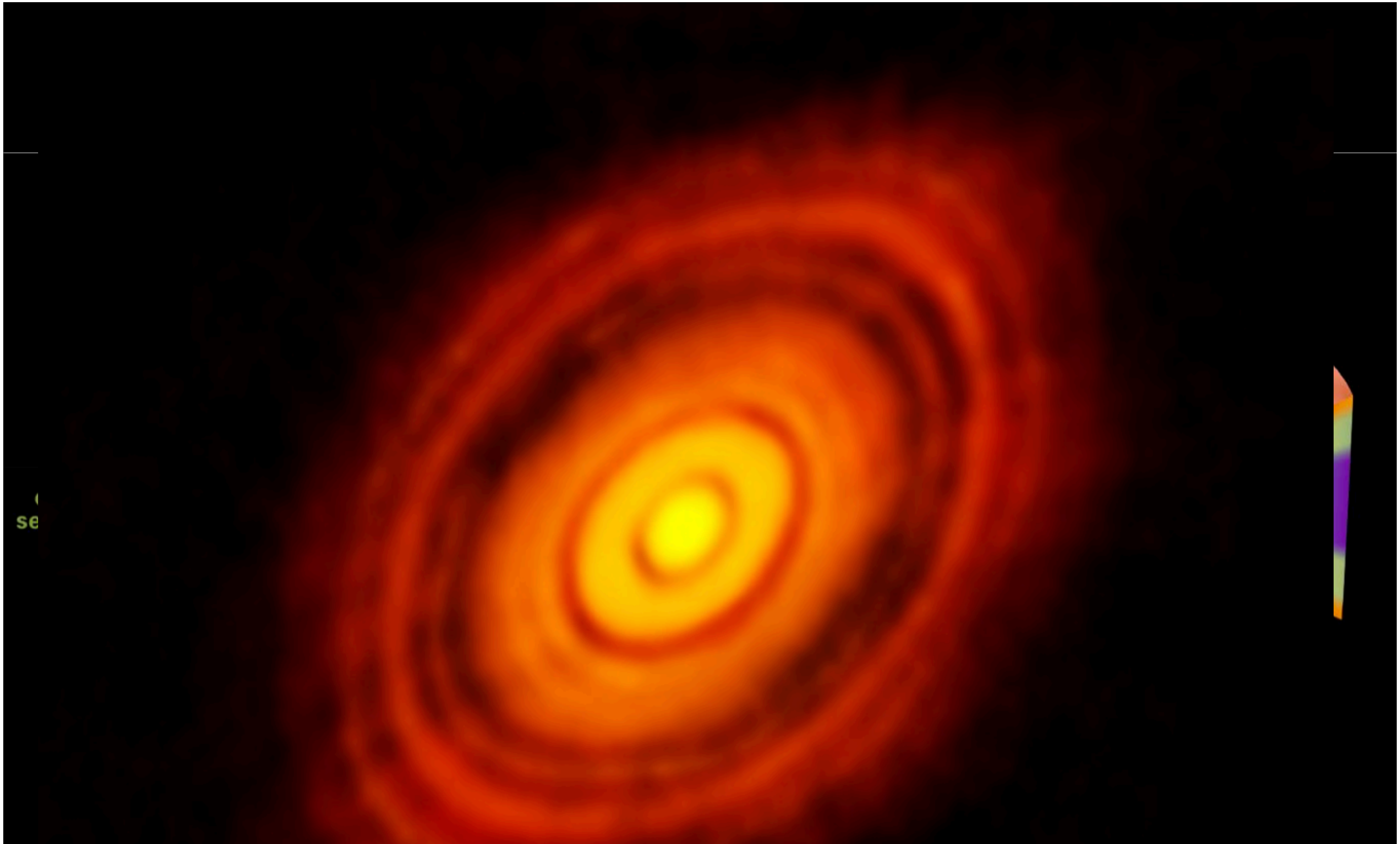


Jørgensen et al. 2012

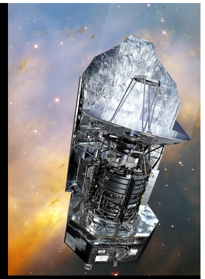
Self-gravitating disks around young protostars ?



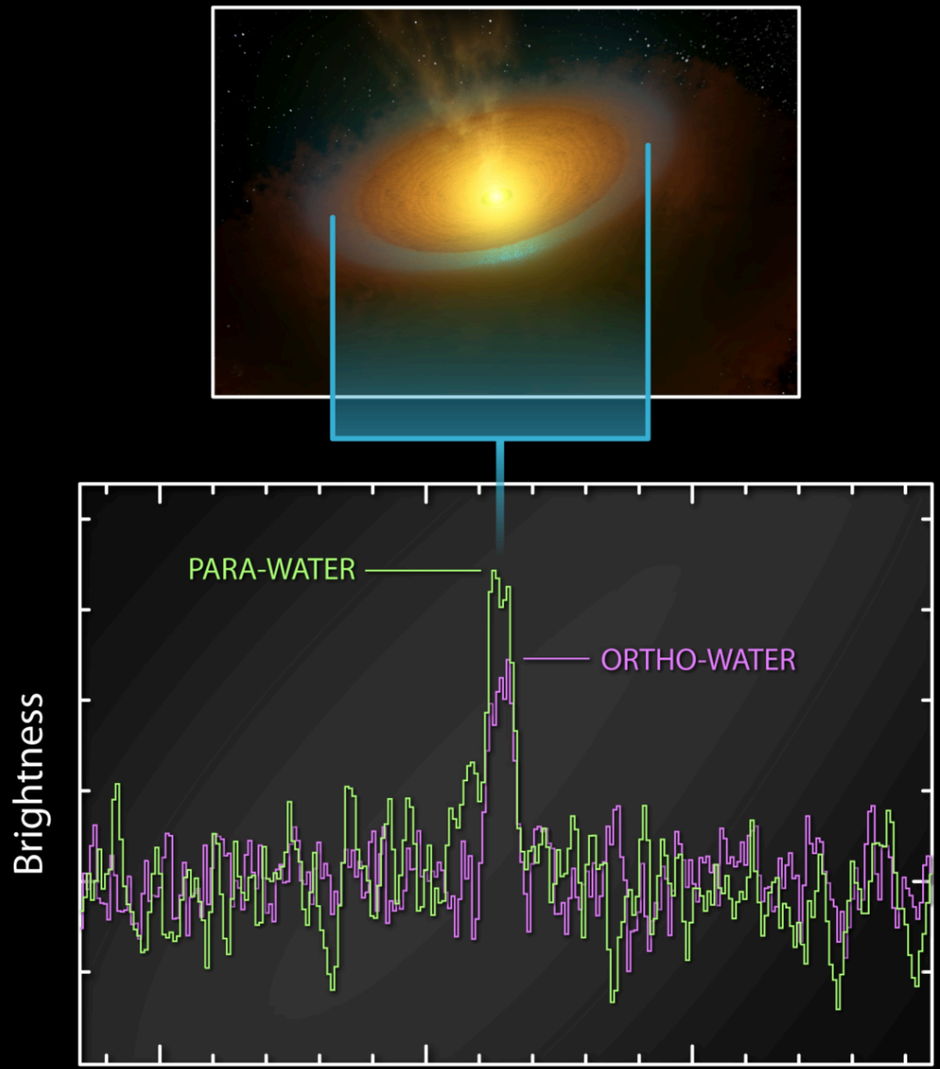
Simulation of ALMA observations of dust continuum emission at 300 GHz of a self-gravitating protoplanetary disk around $1M_{\odot}$ star using 3D radiative transfer (*Douglas et al. 2013; see also Dipierro et al. 2014*).



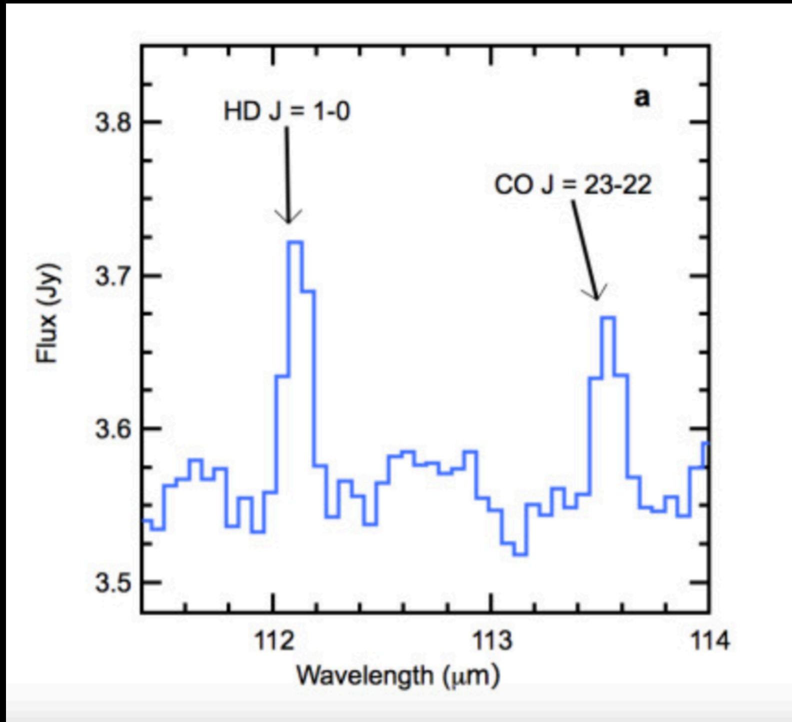
http://www.eso.org/public/news/eso1436/



HD and the disk mass



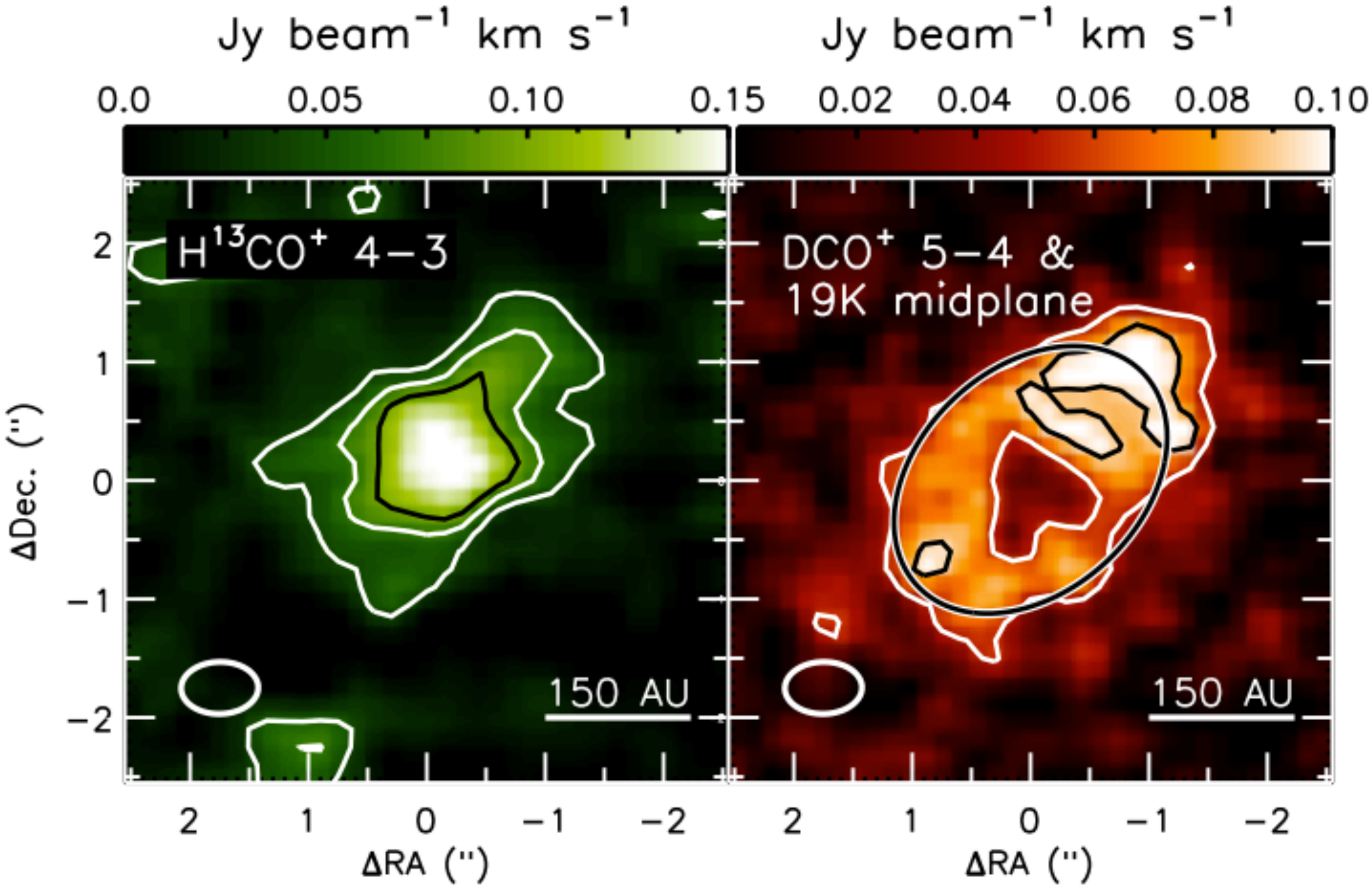
HIFI Spectroscopic Signatures of Water Vapor in TW Hydrae Disk
ESA/NASA/JPL-Caltech/M. Hogerheijde (Leiden Observatory)



Hogerheijde et al. 2011

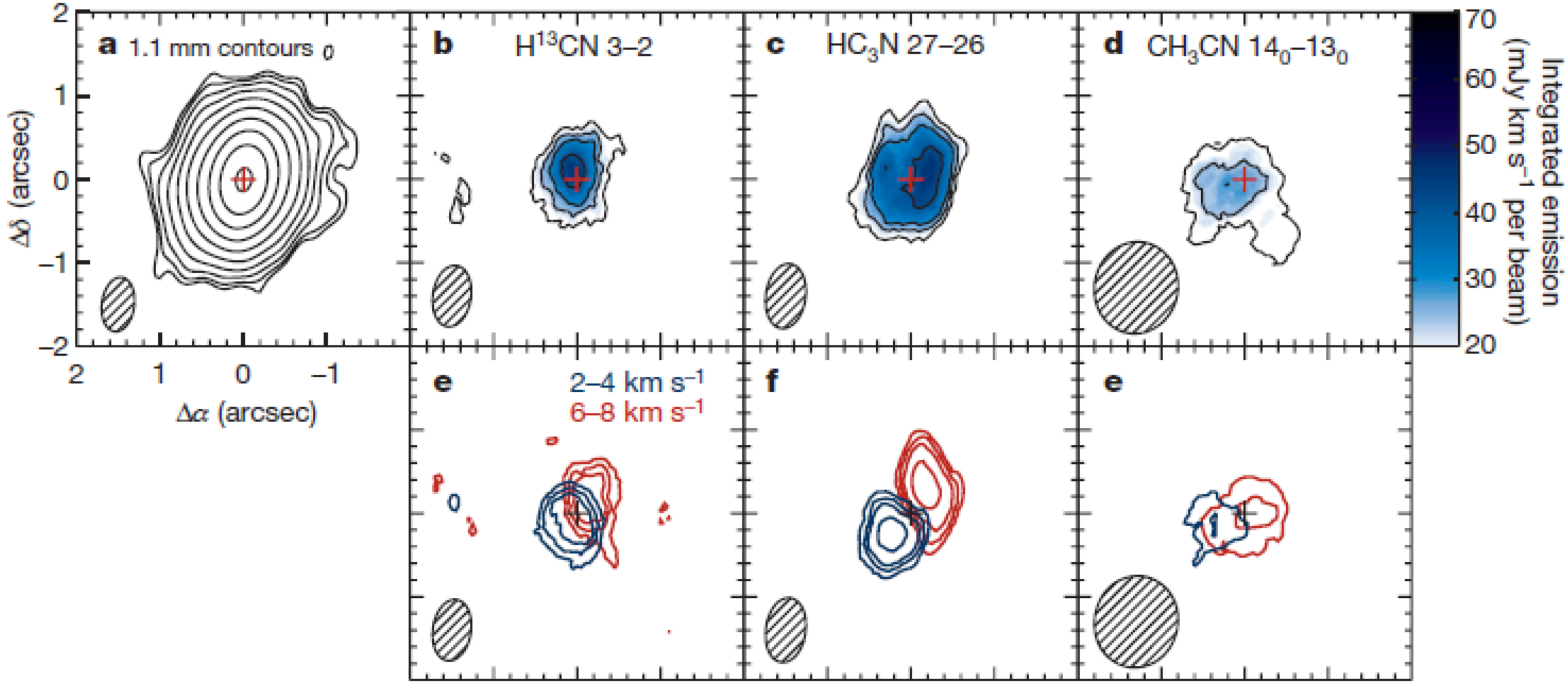
Bergin et al. 2013

ALMA imaging of the CO snowline of HD163296 (*Mathews et al. 2013*)



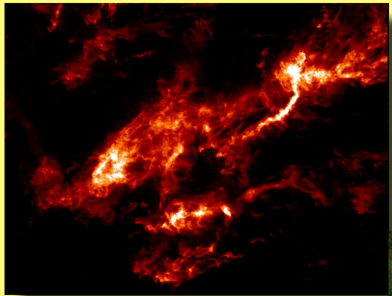
$DCO^+/HCO^+ \sim 0.3$; DCO^+ in a 110-160 AU ring (T = 19-21 K)

Complex cyanides and the comet-like composition of a protoplanetary disk

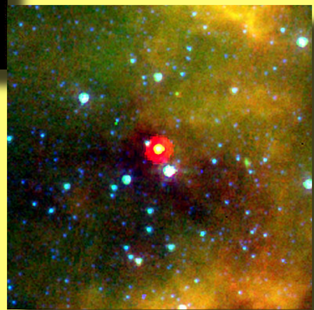


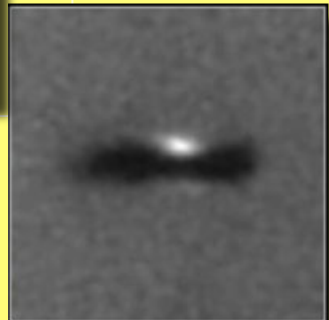
Öberg et al. 2015, Nature

ISM: Herschel (tracers of dark CO gas + high J-CO)
ALMA (tracers of bright CO gas + structure)



Dense clouds: Herschel (dust temperature, light hydrides, H_2O)
ALMA (the central 1000 AU)





Star forming regions:
Herschel (molecular excitation, T_{dust})
ALMA (young disks and outflows)

Protoplanetary disks:
Herschel (atomic lines, HD, H_2O)
ALMA (molecular distribution, snow lines)