School of Physics and Astronomy
FACULTY OF MATHEMATICS & PHYSICAL SCIENCES
UNIVERSITY OF LEEDS

Water and the Earliest Stages of Star Formation

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WISH

INAF - Arcetri

Together with…

Aikawa (Kobe)
Bergin (Michigan)
Codella (INAF/Arcetri)
Douglas (Leeds)
Keto (CfA)
Kristensen (CfA)
Nisini (INAF/Roma)
Pagani (LERMA)
Tafalla (Madrid)
van der Tak (Groningen)
van Dishoeck (Leiden)
Walmsley (INAF/Arcetri)
Yildiz (Leiden)

Outline

- Introduction: pre-stellar cores
- Detection of water vapor:
  - Previous attempts
  - WISH 2010
  - WISH 2012
  - OT2 and work in progress

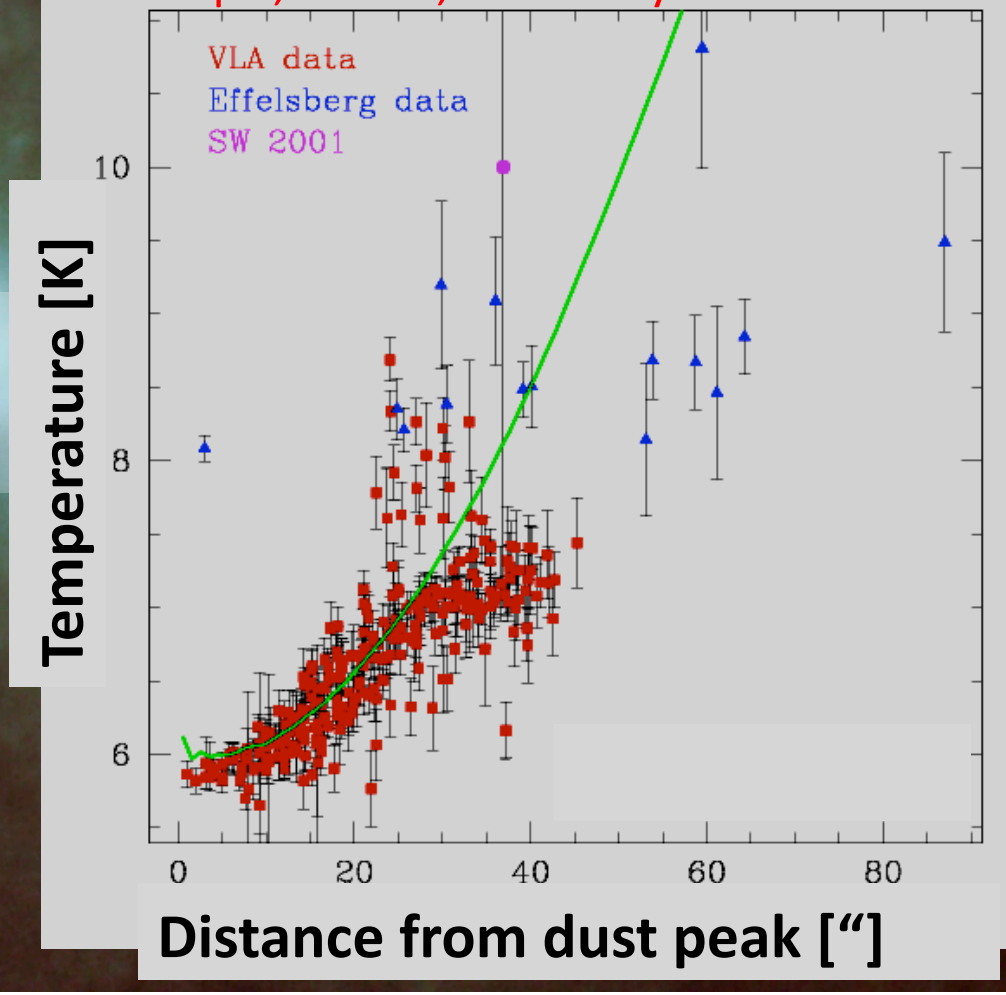
Pre-stellar cores

Pre-stellar cores are gravitationally unstable starless cores

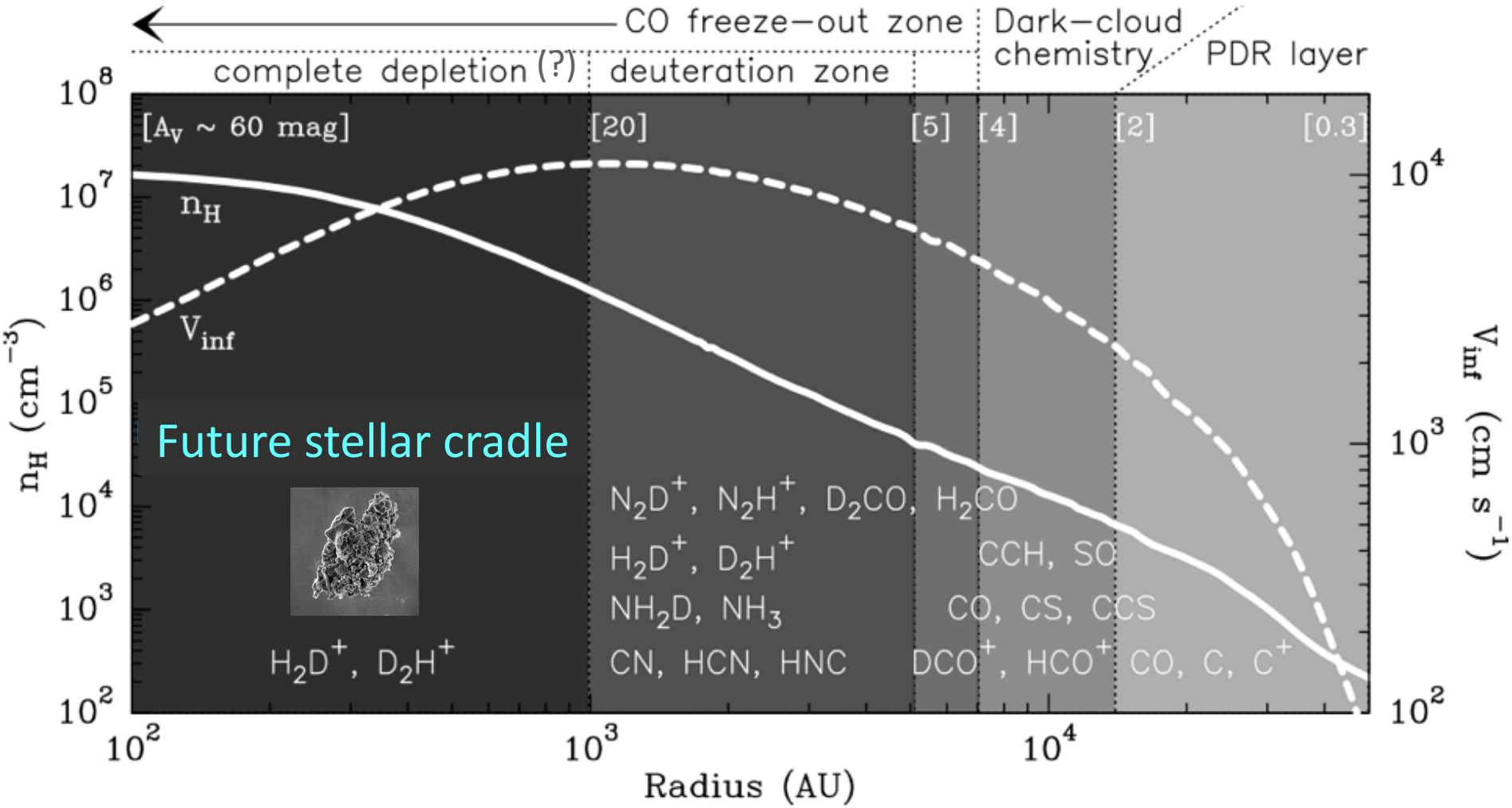
(e.g. Ward-Thompson et al. 1999; Crapsi et al. 2005)

They have temperature gradients (~6-12 K)

Crapsi, Caselli, Walmsley & Tafalla 2007



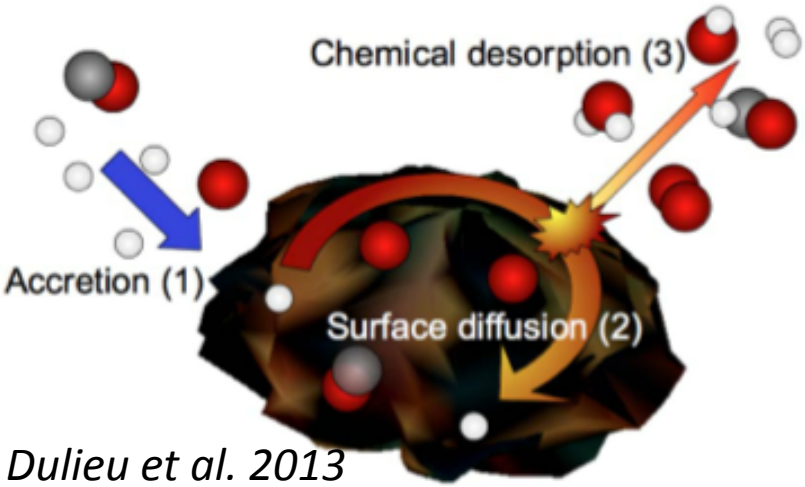
The pre-stellar core physical/chemical structure



Caselli et al. 1999, 2002, 2003; Vastel et al. 2006; Tafalla et al. 2006; Keto & Caselli 2008, 2010

Water vapor in dark clouds

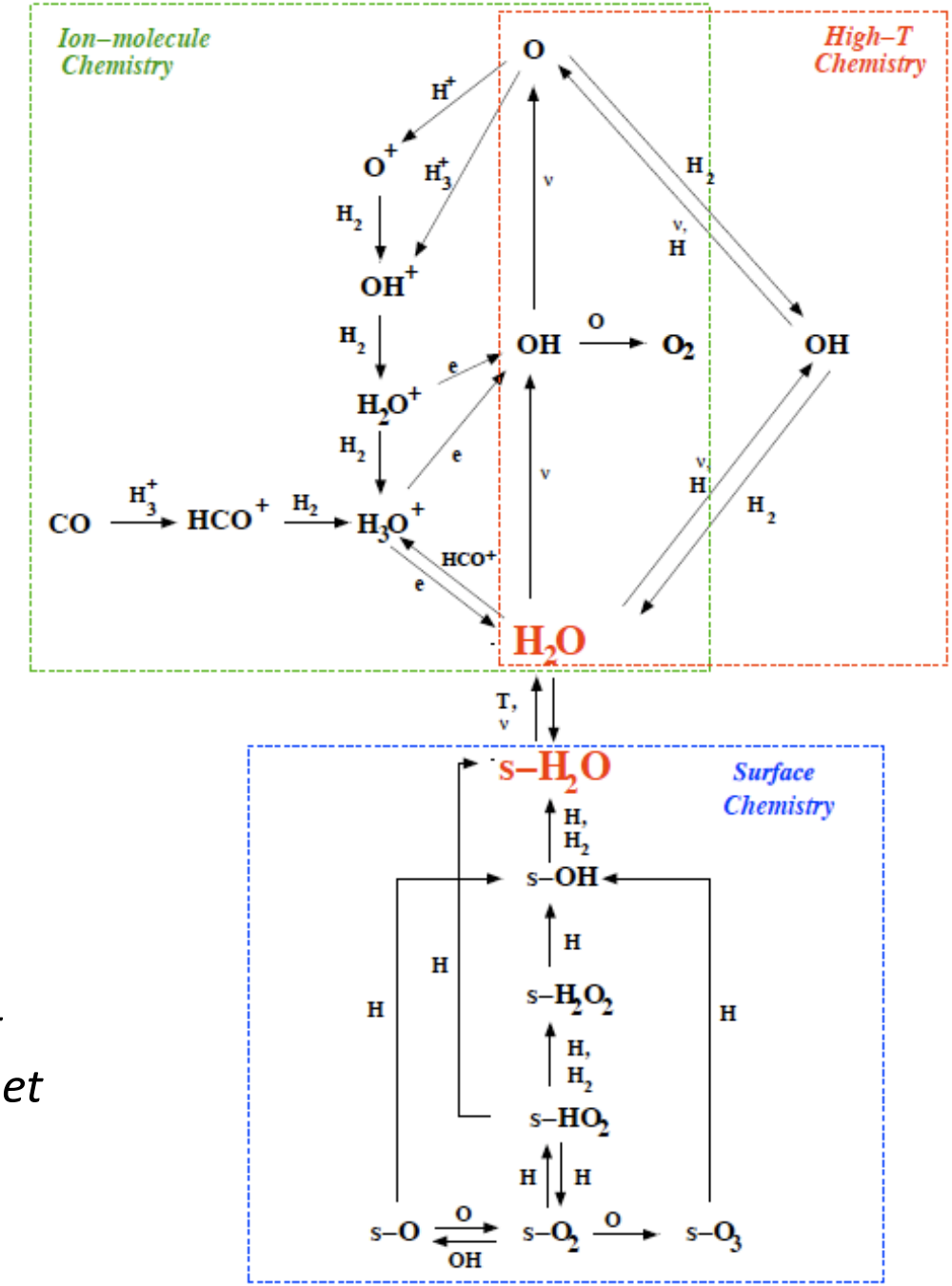
In cold regions, H_2O is mainly formed on the surface of dust grains.



Dulieu et al. 2013

Tielens & Hagen 1982; Cuppen & Herbst 2007; Ioppolo et al. 2008, 2010; Cazaux et al. 2010, 2011; Taquet et al. 2013

(van Dishoeck et al. 2011)

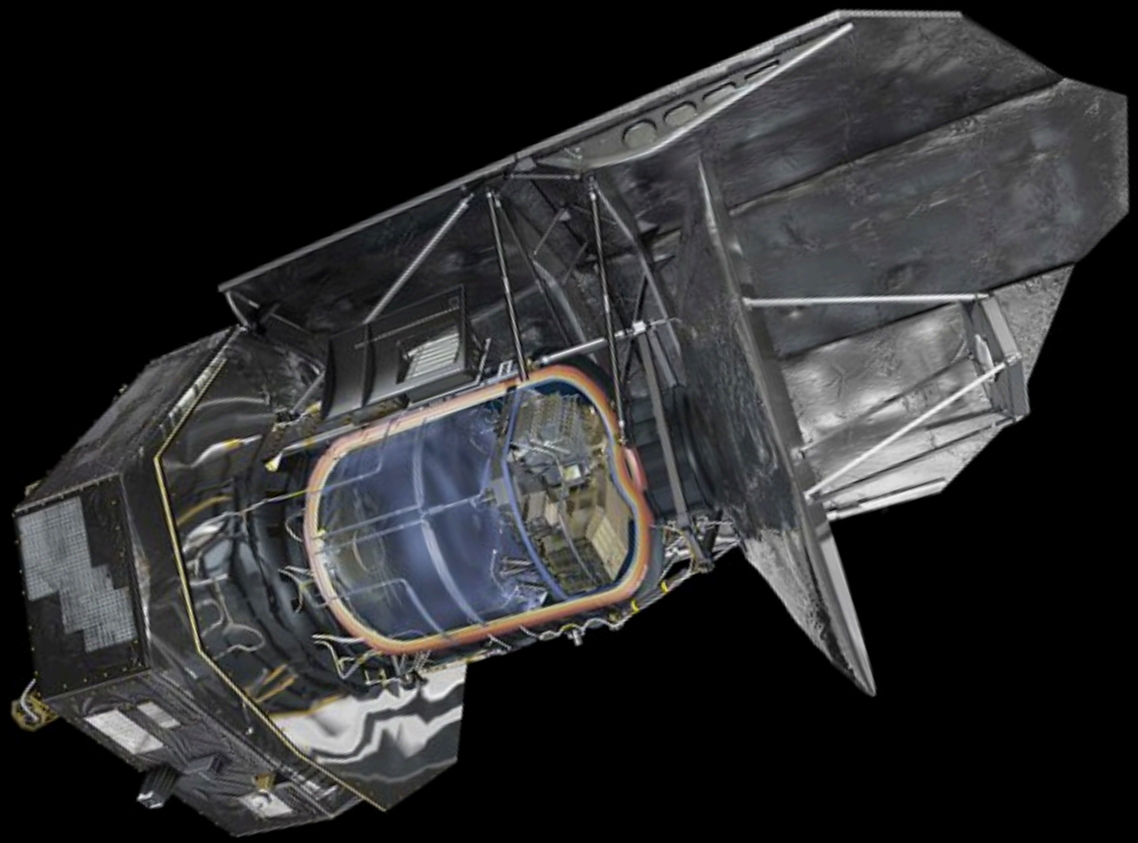


Previous attempts

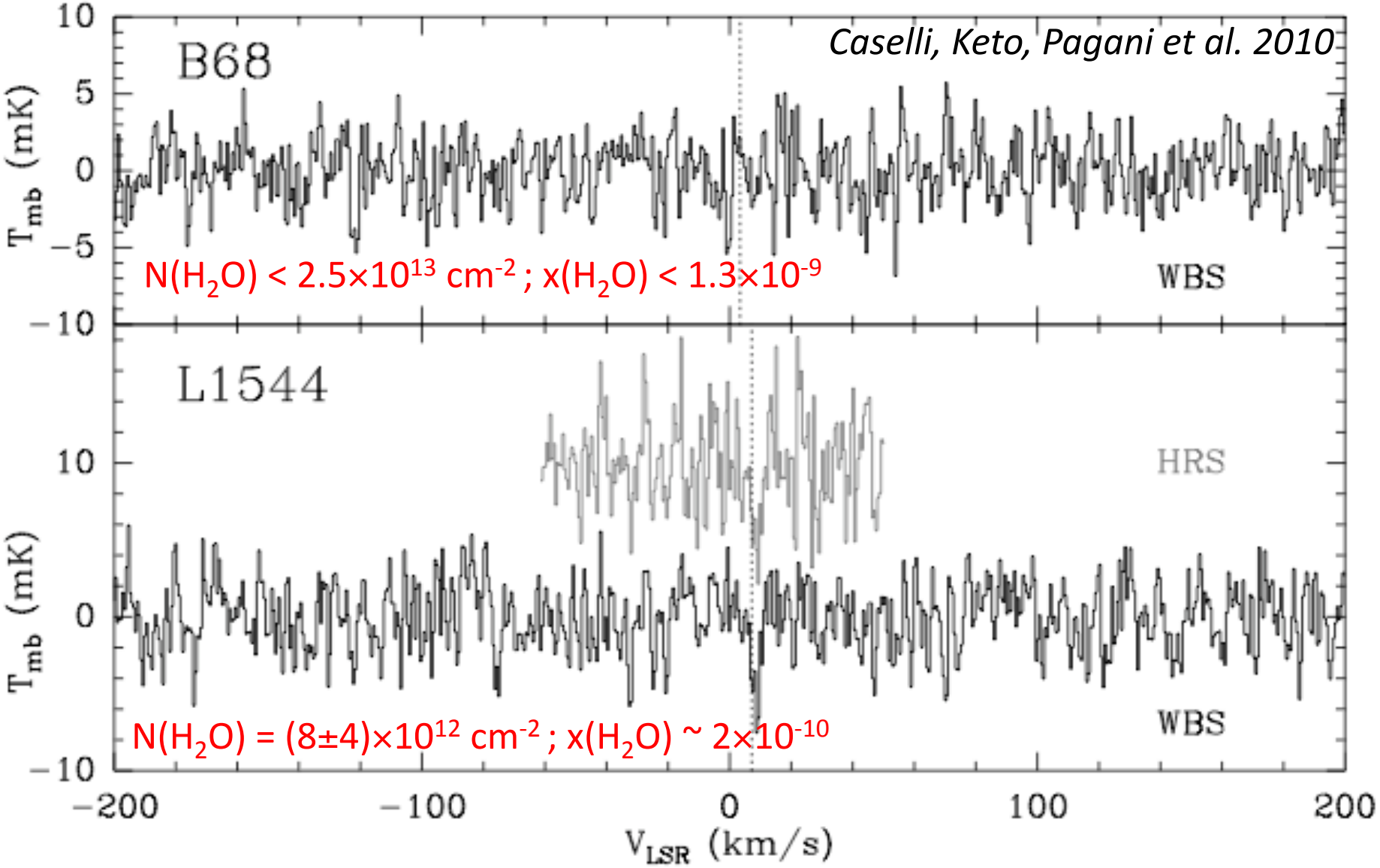
$x(H_2O) < 10^{-8}$

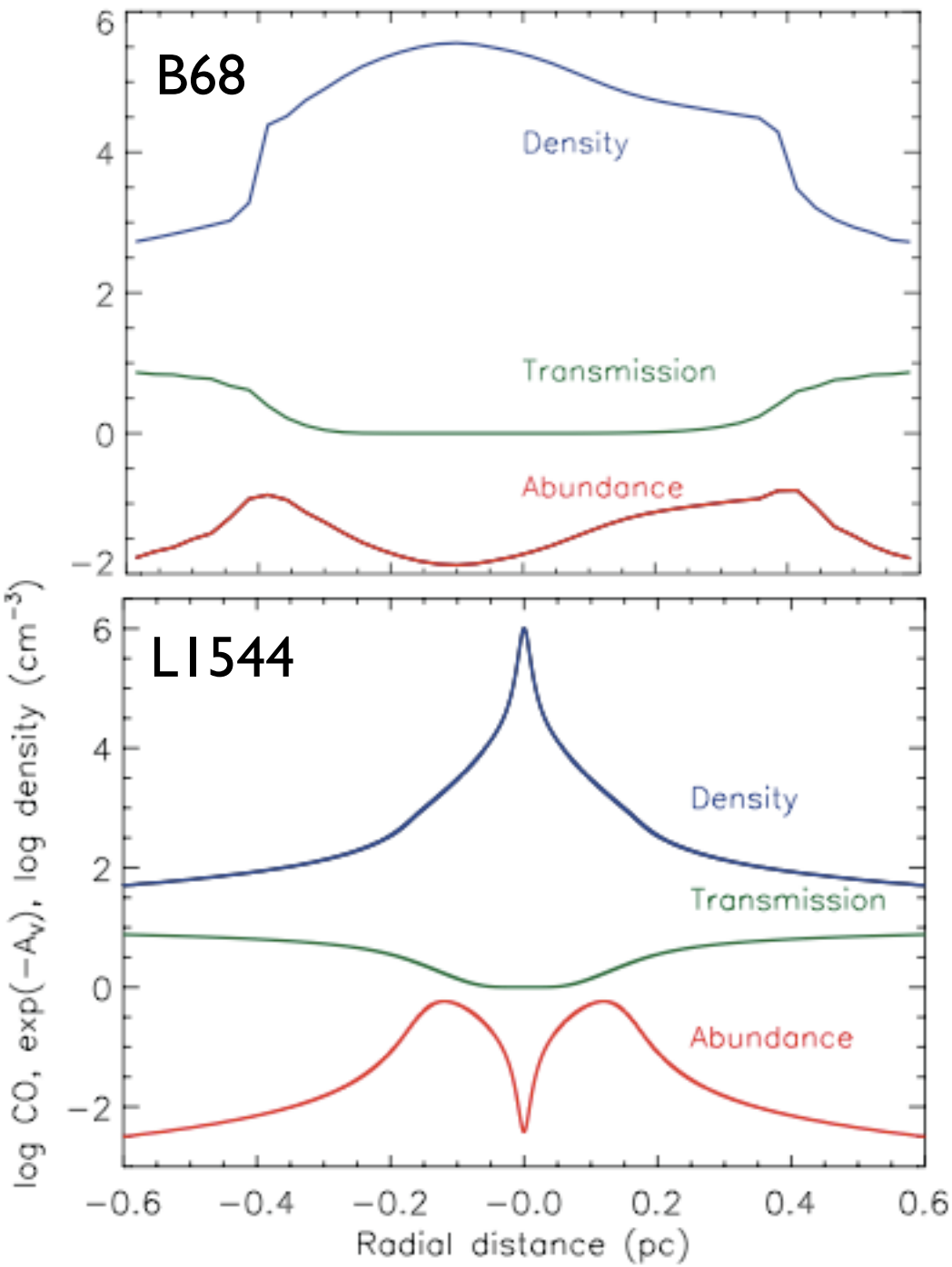
(Bergin & Snell 2002; Klotz et al. 2008)

HERSCHEL HIFI



2010 Data

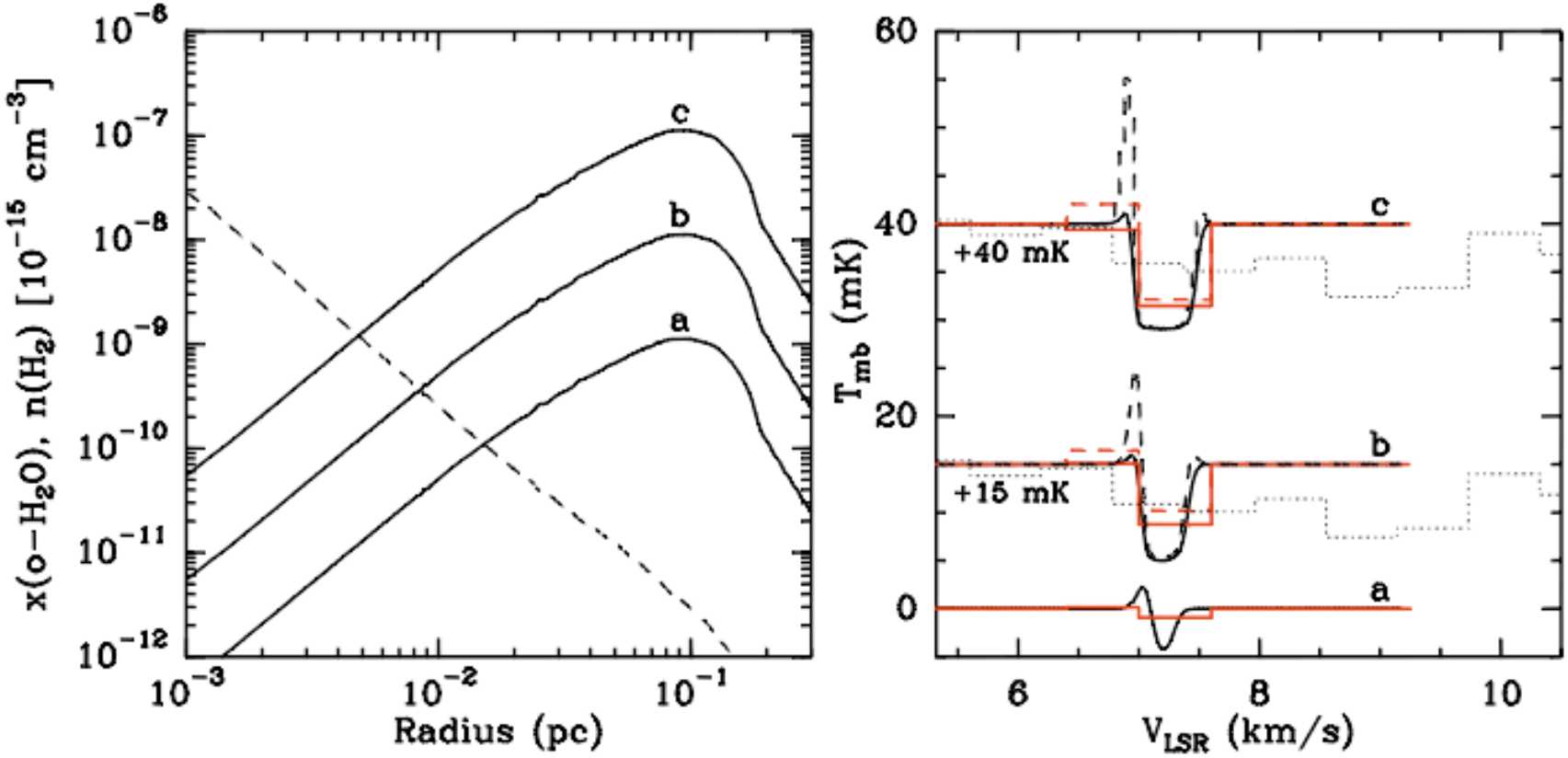

Caselli, Keto, Pagani et al. 2010
B68
N(H2O) < 2.5×10^13 cm^-2 ; x(H2O) < 1.3×10^-9
WBS
L1544
HRS
N(H2O) = (8±4)×10^12 cm^-2 ; x(H2O) ~ 2×10^-10
WBS
Tmb (mK)
VLSR (km/s)
10
5
0
−5
−10
−200
−100
0
100
200



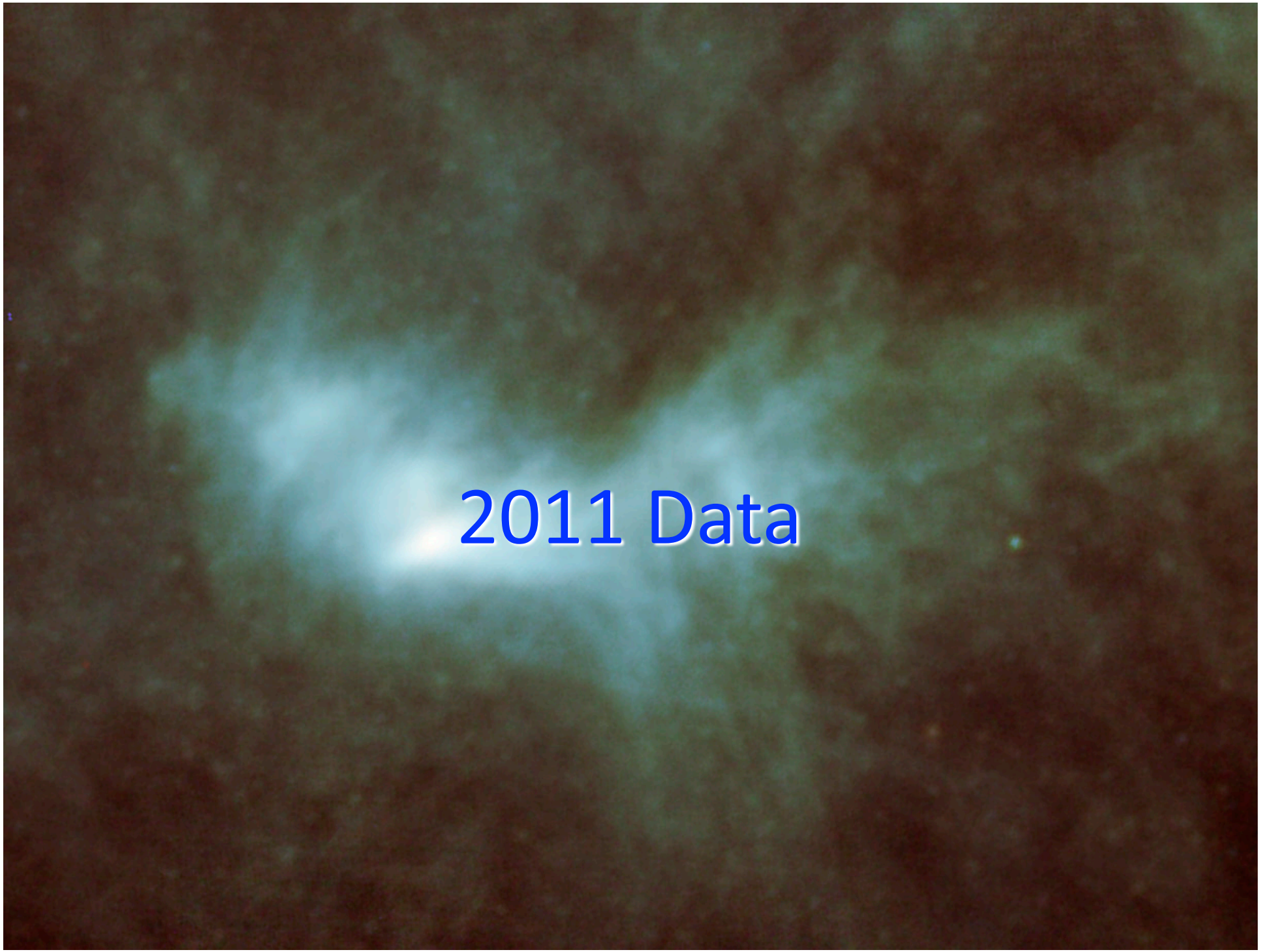
The two classes of starless cores

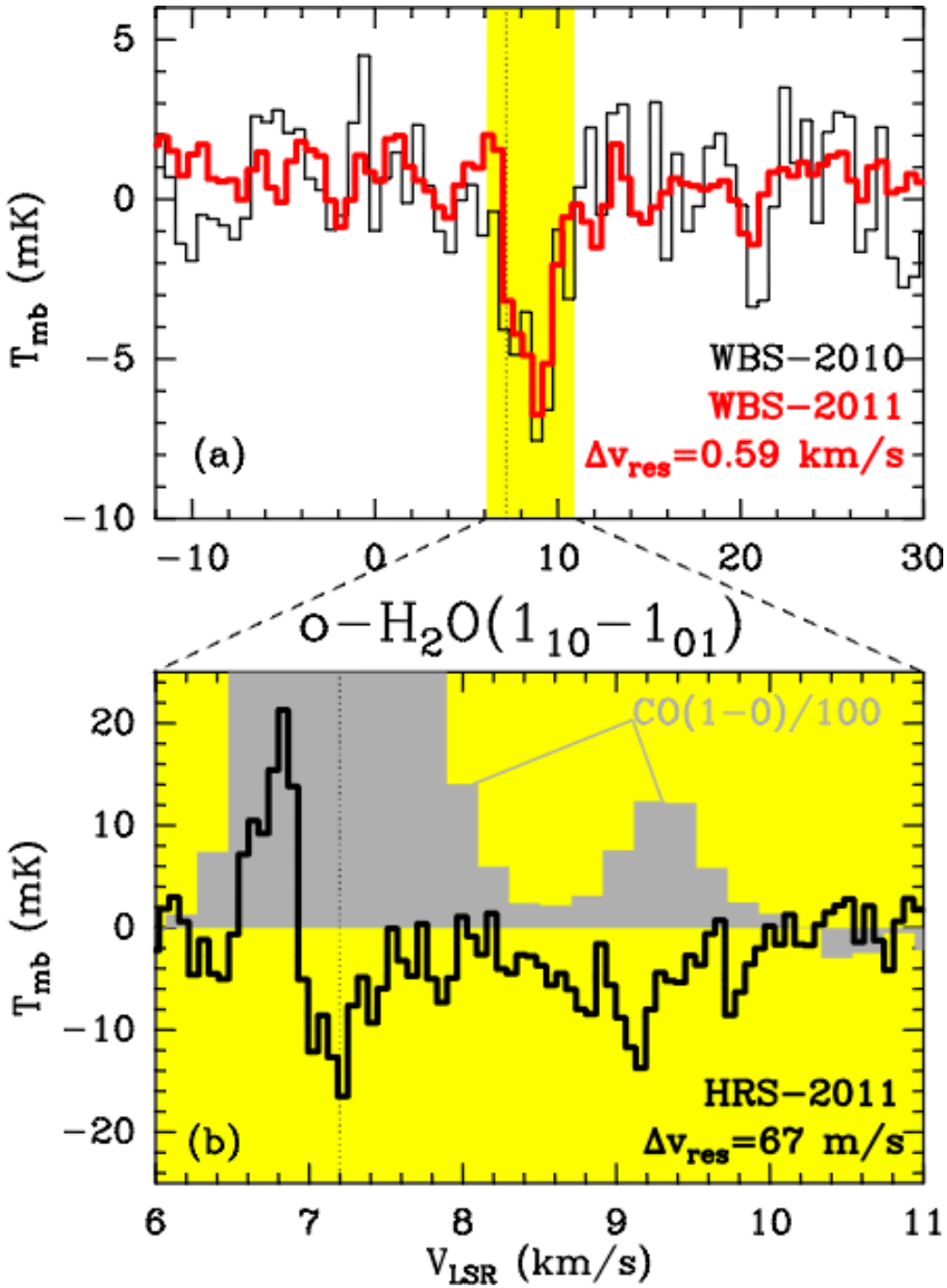
Keto & Caselli 2008

2010 Data



Caselli, Keto, Pagani et al. 2010


2011 Data



Caselli,
Keto,
Bergin,
Tafalla,
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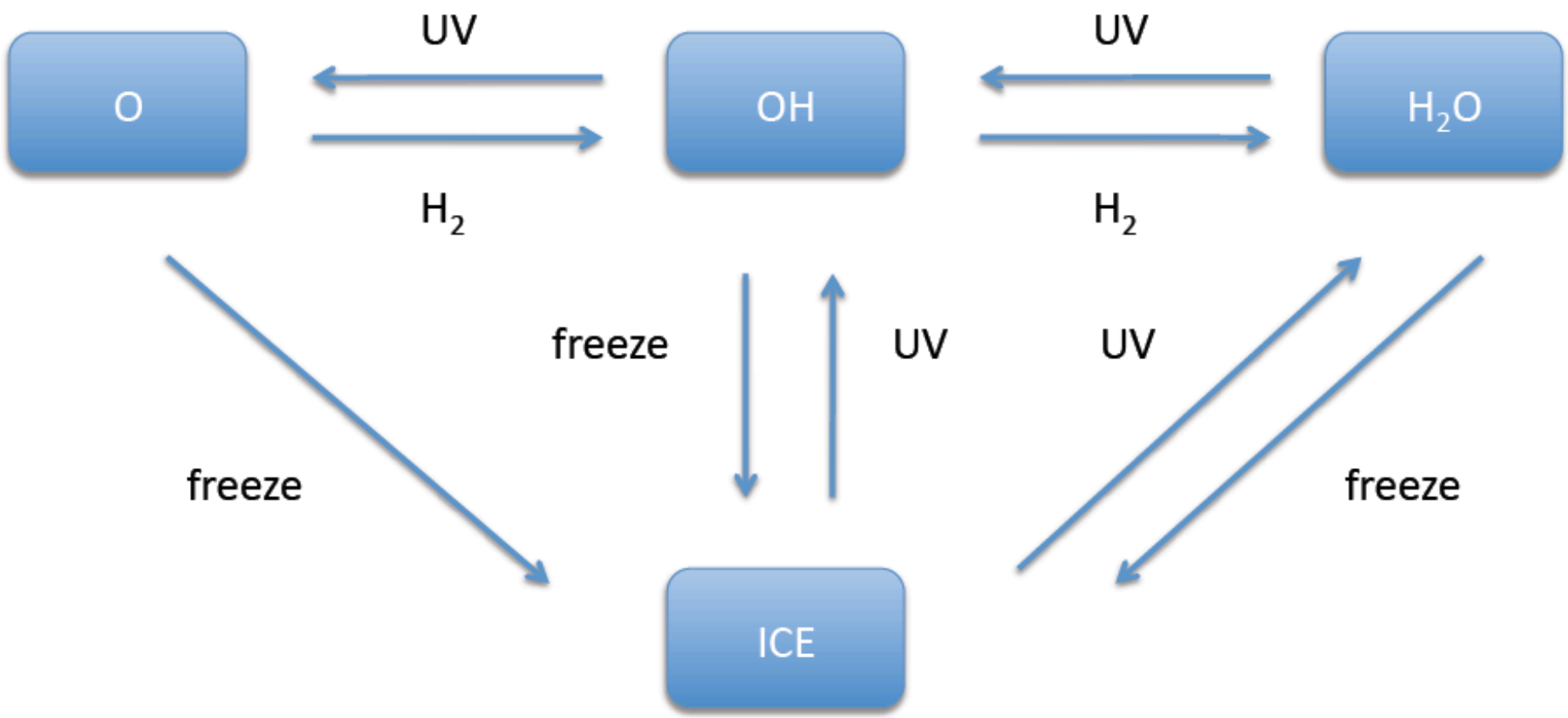
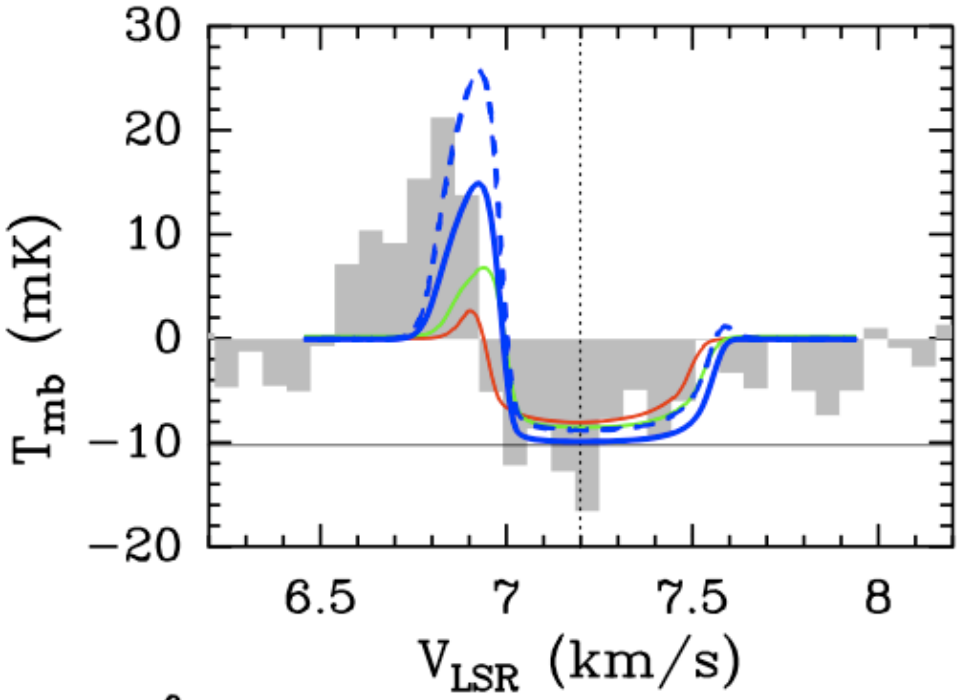
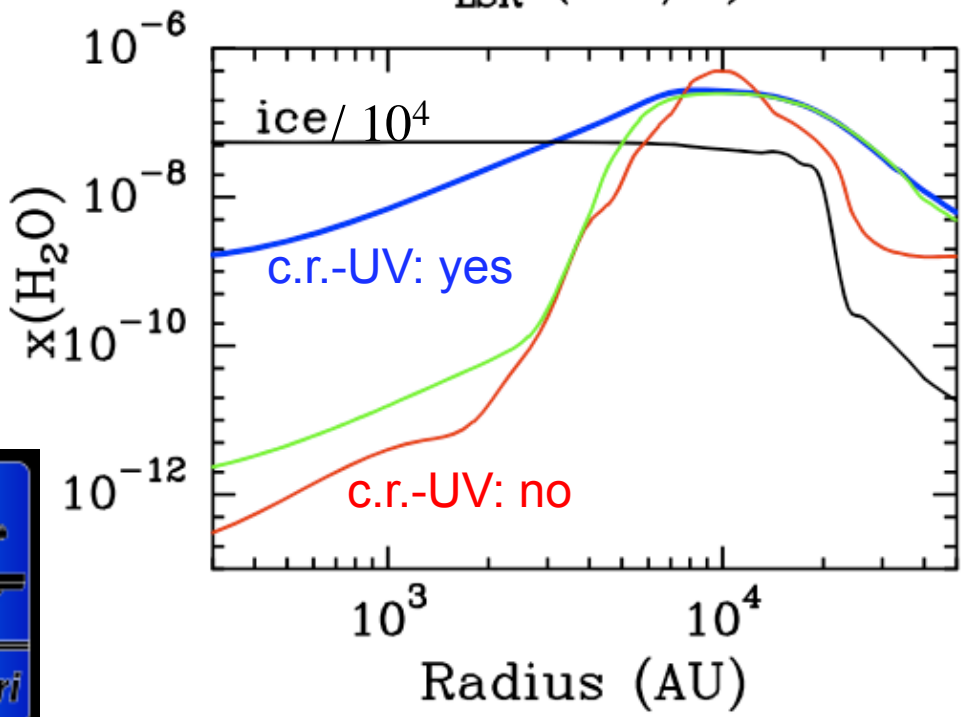
Pagani
Yildiz,
van der Tak,
Walmsley,
Codella,
Nisini,
Kristensen,
van Dishoeck
2012, ApJL

Simplified O-chemistry





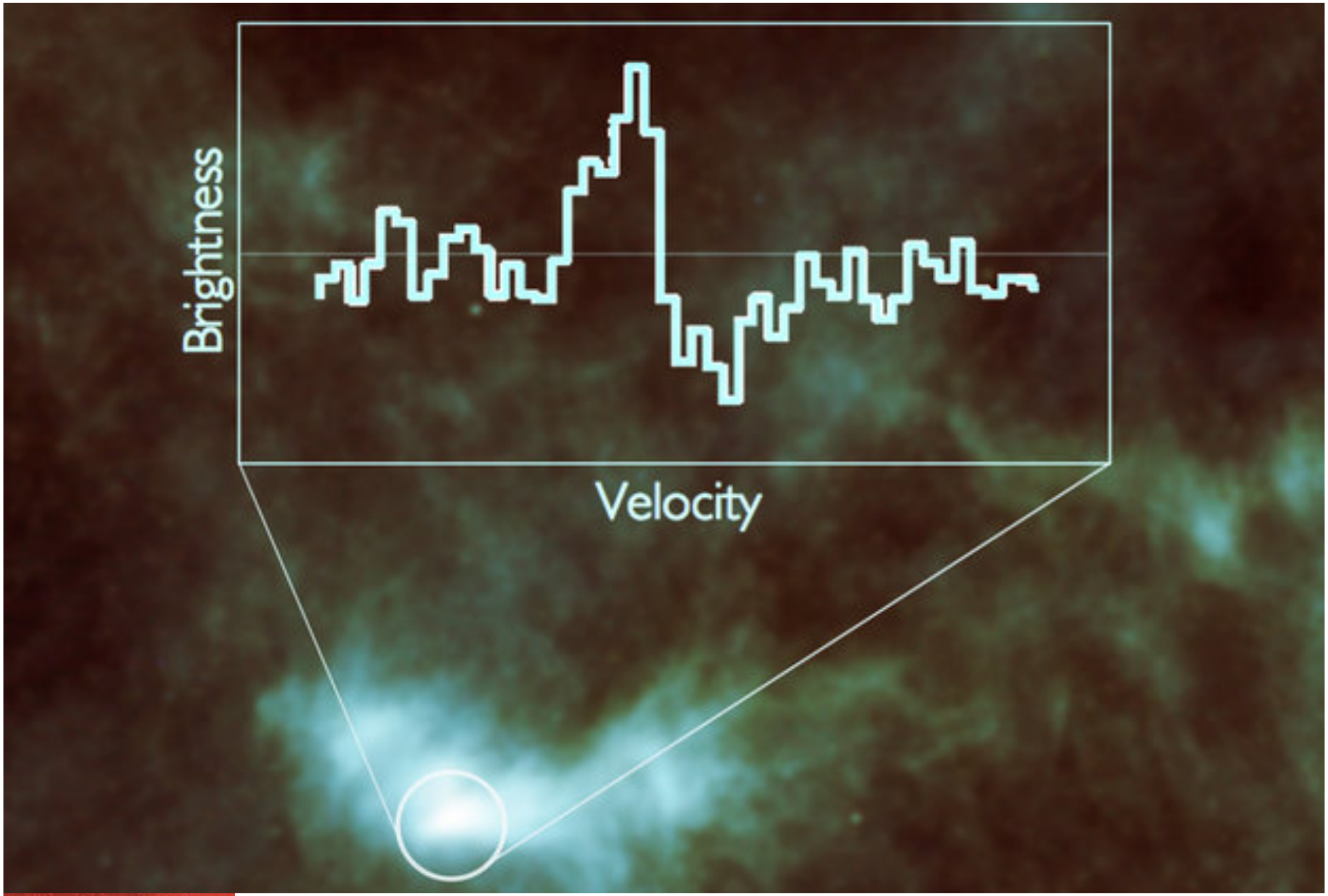


KEY PHENOMENA:

- $x(H_2O) \geq 10^{-9}$ - maintained by FUV photons produced by c.r. (total mass of water vapor: ~0.5 Earth masses; total mass of water ice: ~2.6 Jupiter masses).

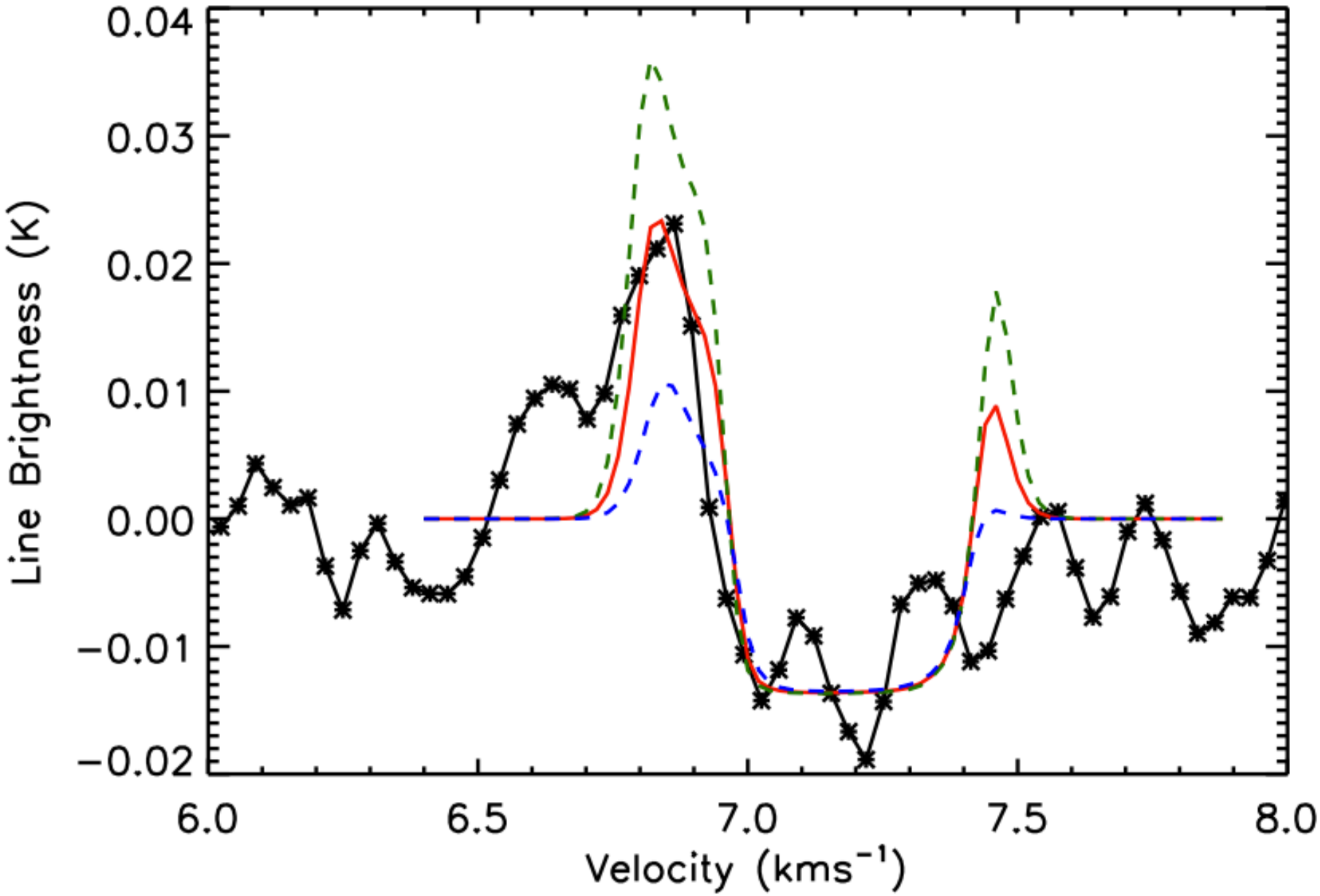
- $n_H \geq 10^6$ cm^{-3}, to explain H_2O emission.

- Gravitational contraction to see blue wing in emission.

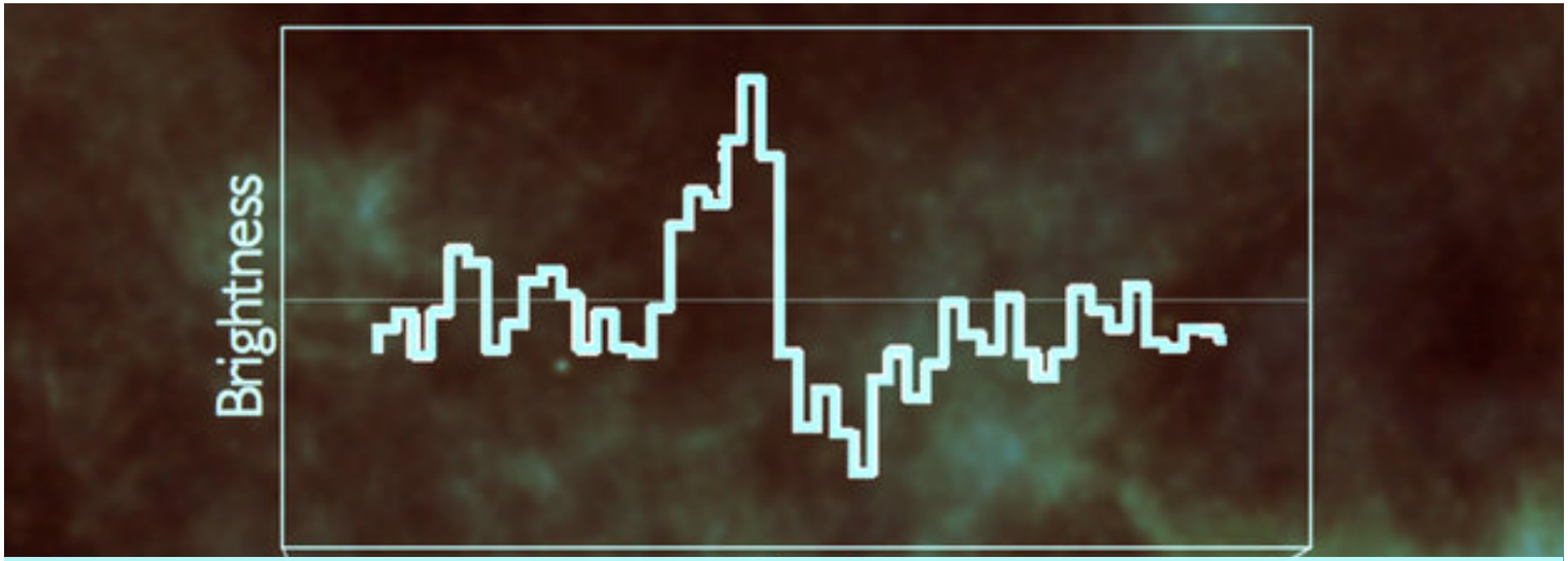


esa

LARGE WATER RESERVOIRS AT THE DAWN OF STELLAR BIRTH



Keto et al. in prep.



The *Herschel Space Observatory* has:

1. detected water vapor in a pre-stellar core for the first time
2. unveiled gravitational infall within the central 1,000 AU
3. measured the total mass of water vapor (~0.5 Earth masses ➔ total mass of water ice ~2.6 Jupiter masses)
4. has given us insight into the radiative transfer and the chemistry of water in cold gas…

A SPECIAL THANK TO:

Eric Keto (CfA)
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Joe Mottram (Leiden Observatory)
Floris van der Tak (SRON)