Water in star-forming regions with Herschel (WISH):

Recent results and emerging trends

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www.strw.leidenuniv.nl/WISH

Aquila / W40
Herschel mage 8 p
André & Gould Be

Water In Star-forming regions with Herschel
The WISH team

Leiden, December 2011

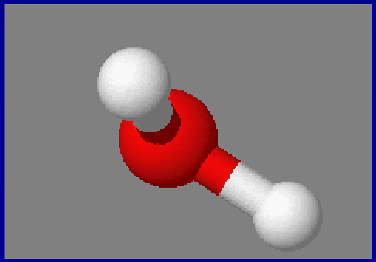
Toledo, June 2011

70+ scientists from 30 institutions (PI: EvD)
15 papers in Herschel A&A first results issues,
25 papers total, see WISH website

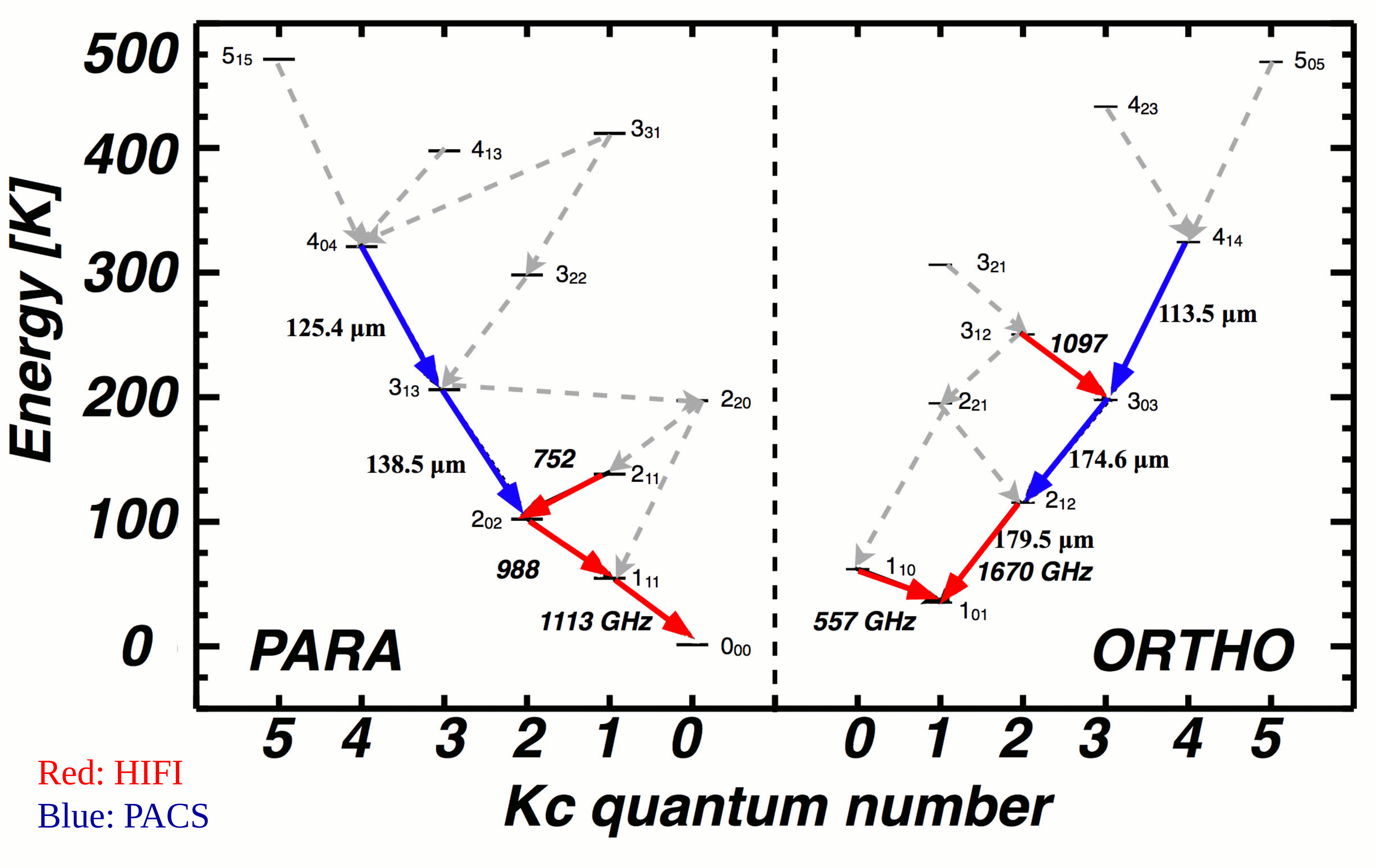
Summary in van Dishoeck et al. 2011, PASP

WISH questions

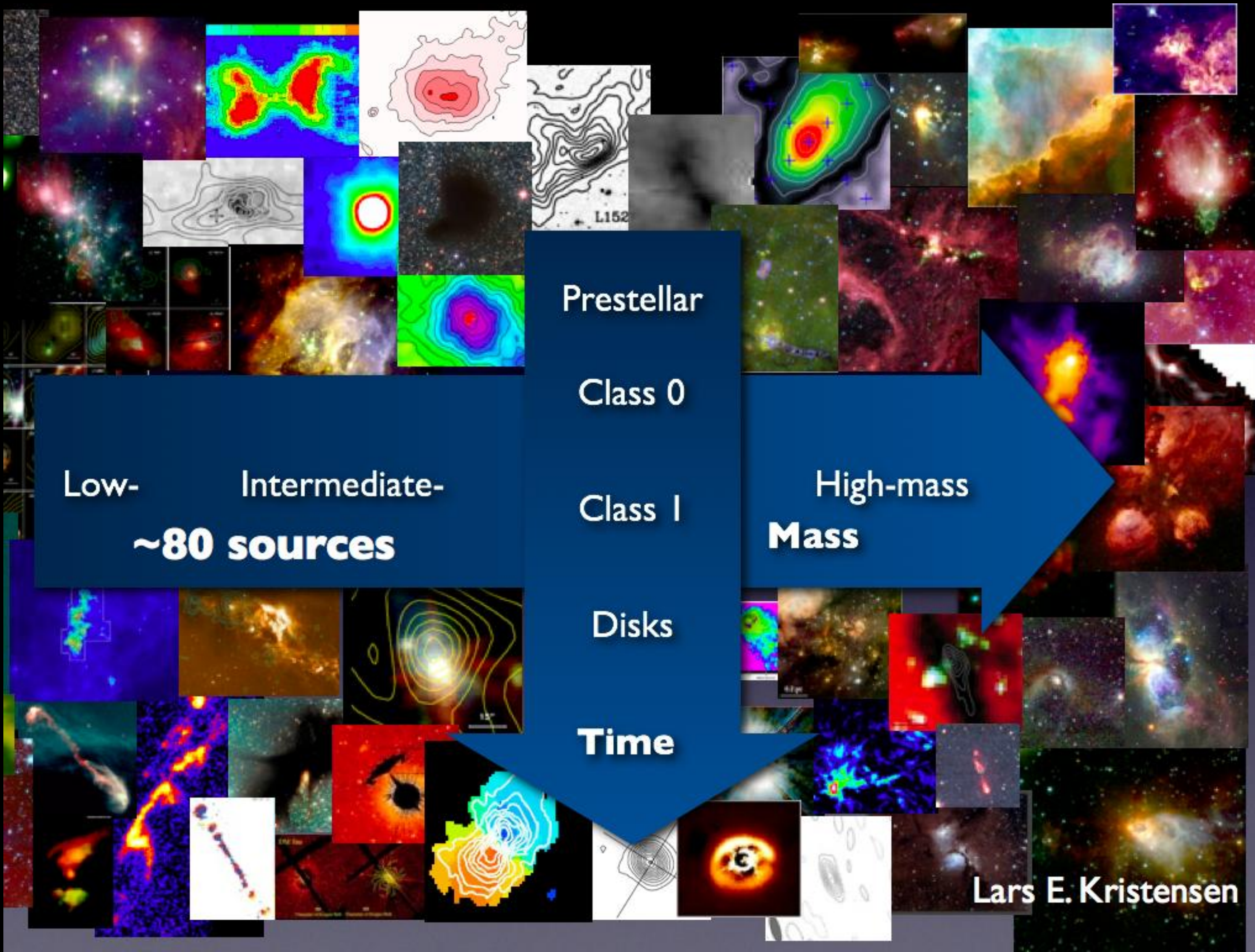
- **Which physical components does water trace?**
  - **Quiescent envelope, hot core, outflows, disks, …**
  - **Gas cooling budget**
- **Where is water formed in space and by which processes?**
  - **Gas vs grains**
- **What is the water 'trail' from clouds to planets?**
  - **Origin of water on Earth**



H_2O lines: HIFI and PACS



Observe mix of low- and high-excitation lines to probe cold and hot environments; Include ^{12}CO 10-9, ^{13}CO 10-9, $C^{18}O$ 9-8, PACS

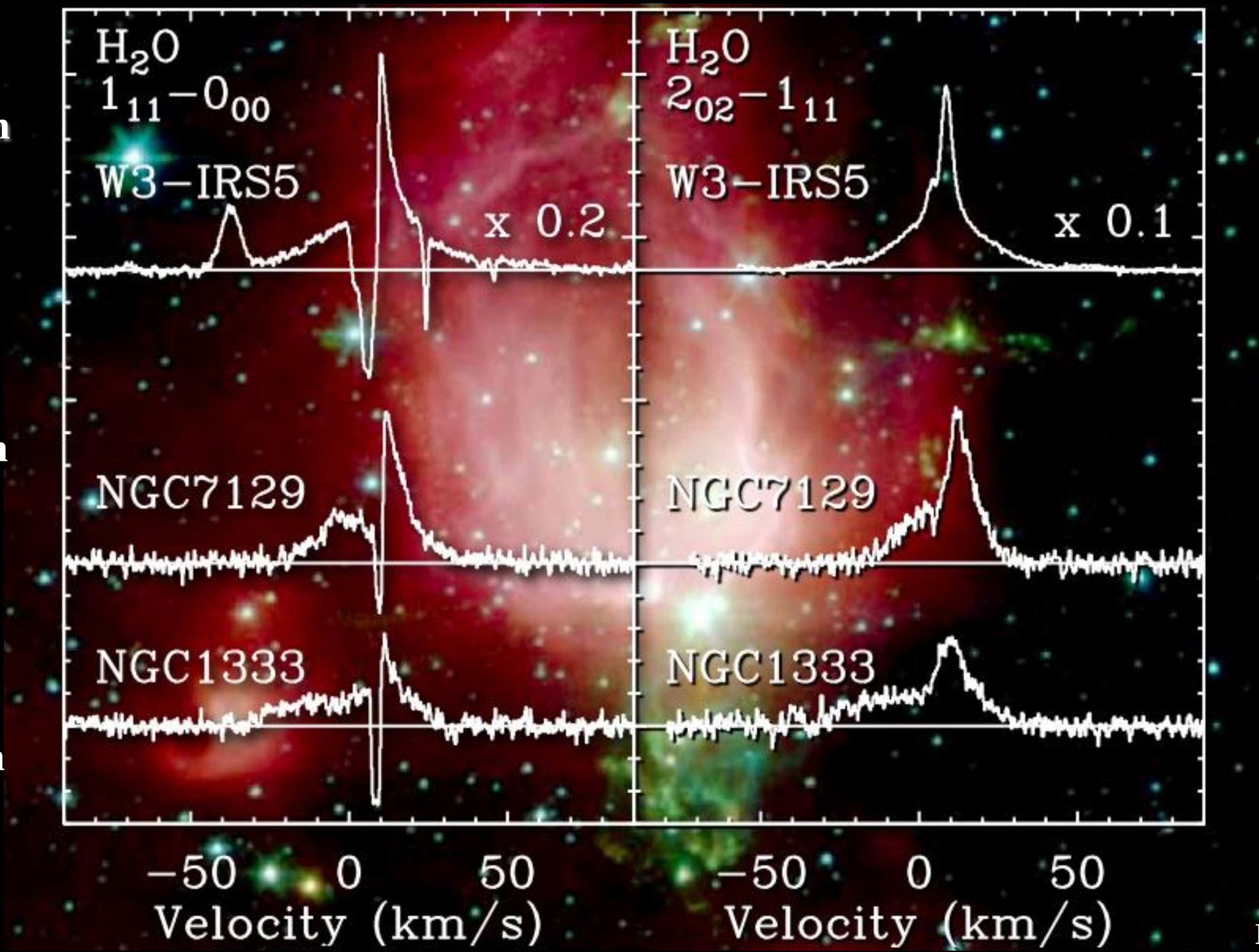

Prestellar
Class 0
Low-
Intermediate-
High-mass
Class I
~80 sources
Mass
Disks
Time
Lars E. Kristensen

Water reveals diverse kinematic components From low to high mass protostars

$10^5\ L_{Sun}$

$430\ L_{Sun}$

$20\ L_{Sun}$

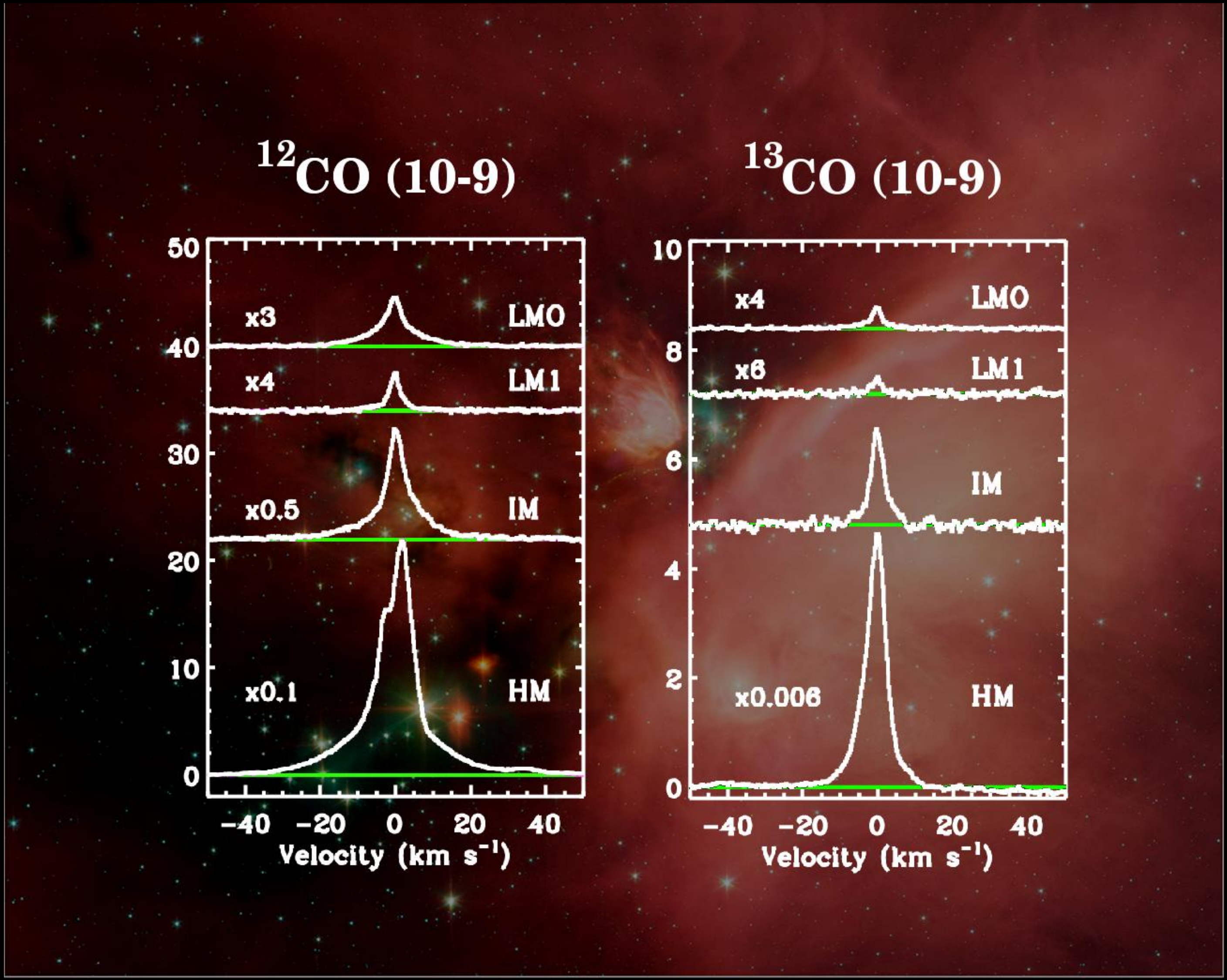


Kristensen et al. 2010
Johnstone et al. 2010
Chavarria et al. 2010

Note similar profiles: broad, medium and narrow

Even $H_2^{18}O$ lines dominated by broad emission for low mass

CO 10-9 from low to high mass

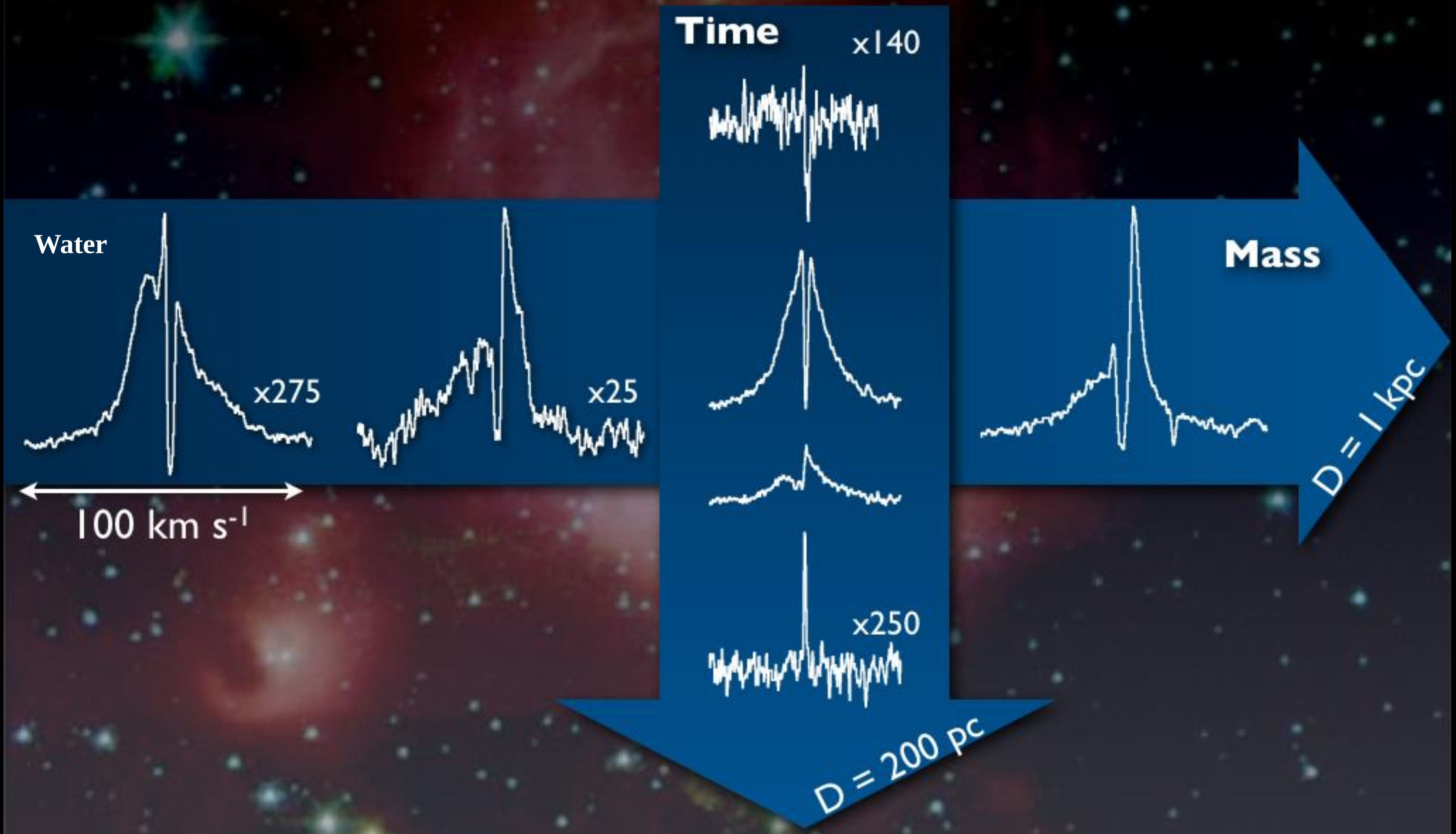


Stacked lines

Note similarity profiles

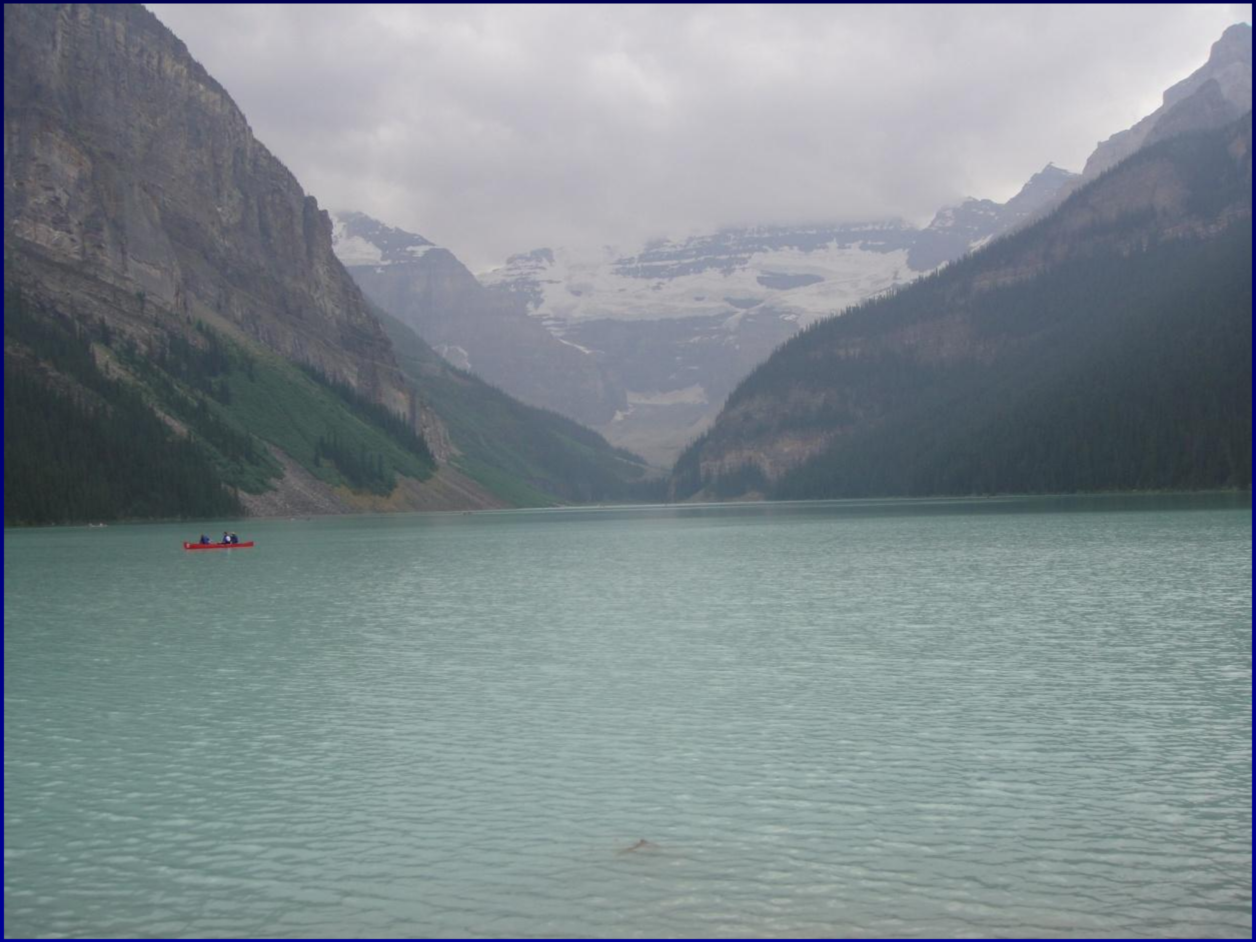
San Jose-Garcia et al.

Trends across mass and time



- Similar profiles from low to high mass protostars except for scale
- Water only bright in embedded phase, not in cores or disks

Where is the water?

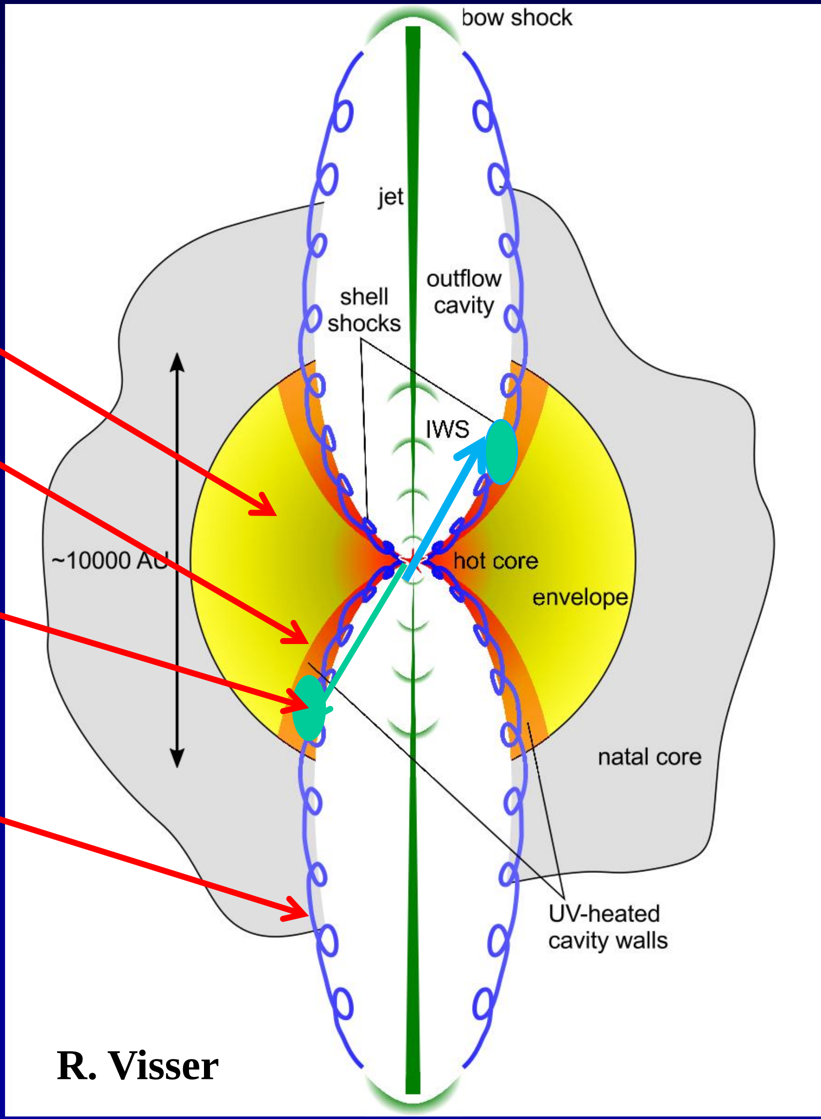


Lake Louise
August 2010

- ‘Streaming’ along the walls?
- Inside the cavity?
- As ice in the envelope?

Physical components

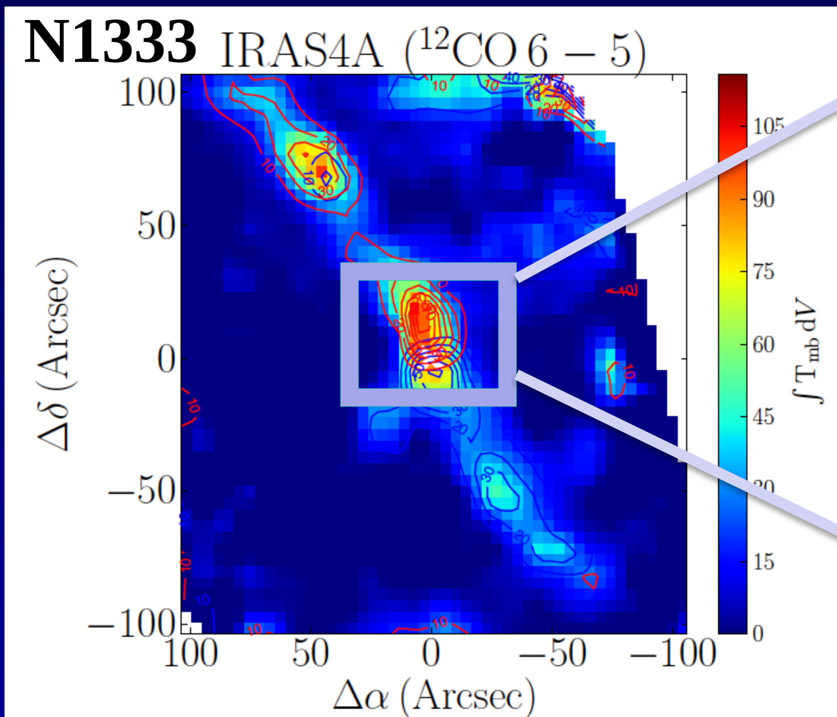
- **Quiescent envelope**
  - **Narrow absorption/emission**
- **UV-heated cavity walls**
  - **Narrow emission CO mid-*J***
- **Currently shocked gas**
  - **H_2O broad, CO high-*J***
- **Entrained outflow gas**
  - **CO low-*J***



Talks Lars Kristensen and Ruud Visser, Poster Joe Mottram

Spatial distribution CO vs H_2O

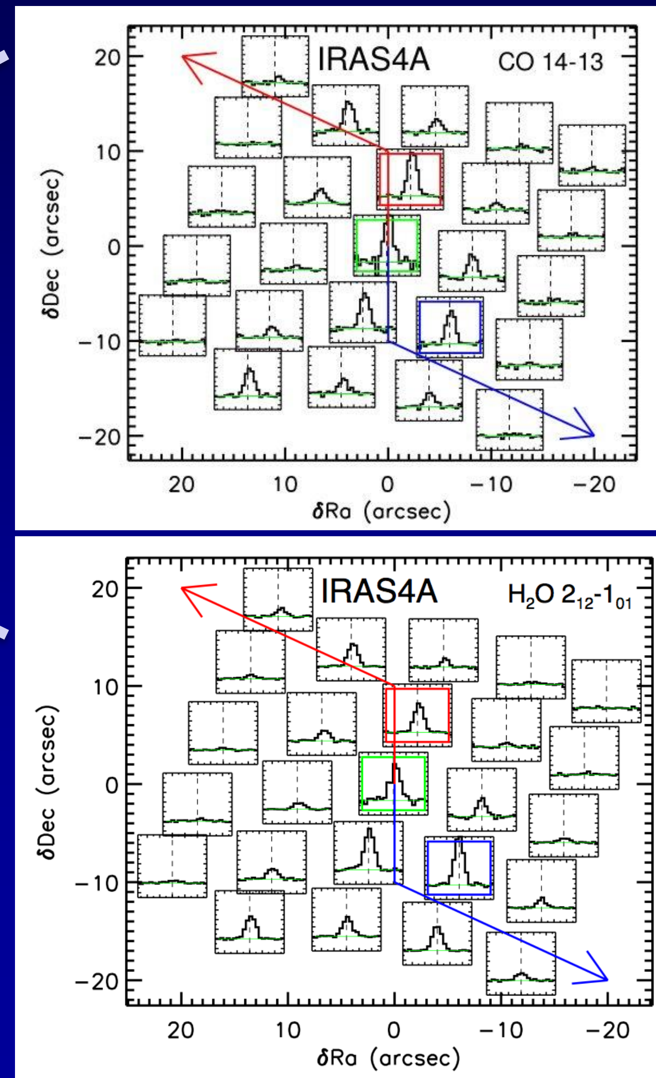
APEX-CHAMP$^+$ CO 6-5



Poster Yildiz+2012

Herschel/PACS

CO 14-13 vs H_2O 2_{12}-1_{01}



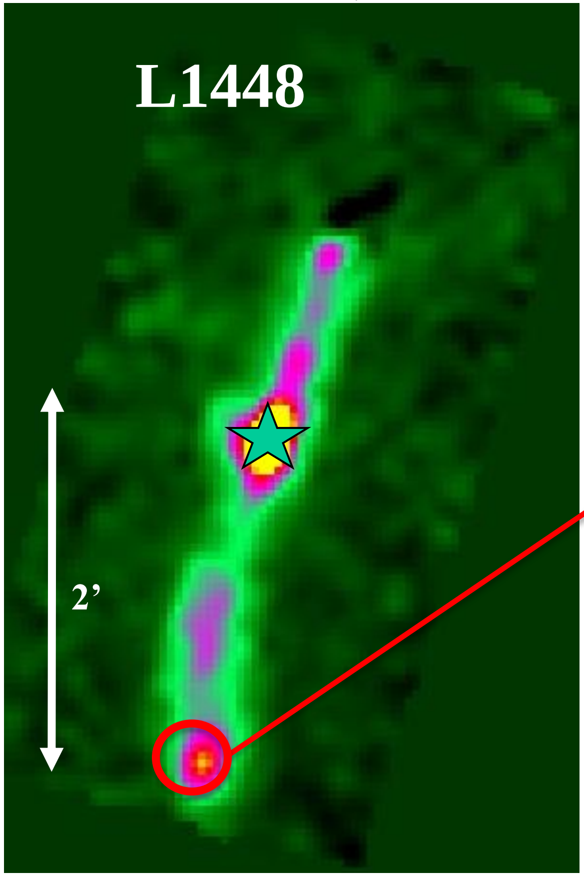
Poster Karska

OH: Poster Wampfler

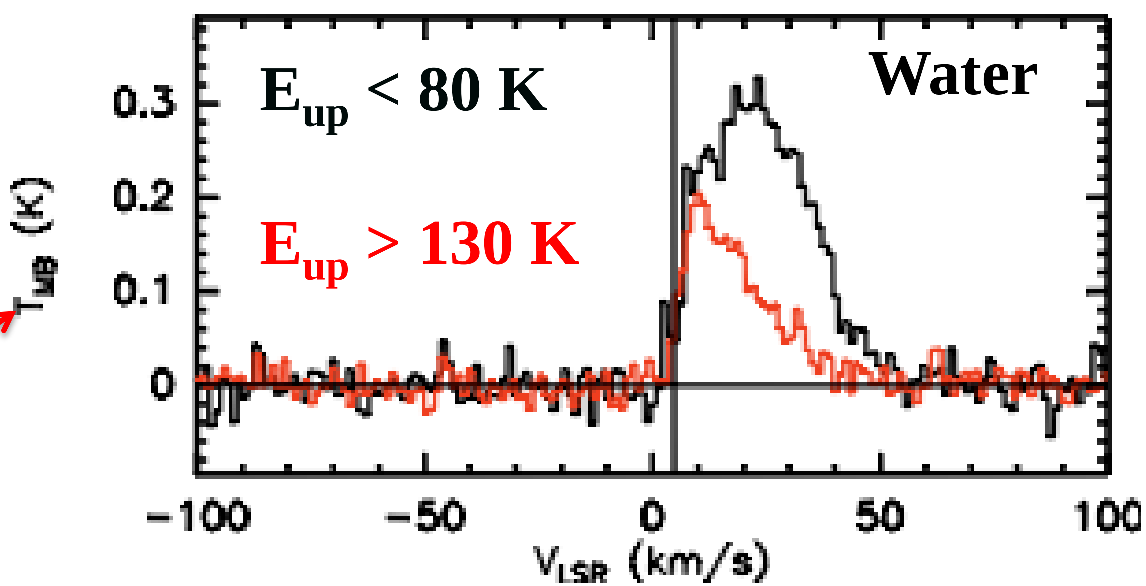
Water follows outflow and high-*J* CO, not low-*J* CO

Shocking water lines

PACS image 179 μm line



L1448 R4

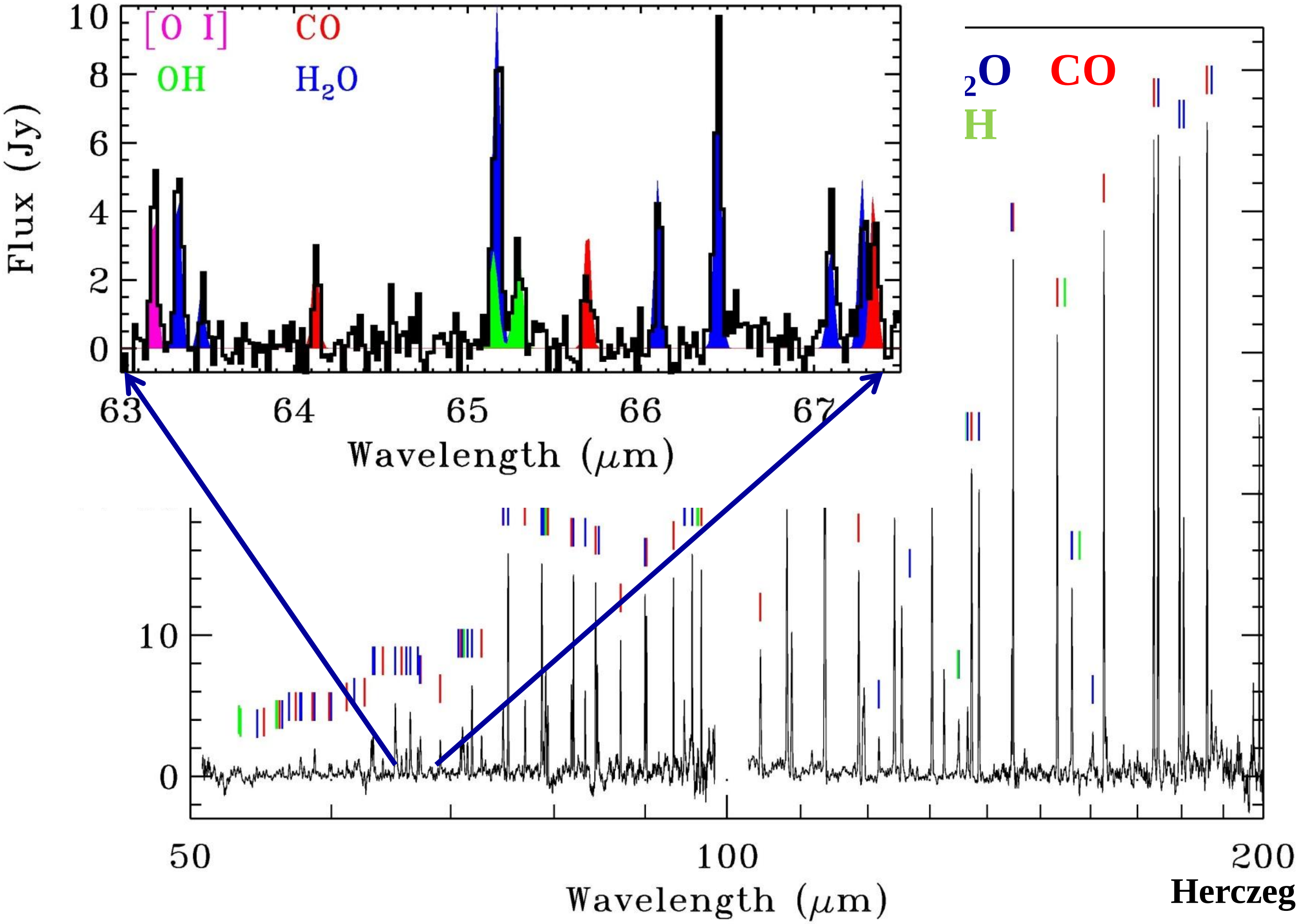


Santangelo et al. 2011
Vasta et al. 2011

- Lower excitation lines trace higher velocities

Poster Santangelo et al.

Rich far-IR shock spectra

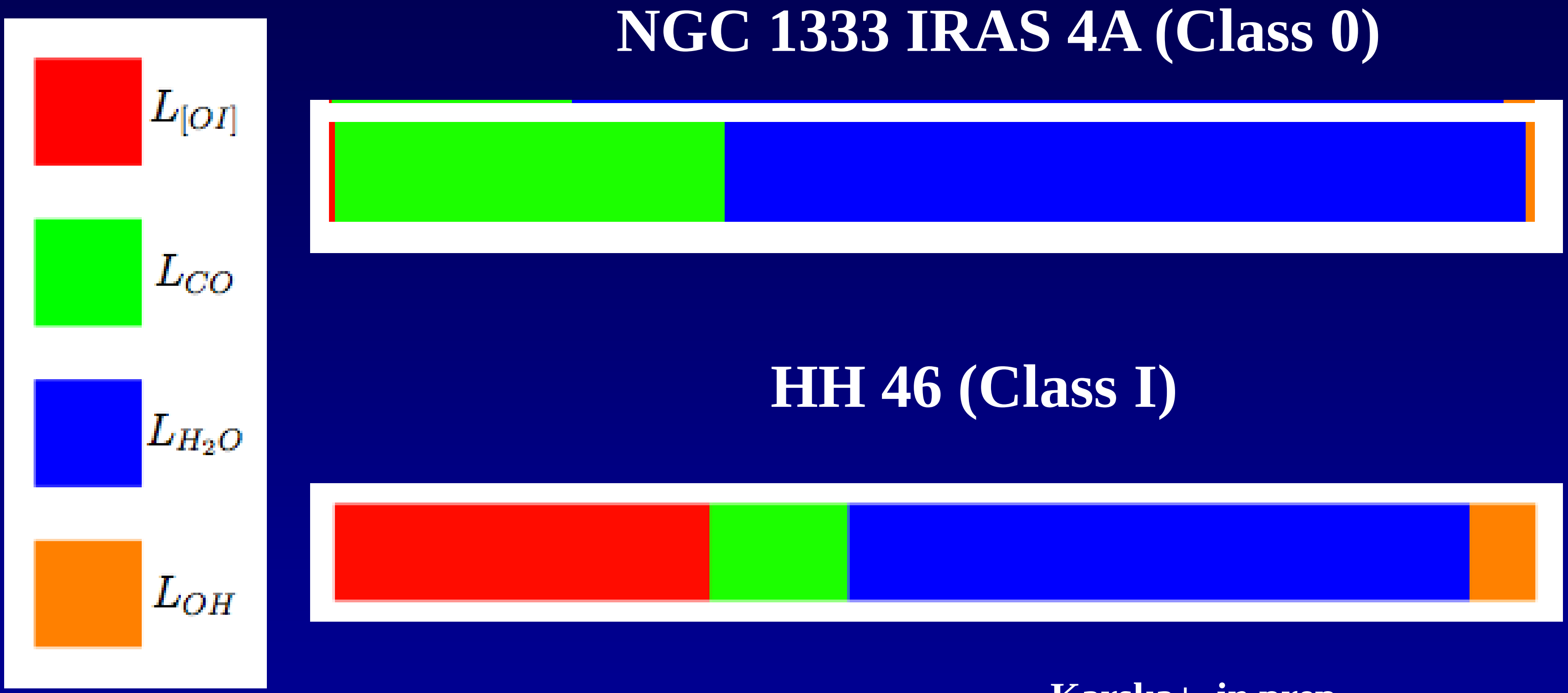


NGC1333 IRAS4B PACS Spectral scan

Herczeg et al. 2012

- All lines assigned to 4 species, from levels up to several thousand K

Far-IR cooling budget



Karska+, in prep.

✧Cooling by [OI] marginal in Class 0, but rises with evolution

✧ H_2O dominates far-IR cooling of deeply embedded YSOs

Conclusion 1

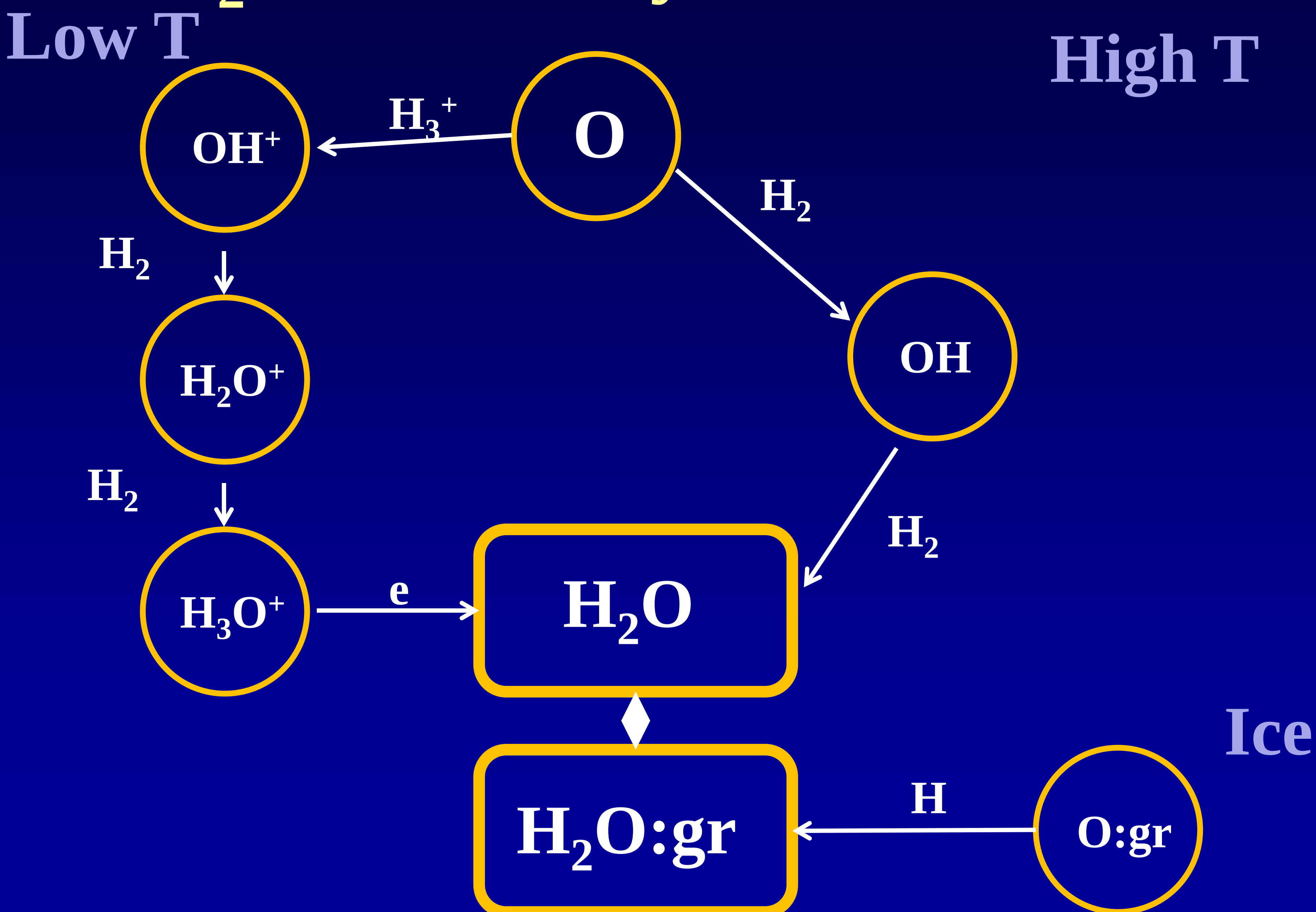
- **Water reveals different physical components of protostellar environment more effectively than does CO**
  - **Kinematic information crucial!**
- **Emission dominated by high *n* (>10^5 cm^{-3}), high *T* (>400 K) shocks**
- **Far-IR cooling budget being quantified**
- **Processes similar from low- to high-mass YSOs**

WISH =

Water IS Hot

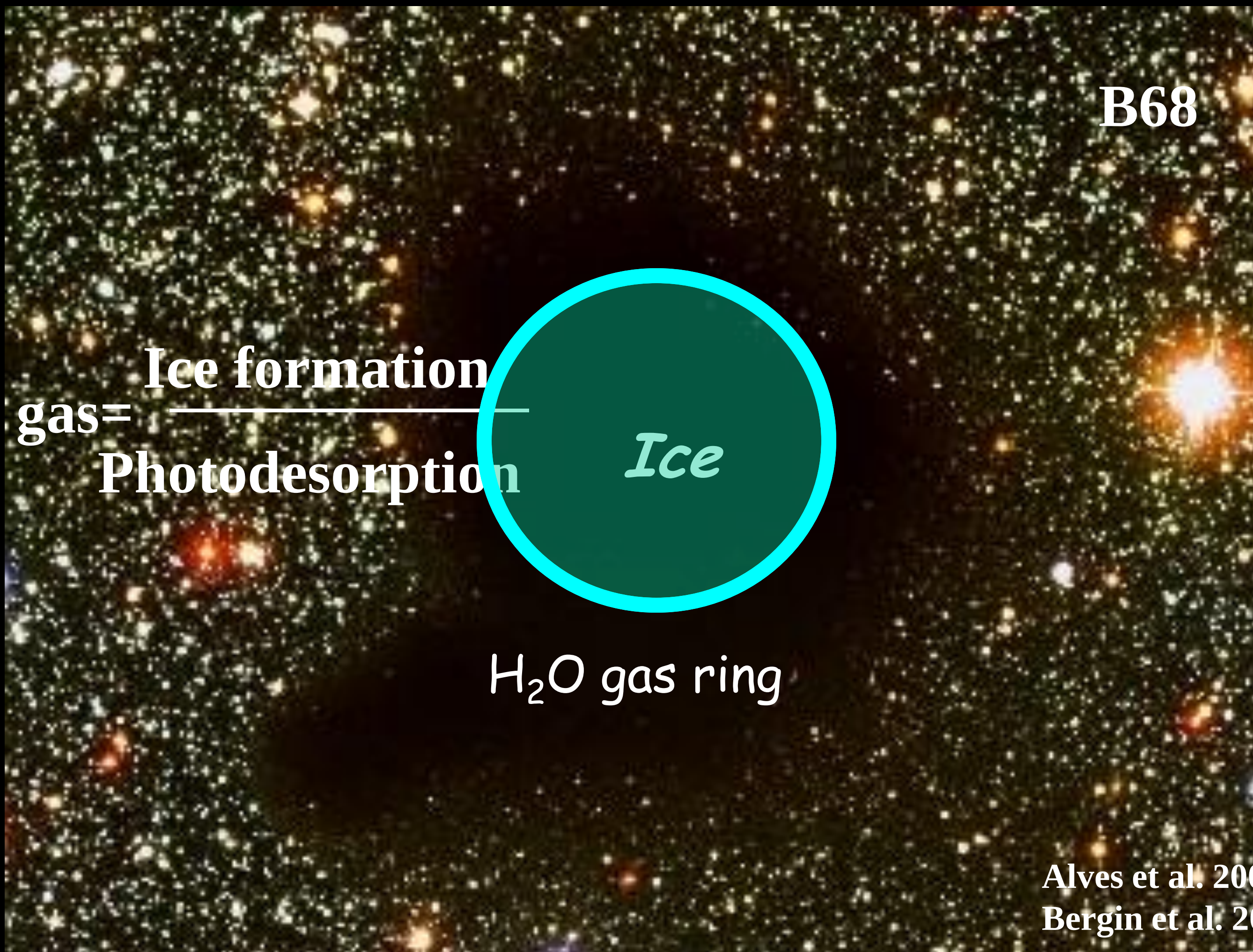
M. Tafalla

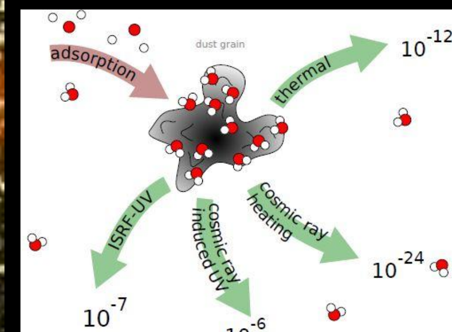
H_2O chemistry: three routes

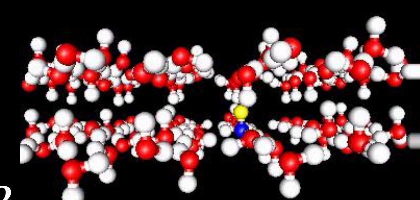


Pre-stellar cores: where is water formed?

$$H_2O\ \text{gas} = \frac{\text{Ice formation}}{\text{Photodesorption}}$$







Lab + Theory

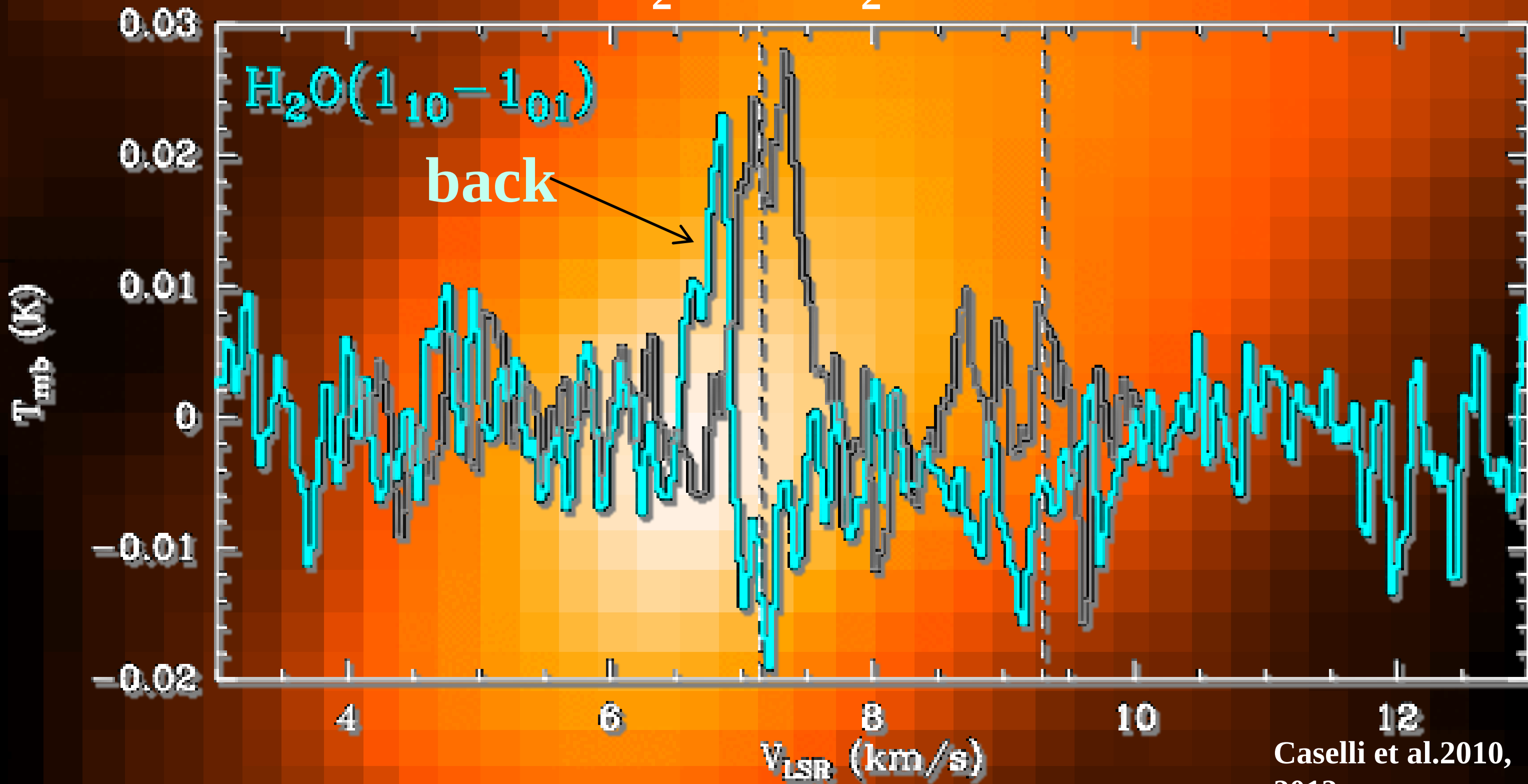
n=2.10^4 – 5.10^6 cm^{-3}, T=10 K

Layer of water gas where ice is photodesorbed

A&vD2008
Öberg et al. 2009

The prestellar core L1544

H_2O vs H_2D^+ /50 **11 hr integration!**

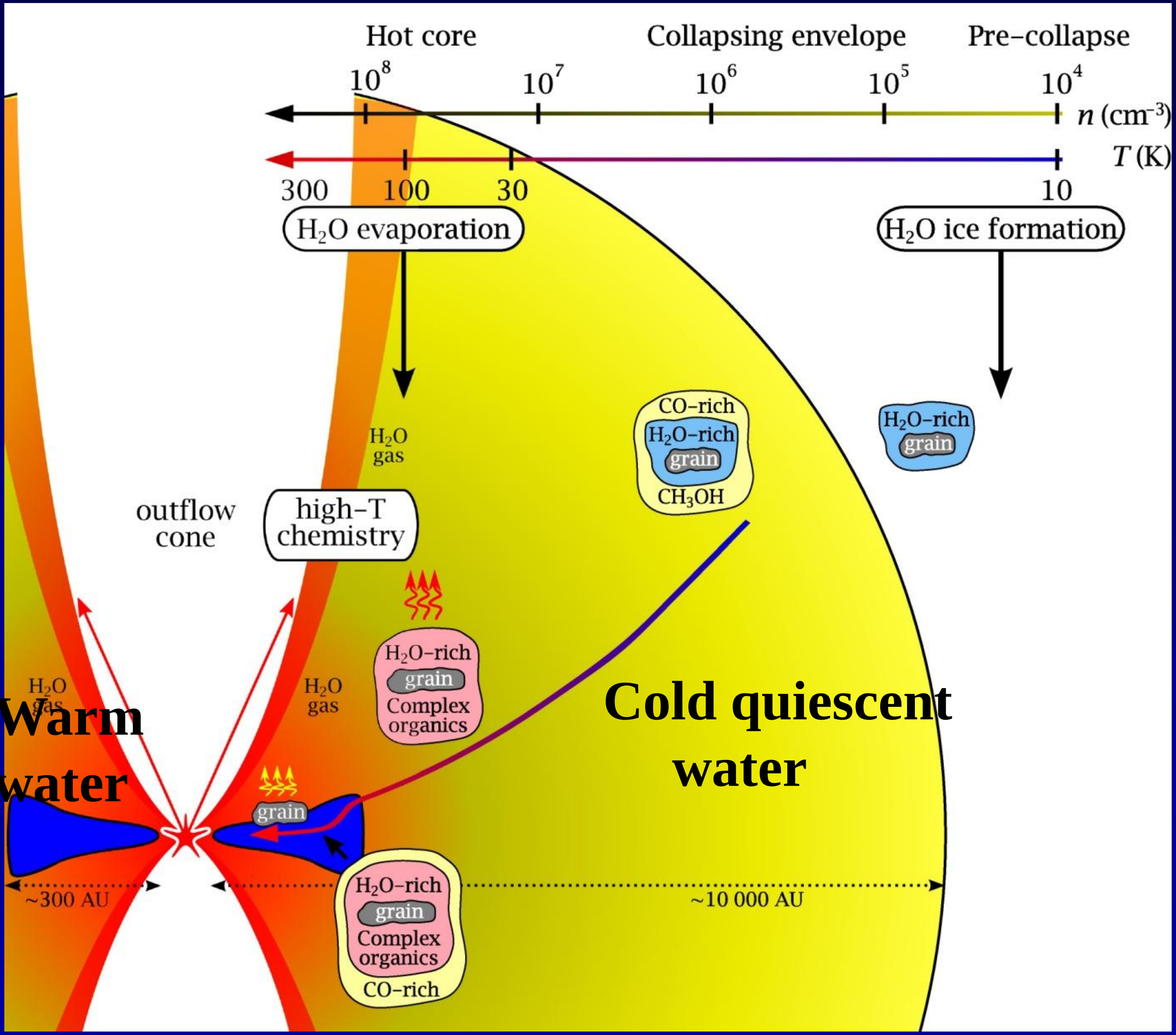


Caselli et al.2010, 2012

- Emission requires high central density ~10^7 cm^{-3}
- Profile indicates infall of 0.1 km/s at 1000 AU

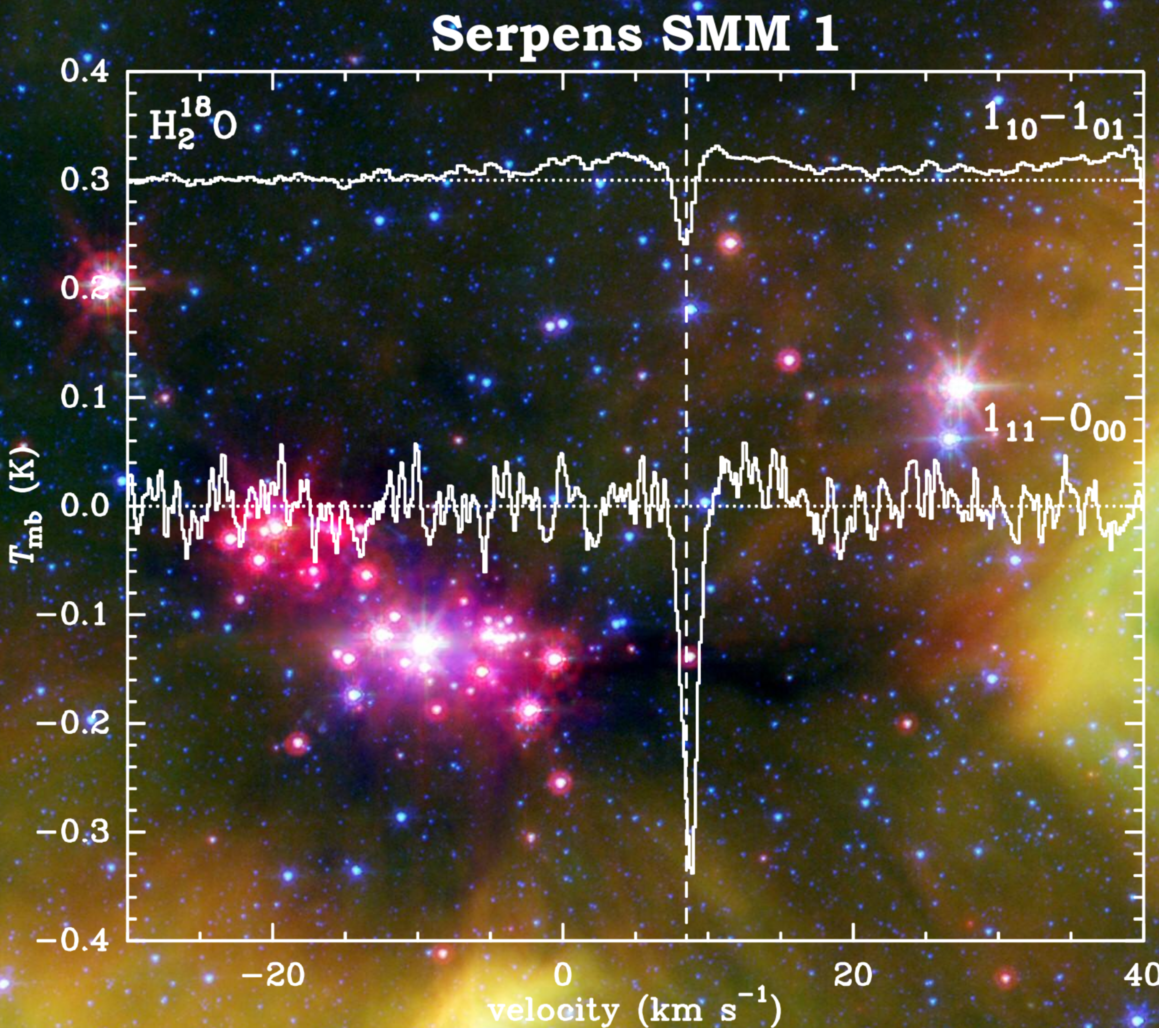
1.3 mm continuum map from Ward-Thompson et al. (1999)

How much water is where?



Visser et al. 2009
Herbst & vD 2009

Cold outer envelope

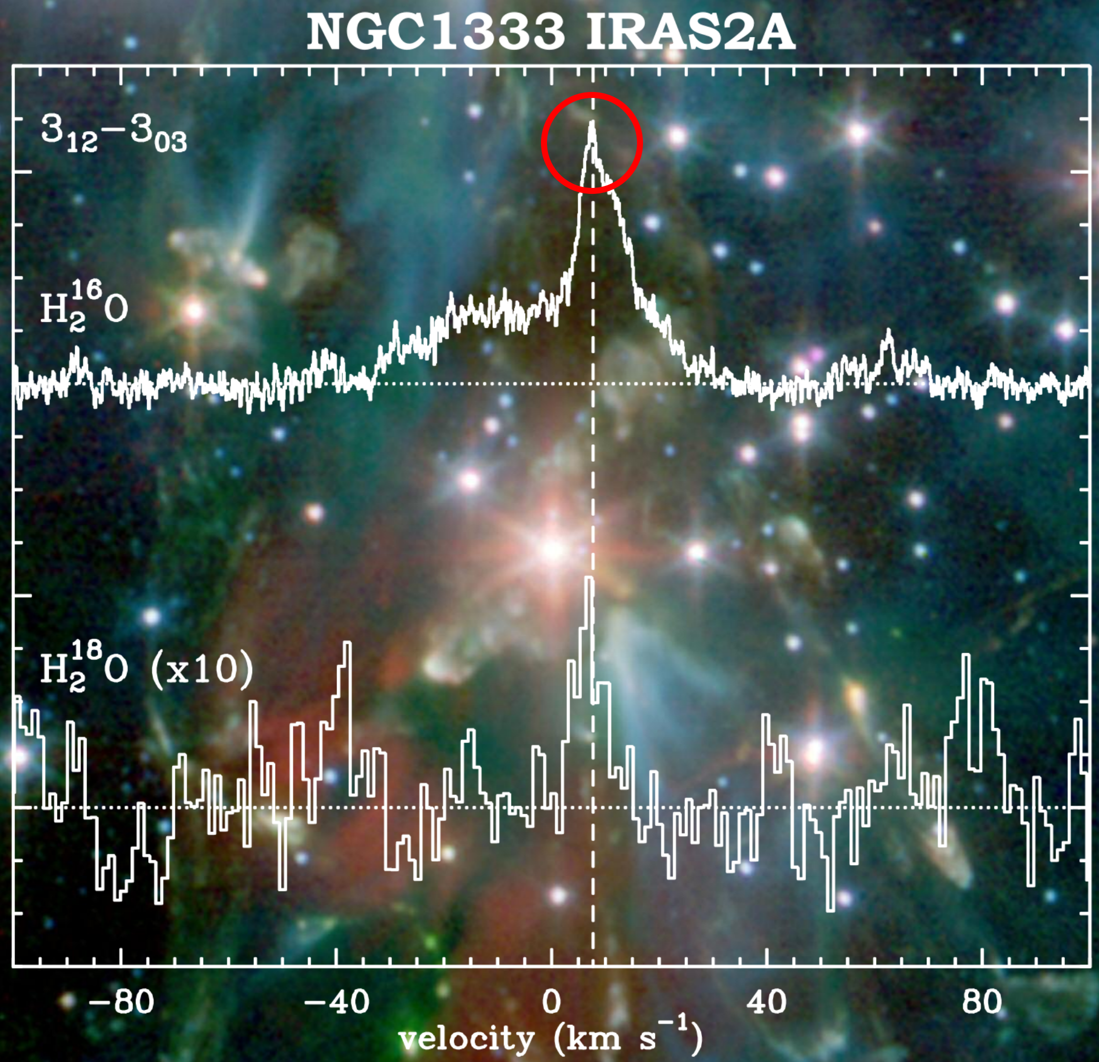


Continuum and emission subtracted

Schmalzl et al. poster

- Outer envelope abundance ~10^{-8} - 10^{-9}

Warm inner abundance

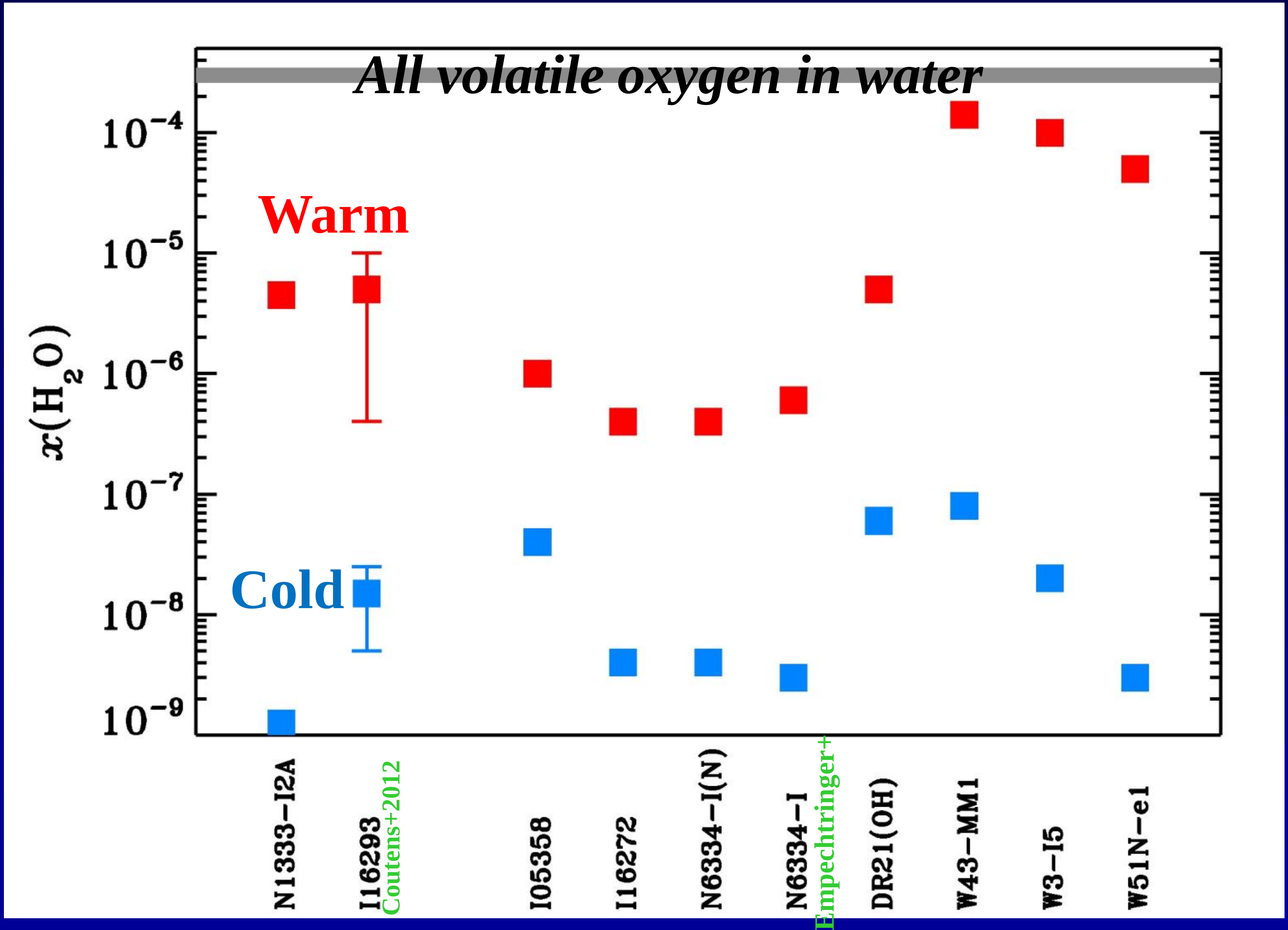


-Deep 5 hr integration on excited line reveals narrow $H_2^{18}O$

- Abundance only ~few $\times 10^{-6}$

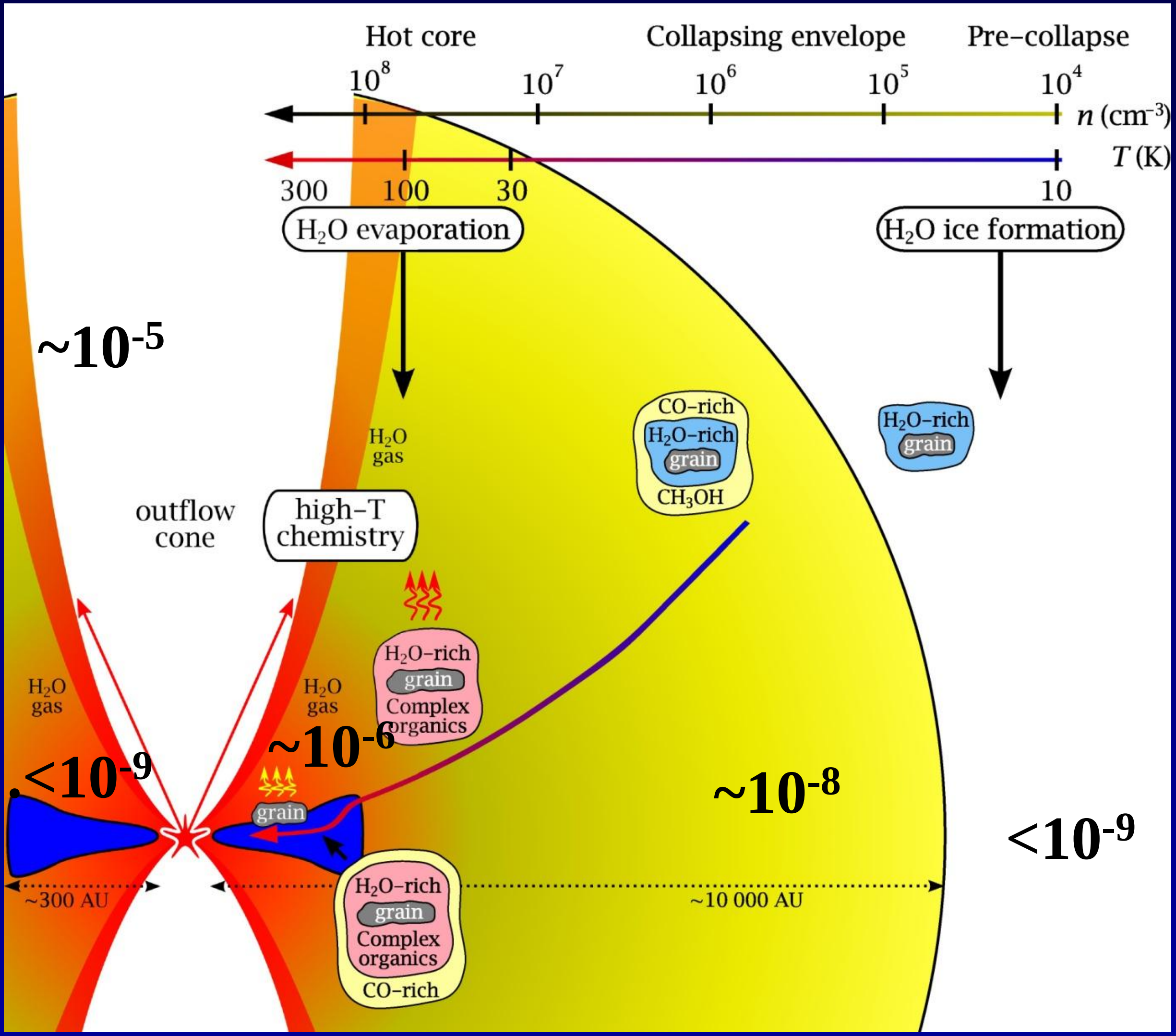
Talk Herpin, poster Choi

Warm and cold water abundances



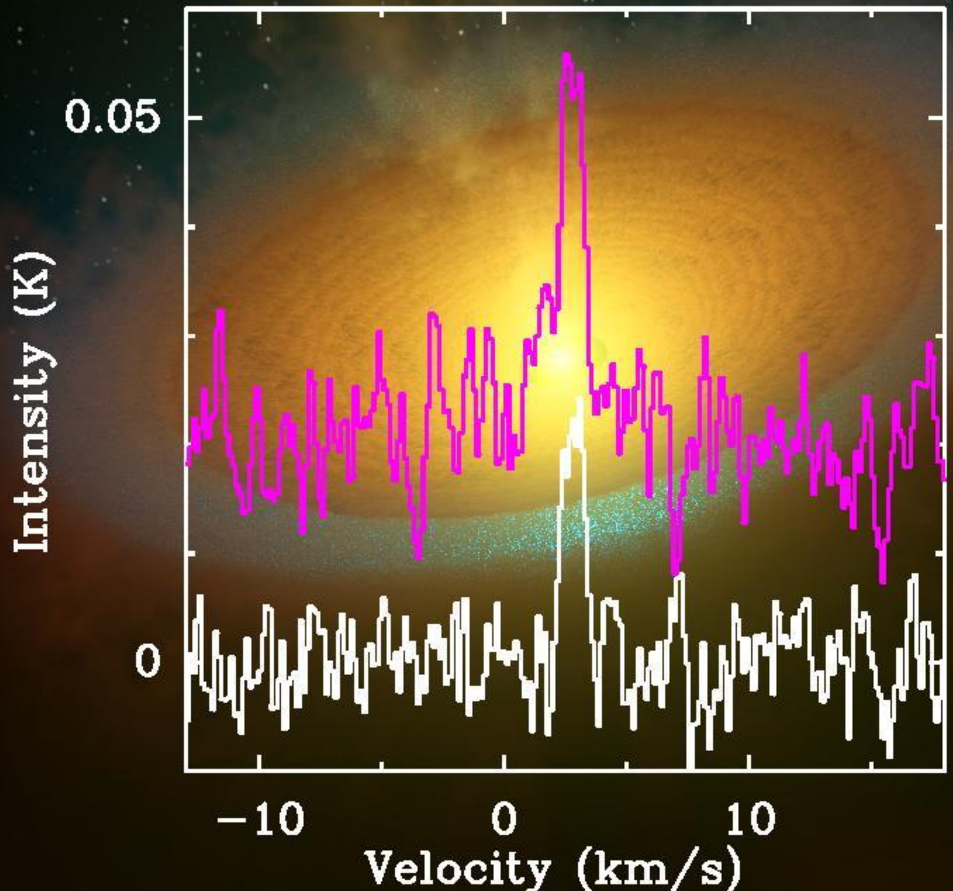
- Why is warm abundance not > 10^{-4}?
- What causes variations from source to source?

How much water is where?



Visser et al. 2009
Herbst & vD 2009

Detection of cold water in disks



p-H_2O 1_{11}-0_{00}
1113 GHz

o-H_2O 1_{10}-1_{01}
557 GHz

Hogerheijde et al. 2011, Science

Talk Michiel Hogerheijde

Conclusions 2

- **Water is formed mostly on grains**
  - **Some in shocks at high *T***
- **Photodesorption controls gas-phase water abundance in cold clouds and disks**
- **Water abundance in hot cores is lower than expected**
  - **Both low- and high-mass sources**
- **Water is transported into disks mostly as ice**

Stay tuned for more water stories during the day