Water in star-forming regions with Herschel (WISH)

E.F. van Dishoeck, Y. Aikawa, R. Bachiller, A. Baudry, M. Benedettini, *A. Benz,* E. Bergin, P. Bjerkeli, G. Blake, S. Bontemps, J. Braine, *S. Bruderer*, *P. Caselli,* J. Cernicharo, L. Chavarria, C. Codella, F. Daniel, C. Dedes, P. Encrenaz, A.M. di Giorgio, C. Dominik, S. Doty, H. Feuchtgruber, *M. Fich*, W. Frieswijk, A. Fuente, T. Giannini, J.R. Goicoechea, Th. De Graauw, F. Helmich, *F. Herpin, G. Herczeg, M. Hogerheijde,* T. Jacq, J. Jørgensen, D. Johnstone, A. Karska, M. Kaufman, E. Keto, *L. Kristensen*, B. Larsson, B. Lefloch, D. Lis, R. Liseau, F. Liu, *M. Marseille, C. McCoey,* G. Melnick, D. Neufeld, *B. Nisini*, M. Olberg, G. Olofsson, L. Pagani, B. Parise, O. Panić, J. Pearson, R. Plume, C. Risacher, D. Salter, N. Sakai, J. Santiago, P. Saraceno, R. Shipman, M. Tafalla, *F. van der Tak, T. van Kempen, R. Visser*, S. Viti, *S. Wampfler,* M. Walmsley, *F. Wyrowski,* S. Yamamoto, *U. Yildiz*

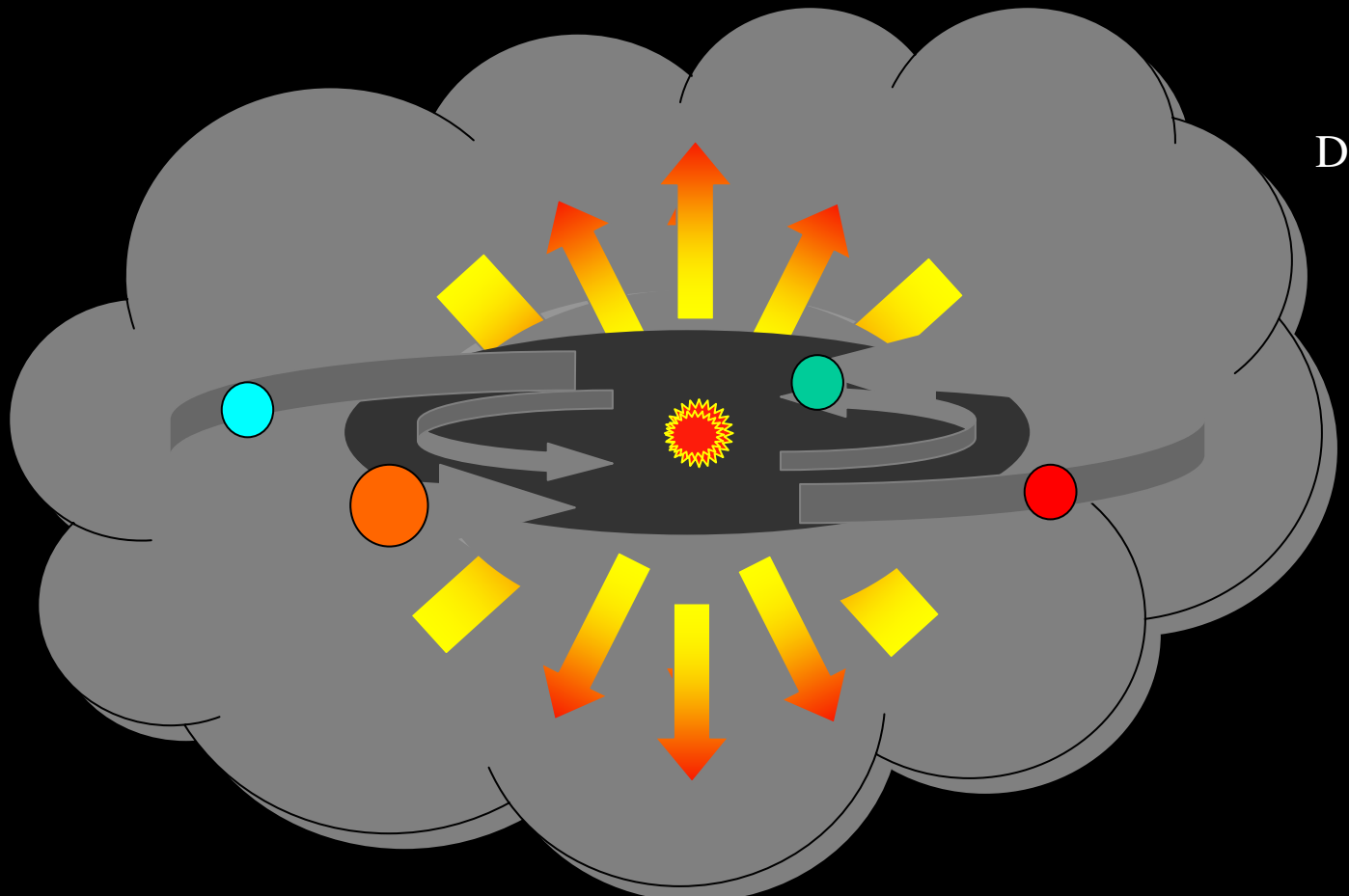
425 hr GT key program using HIFI and PACS

See http://www.strw.leidenuniv.nl/WISH

WISH today

Leiden April 28 2010

Follow water trail during star and planet formation

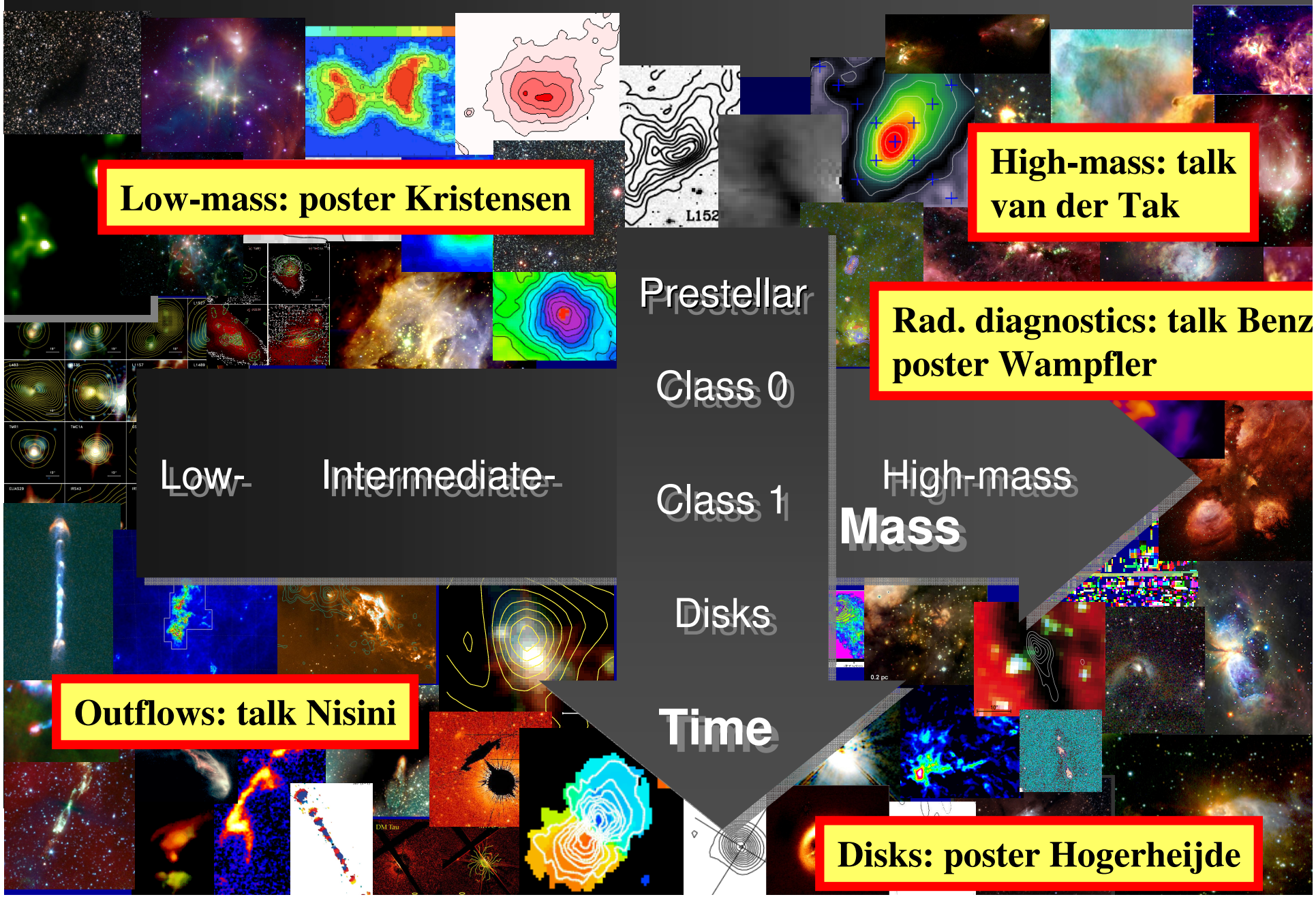


D. Lommen

Dark pre-stellar cores → **Low-mass YSOs** **→ Disks**
Infrared dark clouds **Intermediate mass YSOs**
High-mass YSOs

L.Kristensen

WISH (Images: courtesy MANY)



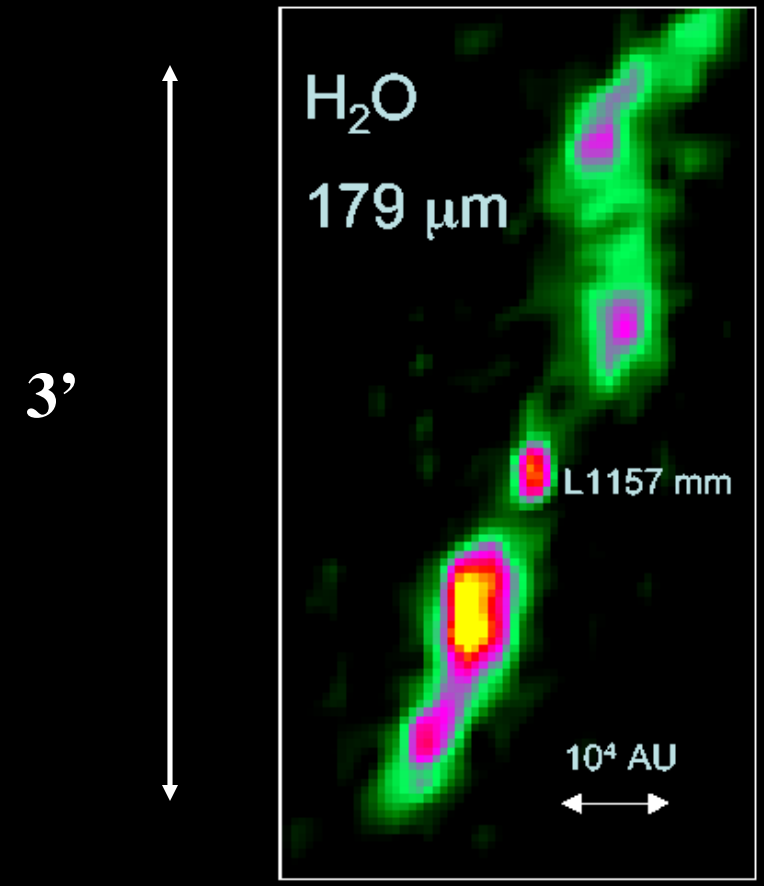
Why water?

- **Unique probe of different physical regimes and processes → natural filter of warm gas**
  - **H_2O abundance shows large variations in SF regions: $<10^{-8}$ (cold) – 3. 10^{-4} (warm) from ISO, SWAS, ODIN**
- **Main reservoir of oxygen → affects chemistry of all other species**
  - **Traces basic processes of freeze-out onto grains and evaporation, which characterize different stages of evolution**
- **Astrobiology: water associated with life on Earth → characterize water 'trail' from clouds to planets, including origin of water on Earth**

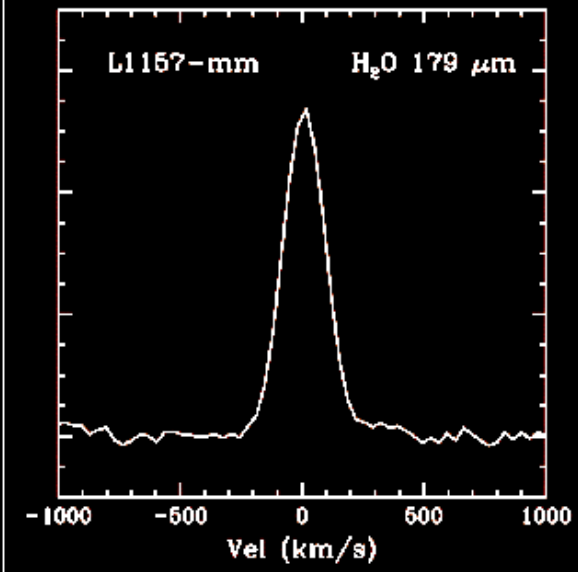
pre-stellar cores → YSO's → disks → comets

Early highlight

Herschel-PACS image of water in proto-stellar systems



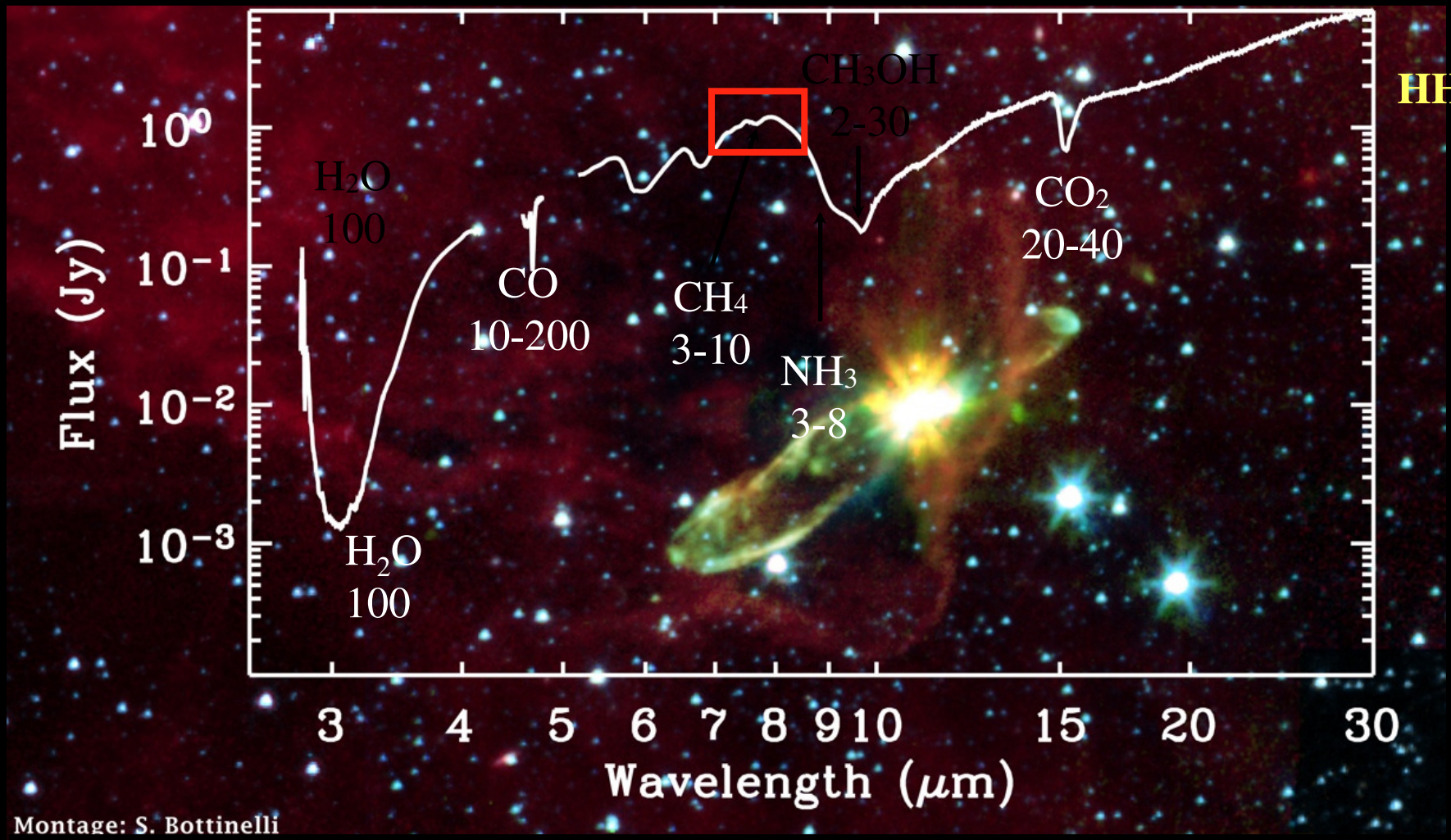
L1157-mm outflow
D = 440 pc, L_{bol} = 11 L_o



Nisini, Liseau, Tafalla, Benedettini et al. (2010)

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

Ices are abundant and common!



Ices can contain significant fraction of heavy elements (50% or more)

Boogert et al. 2008

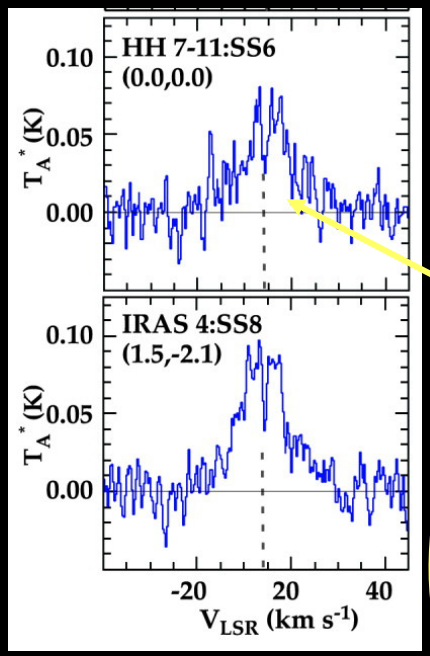
Further motivation

- H_2O as a dynamical probe of warm high density gas: infall, outflow, quiescent gas, mixing, …
- H_2O's role in the thermal balance: when and where does H_2O become dominant cooling or heating agent?
- HDO/H_2O: determined by gas-phase or grain-surface processes?
  - Relation with comets and origin of water on Earth
- H_2O as a radiative transfer challenge: high/low optical depths, masers, ….
- HIFI legacy

Previous observations of H_2O

SWAS H_2O $1_{1,0}$-$1_{0,1}$

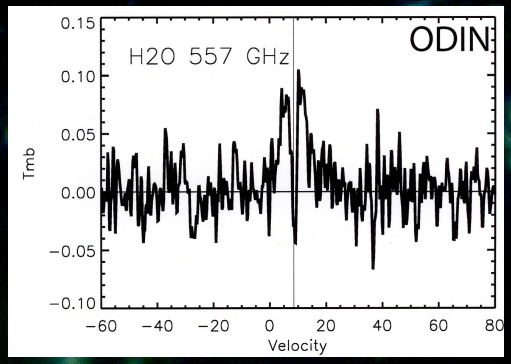
Ø = 3.3′x4.5′



(Bergin et al. 2004)

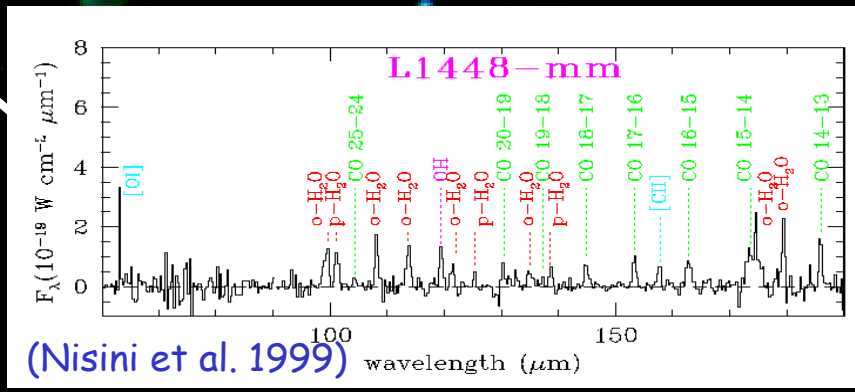
ODIN H_2O $1_{1,0}$-$1_{0,1}$

Ø = 126″



(Olberg et al. 2006)

ISO-LWS 55-180 μm Ø = 80″

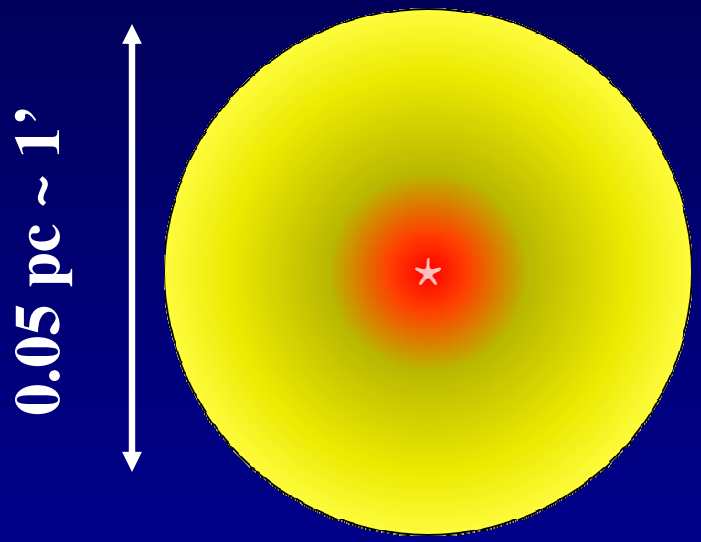


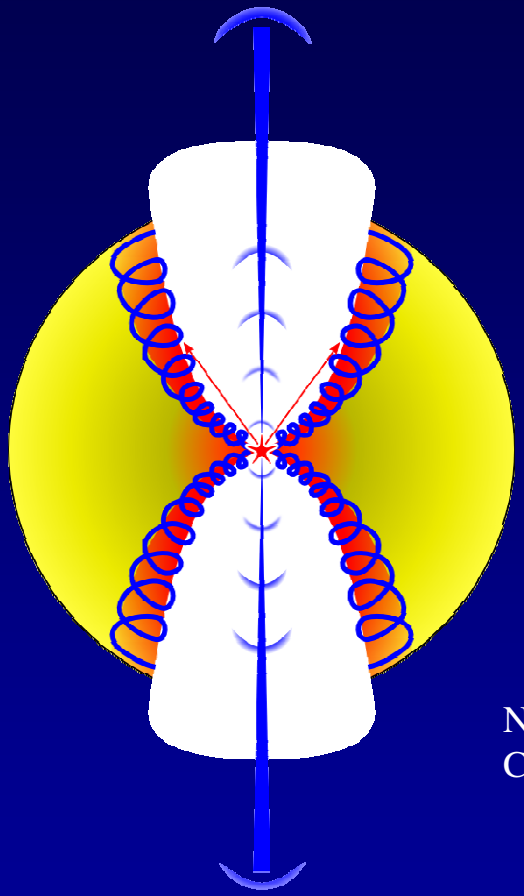
(Nisini et al. 1999)

Herschel Ø = 9.4″ - 40″

⇒ *provides orders of magnitude increase in spatial and/or spectral resolution and sensitivity*

Origin of hot CO and H_2O?





ISO-LWS:
Nisini et al. 2000
Ceccarelli et al. 1999

Passively heated envelope with hot core

Compact (~200 AU) region where H_2O ice evaporates

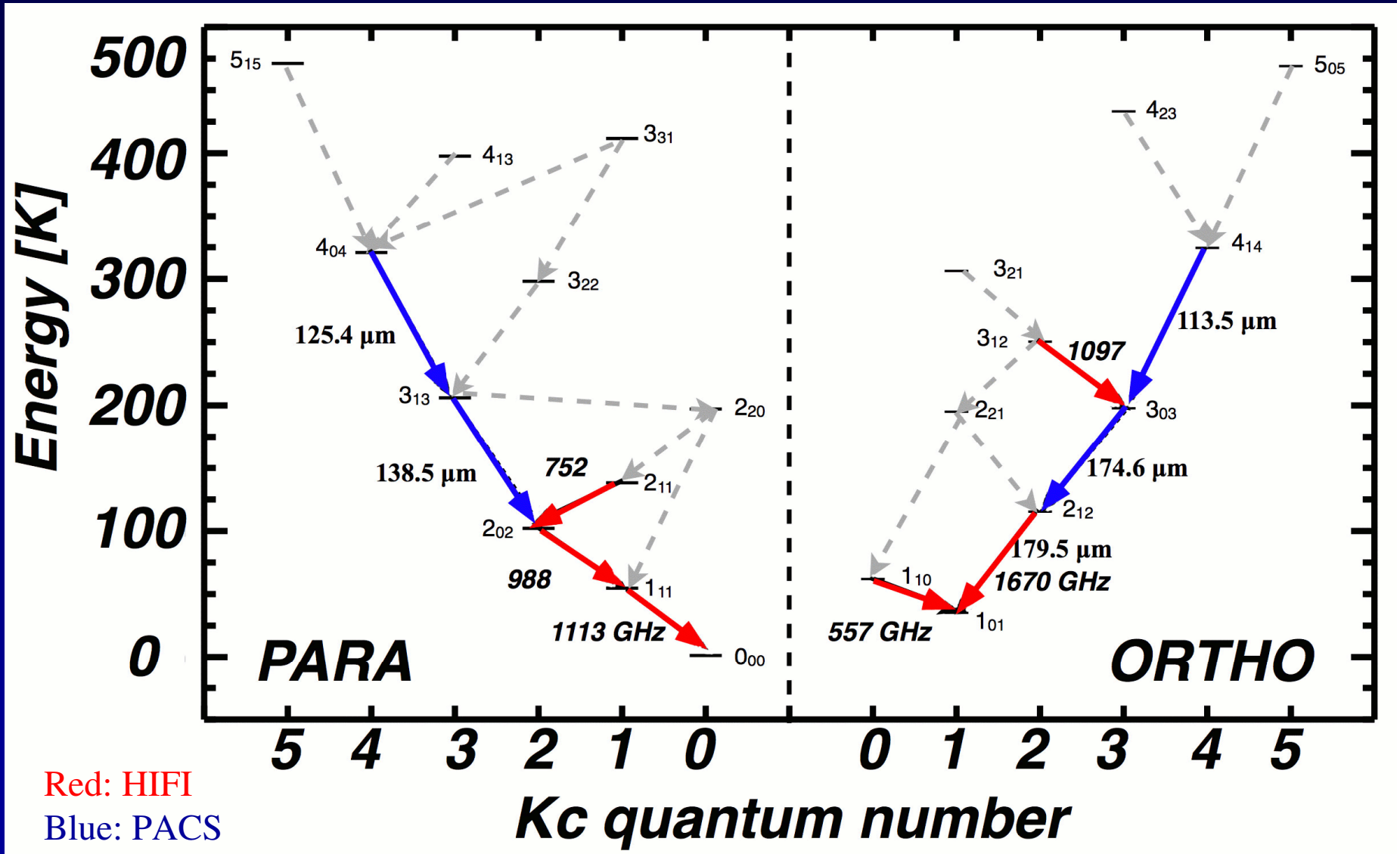
Outflows

Extended emission along outflow; H_2O enhanced in shock

The WISH program

- Survey ~90 sources in a variety of lines of H_2O and chemically related species
  - Typically 10-20 sources in each category
    - Low → High mass YSOs
    - Pre-stellar cores → protoplanetary disks
  - Deep integrations at source positions
  - Maps of outflows on few arcmin scale in selected sources
  - CO and dust continuum to constrain source structure
- Ground-based complementary data
  - Archive will be made publically available
- Radiative transfer and modeling tools

H_2O lines: HIFI vs PACS

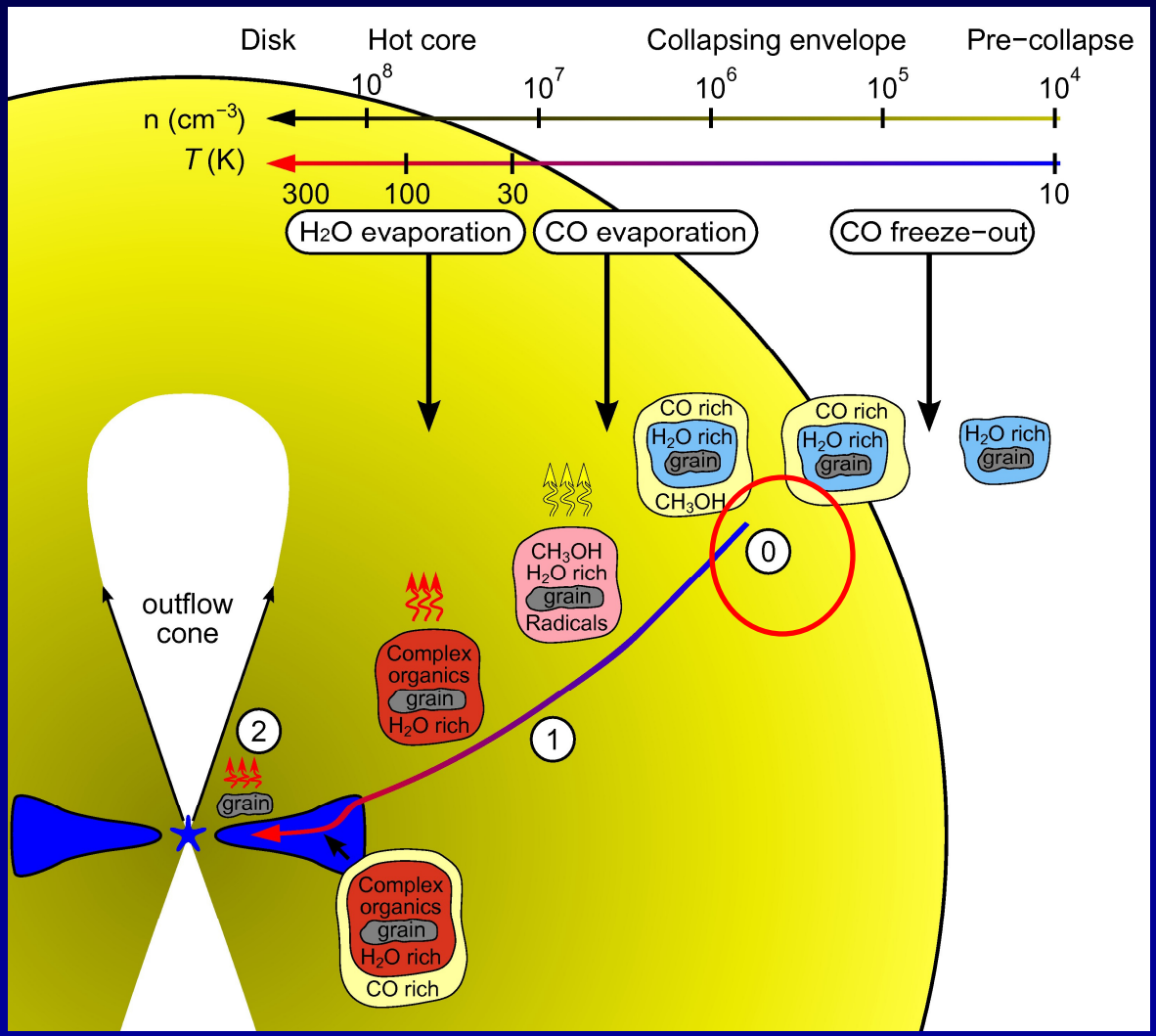


Red: HIFI
Blue: PACS

Observe mix of low- and high-excitation lines to probe cold and hot environments

Follow journey of parcel from cores to disk

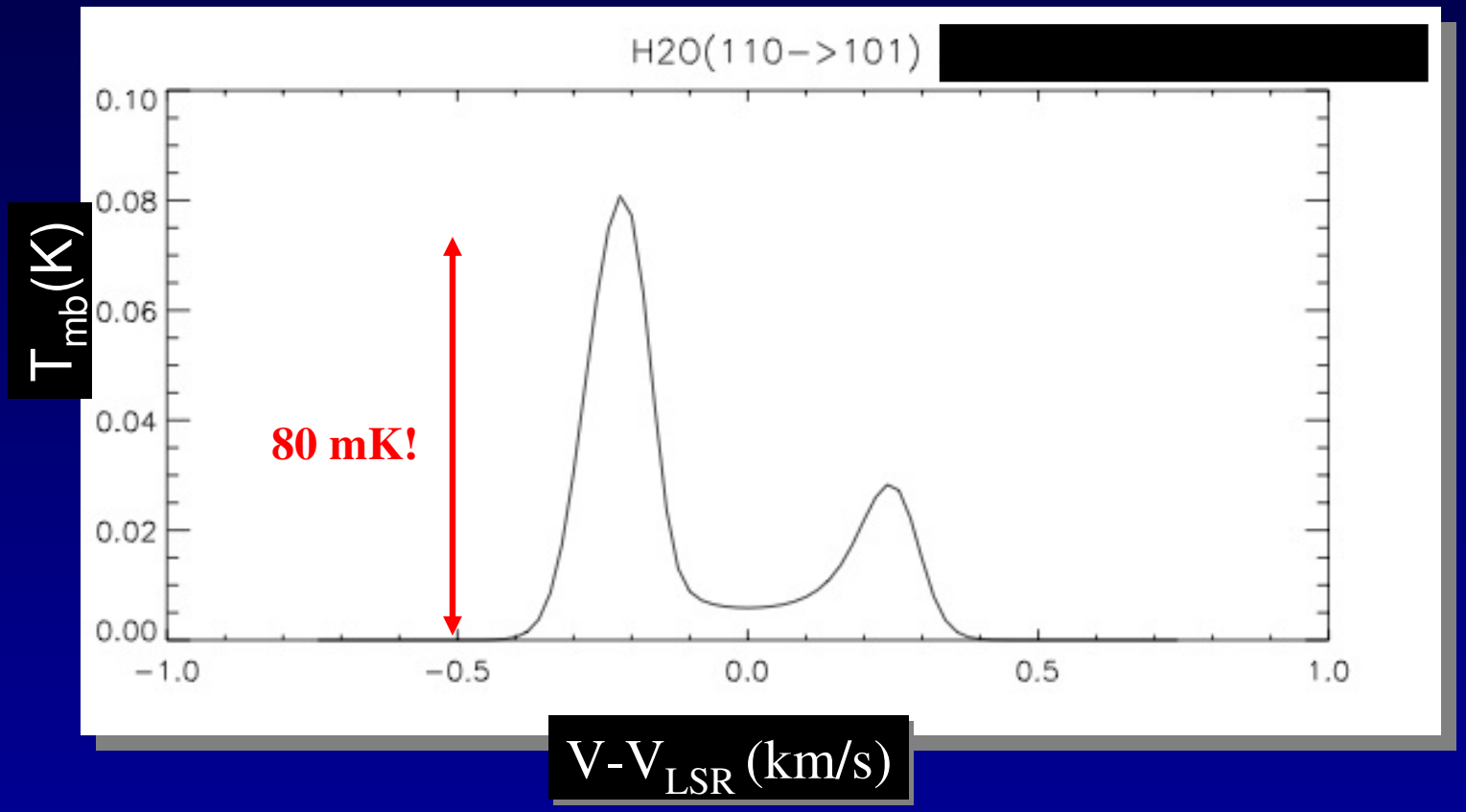
from ice to steam



Herbst & vD
ARA&A 2009

Visser et al. 2009

L1544 Model prediction

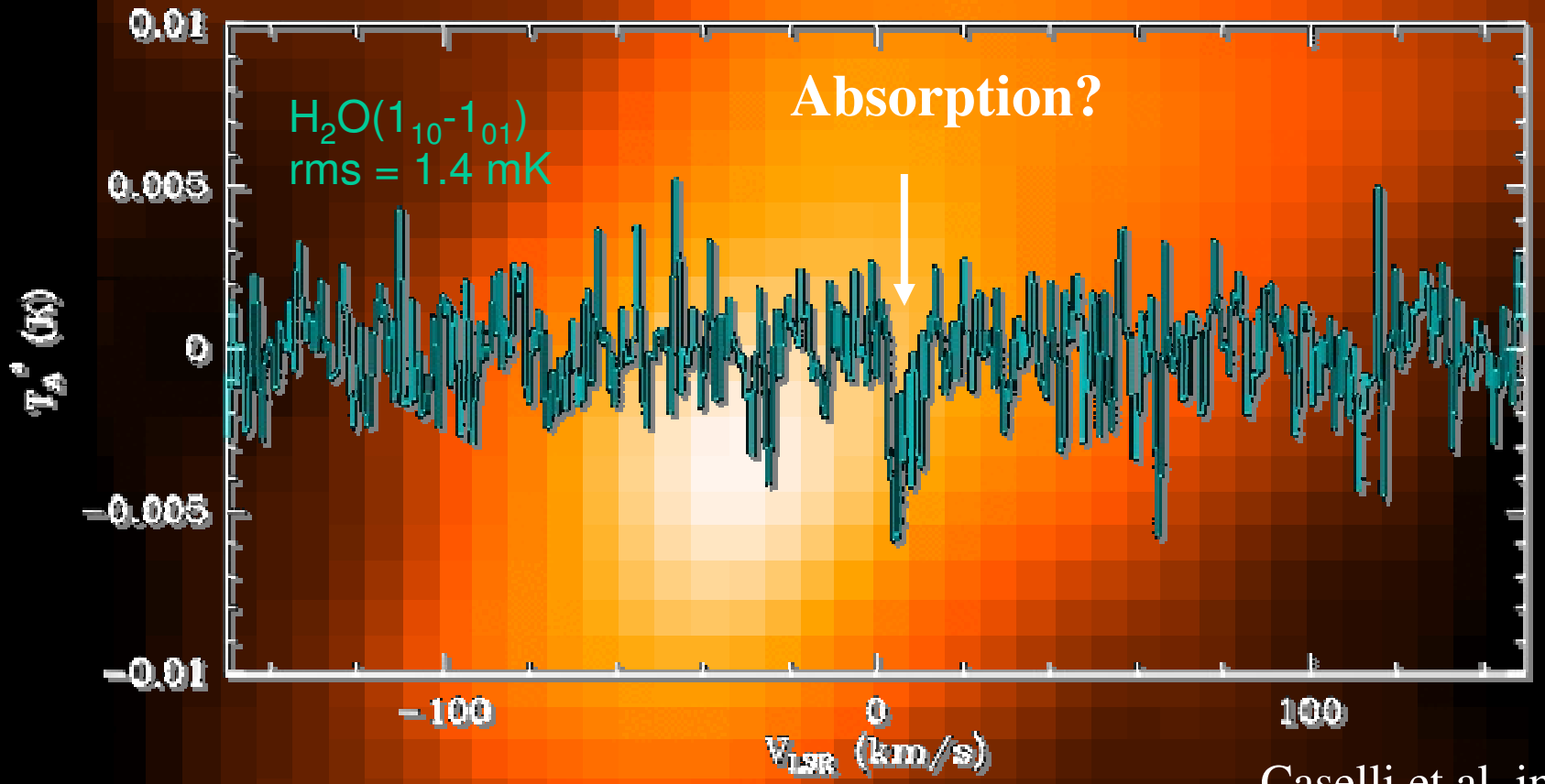


Maximum (undepleted-undissociated) H_2O abundance in model = 5×10^{-9}, consistent with the lowest upper limit found in dark clouds by ODIN ($<7\times10^{-9}$; Harju et al. 2009)

Model convolved with Herschel beam at 557 GHz.

Caselli, Aikawa, Keto et al. in prep

The prestellar core L1544

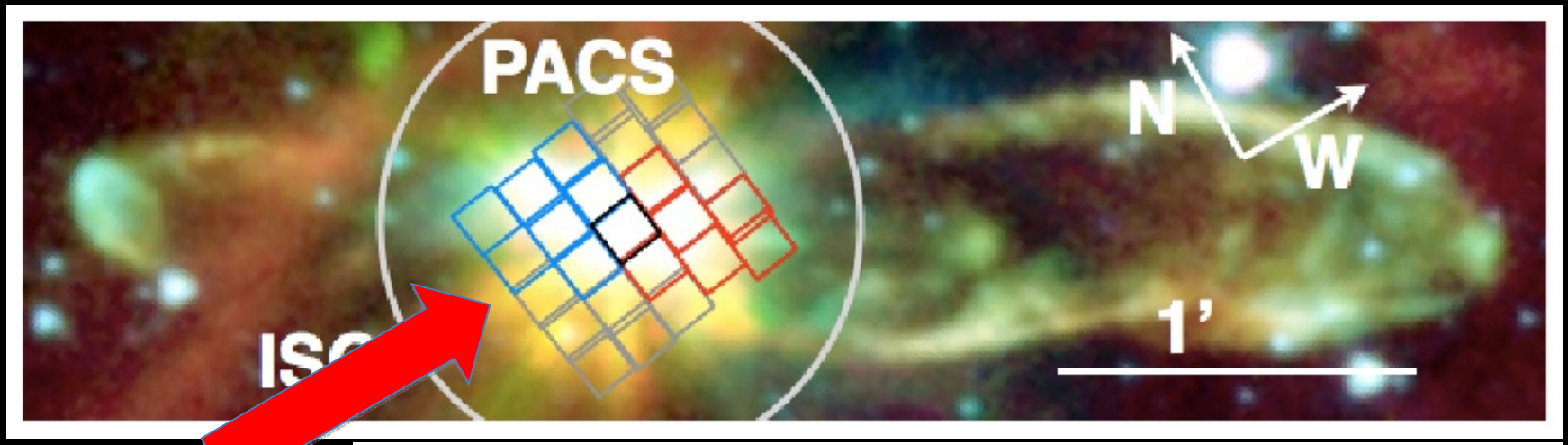


Caselli et al. in prep.

Limit much lower than prediction
Implies water abundance < 10^{-9} for n=10^5 cm^{-3}

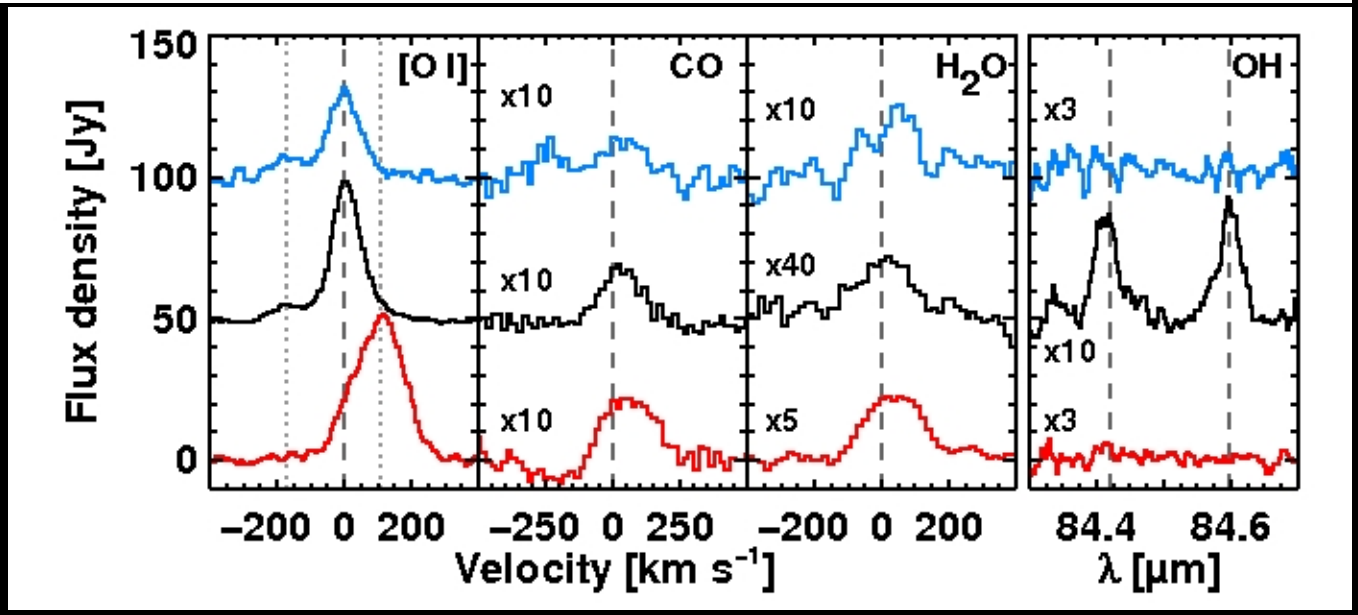
1.3 mm continuum map from Ward-Thompson et al. (1999)

HH46: envelope and outflow



PACS "spaxel" footprint:

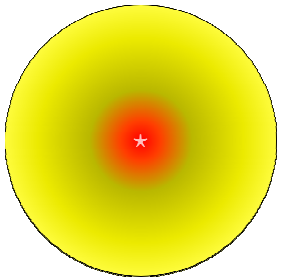
"spaxel"=spatial pixel for IFUs



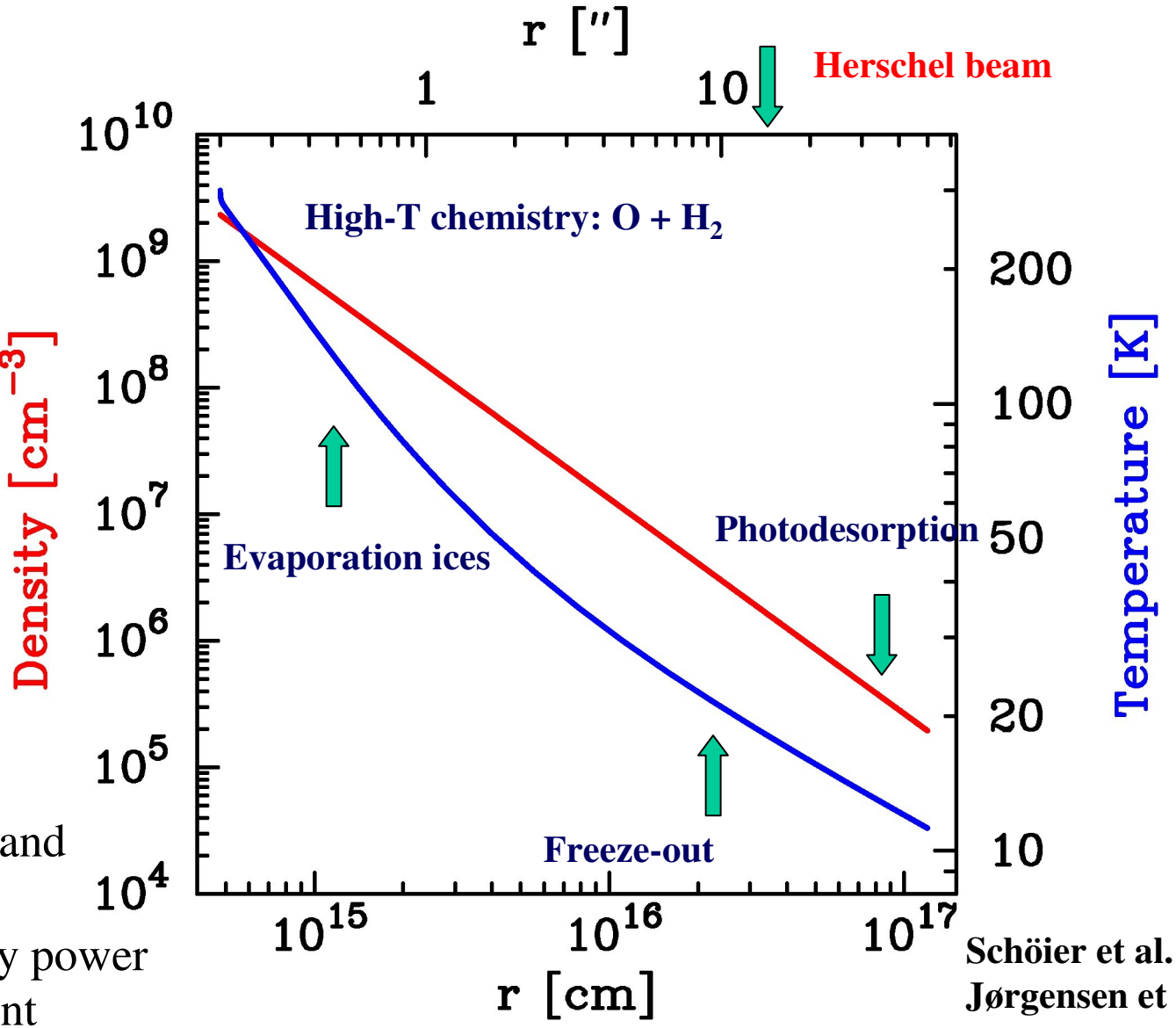
van Kempen, Kristensen, Herczeg et al. 2010

Physical structure protostellar envelope

spherical 'passively heated' model

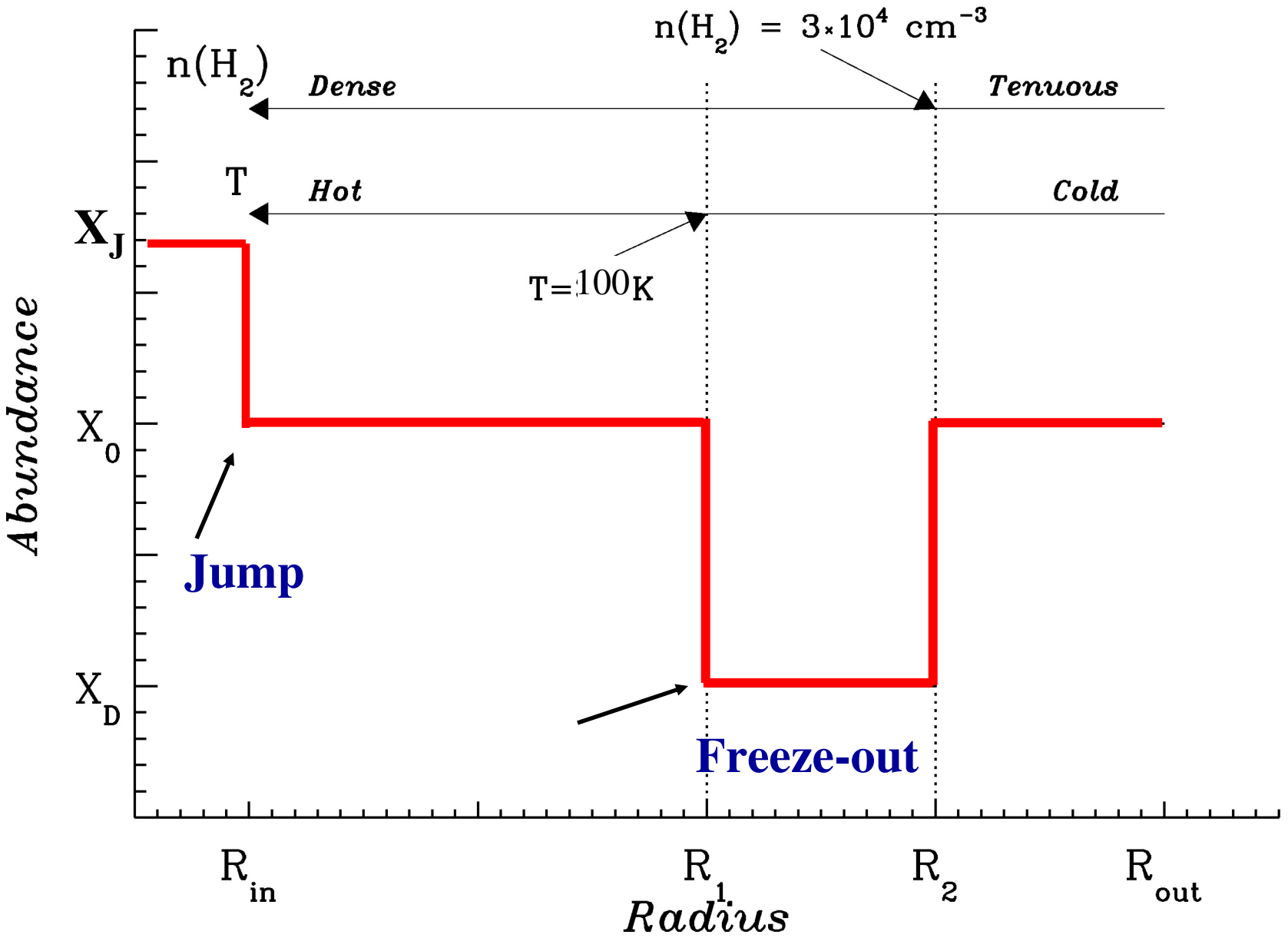


RT model of SED and submm continuum extent → fit density power law, mass and extent



Schöier et al. 2002
Jørgensen et al. 2002

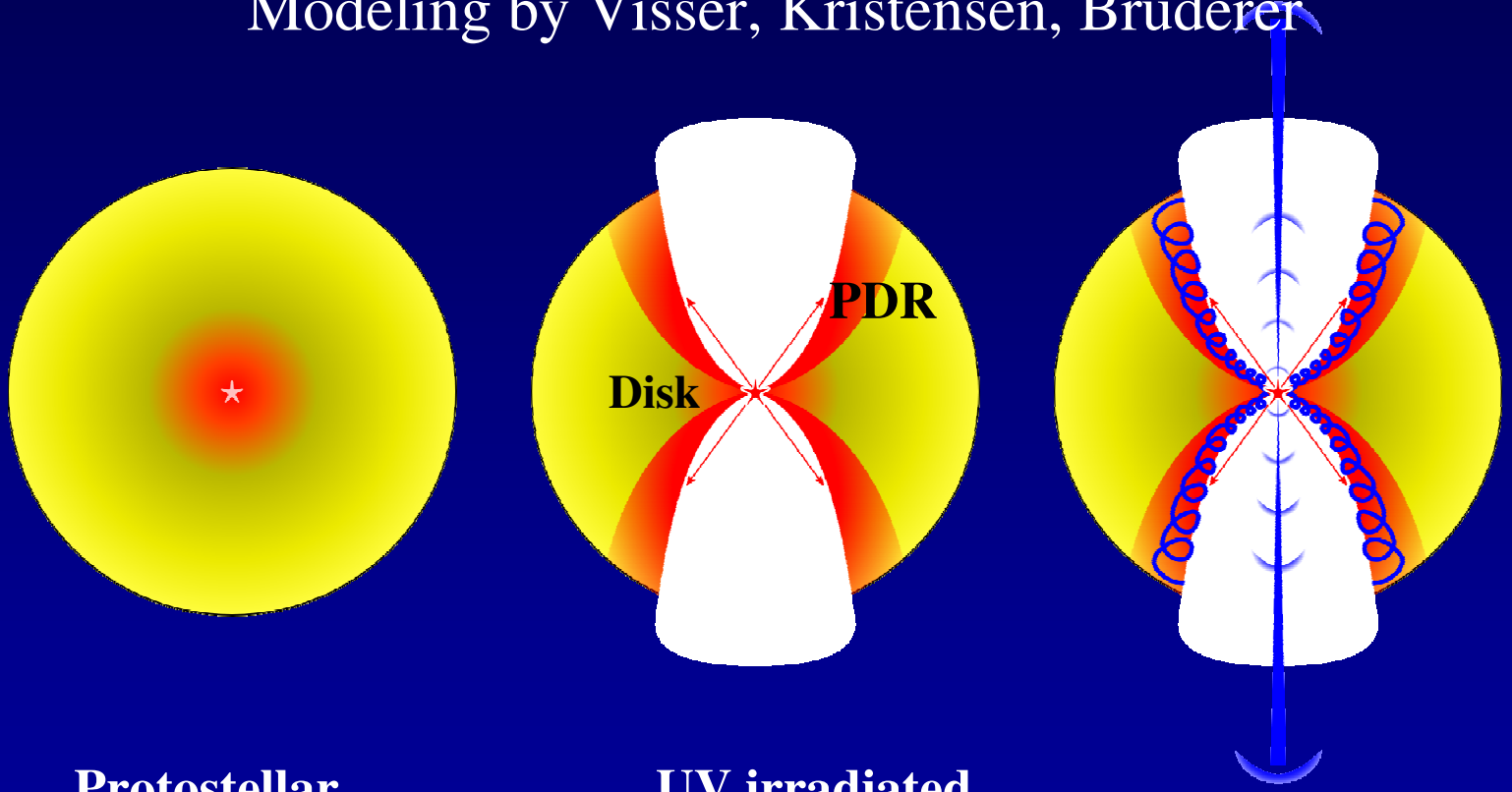
Possible water abundance structure in protostellar envelope



Size freeze-out zone depends on molecule

Which physical component dominates which lines?

Modeling by Visser, Kristensen, Bruderer

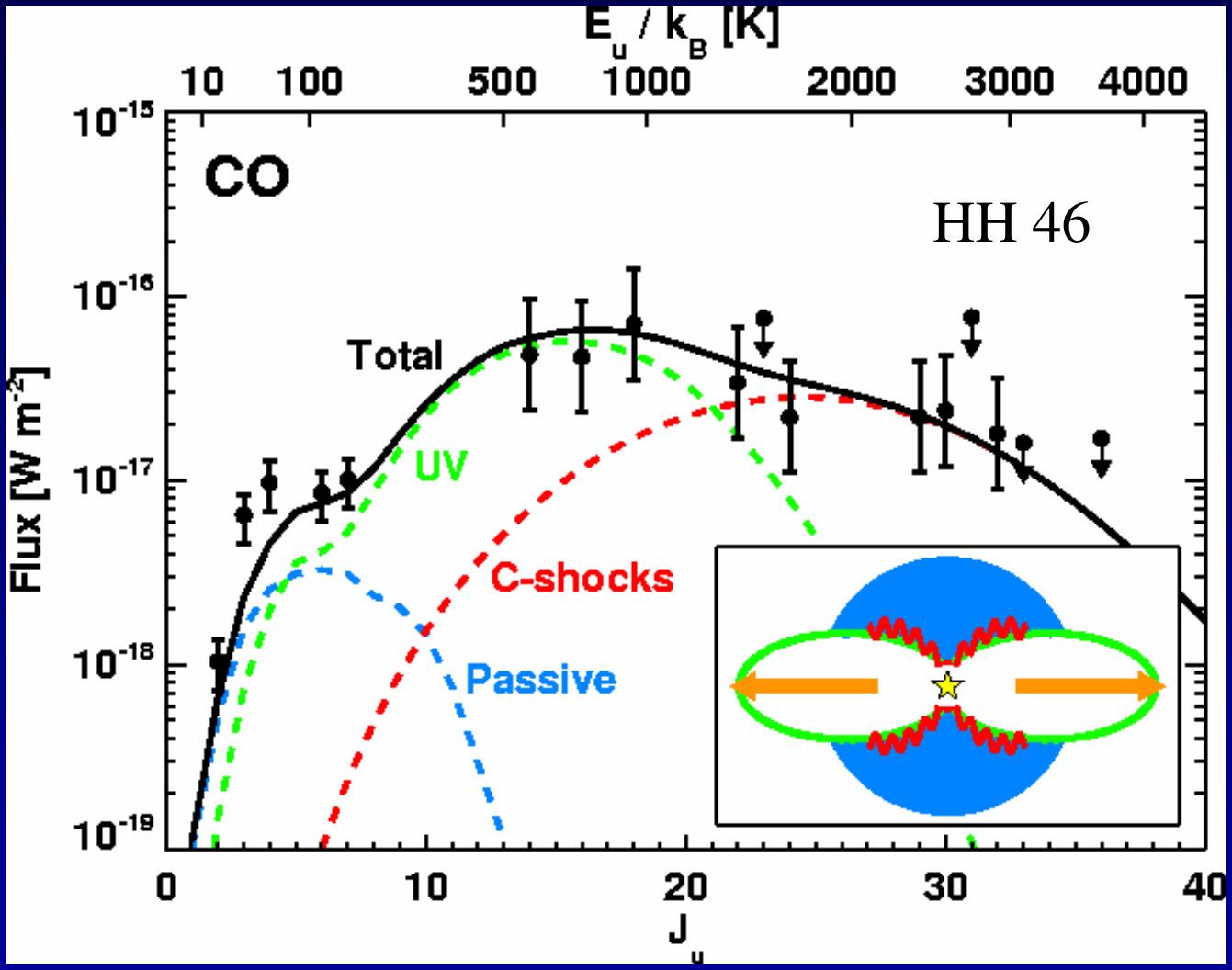


Protostellar envelope with hot core:
Low-J CO

UV irradiated cavity walls, disk surface:
Mid-J CO
Hot water?

Outflow shocks:
High-J CO,
Hot water?
High velocity O I

Origin of hot CO

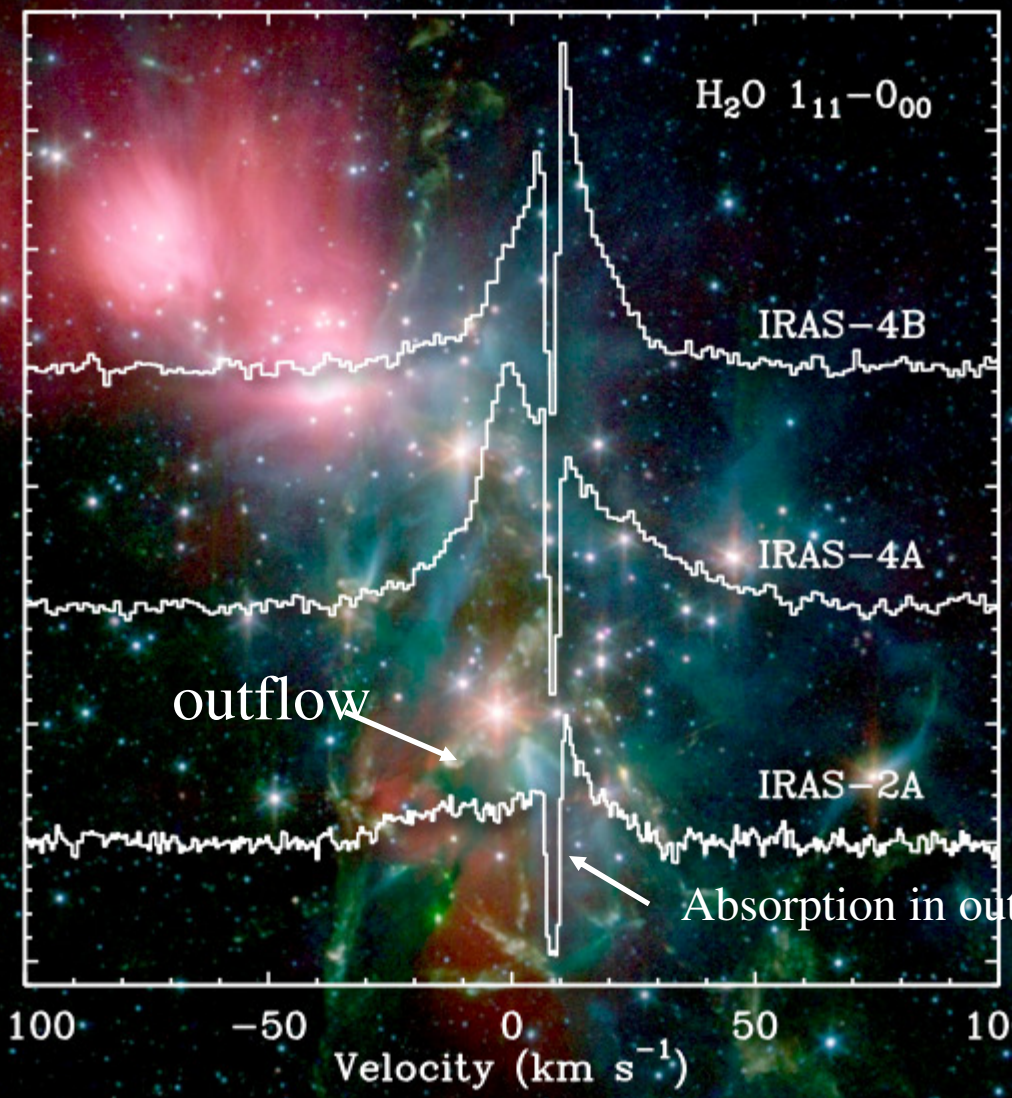


Only parameters: UV field G_o and v_{shock}
For H_2O: likely mix of two processes

van Kempen et al. 2010

Low-mass YSOs: NGC 1333

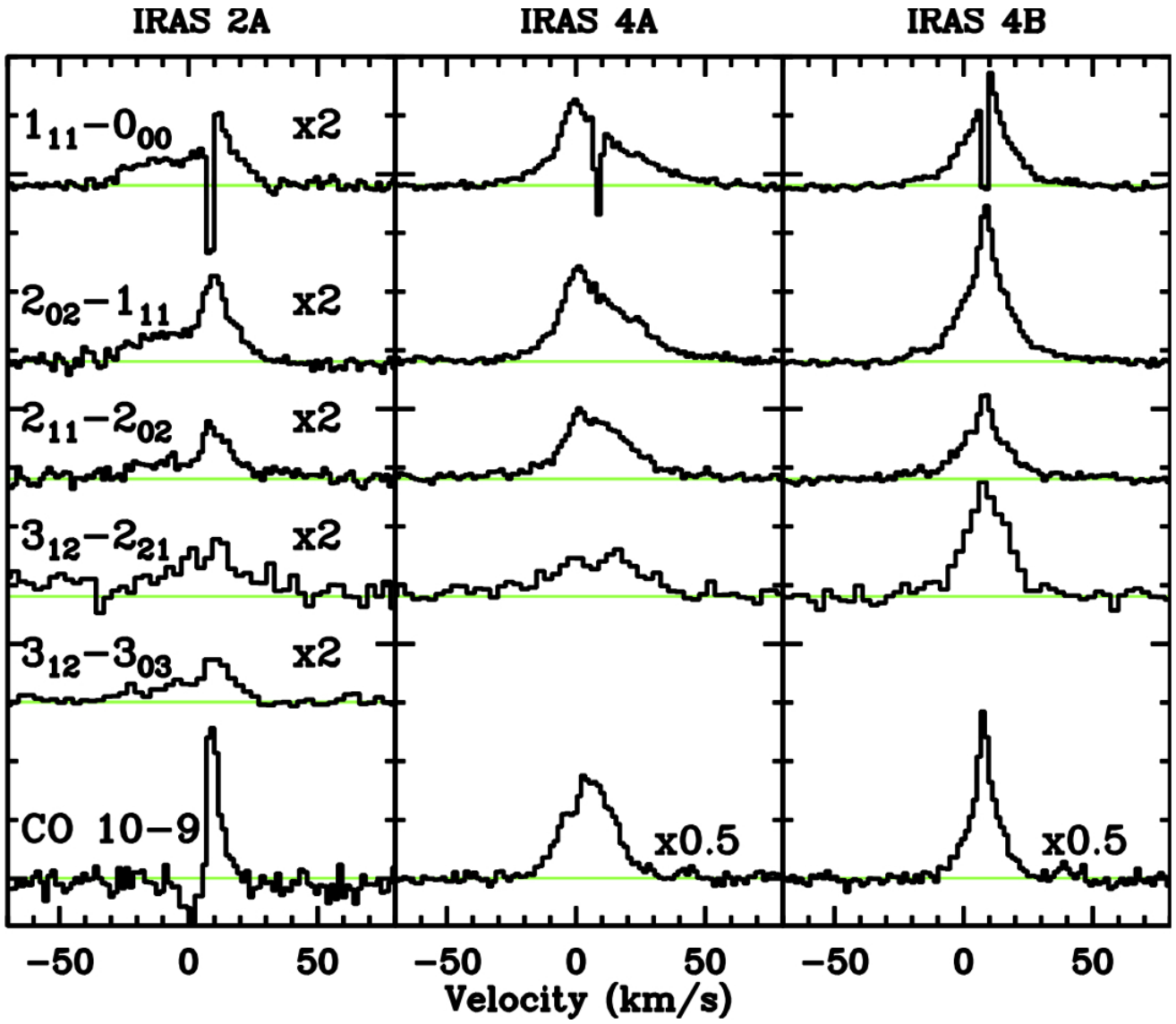
L~20 L_{Sun}
D~250 pc



p-H_2O ground-state line

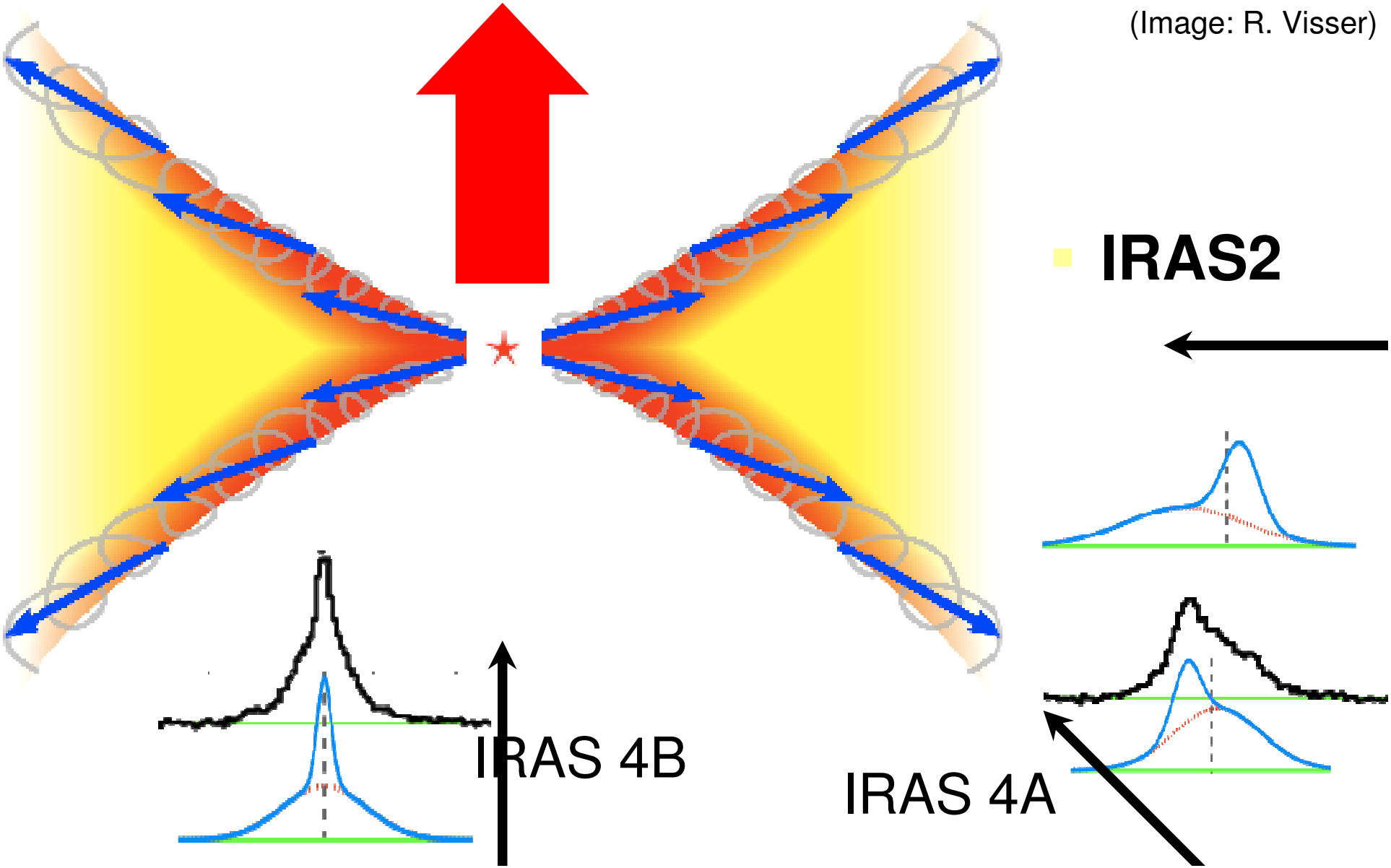
Kristensen et al. in prep

Excited H_2O and CO lines



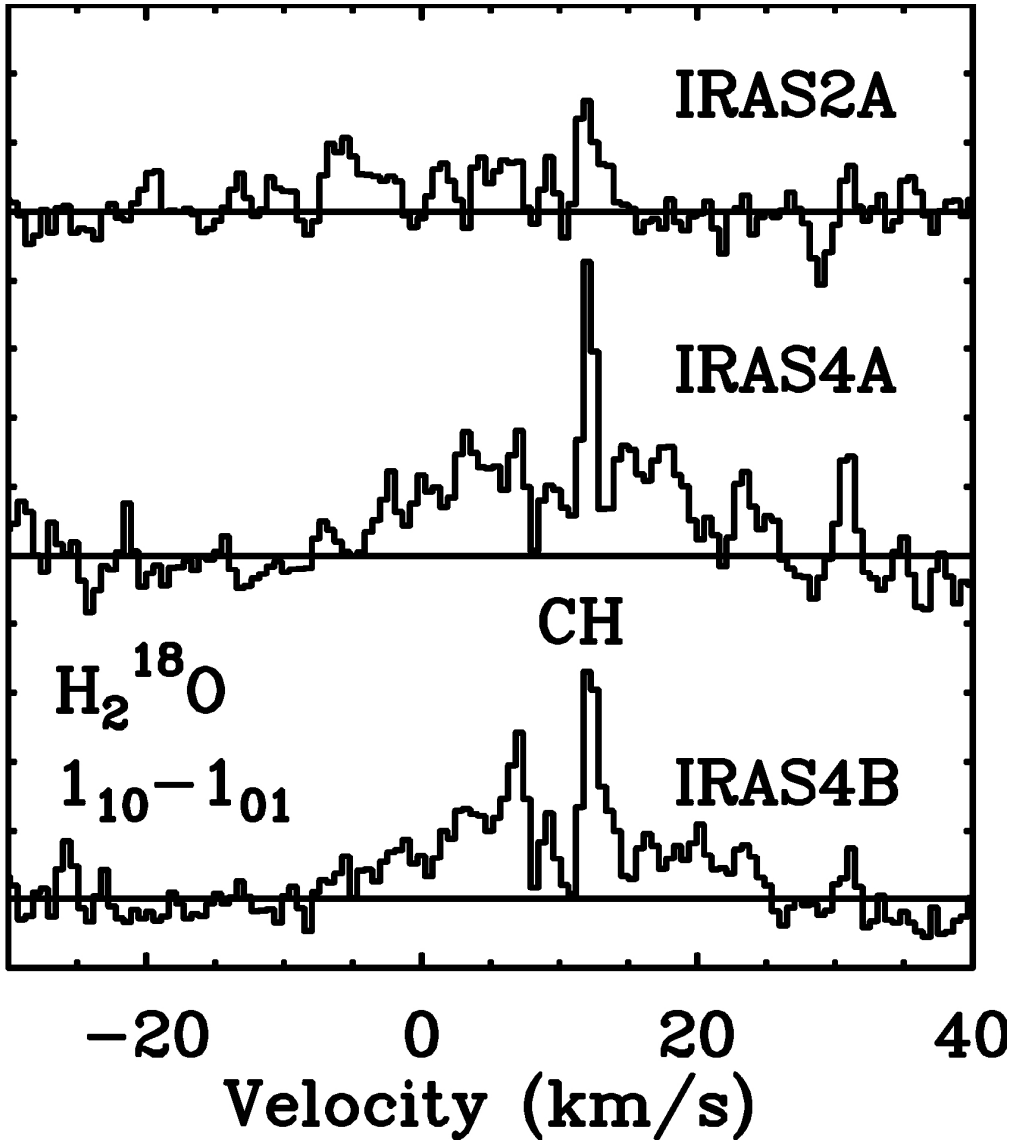
Kristensen, Visser, Yildiz et al. in prep

Line profile related to geometry?

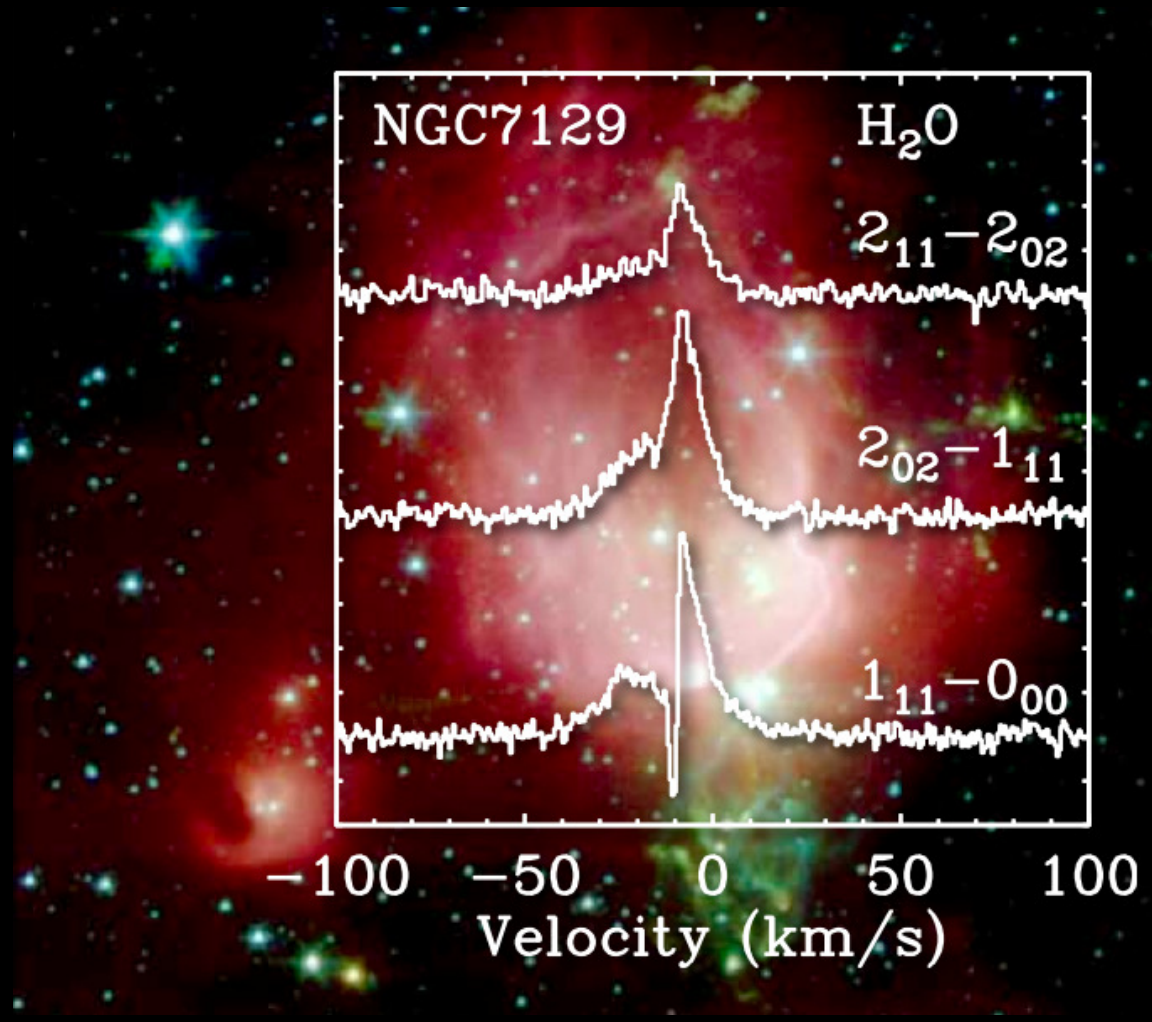


Broad and weak $H_2{}^{18}O$ lines

Abundance H_2O
high in outflow (10^{-5}-10^{-4})
but low in envelope (~10^{-9})



Intermediate mass YSO program

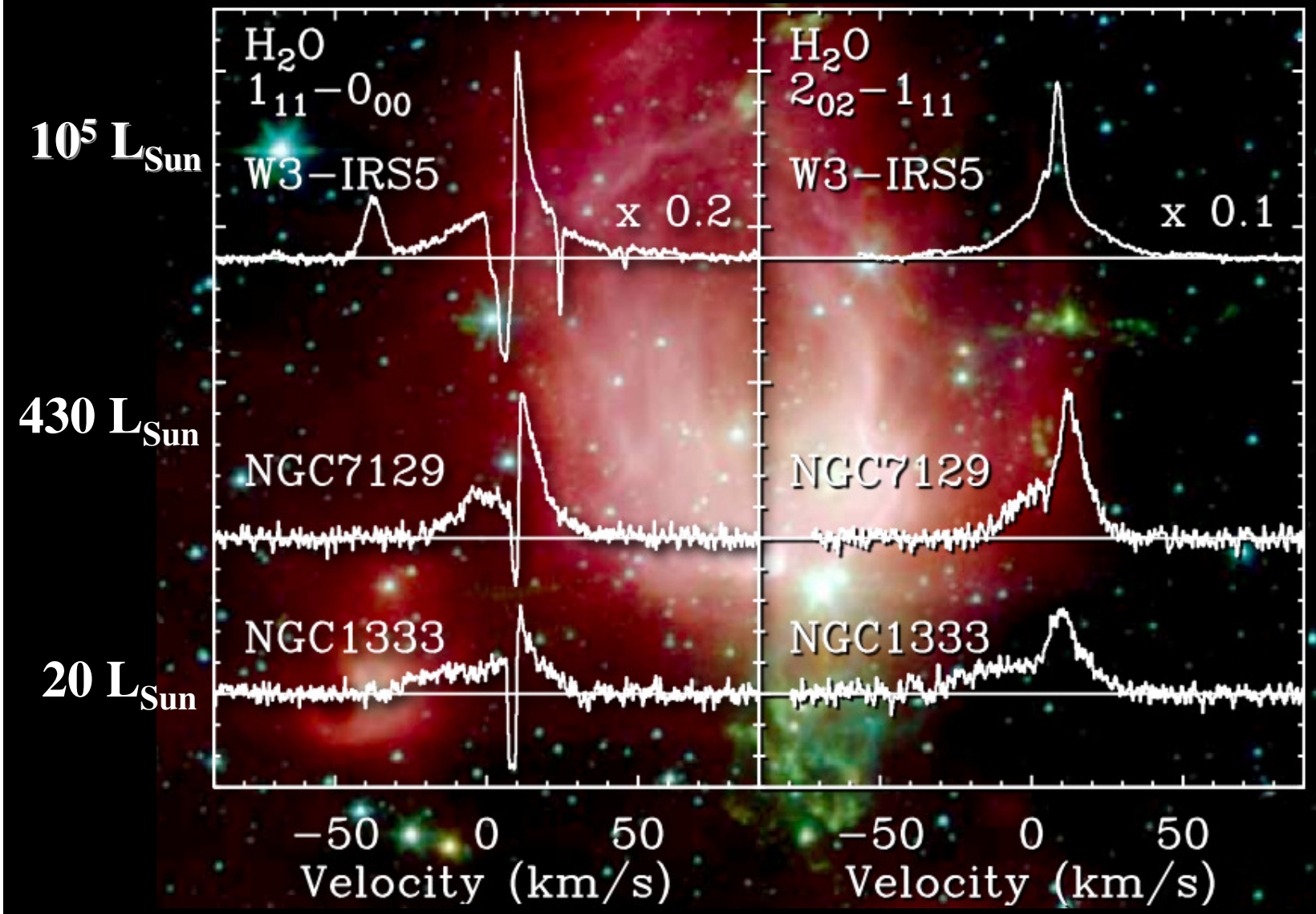


L=430 L_{Sun}
d=1250 pc

Johnstone, Fich, McCoey et al.

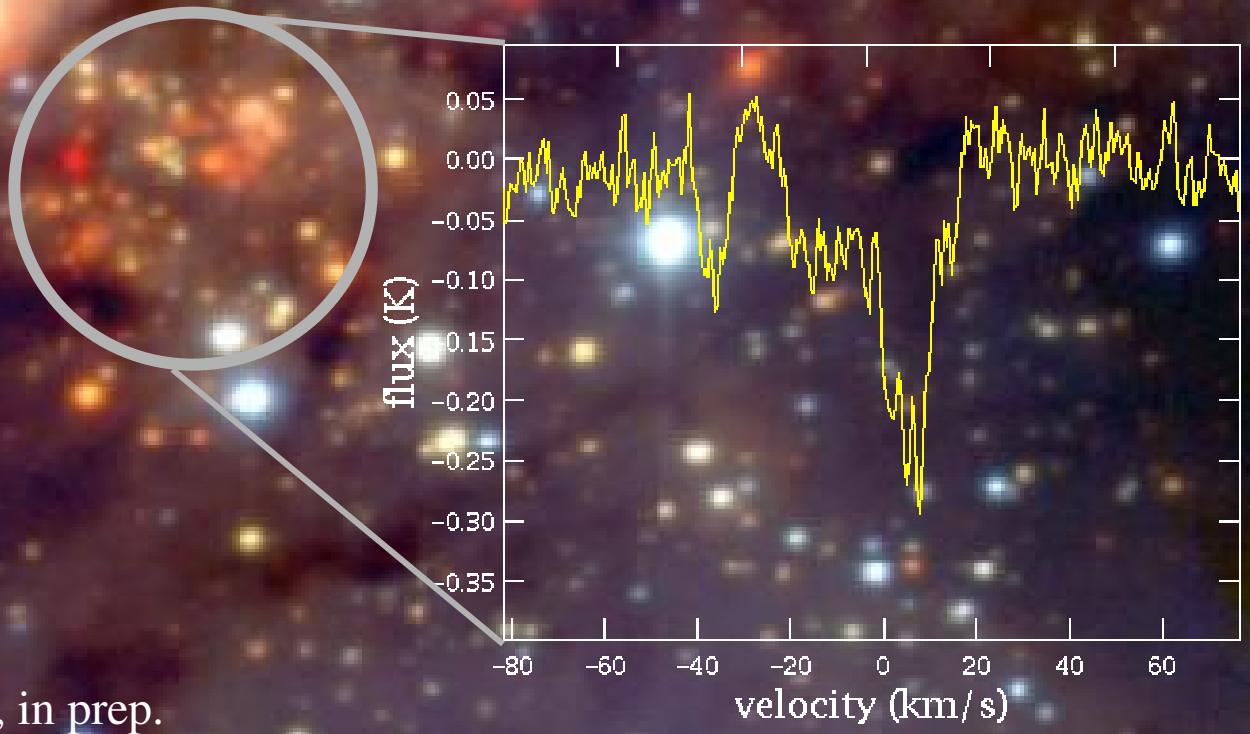
As for low-mass YSO, spherical model cannot fit CO data

From low to high mass YSOs



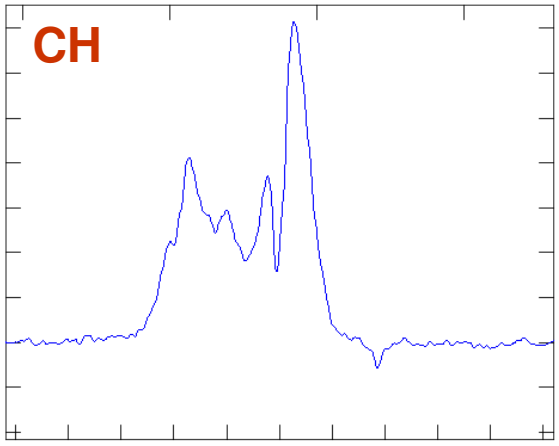
Low and intermediate YSOs similar but high-mass lines much stronger and more complicated line profiles

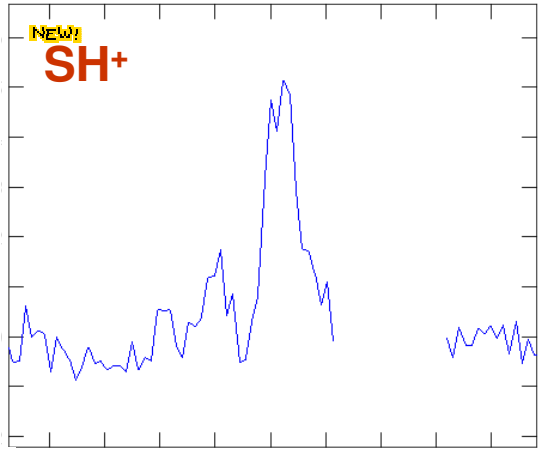
H_2O^+ detected: the 'fourth phase' of water

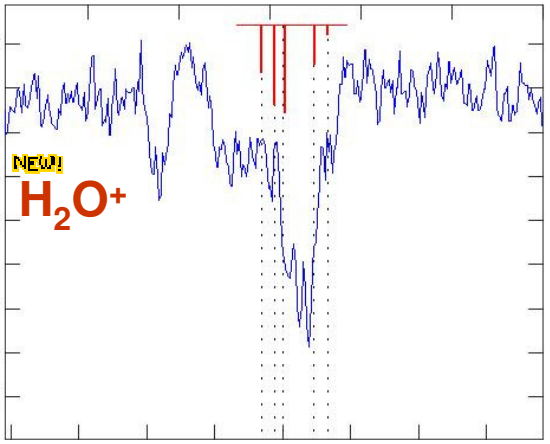


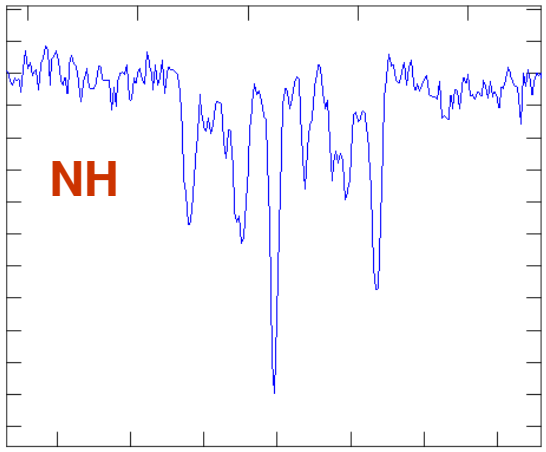
Benz, Bruderer et al. 2010, in prep.

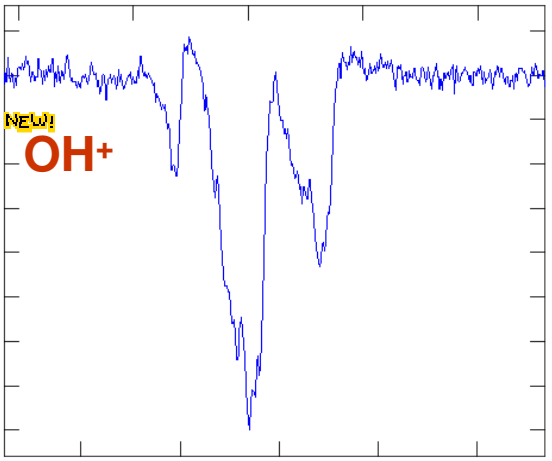
Hydrides in Star Forming Region W3 IRS5

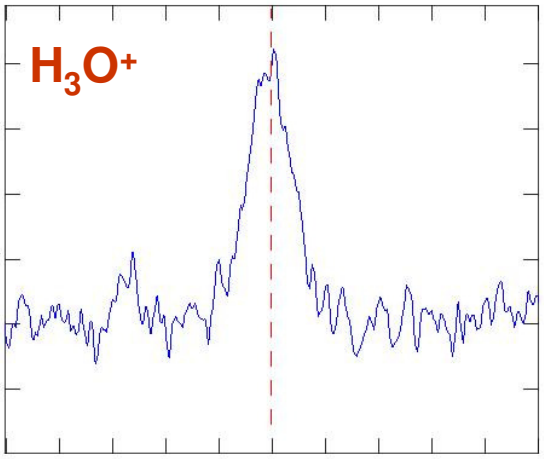










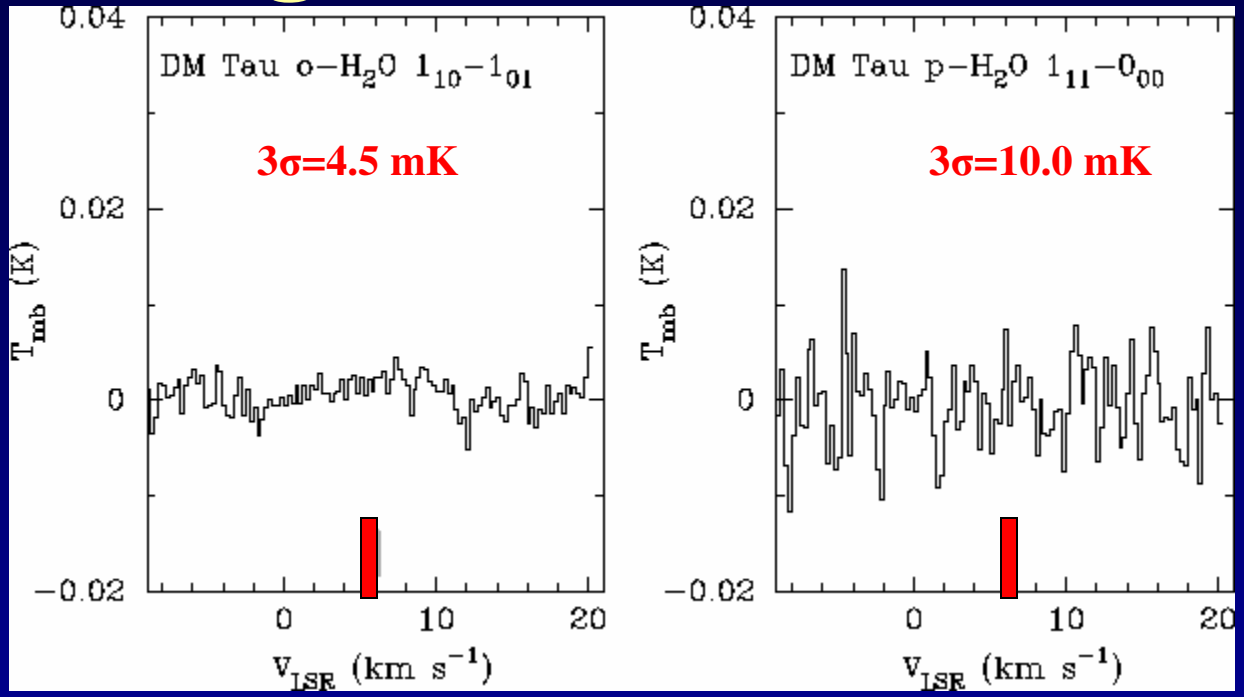


Diagnostics of UV (+ X-rays) heated outflow walls

Benz et al. 2010

Protoplanetary disks probing the cool water reservoir

Deepest HIFI integrations: 6-12 hr



Disk averaged abundance few x 10^{-10}

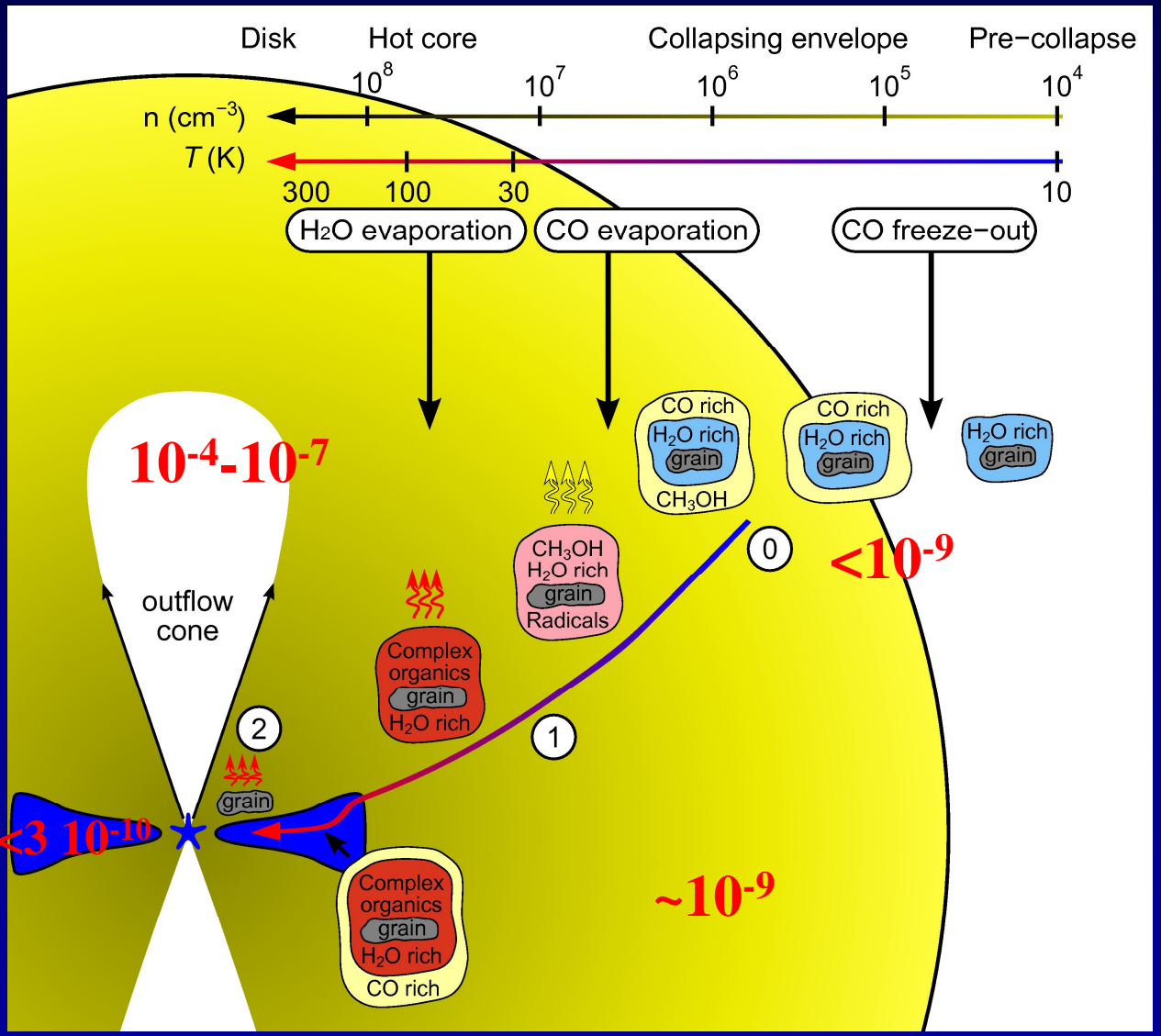
Hogerheijde, Bergin, Dominik, Brinch et al.

- Models predict line intensities of a few to several tens of mK
- Observations rule out some models
- Comparison to 'warm' CO and CI may be essential to see if
  - disks lack warm gas
  - warm gas in disks is 'dry'
  - water vapor at low *T* is 'dark'

Conclusions

- **HIFI works great!**
- **Gaseous water abundance in cold regions is very low**
  - **Lower than thought before (unless 'dark')**
  - **Water (vapor) is *not* everywhere!**
- **Warm CO and H_2O emission is dominated by shocks + UV photon heated component along outflow walls**
  - **No emission detected (yet) from hot core**
- **Herschel CO and H_2O lines require models beyond spherical symmetry**
- **H_2O line profiles excellent probes of geometry**

Where is water in protostellar envelopes?



All numbers preliminary

Where it all started….

Keukenhof, mei 1982

Thanks to the HIFI and PACS instrument teams!