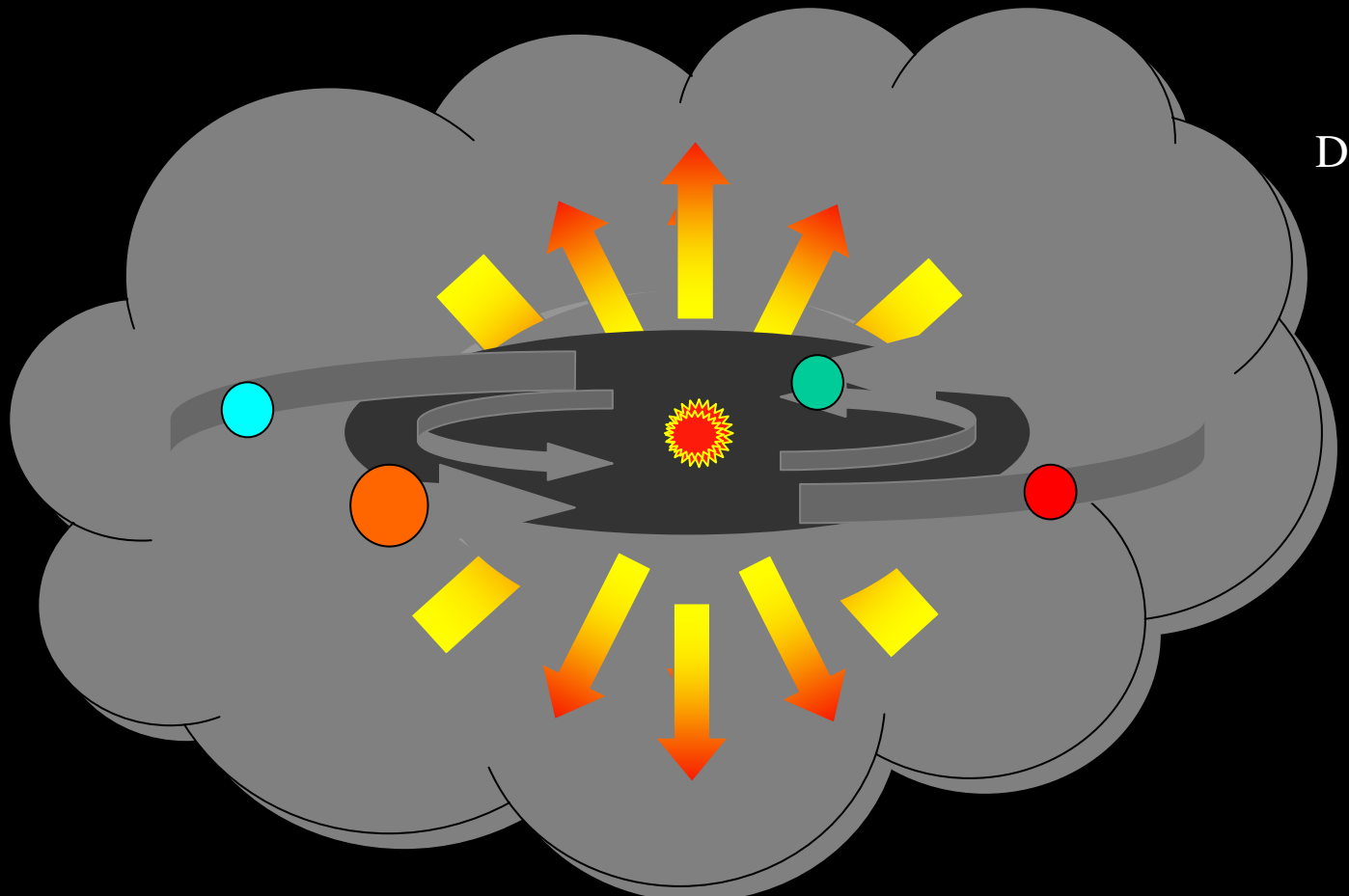
Water In Star-forming regions with Herschel

- A 429 hr GT key-program with Herschel to study the physical and chemical structure of star forming regions focussing on H_2O and its related species
- Program covers ~90 sources ranging from pre-stellar cores, low- to high-mass protostars in different evolutionary stages as well as protoplanetary disks
- Both HIFI and PACS-spectroscopy are used
  - Includes small maps up to ~2'x2'
- Collaboration of ~70+ scientists from 30 different institutes

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

Follow water trail during star and planet formation



D. Lommen

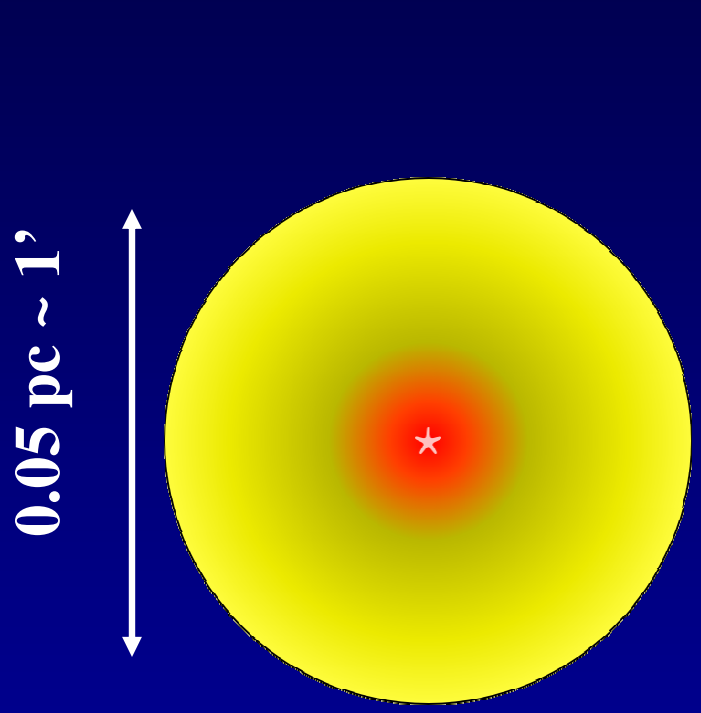
Dark pre-stellar cores → **Low-mass YSOs** **→ Disks**
Infrared dark clouds **Intermediate mass YSOs**
High-mass YSOs

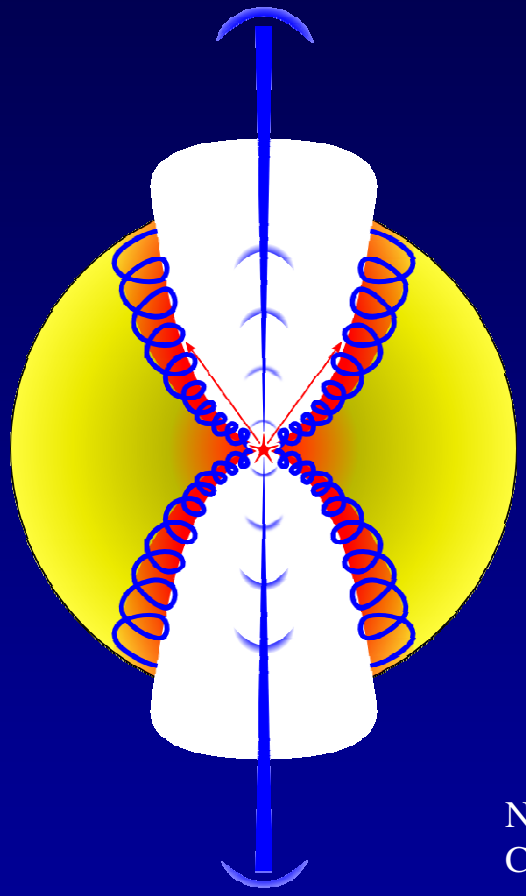
Why water?

- **H_2O abundance shows large variations in SF regions: $<10^{-8}$ (cold) – 3. 10^{-4} (warm) → unique probe of different physical regimes**
  - **Natural filter of warm gas**
- **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

Origin of hot CO and H_2O?





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

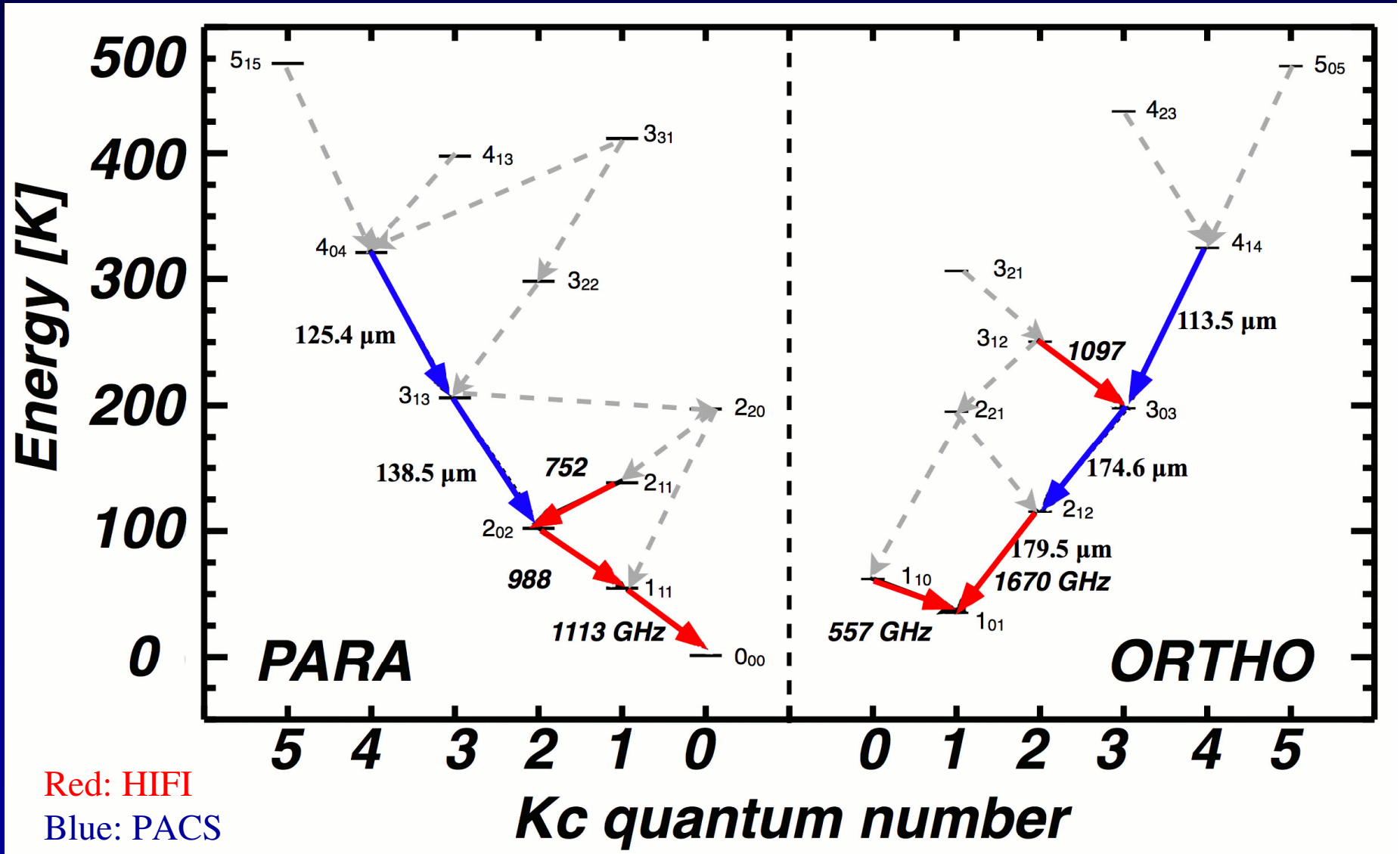
Hot core:

Compact (~200 AU) region where H_2O ice evaporates

Outflows

Extended emission along outflow; H_2O enhanced in shock

H_2O lines: HIFI vs PACS



Red: HIFI
Blue: PACS

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

SDP Data

- **Received:**
  - **L1157: Low-mass Class 0 YSO**
    - **outflow map 179 μm H_2O line**
  - **HH 46: Low-mass Class I YSO**
  - **NGC 7129: Intermediate mass YSO**
- **Still pending:**
  - **Complete PACS spectral scans of**
    - **Class 0 low-mass YSO**
    - **High mass YSO**
  - **All HIFI SDP/PSP data**

WISH-team

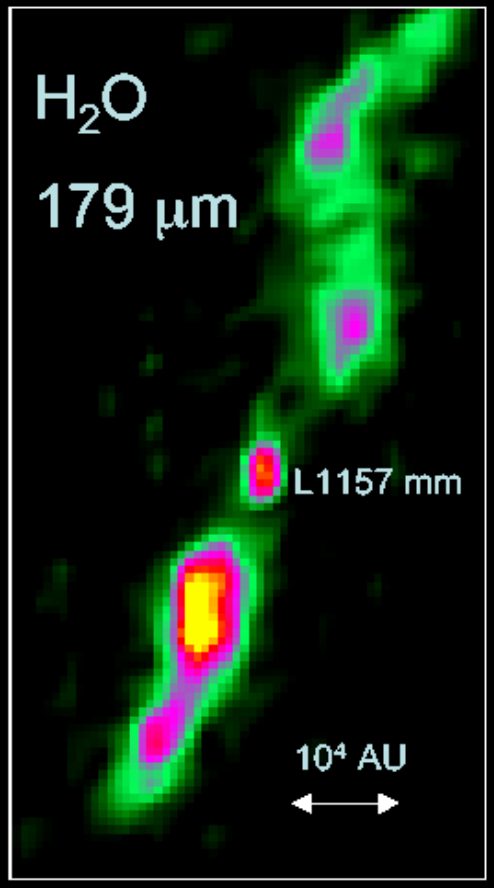
- *E.F. van Dishoeck*, Y. Aikawa, R. Bachiller, A. Baudry, M. Benedettini, *A. Benz*, E. Bergin, P. Bjerkeli, G. Blake, S. Bontemps, J. Braine, A. Brandeker, S. Bruderer, *P. Caselli*, J. Cernicharo, L. Chavarria, C. Codella, F. Daniel, C. Dedes, P. Encrenaz, A.M. di Giorgio, C. Dominik, S. Doty, H. 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*, M. Marseille, C. McCoey, G. Melnick, D. Neufeld, B. Nisini, M. Olberg, G. Olofsson, L. Pagani, 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

(blue indicates subteam leader)

Those who did the work to make this presentation possible….

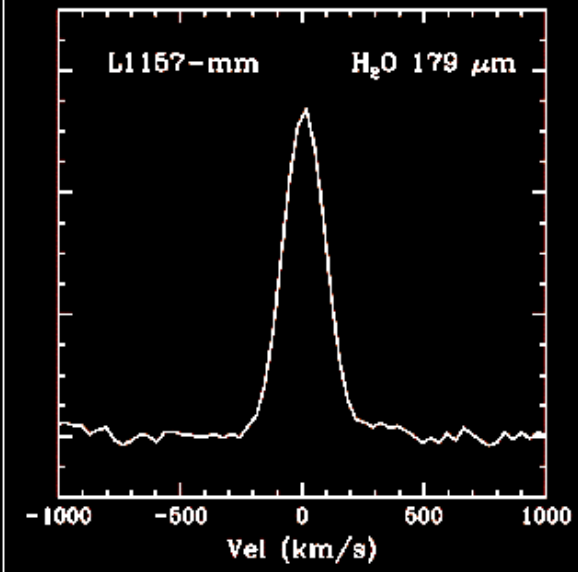
- **E.F. van Dishoeck, Y. Aikawa, R. Bachiller, A. Baudry, *M. Benedettini*, A. Benz, E. Bergin, P. Bjerkeli, G. Blake, S. Bontemps, J. Braine, A. Brandeker, *S. Bruderer*, P. Caselli, J. Cernicharo, L. Chavarria, C. Codella, F. Daniel, C. Dedes, P. Encrenaz, A.M. di Giorgio, C. Dominik, *S. Doty*, *H. 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, M. Marseille, C. McCoey, G. Melnick, D. Neufeld, *B. Nisini*, M. Olberg, G. Olofsson, L. Pagani, 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**

Herschel-PACS image of water in proto-stellar systems



3’

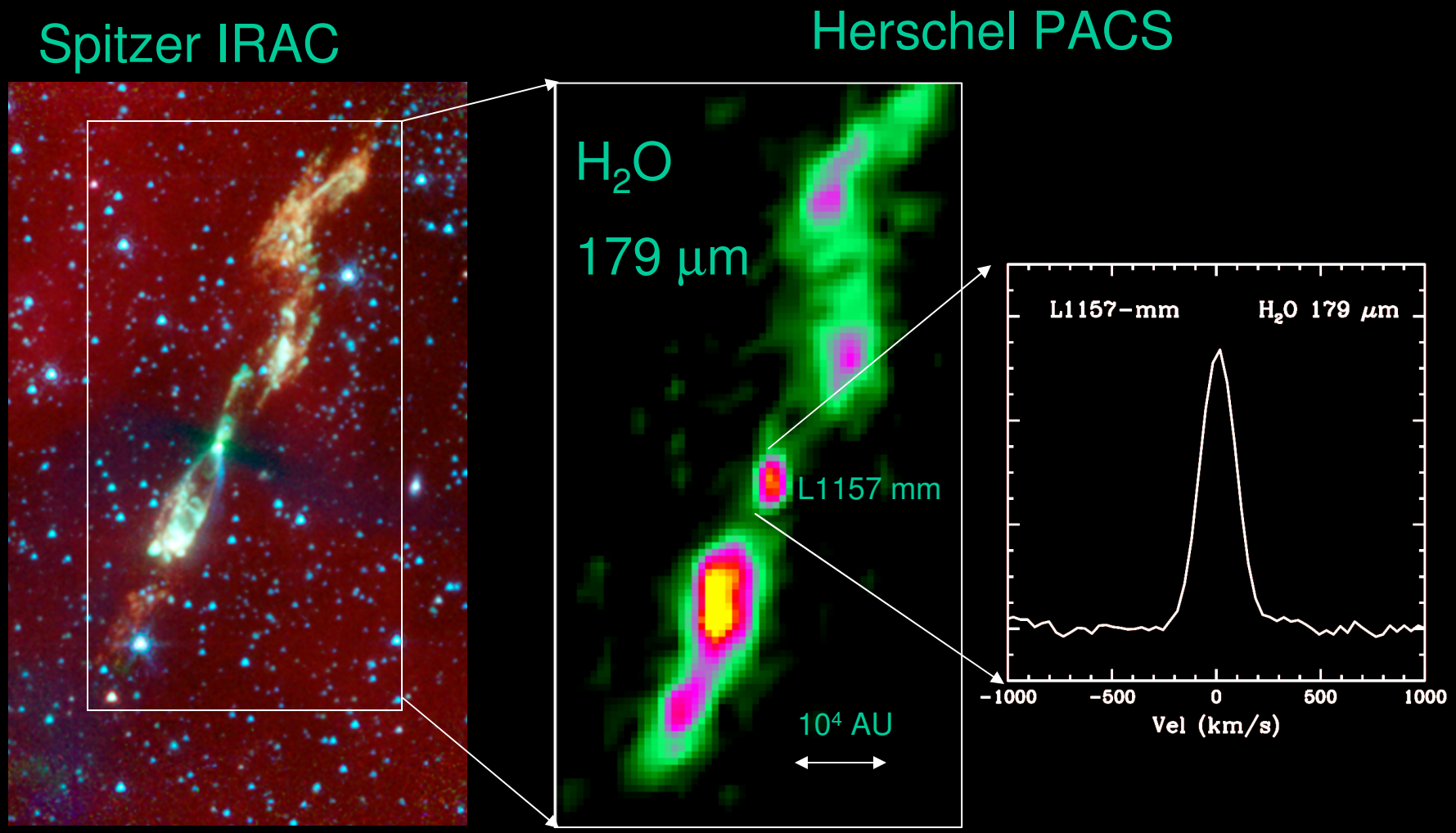
L1157-mm outflow
D = 440 pc, L_{bol} = 11 L_o



Nisini, Liseau, Tafalla, Benedettini et al.

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

Water traces interaction more directly than Spitzer

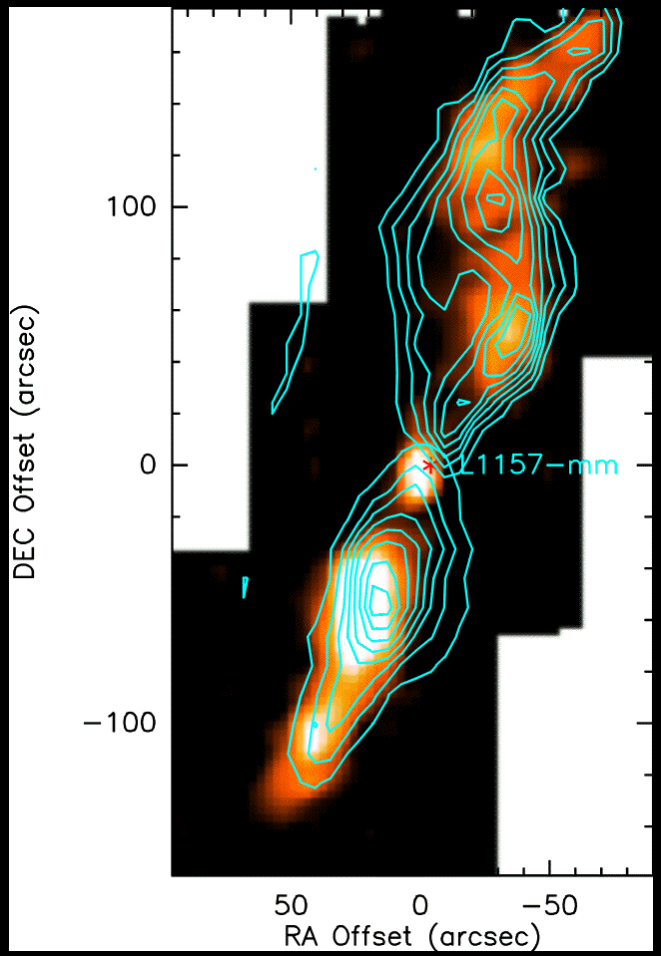


Looney et al. 2008

- Strong water emission from the embedded protostar

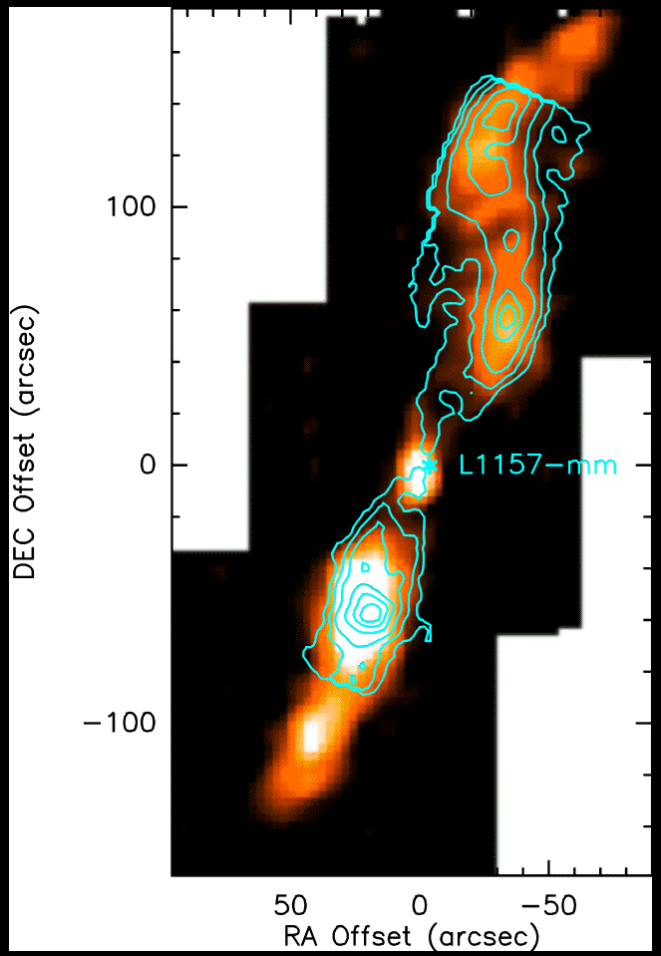
Comparison with other gas main coolants

CO 2-1



Bachiller et al. 2001

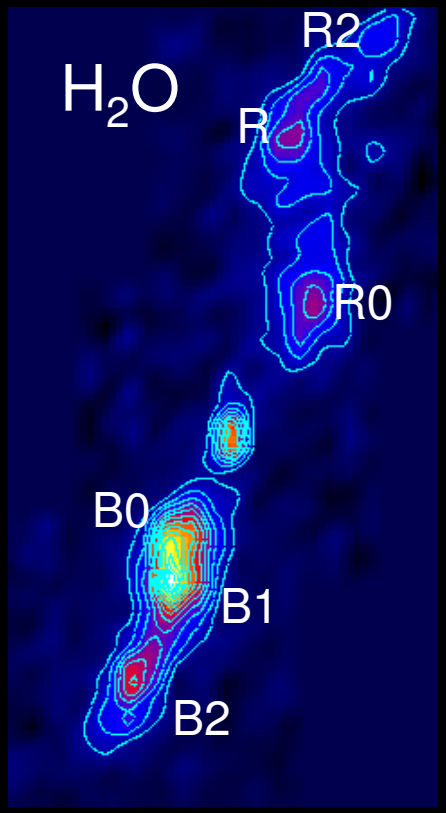
H_2 0-0 S(1) 17μm

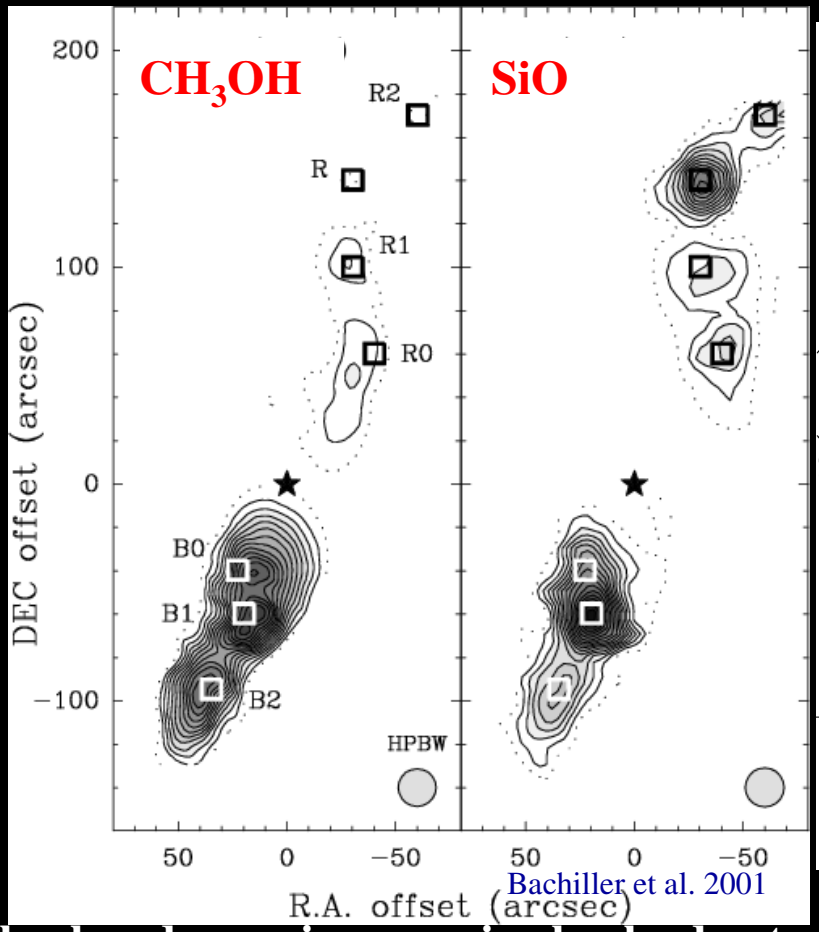


Neufeld et al. 2009

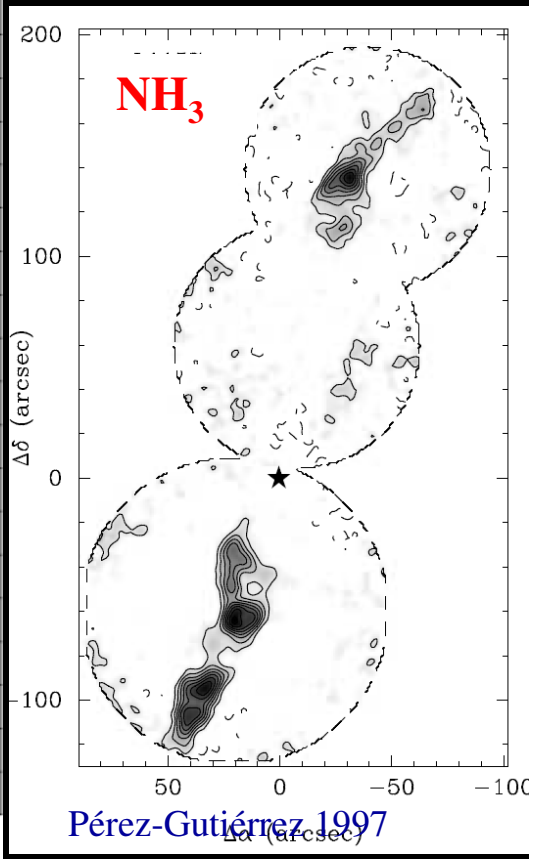
- **Correlation between H_2O and H_2 warm gas at T ~ 300 K**
- **All coolants observed → can determine total energy budget**

Shock enhanced molecular abundances





Bachiller et al. 2001



Pérez-Gutiérrez 1997

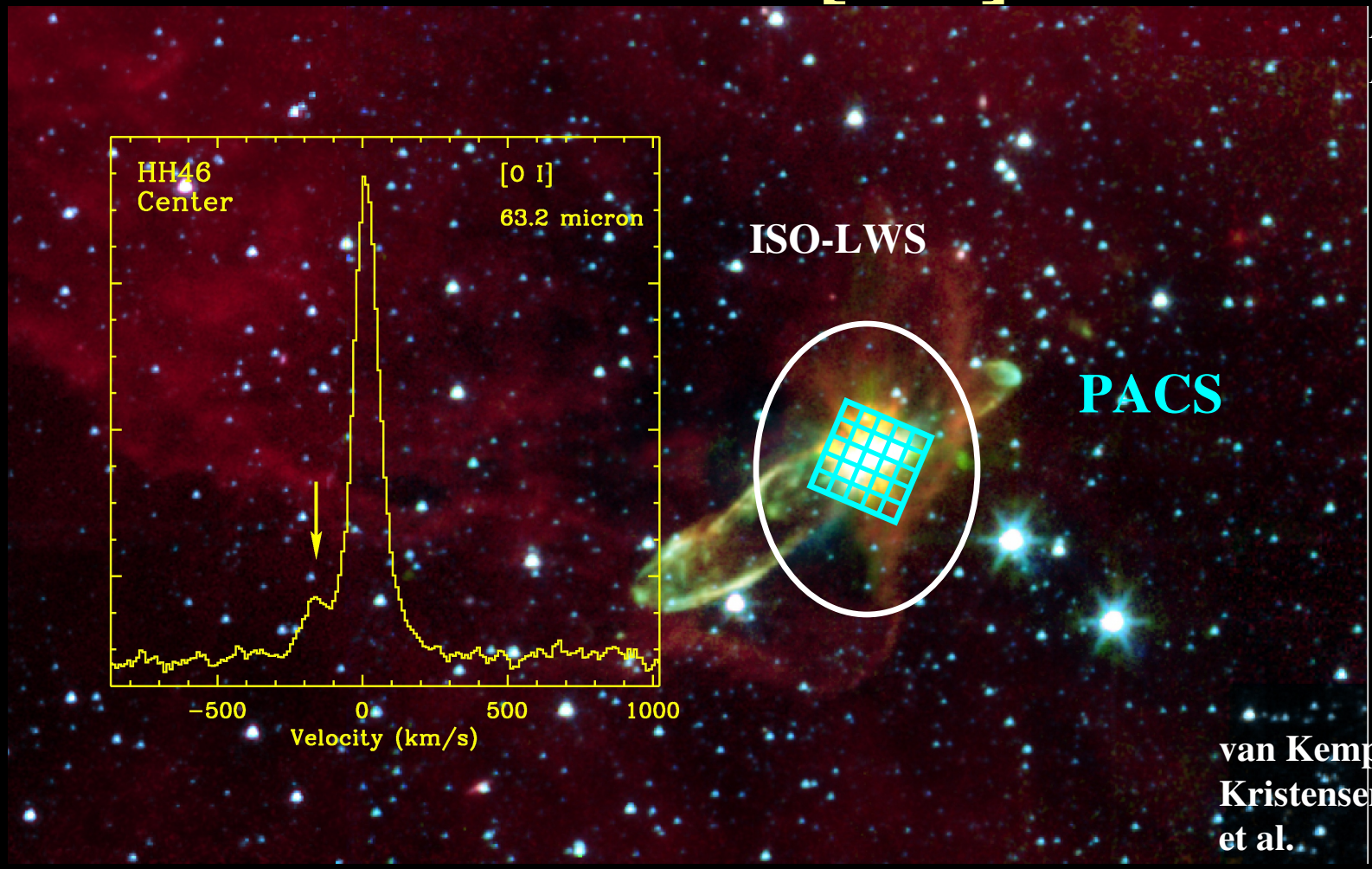
Water and other molecule abundances increase in shocks due to desorption from grain mantles and shock induced chemical reactions

→ relative intensities between peaks change with tracer

→ H_2O, SiO and NH_3 trace the regions at higher density

→ Only H_2O traces all the hot spots

HH 46 low-mass YSO: velocity resolved [O I]



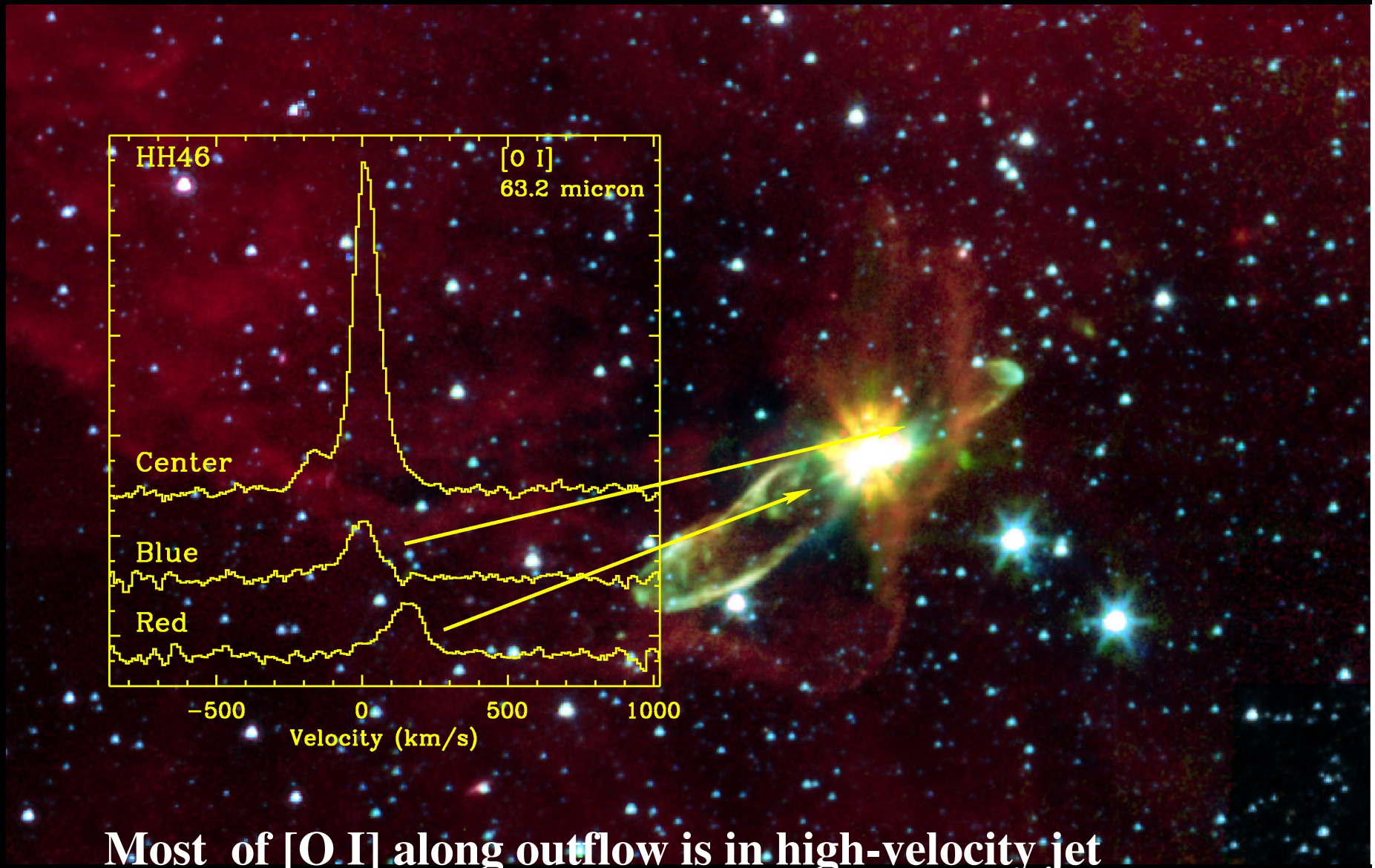
L_{bol}~12 L_o
D=450 pc

Spitzer Image: Noriega-Crespo et al. 2004

van Kempen, Kristensen, Herczeg, et al.

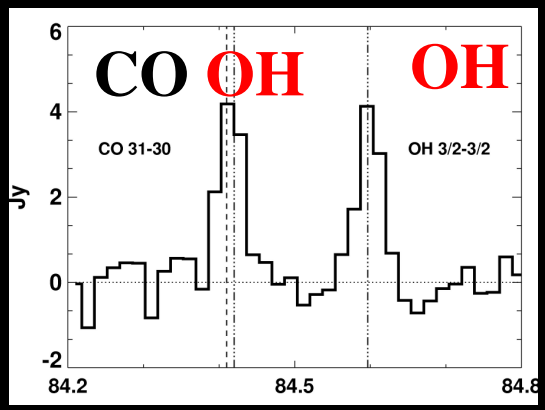
[O I] also present in high velocity (~200 km/s) jet!

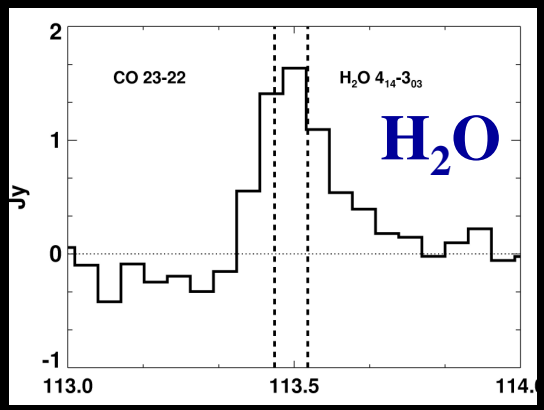
HH 46 [O I]

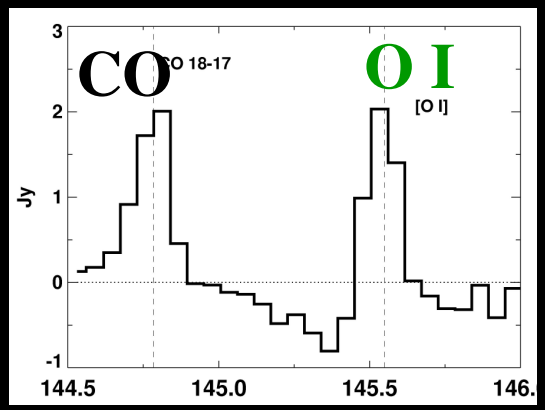


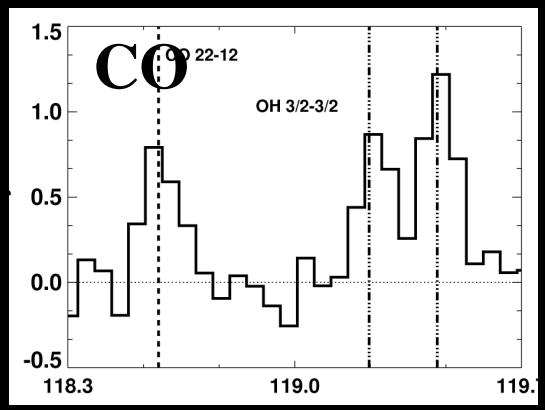
Most of [O I] along outflow is in high-velocity jet

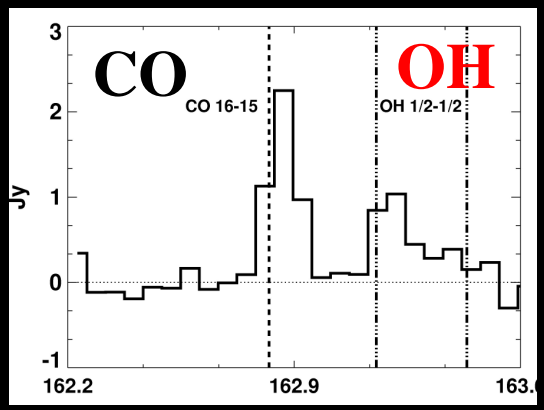
Many lines detected on source

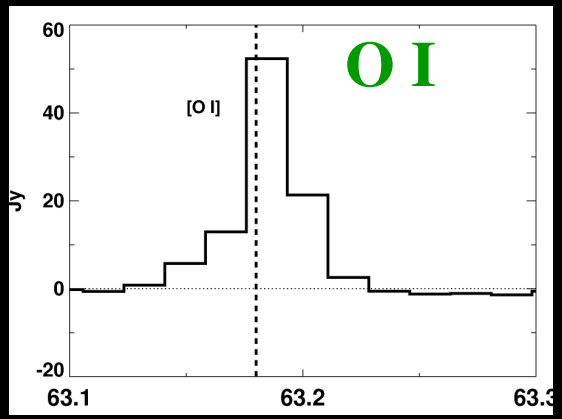








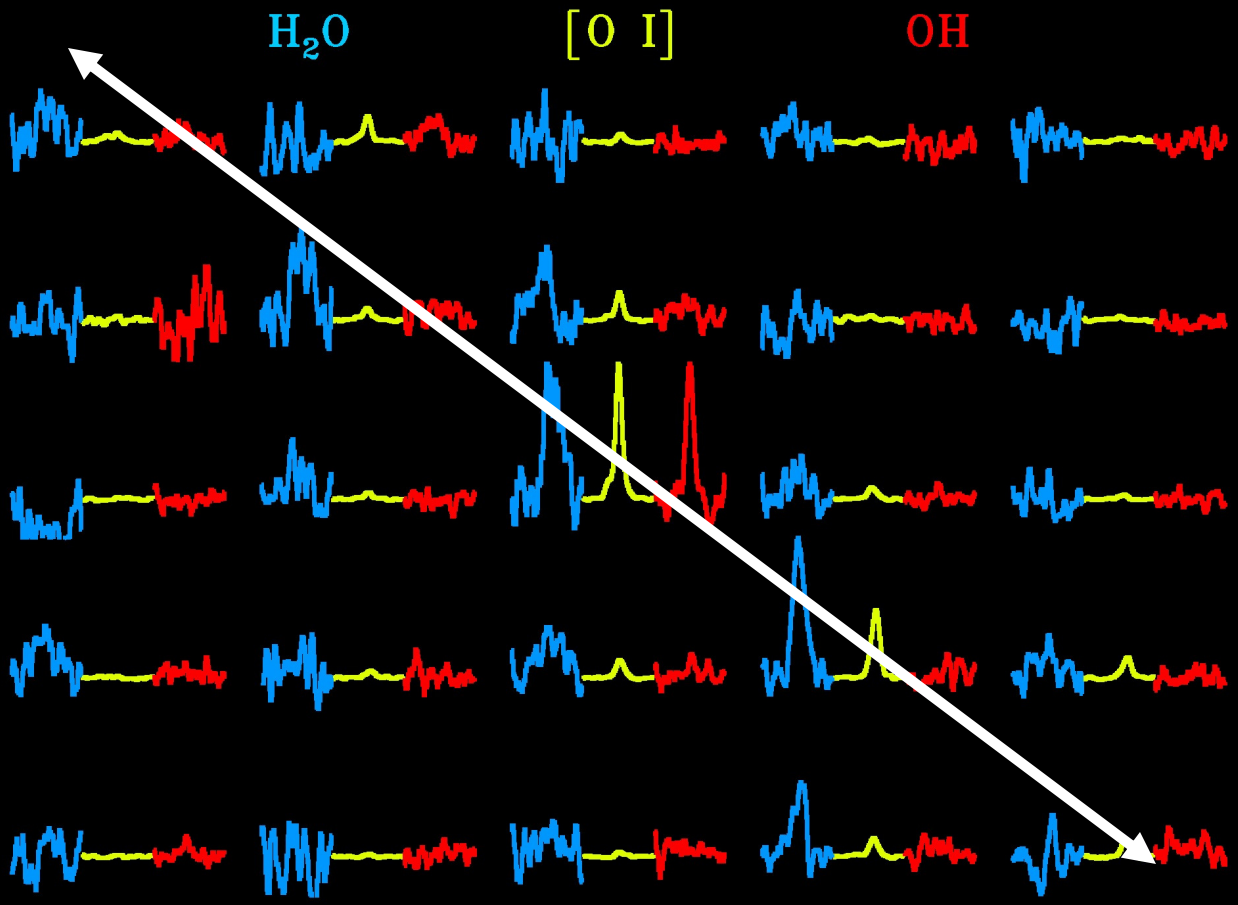




Binned spectra
Warning: fluxes uncertain by 50%

Van Kempen, Kristensen, Herczeg, Wampfler, Bruderer, Benz et al.

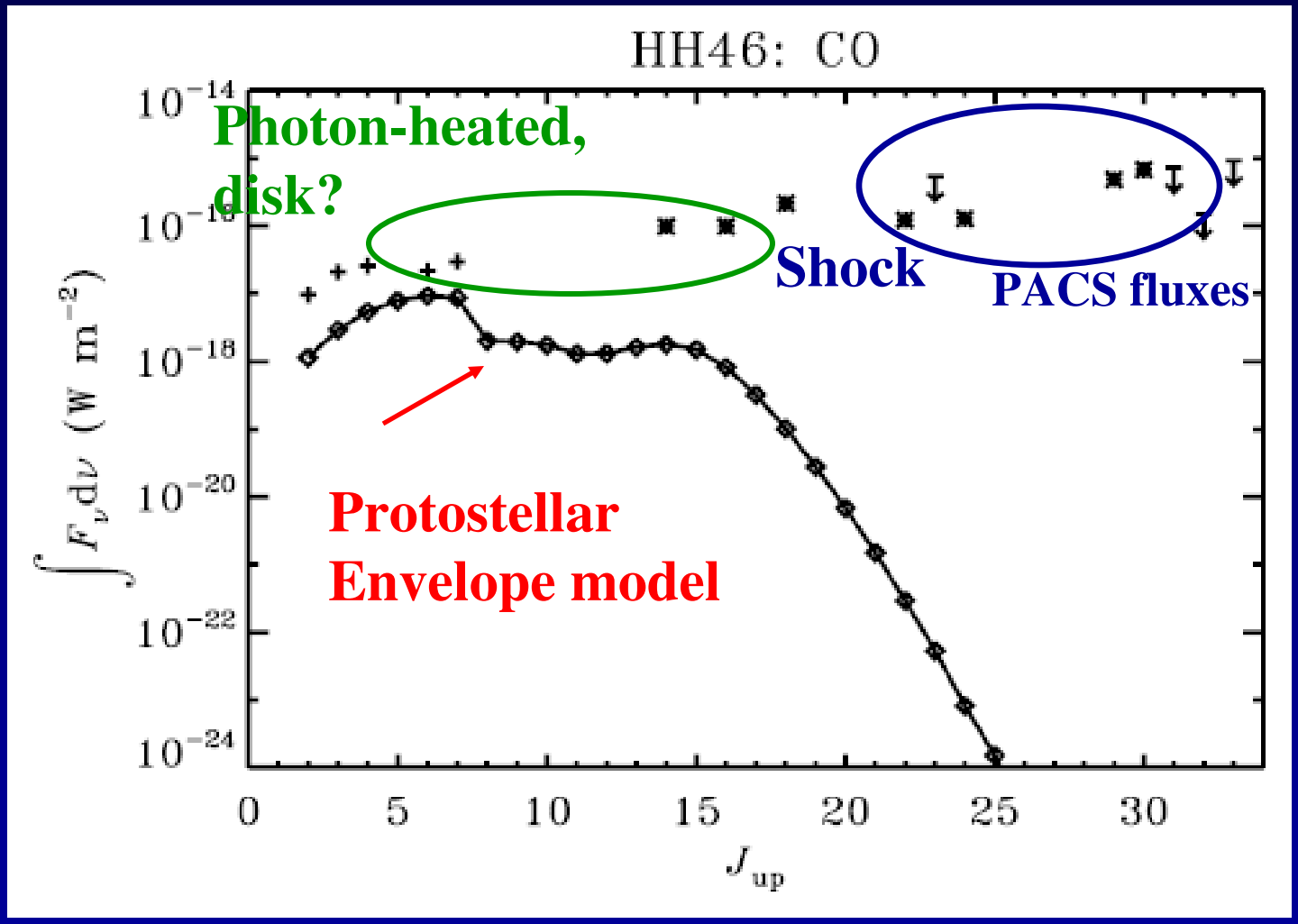
Different species have different distributions



Note: orientation outflow switched in RA compared with Spitzer image

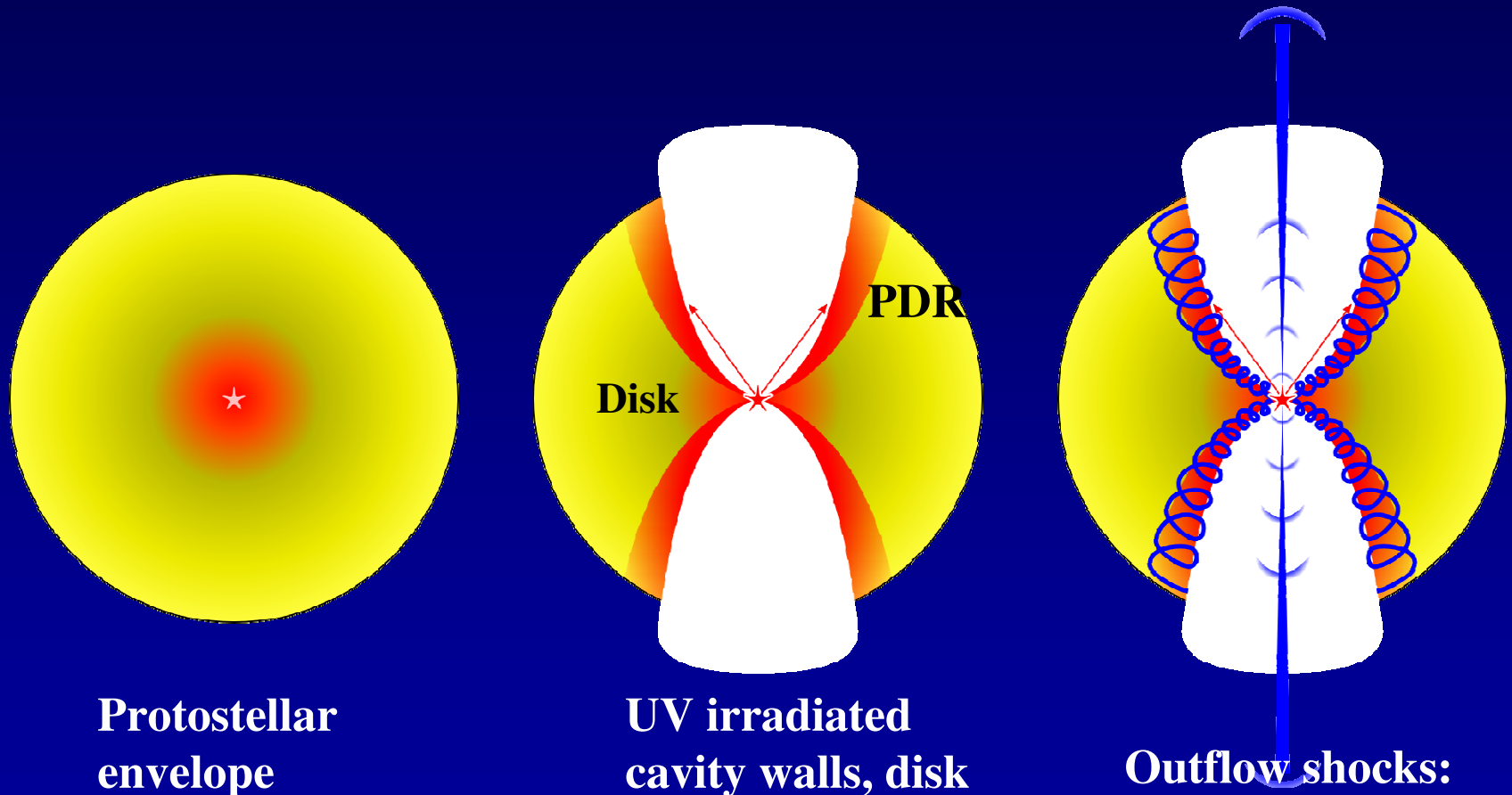
- H_2O extended along outflow, but OH peaking on source
- [O I] falling off rapidly along outflow

Origin of hot CO?



Visser, Bruderer, Kristensen, van Kempen et al.

Which physical component dominates PACS lines?

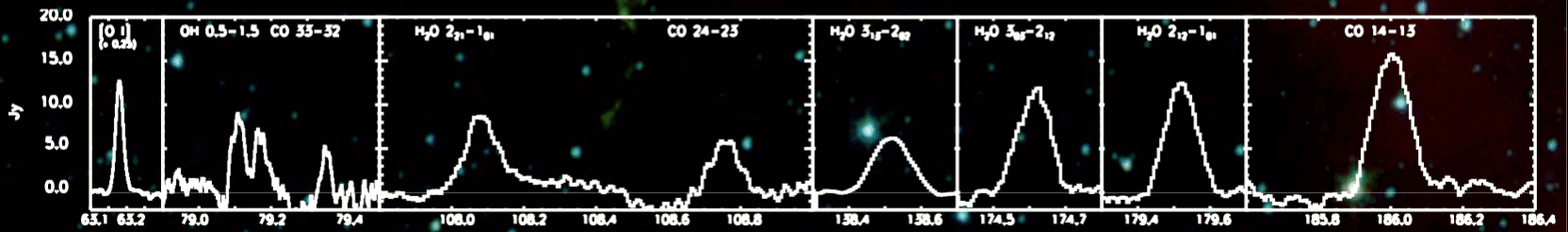


Protostellar envelope with hot core: Low-J CO

UV irradiated cavity walls, disk surface: Mid-J CO? Quiescent O I?

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

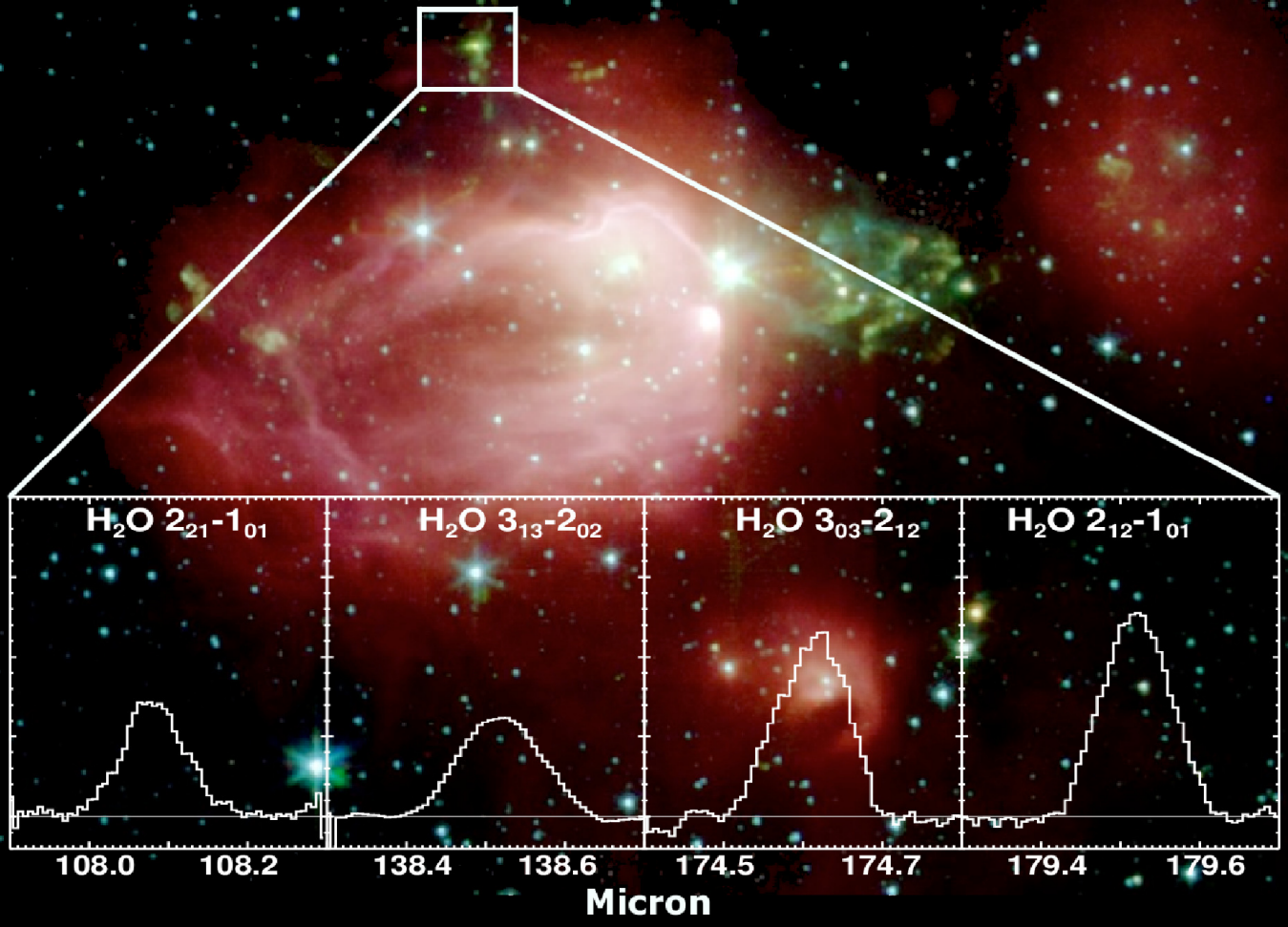
Intermediate mass YSO NGC 7129 FIRS2



- Strong H_2O, OH, CO and [O I] lines detected
- Cannot be fit with protostellar envelope model only

Watering the Rose

Need HIFI to disentangle different components!



Spitzer image
Megeath et al.

Johnstone, Fich, Fuente, et al.

PACS detects water in the "Valentine Day's" Nebula (NGC 7129)