

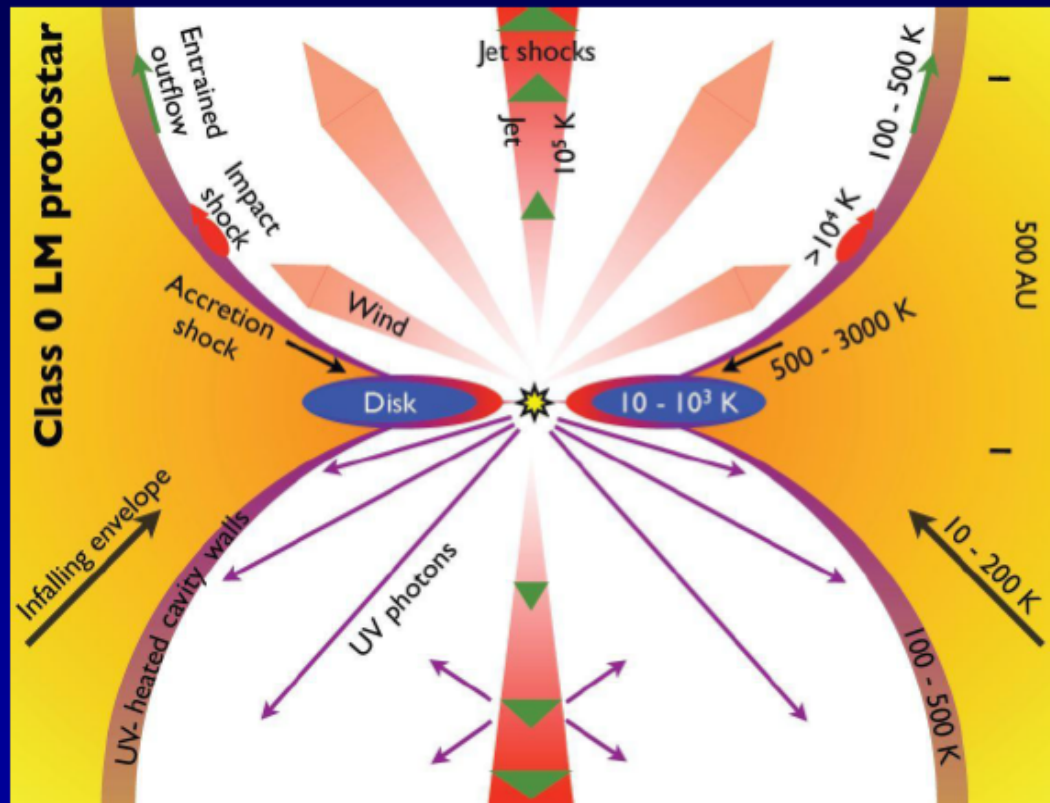
Spectroscopy of protostellar systems: Herschel observations and the role of SPICA

Brunella Nisini

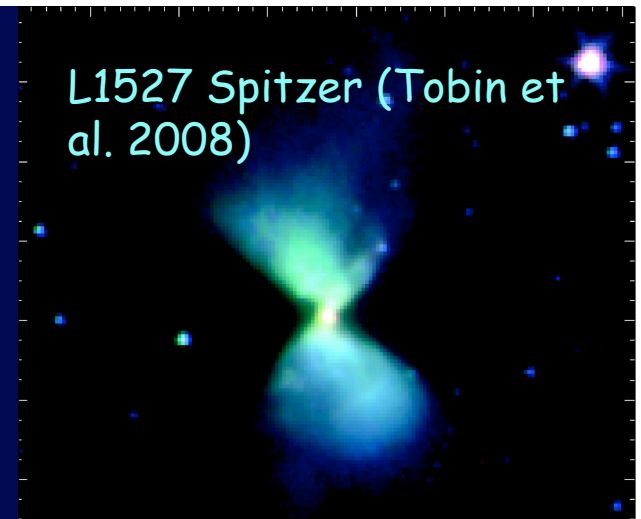


INAF Osservatorio
Astronomico di Roma

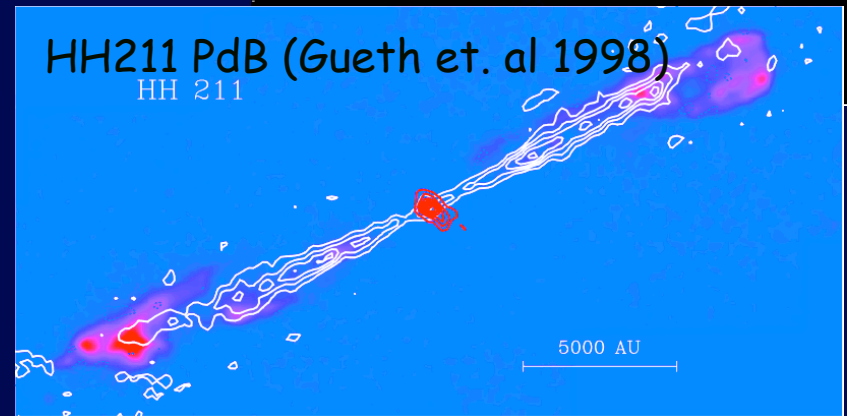
Protostellar systems



L1527 Spitzer (Tobin et al. 2008)



HH211 PdB (Gueth et al. 1998)

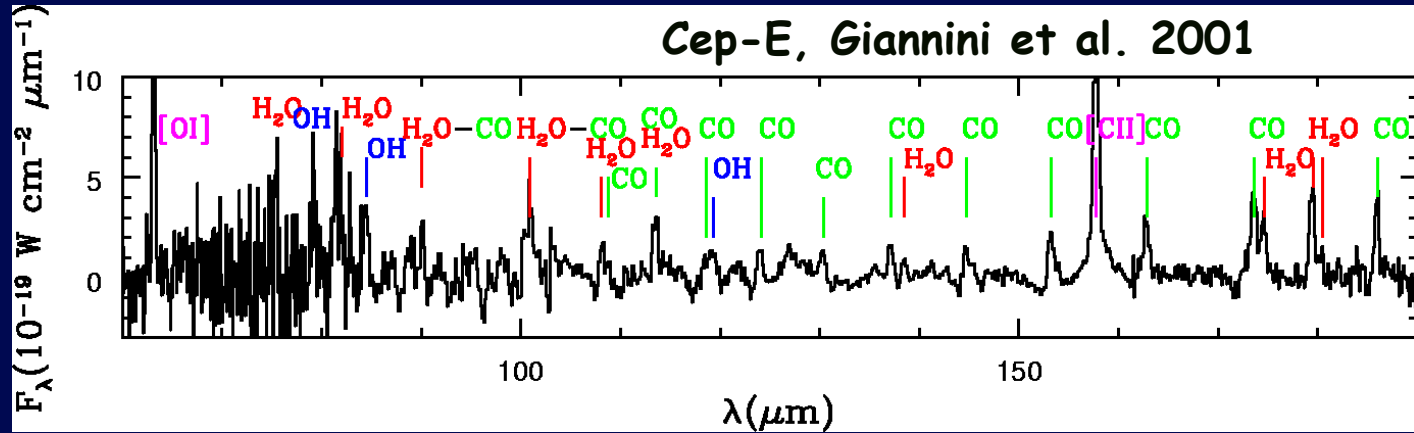


Ingredients: infalling envelope, massive accretion disk, jets&winds, cavities

- High extinction and warm gas ($A_v > 50$ mag, $T \sim 100-2000$ K)
- Main route of gas cooling is line emission from mid- to far-IR (H_2 , CO , O , H_2O)



ISO-LWS: First systematic studies of far-IR spectra of protostars

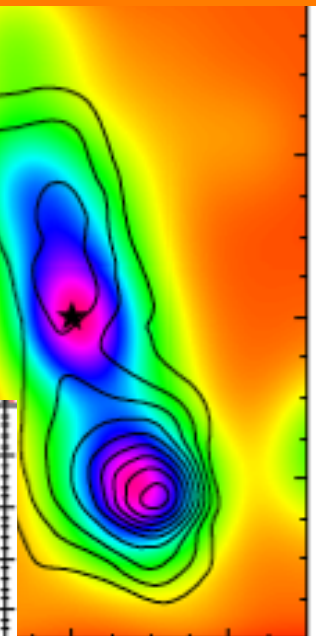
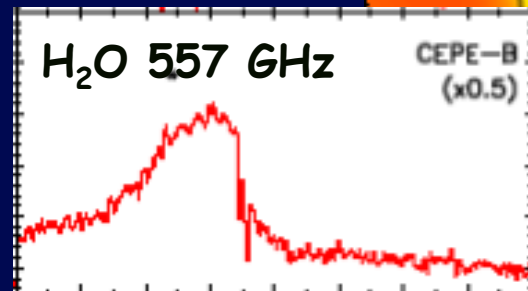


Herschel: big step in spectral/spatial resolution, sensitivity

- PACS line mapping capabilities at 10 arcsec resolution (direct precursor of Safari)
- HIFI spectral line profiles

Tafalla et al. 2013

H₂O 179um vs IRAC



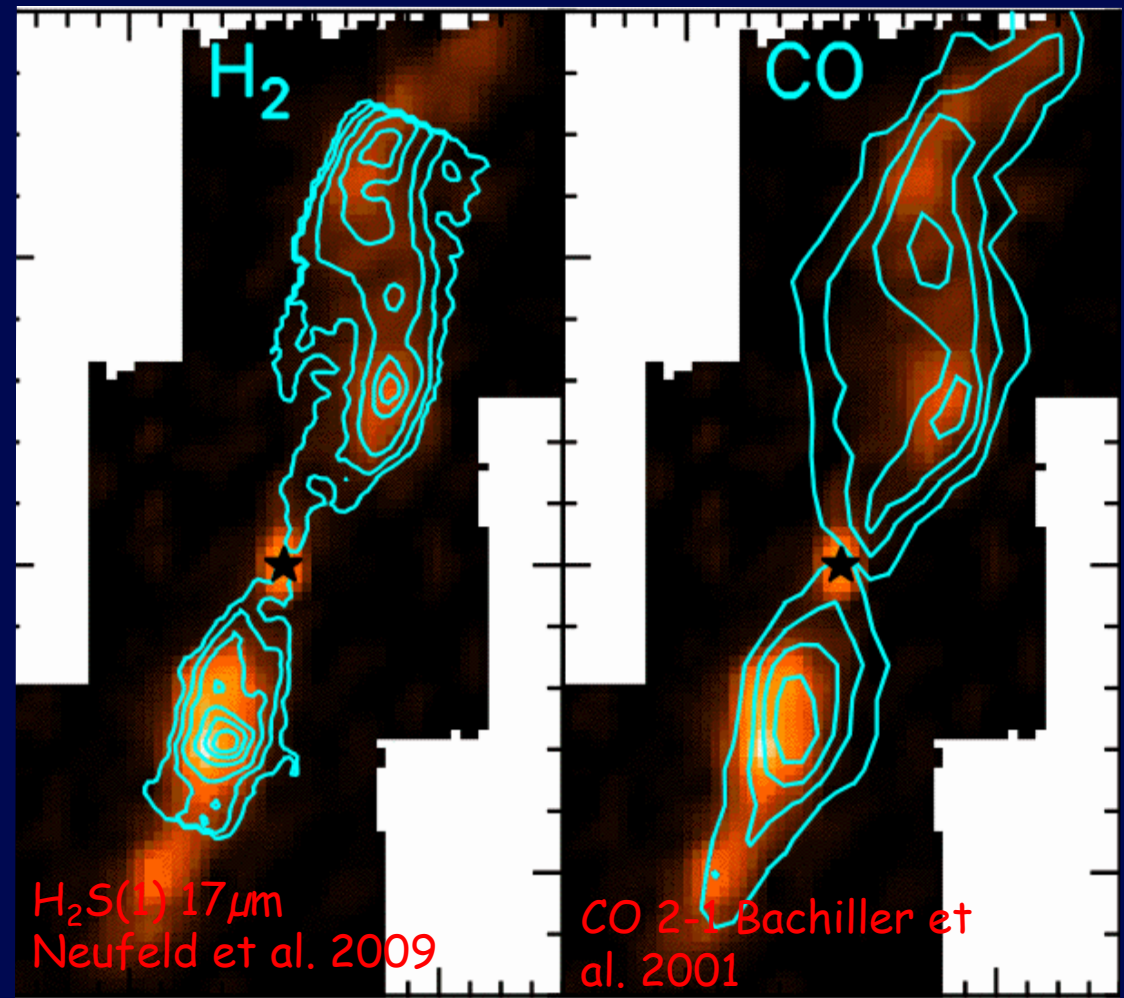
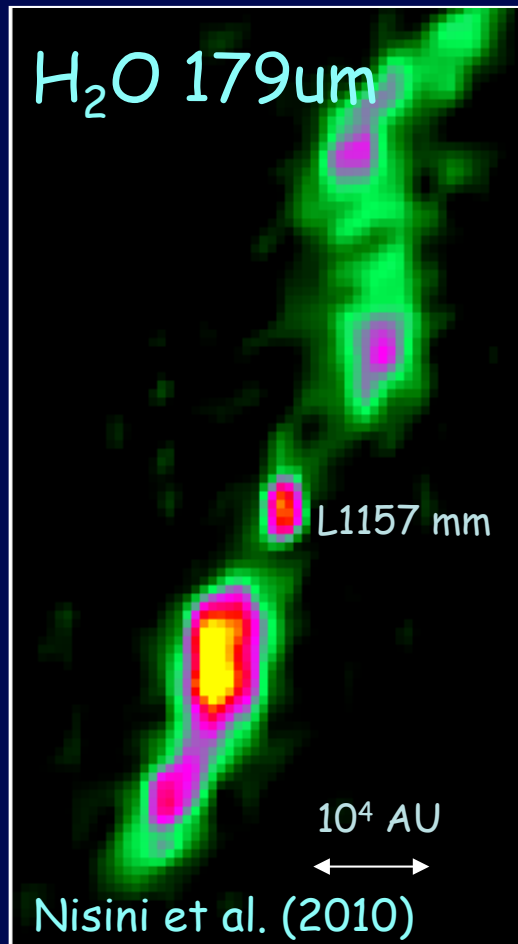
Different Herschel KP addressing the study of protostellar systems

- **DIGIT** (Dust, ice & gas, P.I. N. Evans): PACS spectral scans of samples of embedded and T Tauri stars
- **CHESS** (Chemical HErschel Survey of Star forming regions, P.I. C. Ceccarelli): HIFI + PACS full scans of selected sources



- **WISH**: Water in star forming regions with Herschel (P.I. Ewine van Dishoeck)
- Survey a selected set of H_2O , CO , O , OH lines in samples of YSOs with the **HIFI** and **PACS** spectrometers

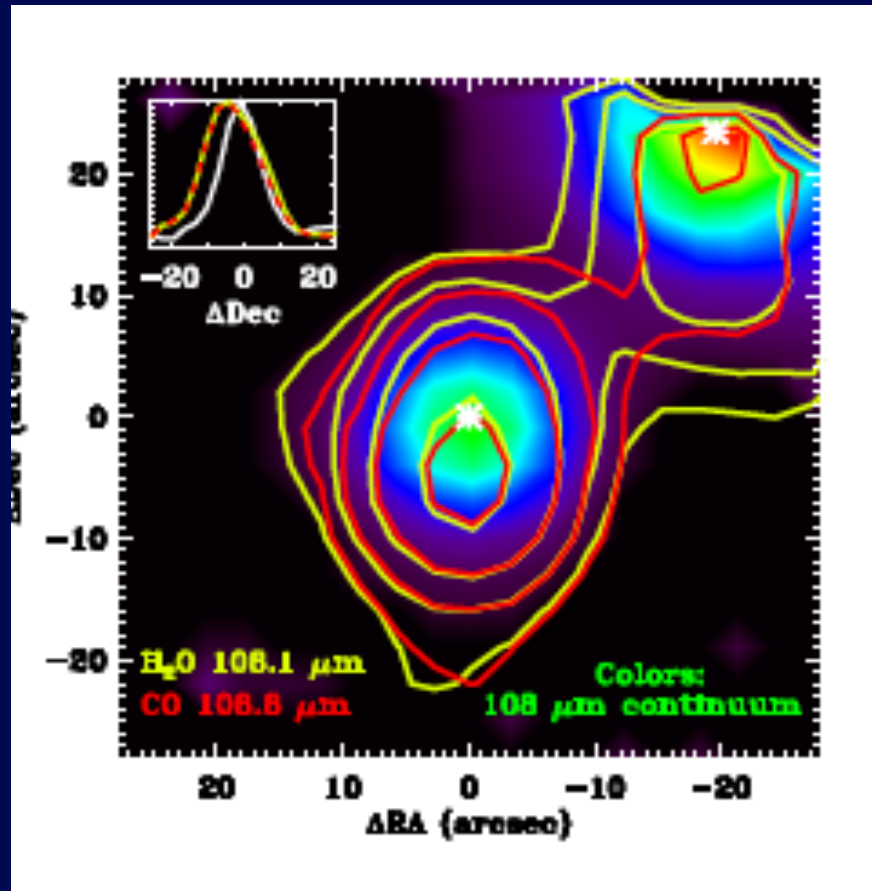
PACS line maps of protostellar systems: first maps of water distribution



- Emission localized on shock spots and on-source
- Correlation with H₂ warm gas
- On-source $\rightarrow A_v > 50$ mag

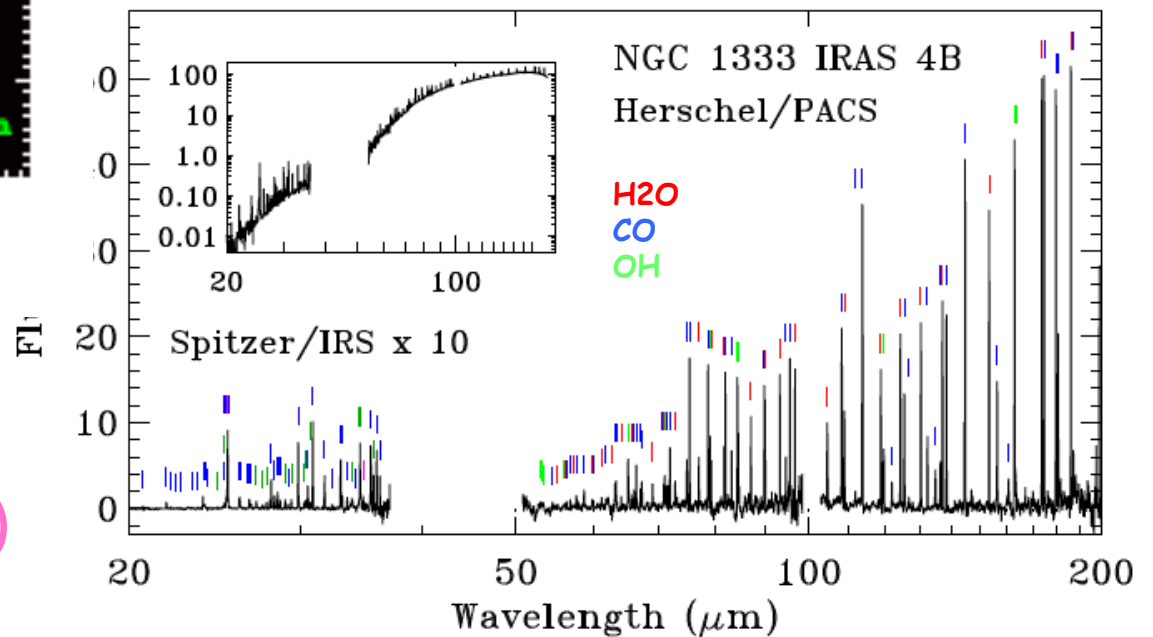
PACS observations: spatial resolution!

NGC1333-IRAS4B Herczeg et al.2012

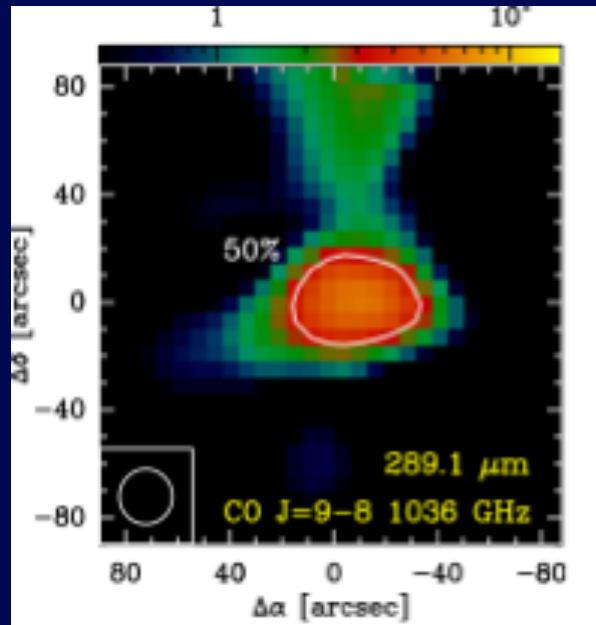


- Offset between line and continuum emissions
- Forest of lines at high excitation (up to CO 49-48)

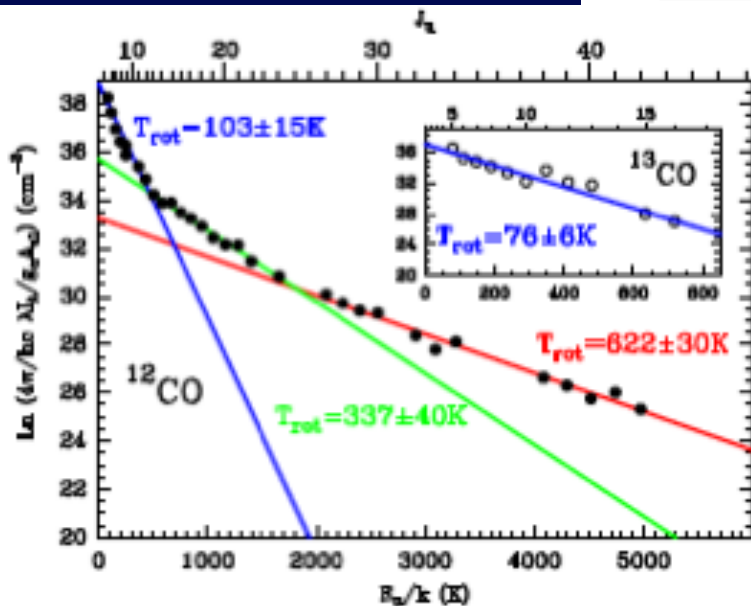
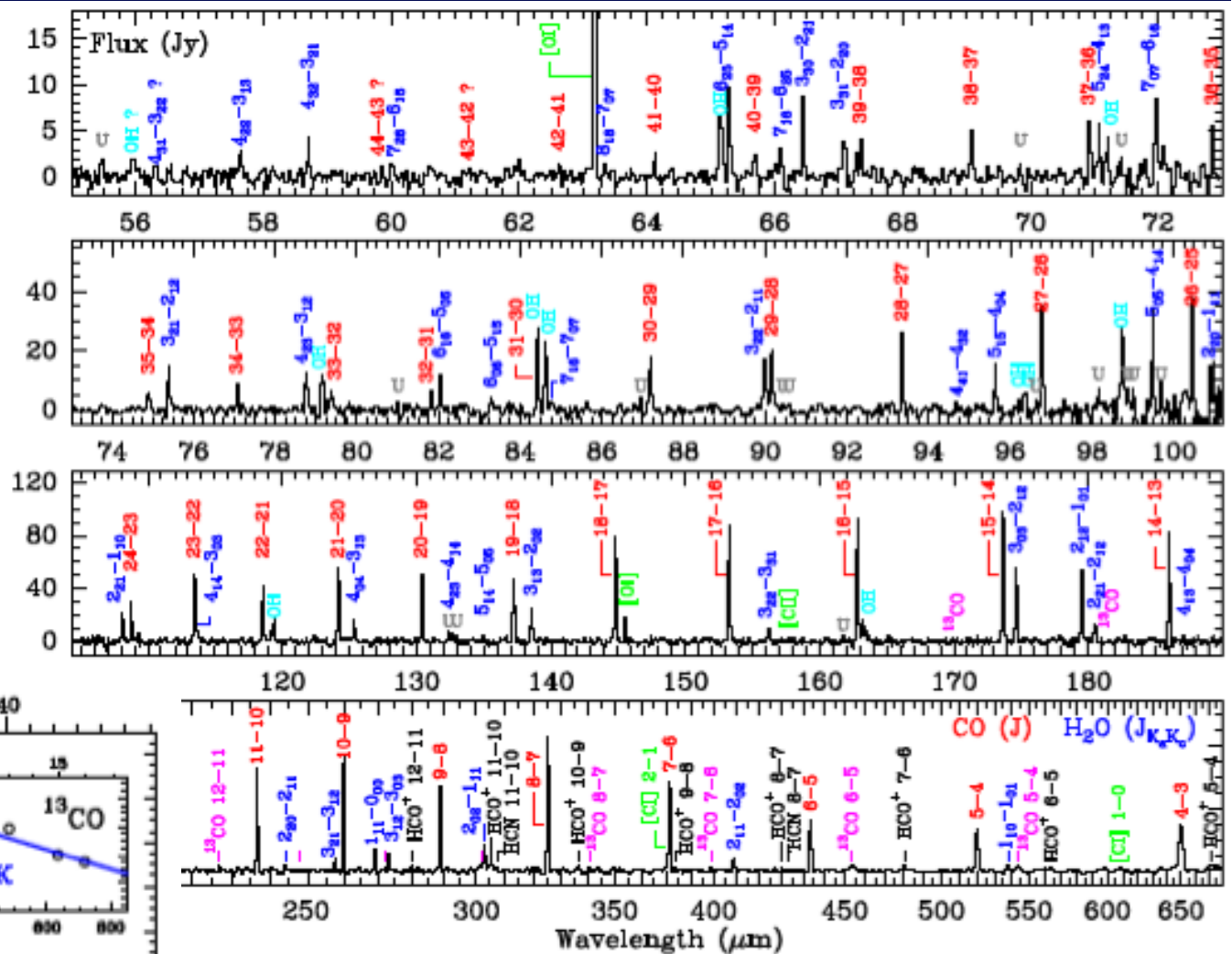
Emission consistent with an hot (T up to 1500 K) and dense ($n = 2 \cdot 10^6 \text{ cm}^{-3}$) shocked gas



Serpens SMM1 PACS + SPIRE spectrum

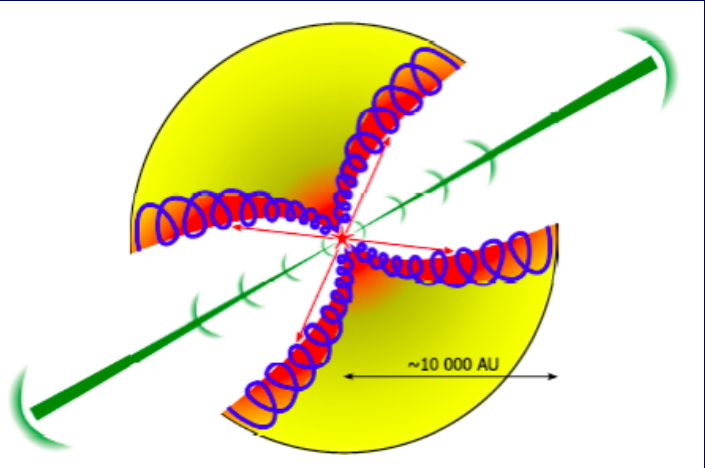


Goicoechea et al. 2012

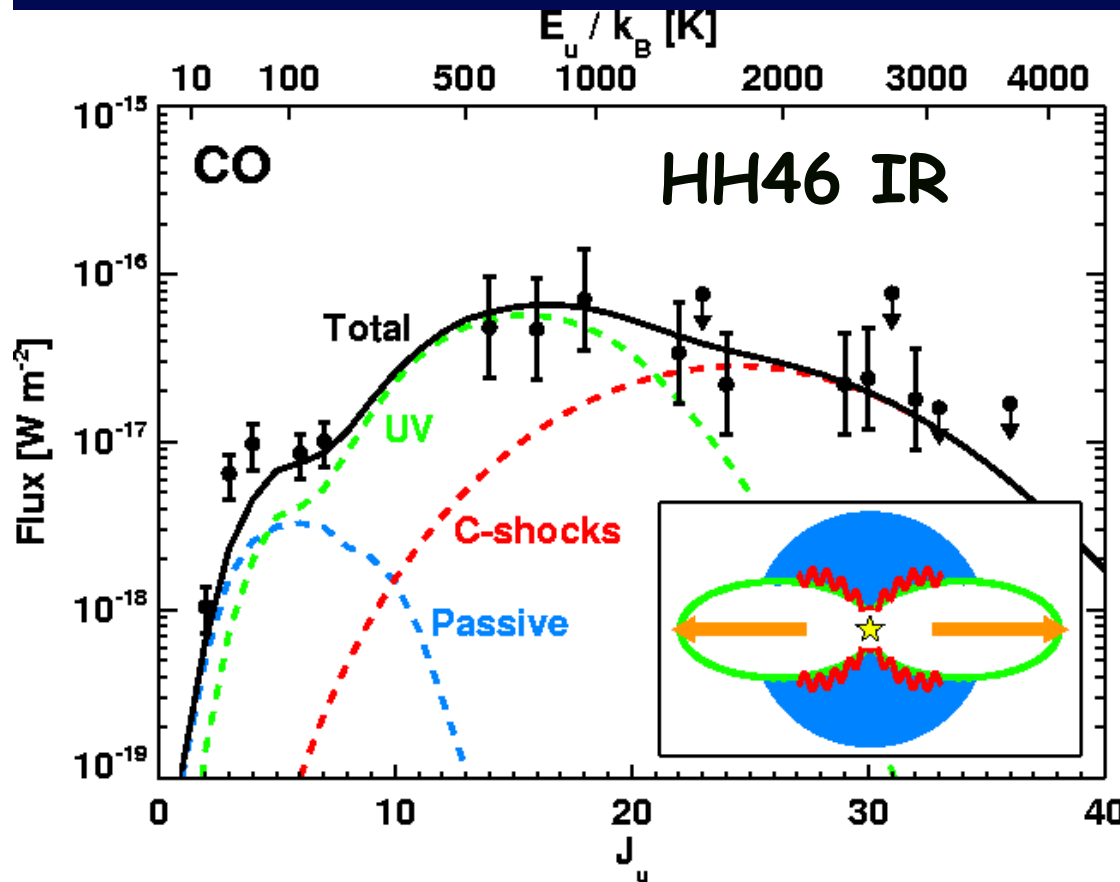


Different gas components in the not resolved region

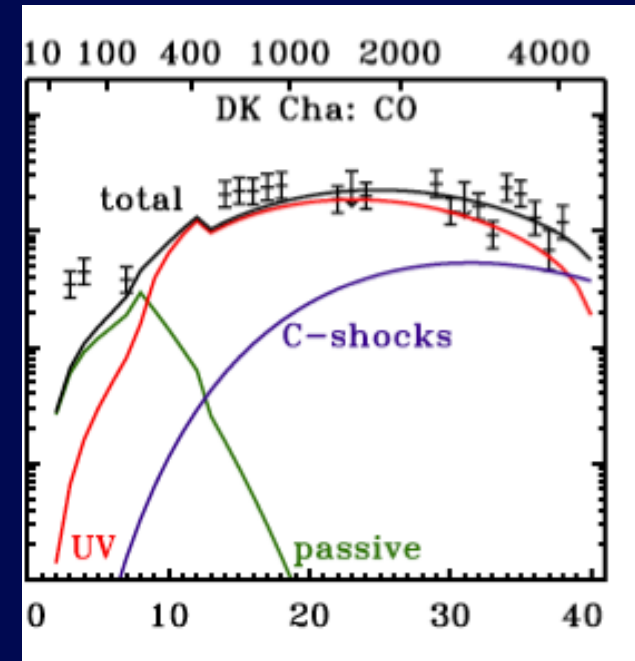
Attempt to model the different components



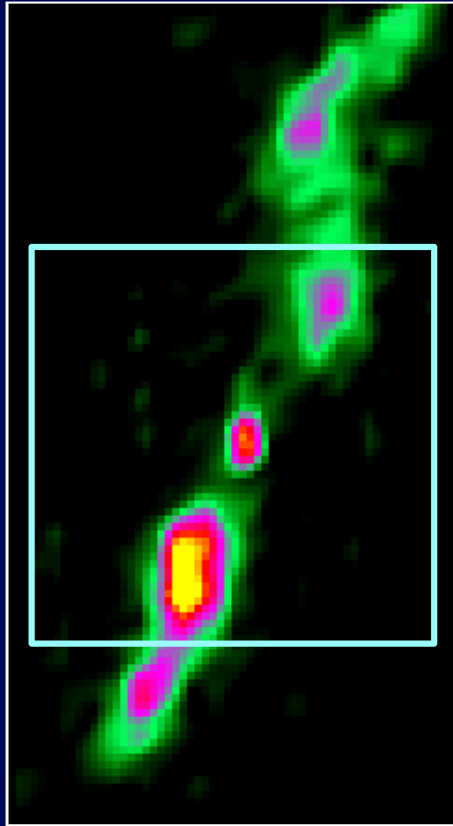
- Passively heated envelope
 - FUV heated cavity
 - Shocks
- Relative contribution change with evolution



Visser et al. 2012



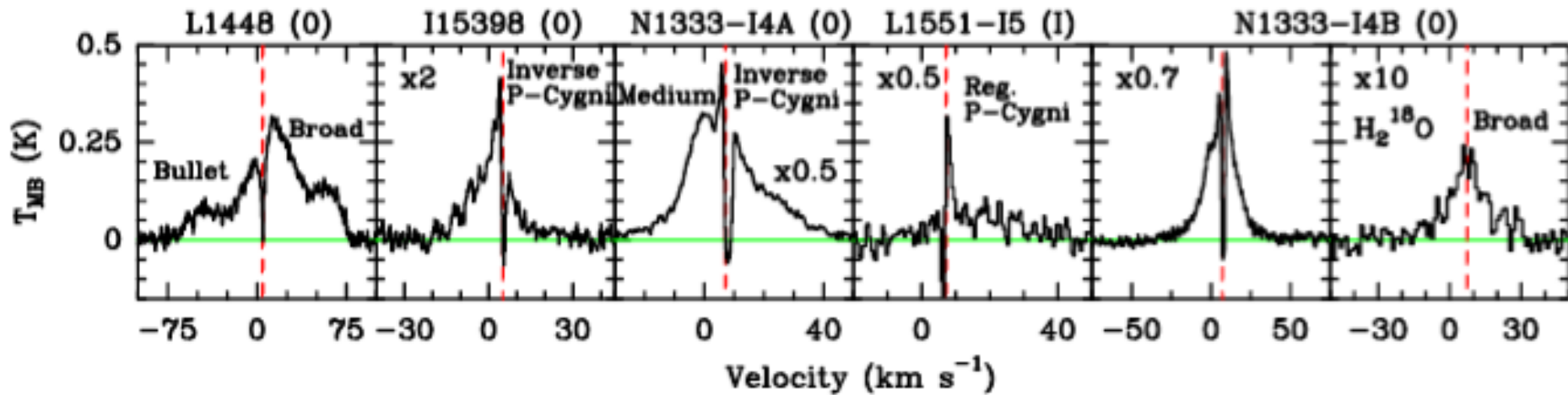
The role of SPICA- SAFARI



- No improve with respect to PACS in spatial and spectral resolution
- Significant improve in spatial coverage and speed (sensitivity and spectral coverage)

→ Suited for large spectral surveys (*explore evolutionary and luminosity effects/symultaneously cover source+outflow*)
→ Will benefit from Spitzer/Herschel photometric surveys for source selections

HIFI: H₂O line profiles

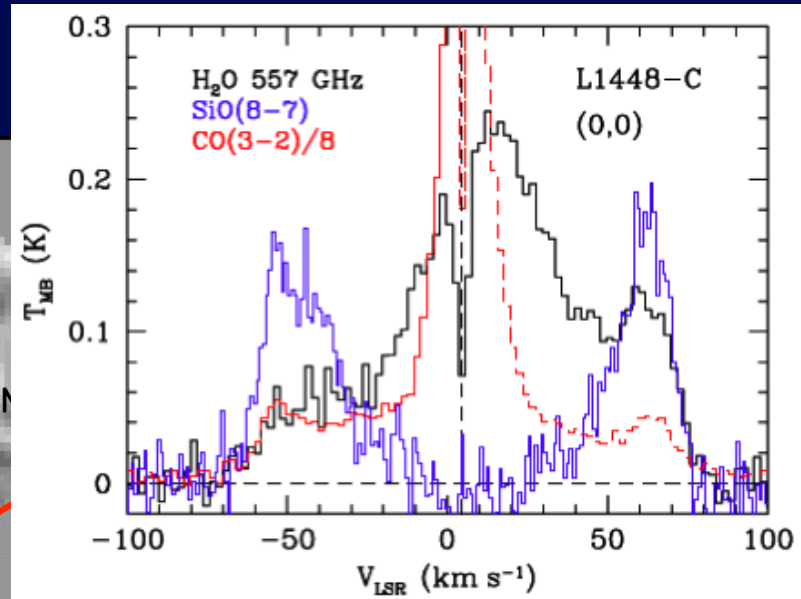
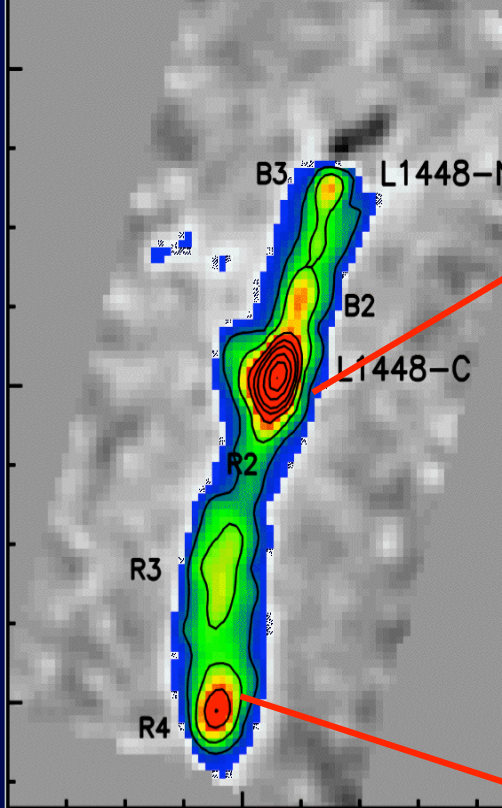


Variety of features probing the different components (infalling envelope, outflows, jets)

Unique probe of high pressure gas

L1448

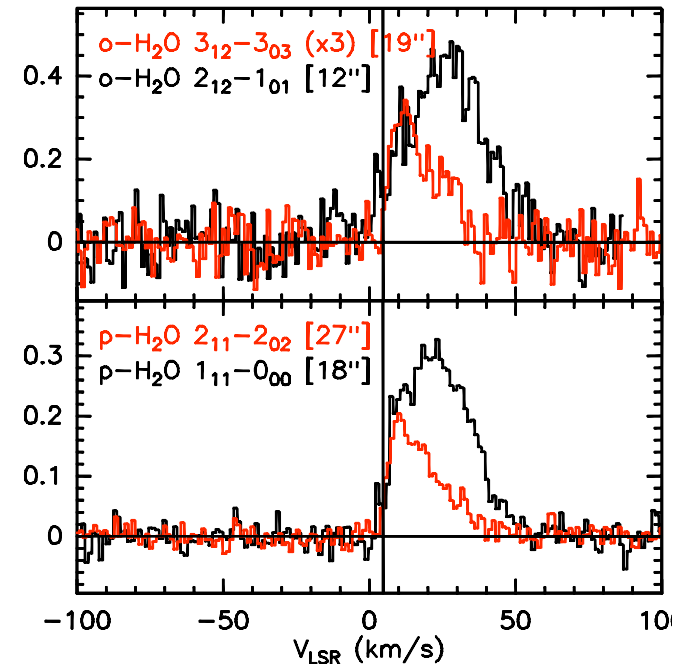
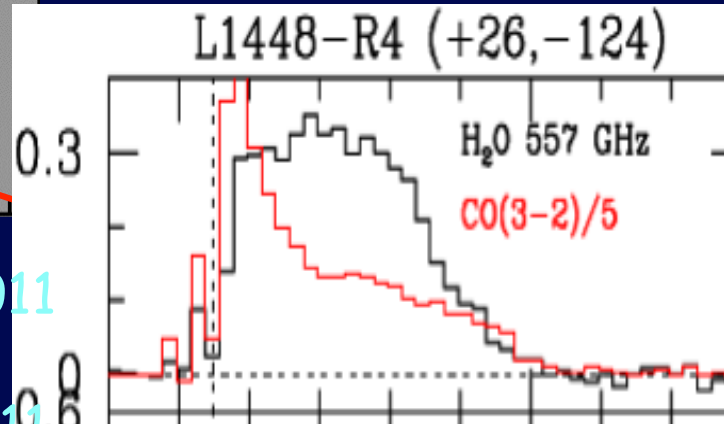
$\text{H}_2\text{O } 2_{12}-1_{01}$



H_2O broad component uniquely trace high pressure shocked gas ($nT \sim 10^9 \text{ cm}^{-3}\text{K}$)

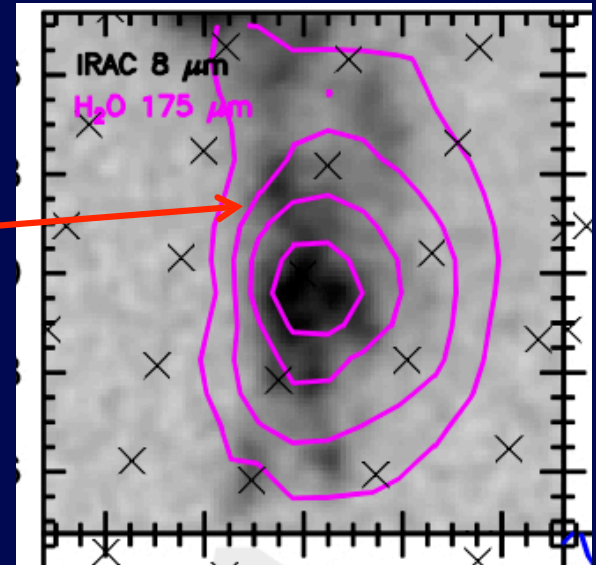
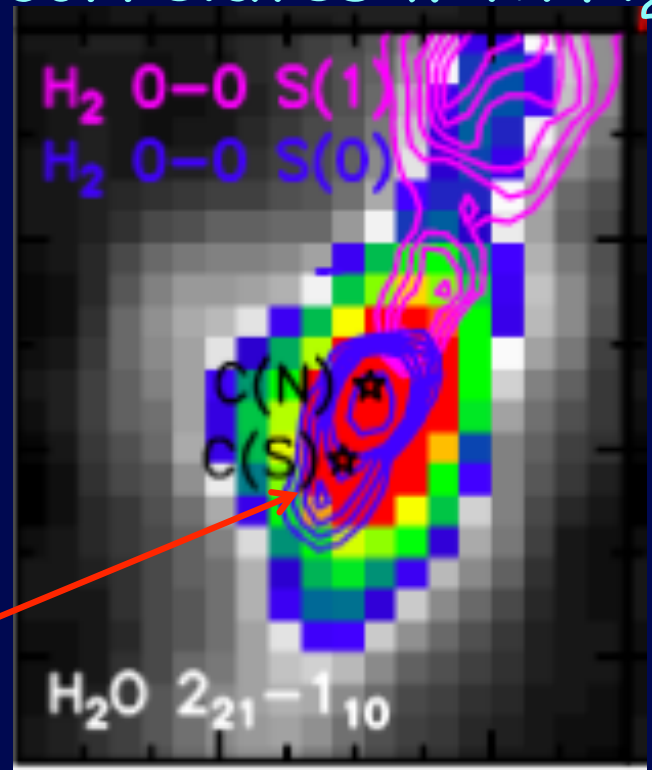
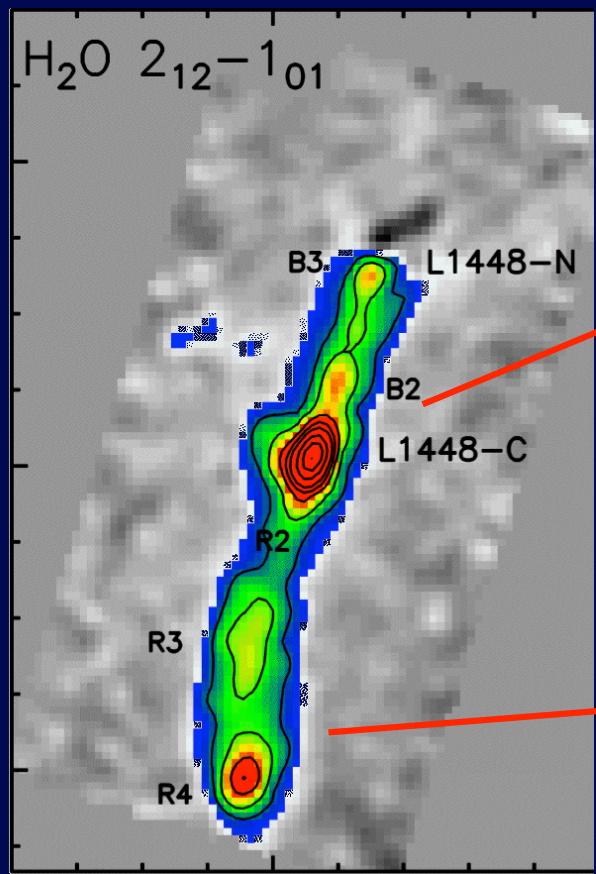
$E_{\text{up}} < 80 \text{ K}$

$E_{\text{up}} > 130 \text{ K}$



Santangelo et al. 2011
 Nisini et al. 2012
 Kristensen et al. 2011
 Tafalla et al. 2013

Water strictly correlates with H₂ mid-IR emission

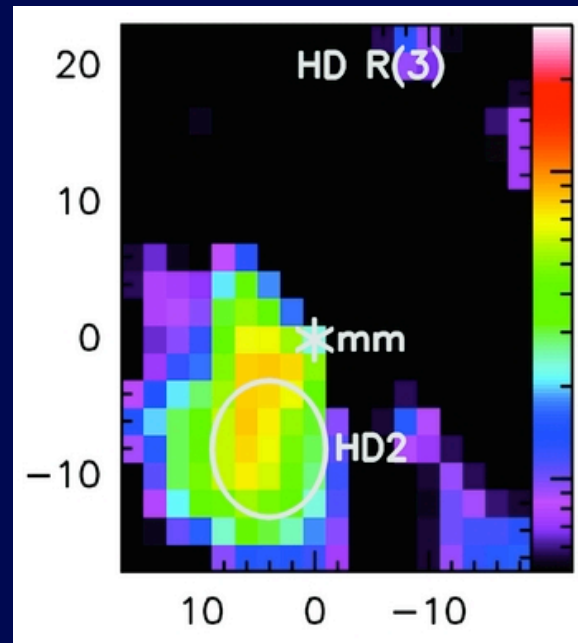
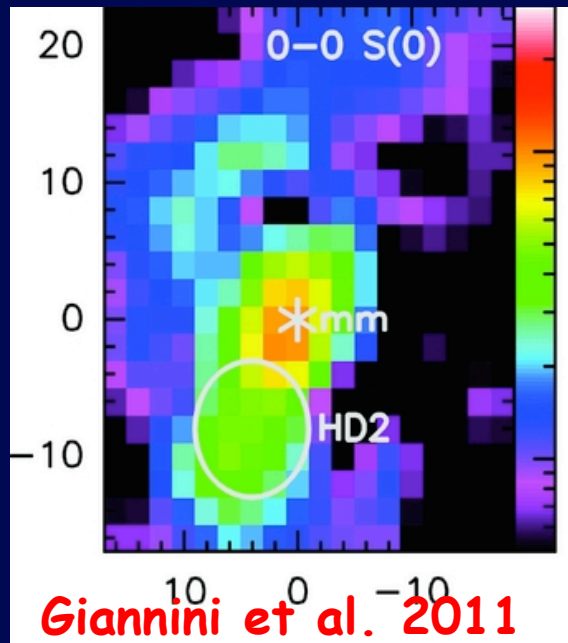


Understand the origin of H₂O velocity components

- High temperature ($T > 300$ K) and density ($n > 10^6$ cm⁻³) gas → hardly traced by any sub-mm molecular line (ALMA of little use)
- Velocity resolved H₂ 0-0 lines as a unique tool to investigate the gas components traced by water
→ Spica HR-MCS
- Unique possibility to have a direct measure of H₂O **abundance** in the different kinematical components

Observations of Hydrogen deuteride (HD)

- Fundamental line at 112 μ m (Safari)
- Other lines: R(1) 56.2 μ m, R(2) 37.7 μ m (Safari)
R(3) 28.5, R(4) 23.0 (MCS)
- Observed by Spitzer in shocks (e.g. Neufeld et al. 2006)
- **[D/H] in dense gas $\sim 7.5 \times 10^{-6}$**



Different morphology
of H₂ S(0) and HD R(3)

Variation of abundance
or excitation effects

- in conjunction with H₂ observations: set constraints on the deuterium abundance in dense clouds
- HD 112 μ m line proxy for H₂ in the most embedded sources

Summary

SPICA possible projects (limited and biased..)

- Safari: spectroscopic surveys of large samples of protostars selected from Herschel surveys
- MCS: UNIQUE opportunity to observe velocity resolved H_2 0-0 lines --> proxy for interpreting H_2O HIFI data
- MCS+Safari: UNIQUE opportunity for HD studies