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

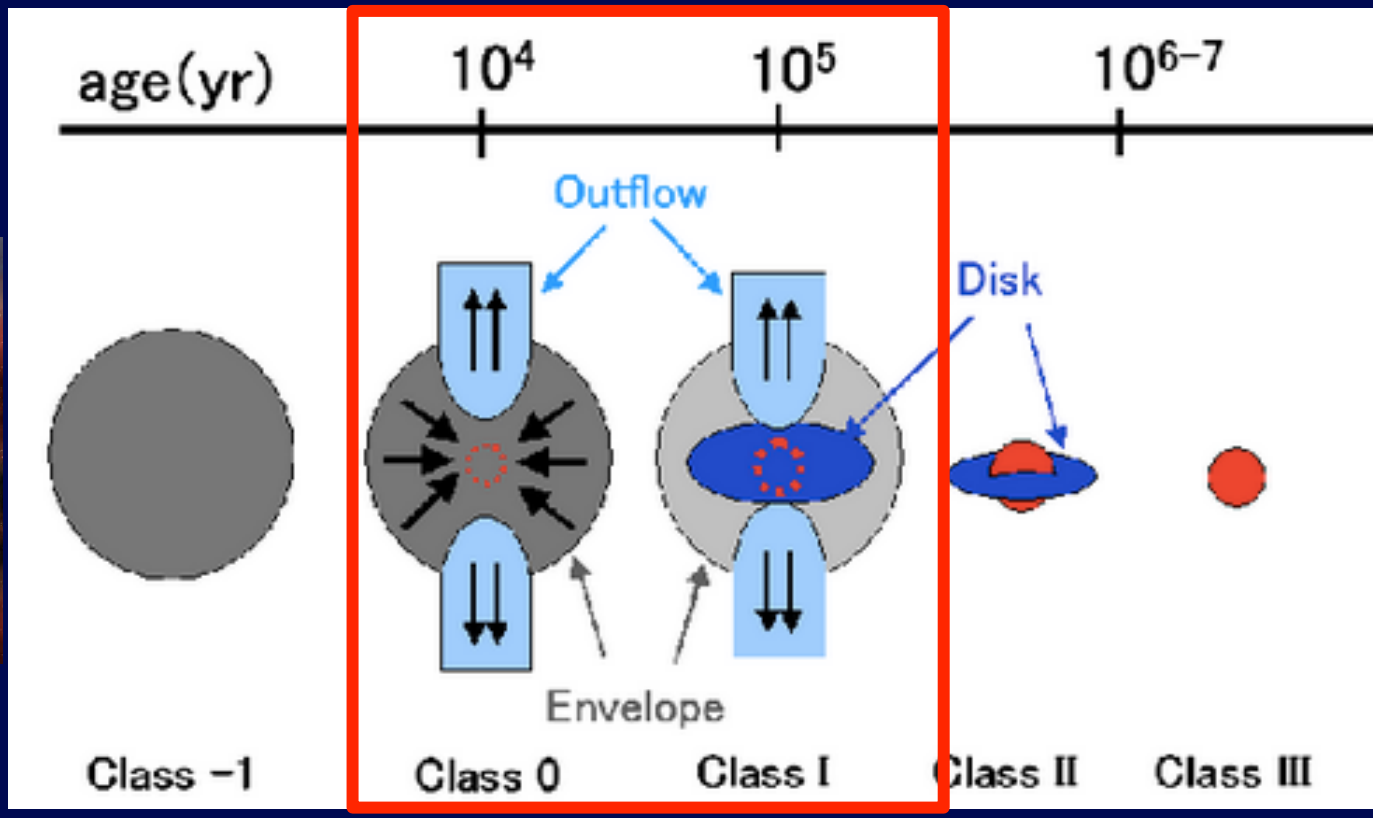
Brunella Nisini

INAF Osservatorio Astronomico di Roma

Jets and Disks at INAF collaboration

→ A biased and not-complete view of what SPICA could do for protostellar studies

Following proto-stellar evolution



- High extinction and warm gas (Av > 40 mag, T ~ 100-2000 K)
- Main route of gas cooling is line emission from mid- to far-IR (H_2, CO, O, H_2O)

➔ Space far-IR facilities are the only way to study the active regions

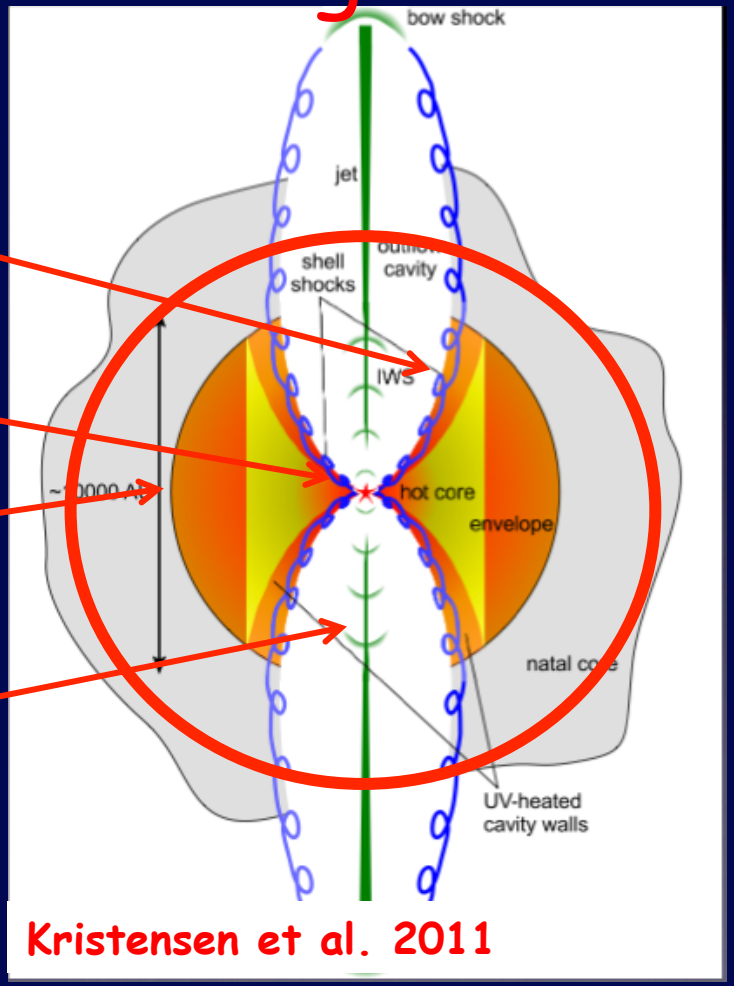
The complex structure of the inner protostellar regions

Cavity walls

Hot core/disk

Infalling envelope

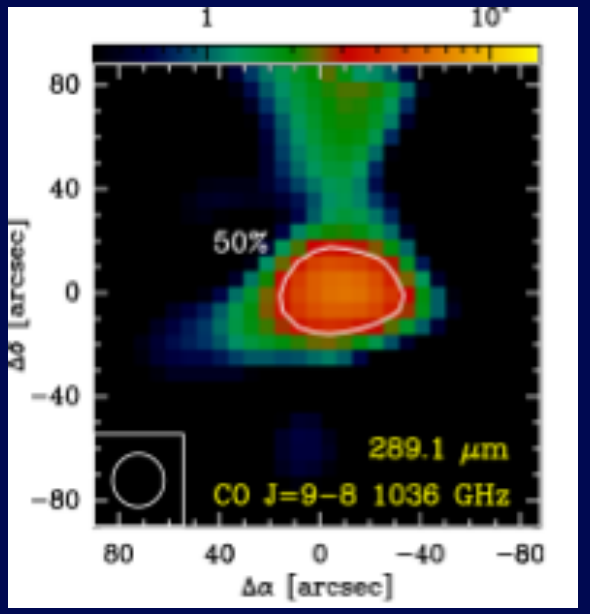
Jets/winds



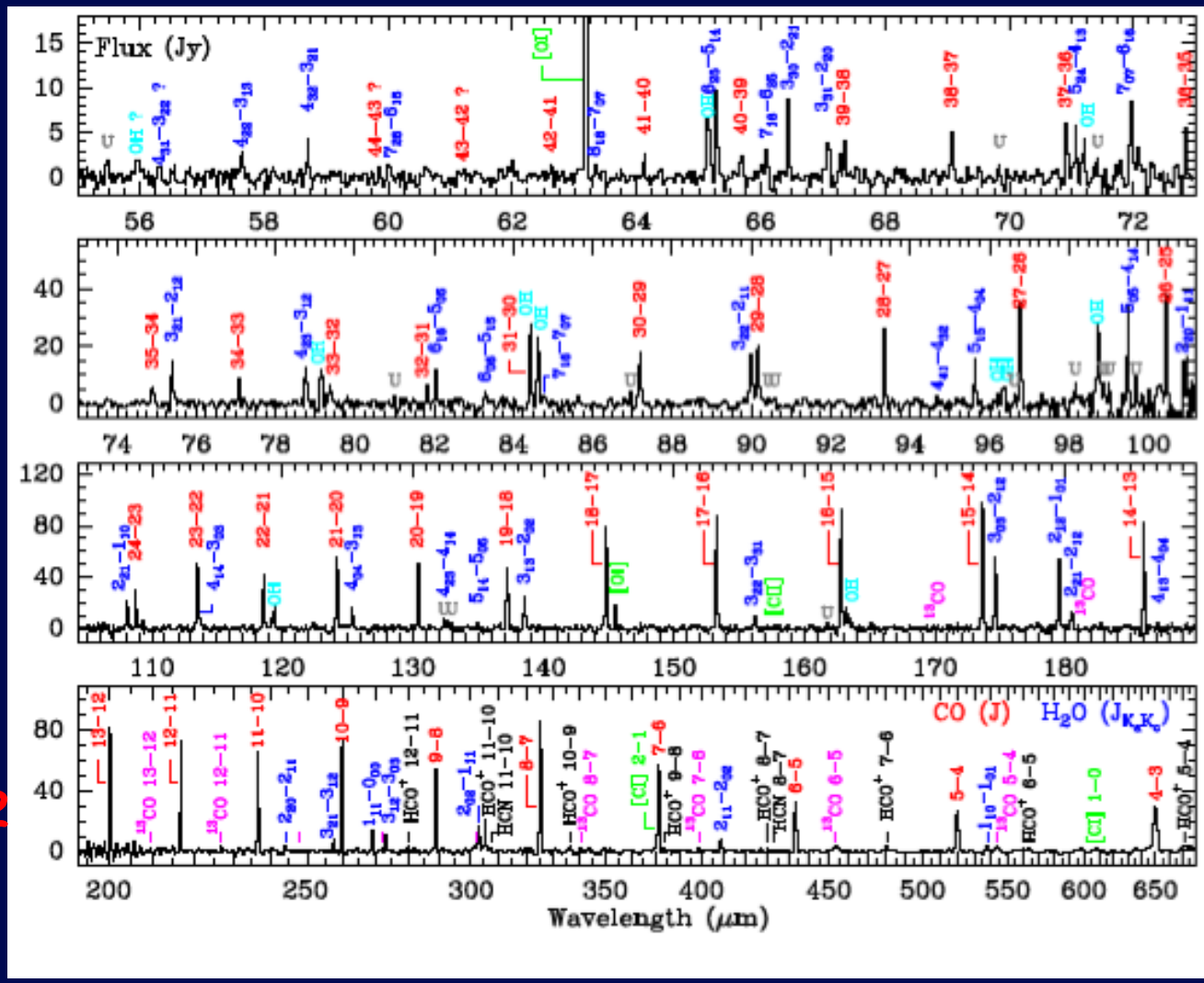
Kristensen et al. 2011

Complex systems: different regions spatially not resolved

PACS & SPIRE spectra of YSOs



Goicoechea et al. 2012

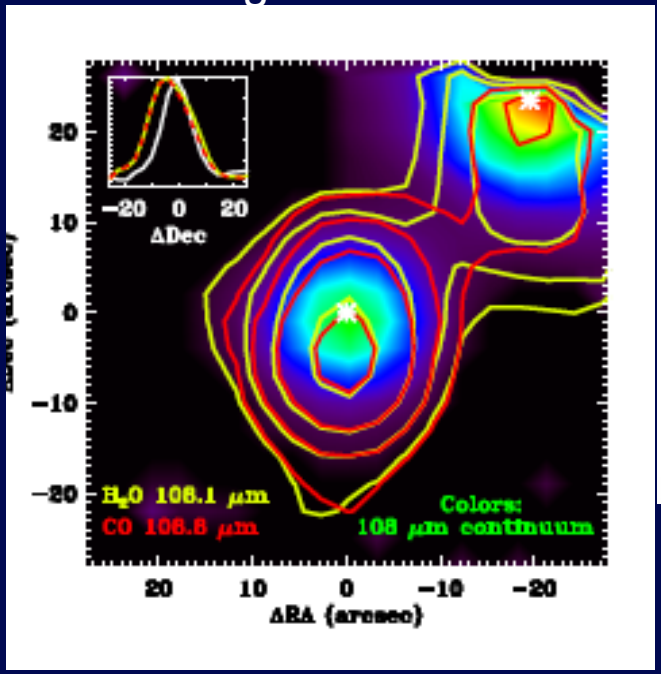


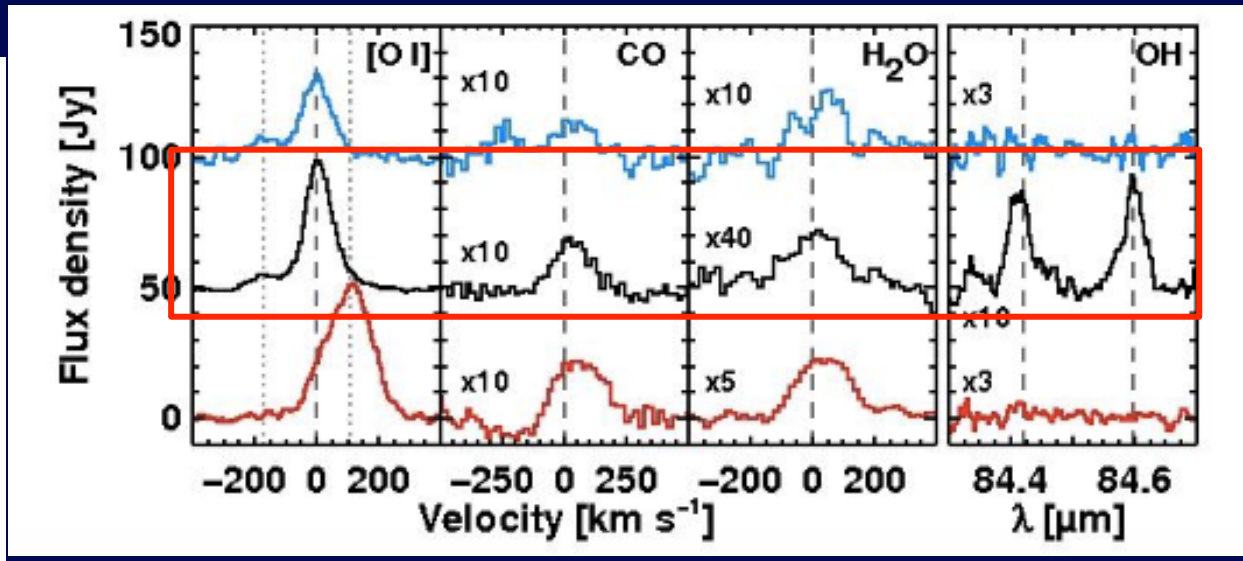
Different gas components in the not resolved region

OI, CO, H_2O, OH

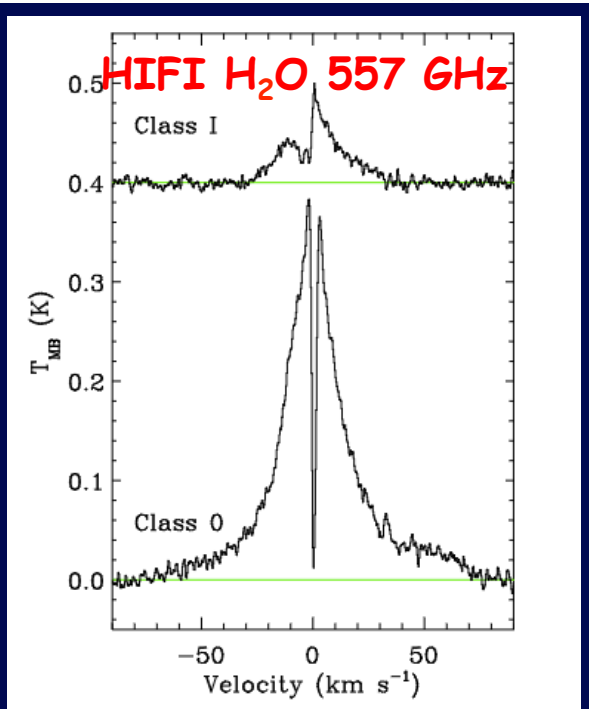
Which component is traced by the FIR lines ?

Herczeg+ 2012





HH46IRS
van Kempen+ 2010

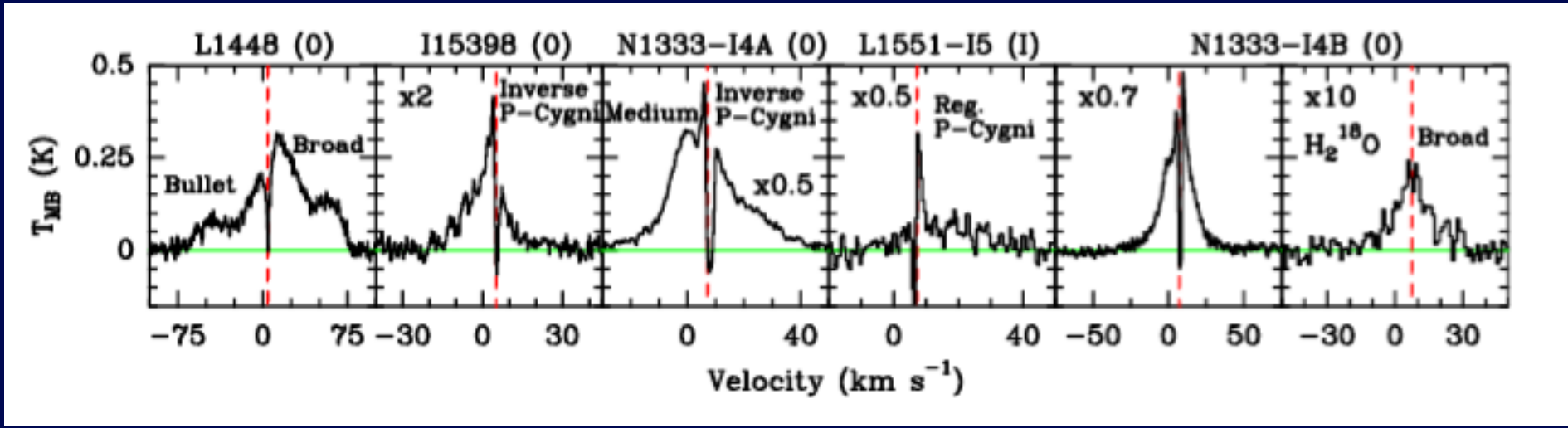


Van Dishoeck + 2012

FIR molecular emission in the more active class0/I sources dominated by outflows

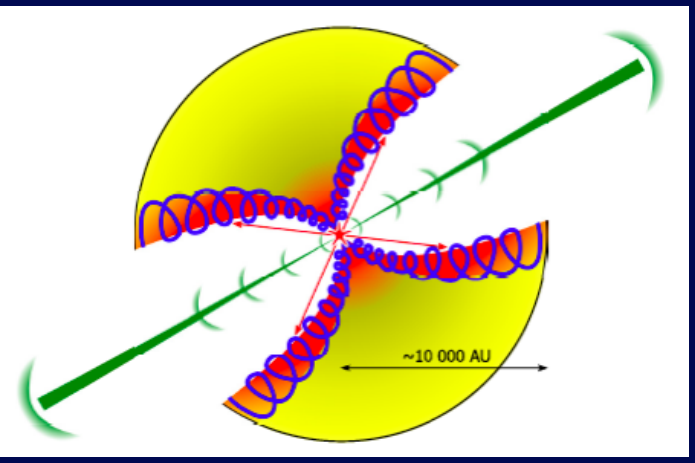
- Offsets wrt continuum
- Line-widths > 30 km/s

HIFI: H_2O line profiles



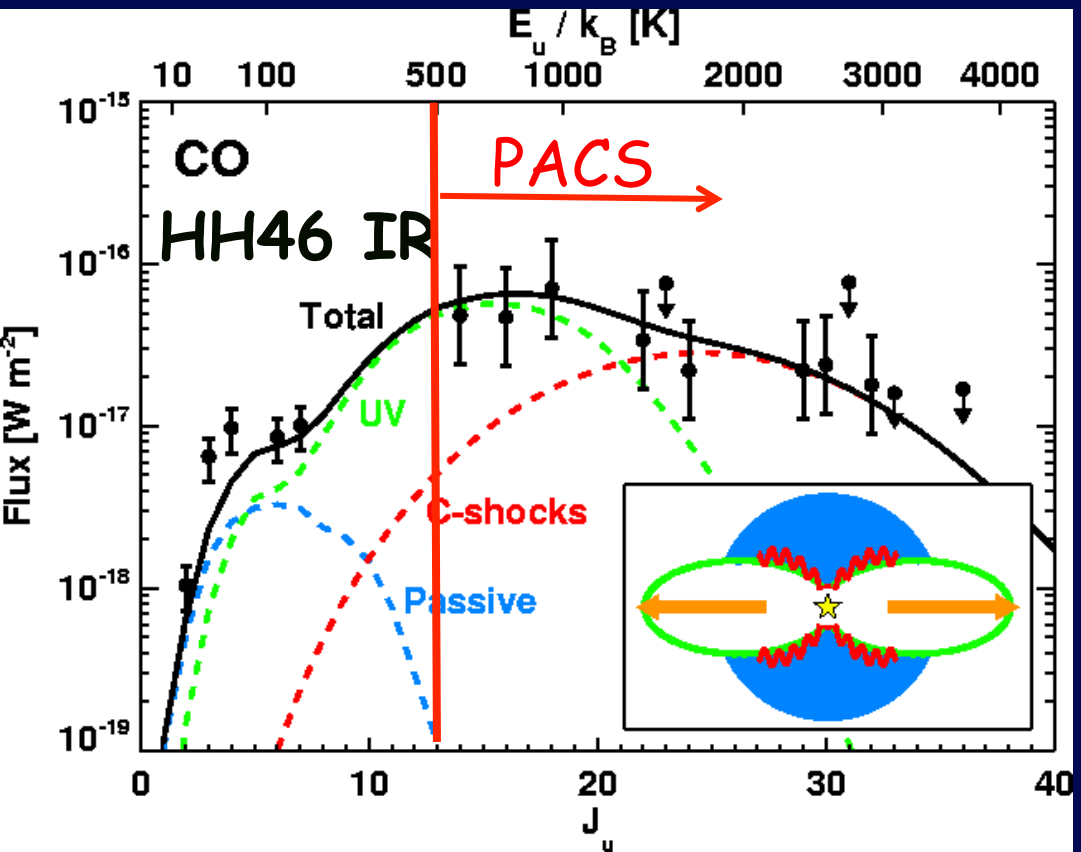
Variety of features probing the different components (infalling envelope, outflows, jets)

Attempt to model the different components

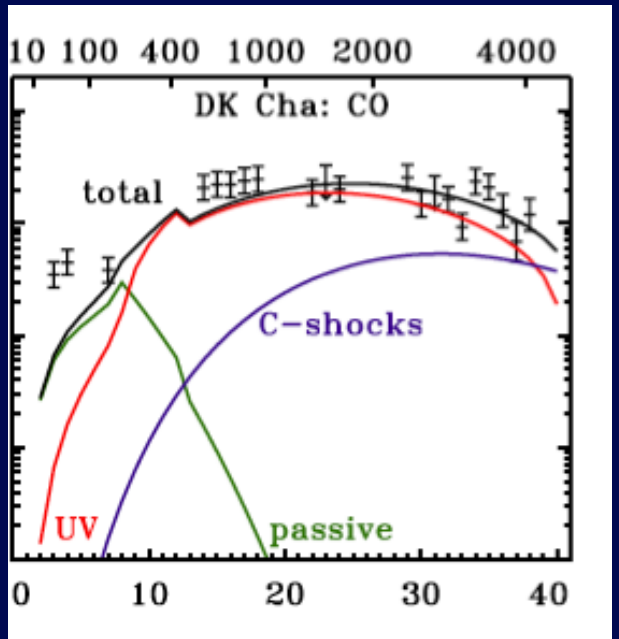


- Passively heated envelope
- FUV heated cavity
- Shocks

→ **Relative contribution change with evolution**



Visser et al. 2012



A spectroscopic survey with SPICA

With low spectral/spatial resolution only global questions can be addressed:

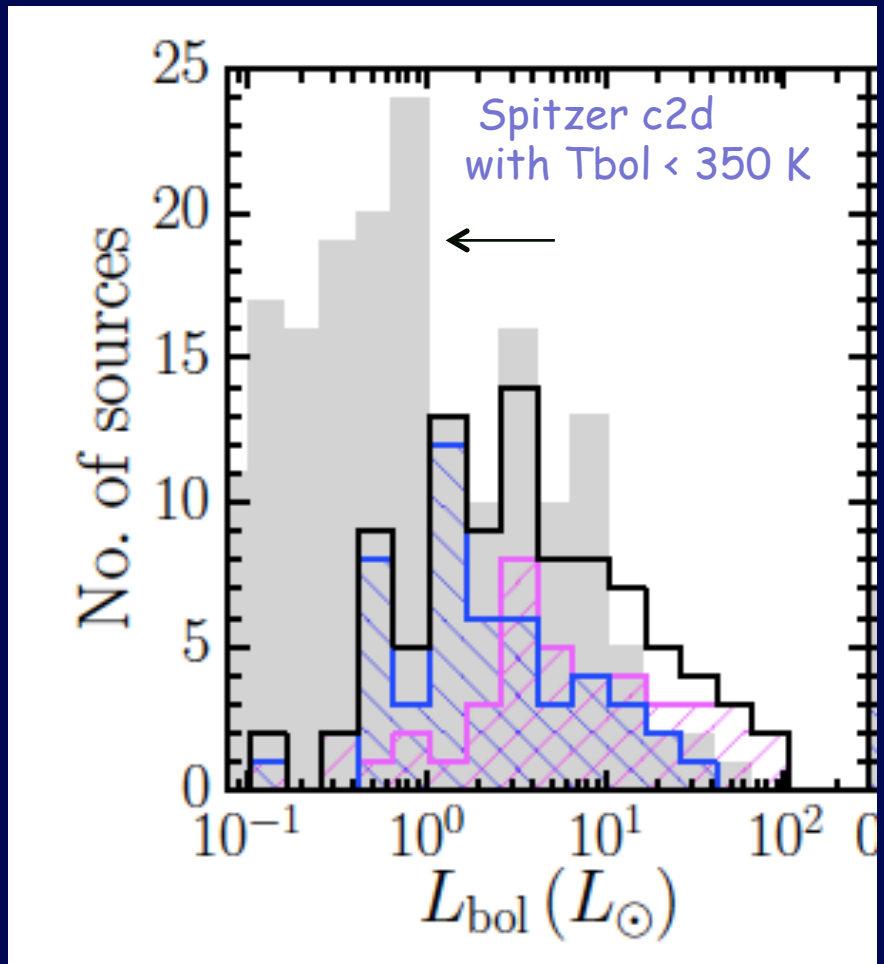
→ Which are the main gas cooling channels during the various *-form stages ? Are 'averaged' physical conditions changing ?

→ Are there molecular abundance variations with age/ luminosity of protostars ?

→ What is the feedback of protostellar jets/outflows on their surrounding ?

Herschel spectral surveys

About 100 class 0/I sources observed by PACS (and HIFI) as part of WISH-WILL (P.I. E. van Dishoeck), DIGIT (P.I. N. Evans)

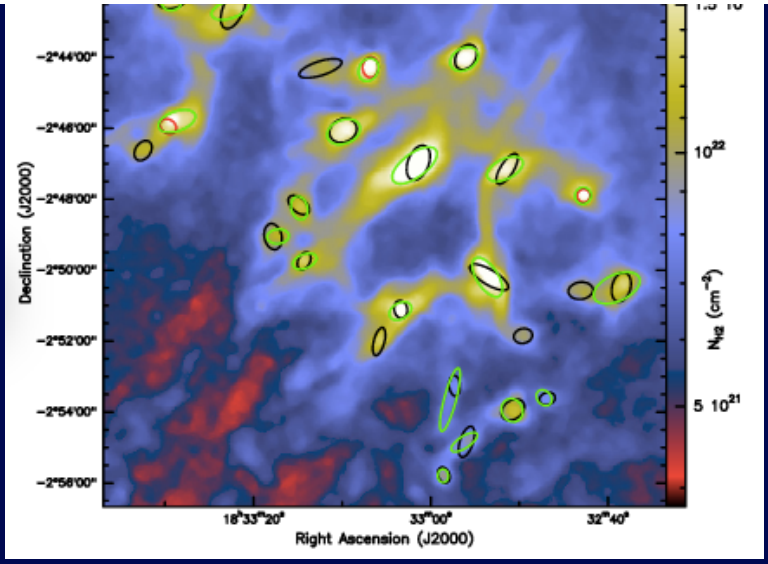


Mottram et al. 2016

Survey of embedded protostars:

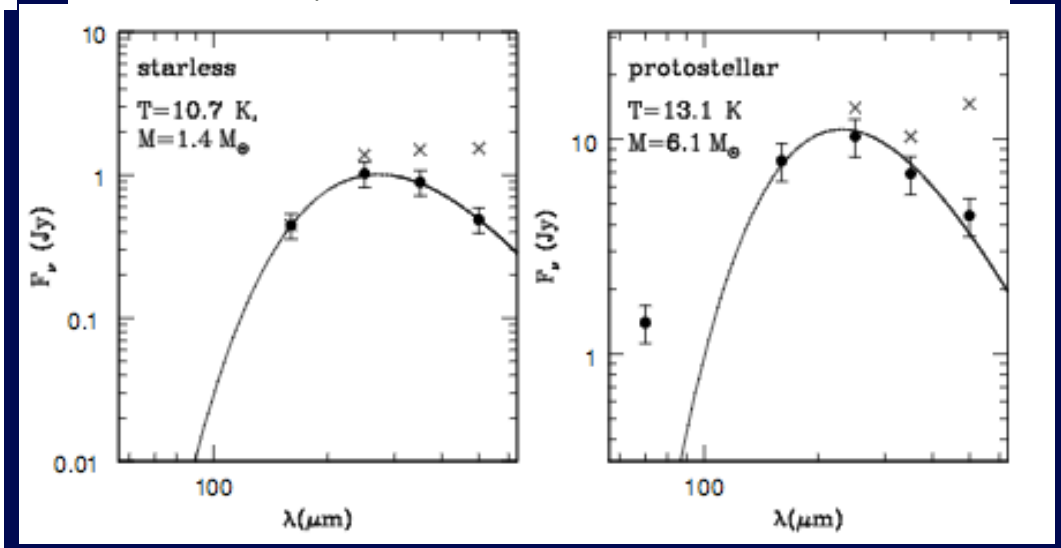
Photometric surveys with Herschel: census of pre- and proto-stellar sources:

Cores in the Aquila region



Könyves et al. 2015

Pre- and proto-stellar sources



Giannini et al. 2002

With SPICA-SAFARI

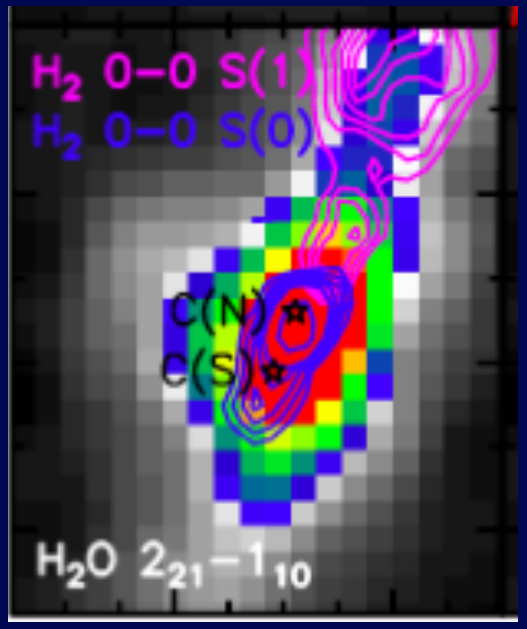
→ explore evolutionary and luminosity effects

→ establish when an heating source is switched on

Direct measure of $N(H_2)$ in protostellar envelopes

→ Absolute molecular abundance determinations in protostellar enevlopes rely on CO abundance or dust/gas ratio

→ SMI observations of S(0) 28um & S(1) 17um can directly probe the H_2 gas with T>100 K
→ SAFARI observations of HD 1-0 112um (T>60 K)



Nisini et al. 2013

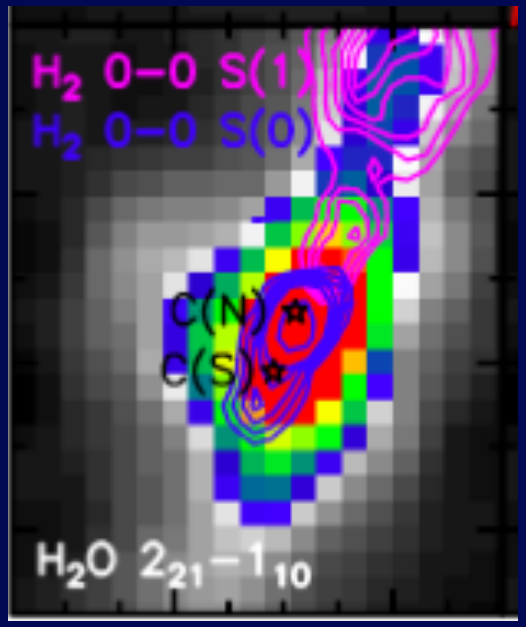
Possible confusion between envelope and outflowing gas

→ Would take advantage by the high resolution of SMI-HRS

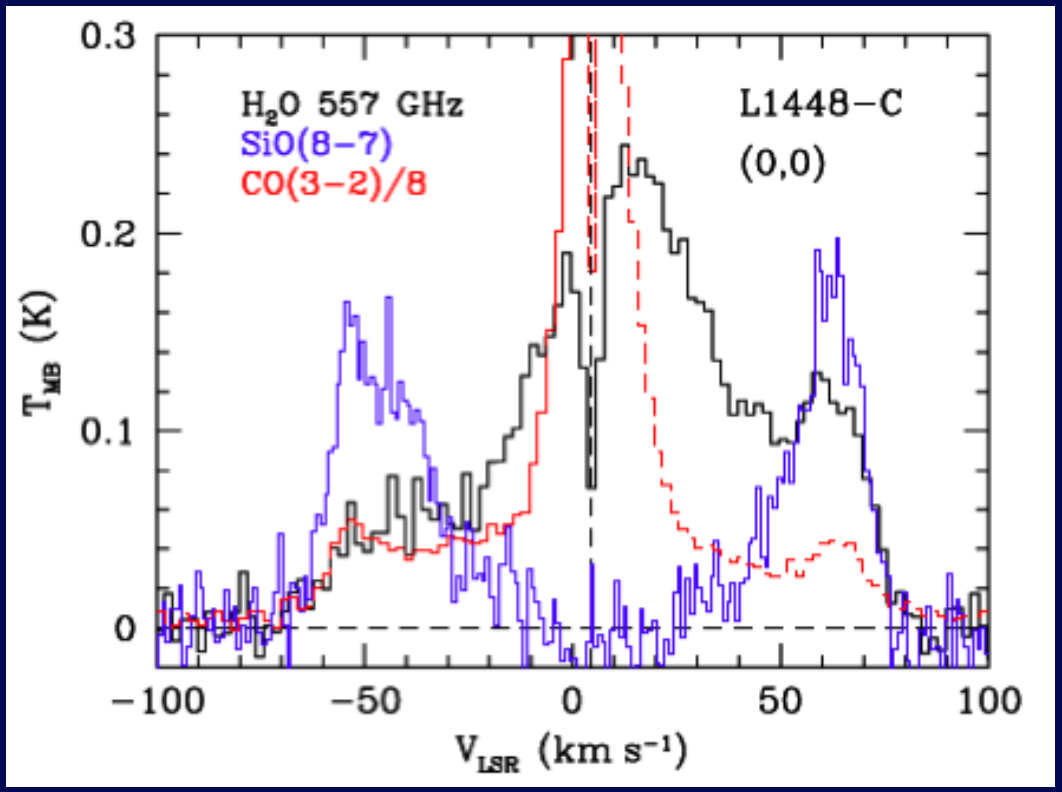
Measuring water abundance

Physical conditions derived from HERSCHEL multi-line observations:

- High-T (> 300 K), high-dens (> $10^5 cm^{-3}$)
- similar to *no other species* observable from ground
- Abundance determinations between 10^{-7}-10^{-5}

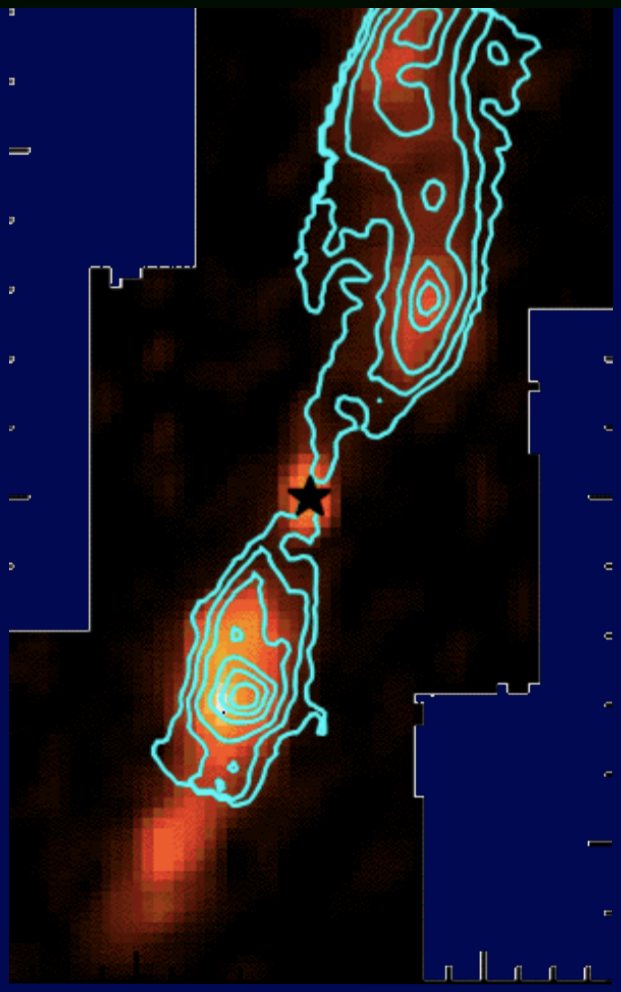


Nisini et al. 2013



Spatial correlation with H_2 mid-IR emission

PACS-H_2O 179um +
Spitzer H_2 17um



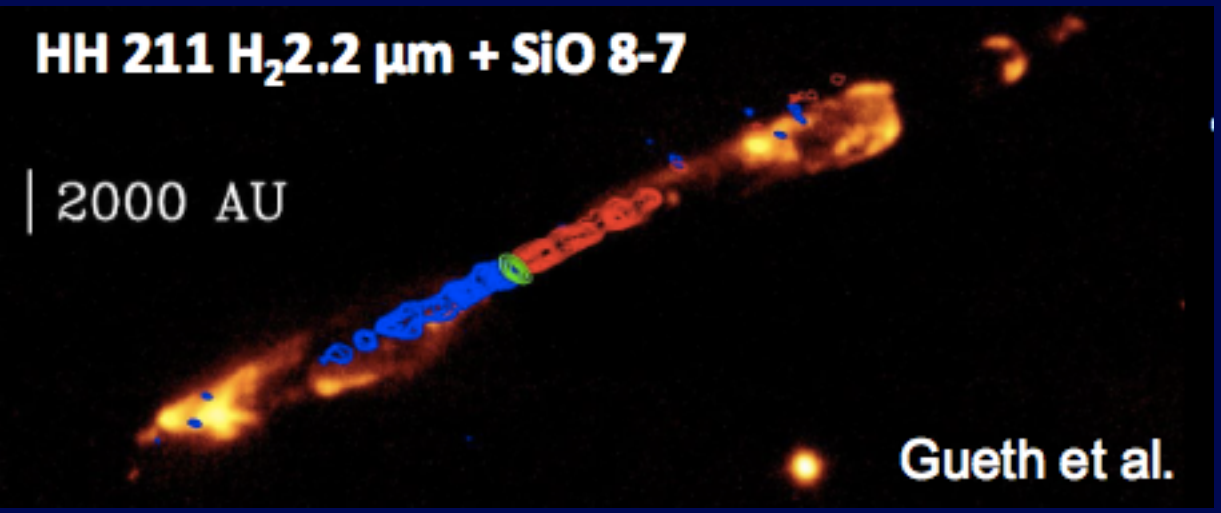
Velocity resolved H_2 0-0 lines as a unique tool to investigate the gas components traced by water

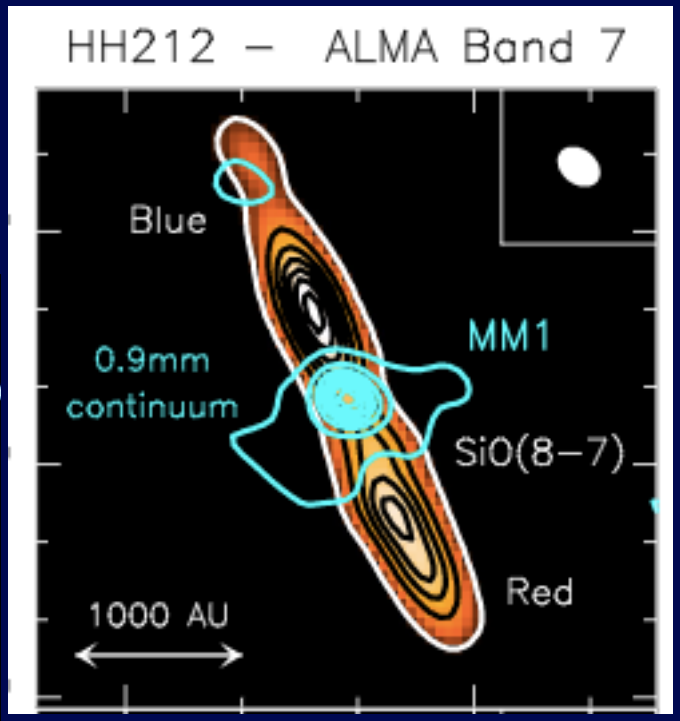
→ **Spica SMI-HRS**

Unique possibility to have a direct measure of **H_2O abundance** in the different kinematical components

Origin of mass loss in protostars: tracing the atomic jets in class 0 sources

CO, SiO collimated jets
Similar to T Tauri jets



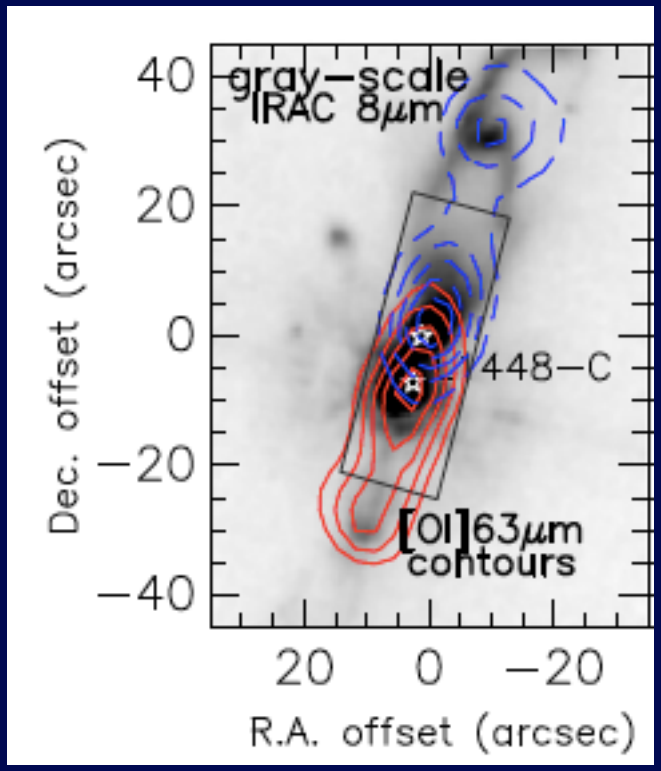


Codella et al. 2014

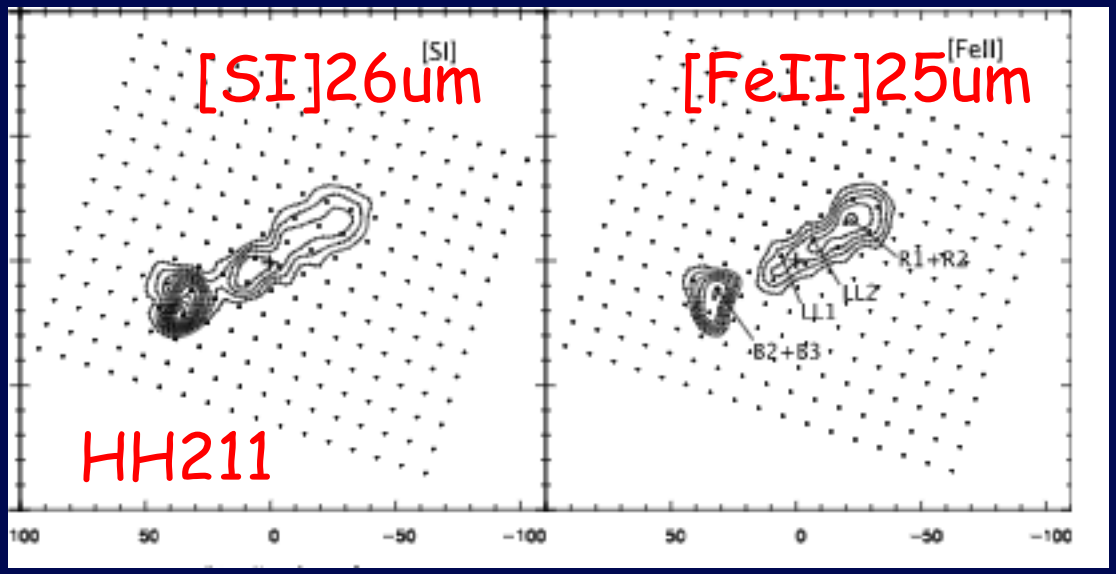
- Are the jets intrisically molecular or only the cold envelope of embedded atomic jets ?
- How warm are the molecular jets ?

Atomic jets observed with Spitzer and Herschel

PACS-[OI]63um



Nisini et al. 2015



Dionatos et al. 2011

SAFARI will resolve the fastest [OI] jets (V > 100 km/s)

SPICA-SMI will do velocity resolved observations in:
[FeII] at 17.9um
H_2 S(0) at 12.3um
H_2 S(1) at 17.0um
+maps of many more lines

Mass accretion in embedded protostars

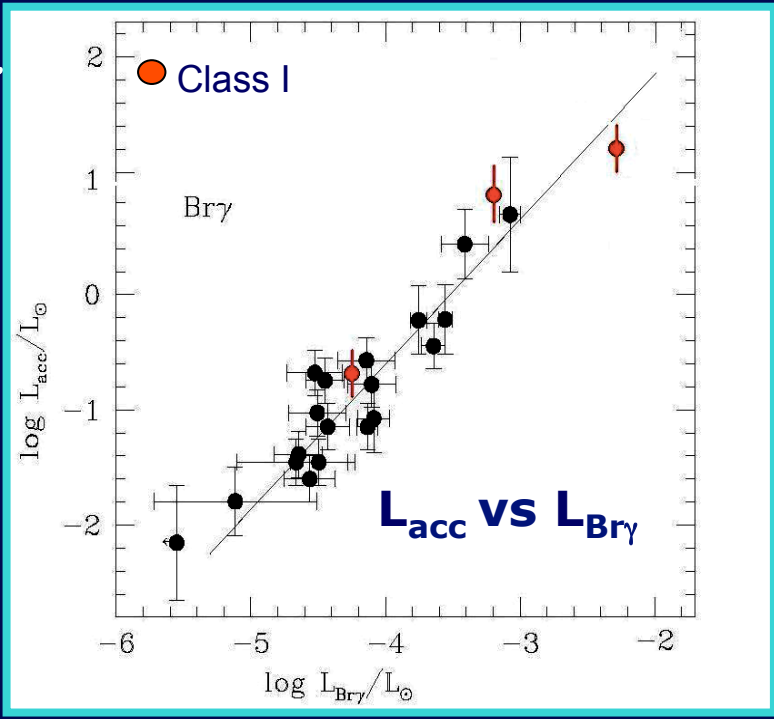
→ How do we know the evolution of mass accretion with time?

→ Are class 0/I really accretion dominated sources?

- Class 0 sources: assume Lbol = Lacc
- Class I sources: Lacc/Lbol variable 0.1-0.8 (Antoniucci et al. 2008)

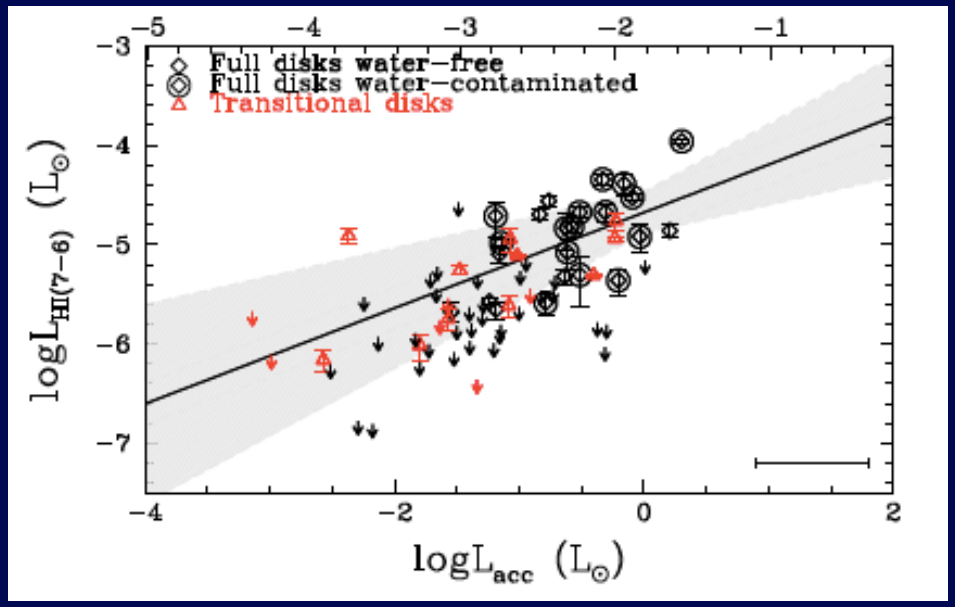
In T Tauri stars, UV excess or luminosity of HI lines:
Muzerolle et al. 1996, Alcala' et al. 2014

In class I extinction too poorly known



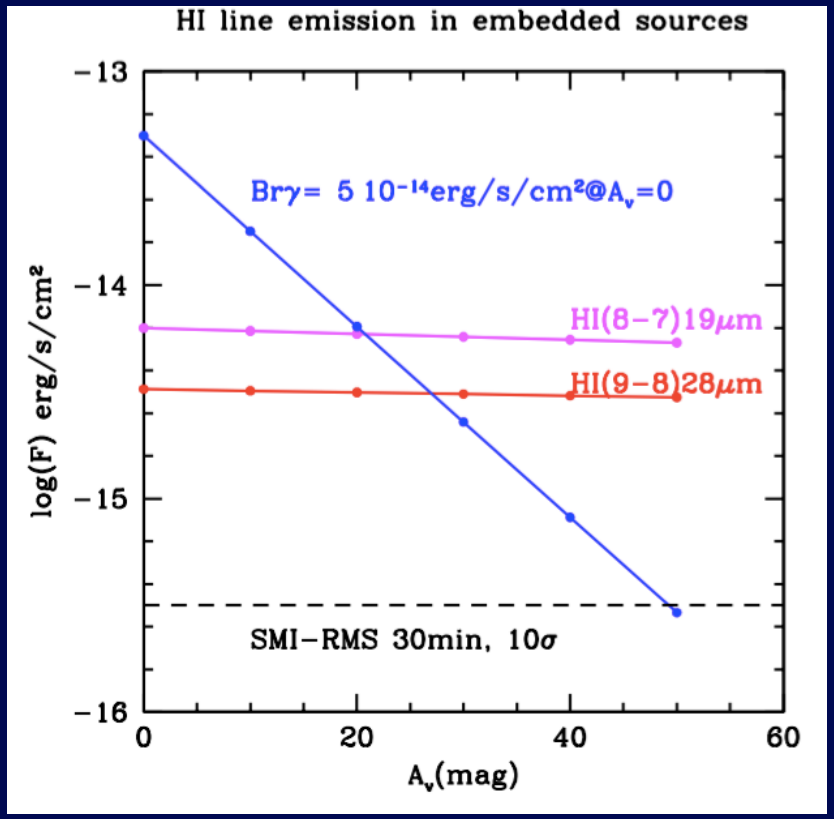
Measuring accretion luminosity with mid-IR HI lines

HI(7-6)12um vs L_{acc} in T Tauri stars

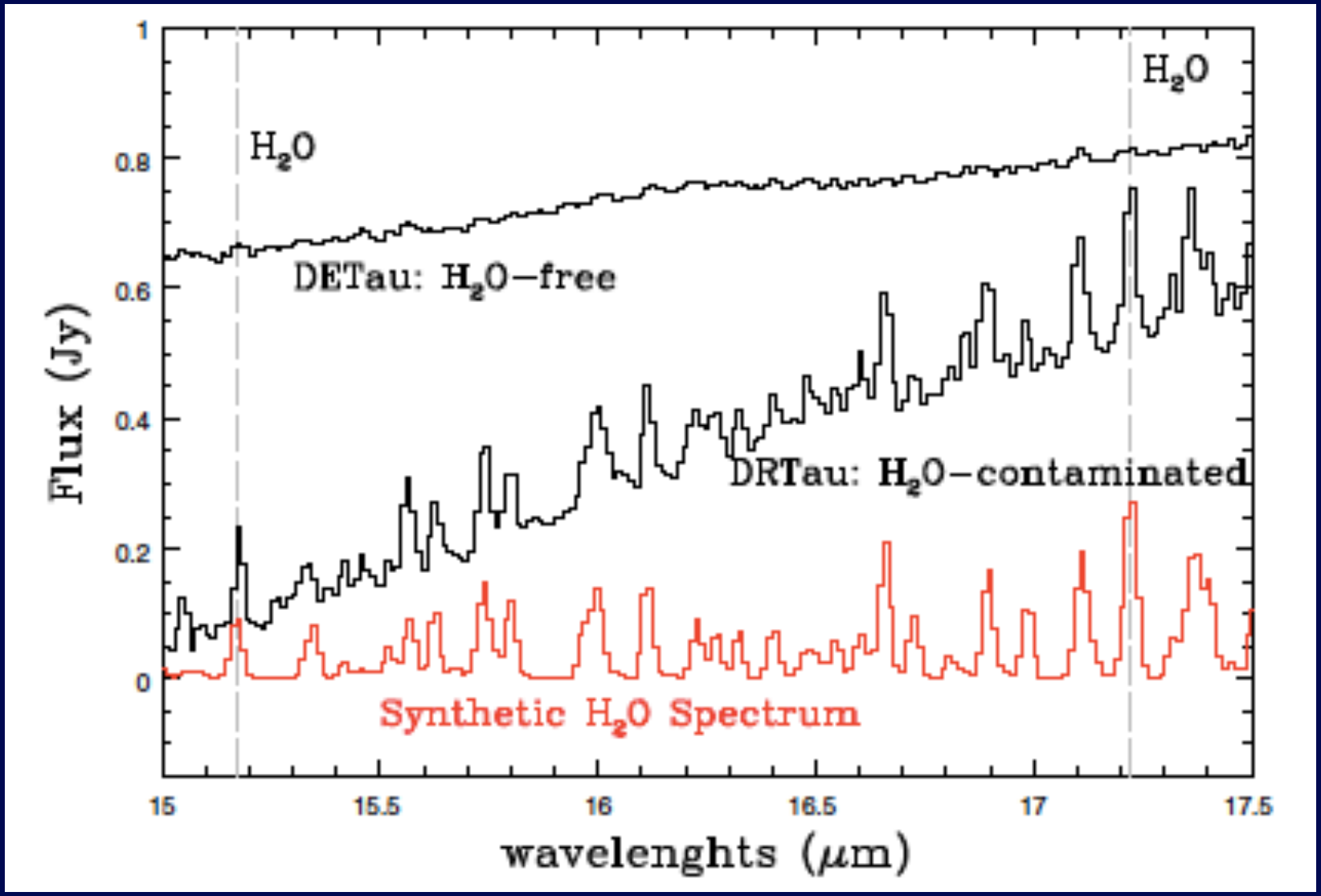


Rigliaco et al. 2014

HI flux vs Av



Importance of moderate resolution for blending



Spitzer R = 600

Conclusions

Scientific area in which SPICA can give important contributions:

- Specroscopic census of the youngest objects identified by Hershel → SAFARI
- Measure of N(H_2) for abundance determinations → SAFARI (HD) + SMI -HRS
- Characterize accretion and jets in class0/classI sources → SMI-MRS/HRS