Observing water in proto-stellar outflows with *Herschel*: the case of L1448

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I. Introduction

H_2O is one of the most abundant molecules in star-forming regions and a unique probe of the physical properties and the chemical processes in proto-stellar outflows.
In the framework of the WISH ("Water In Star-forming regions with *Herschel*") key program, we present *Herschel* observations of H_2O towards the outflow driven by the L1448 low-mass proto-stellar system, located in the Perseus cloud (d=235 pc).

The instruments on board the *Herschel* Space Observatory, providing both high spatial and spectral resolution over a large wavelength range, are ideal to study the kinematics and the physical conditions of the warm shocked gas.

II. Observations: HIFI & PACS maps

The L1448 outflow has been mapped, with the HIFI and PACS instruments (Fig.1), in the ortho-H_2O 1_{10}-1_{01} 557 GHz and para-H_2O 2_{12}-1_{01} 1670 GHz lines respectively.

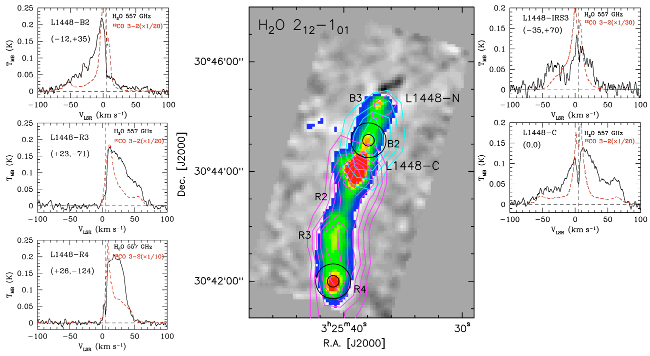

Fig.1: PACS ortho-H_2O 2_{12}-1_{01} map towards L1448 and HIFI ortho-H_2O 1_{10}-1_{01} contours of the blue- and red-shifted gas. The largest and the smallest beam sizes of the HIFI line survey observations in R4 and B2 are marked as black circles. The overlay between HIFI spectra and CO(3-2) spectra is shown for 5 positions along the flow.

The outflow from the L1448-C source is well delineated by the H_2O emission, with peaks corresponding to active shock regions (Bachiller et al. 1990); while no emission is detected north of the L1448-N source, where the PACS 1670 GHz line is seen in absorption.
The comparison between H_2O and CO suggests that **H_2O is a unique probe of the gas component at intermediate velocities (≈10-40 km s^{-1})**.

III. Observations: HIFI line survey

Several ortho- and para-H_2O lines have been observed in R4 and B2 along L1448 (Fig.1) with HIFI. The aim was to study the H_2O excitation conditions in the shocked gas, exploring excitation variations with velocity.

<u>**R4**</u> (Fig.2 – *left*): broad emission of about 50-60 km s^{-1} associated with the R4 position.
Lines with E_u<80 K peak at higher velocity (25 km s^{-1}), while lines with E_u>137 K peak at lower velocity (10 km s^{-1}). This indicates that **the excitation decreases with velocity**.
Quite good overlap is found between SiO and H_2O in R4.

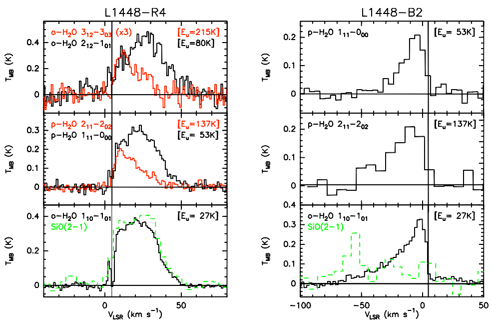

Fig.2: <u>*Left*</u> - R4 H_2O spectra. In the lower panel, the ortho-H_2O 1_{10}-1_{01} line at 557 GHz is shown in black, overlaid on the IRAM-30m SiO(2-1) line in green (Nisini et al. 2007). <u>*Right*</u> - B2 H_2O detected lines. In the lower panel, the B2 ortho-H_2O 1_{10}-1_{01} is shown in black, overlaid on the IRAM-30m SiO(2-1) emission line in green (Nisini et al. 2007).

<u>**B2**</u> (Fig.2 – *right*): all the detected lines, unlike the R4 position, show a similar profile with a wing extending up to more than -50 km s^{-1}.
There is little overlap between H_2O and SiO emission, with the SiO confined in the extremely high velocity gas, where H_2O is instead very weak.

IV. Excitation Analysis

The excitation conditions of the gas in R4 and B2 along the L1448 outflow have been analyzed (Fig.3).
The two velocity components in R4 (R4-LV and R4-HV) have been studied separately.

<u>**R4**</u>: in R4-LV the lines are reproduced (within the errors) only considering a very high-density (n_{H2}~10^7 cm^{-3}) and extended gas with T=500-600 K (*green*); while they are not fitted by the lower density gas component (n_{H2}~3 10^4 cm^{-3}) inferred from the SiO (Nisini et al. 2007) emission (*blue*).
The **lower excitation of R4-HV** in respect to R4-LV could be due to **either a lower T** of ~150 K (*green*) **or a lower n_{H2}** of ~10^6 cm^{-3} (*red*).

<u>**B2**</u>: we derived velocity-averaged physical conditions that again point towards a warm (T=400-500 K) and dense (n_{H2}~10^6-10^7 cm^{-3}) gas.

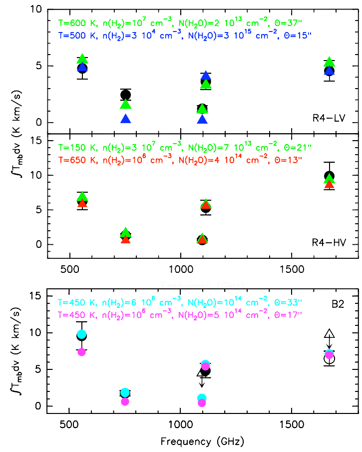

Fig.3: Comparison between the observed intensities in the two velocity components of R4 (*upper* for R4-LV and *middle* for R4-HV), the total observed intensity in B2 (*lower*) and the intensities predicted by LVG models (RADEX, Van der Tak et al. 2007) in the plane parallel geometry. Different approaches have been tested.

<u>COMPARISON WITH THE SHOCK MODELS:</u>

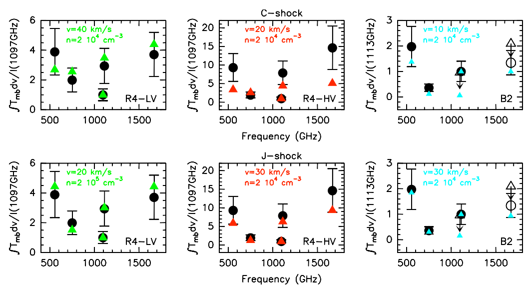

Fig.4: Comparison between the observed HIFI H_2O line ratios of the two velocity components in R4 and of B2 and the ones predicted by C-type (*upper*) and J-type (*lower*) shock models from Flower & Pineau De Forêts (2010).

The shock conditions of all components appear to be more consistent with **J-type shock models** (Fig.4). The predicted pre-shock density for R4-LV is higher than the one predicted for R4-HV, supporting the lower-density model for R4-HV (*red* in Fig.3).
The J-type shock scenario is also in agreement with the PACS detections of OI (R4 and B2) and OH (B2), meaning that possibly H_2O is dissociated (Santangelo et al. in prep.).

V. Conclusions

Herschel observations of H_2O emission towards the outflow driven by the L1448 low-mass proto-stellar system have been presented, as part of the WISH key program:

- H_2O appears to be **unique** in tracing gas components at **intermediate velocities** (~10-40 km s^{-1})
- The two investigated positions (R4 and B2) show **strong differences** in the line profiles. In particular, R4 shows strong **variations in the excitation conditions as a function of velocity**
- The observed emission is best represented by a **very dense** (n_{H2}~10^6-10^7 cm^{-3}) and **warm** (T=400-600 K) gas, having **moderate H_2O column densities**: N_{H2O}~10^{13} cm^{-2} in R4-LV and 10^{14}-10^{15} cm^{-2} in R4-HV and B2, corresponding to H_2O/H_2~10^{-5} in B2 and 2 10^{-6} in R4 after comparison with N_{H2} derived from Spitzer observations (Giannini et al. submitted). Similar results are found also in Vasta et al. poster on L1157 (n.96 session 2)
- These physical conditions are better reproduced by a **J-type shock**, where **high-density compression factors** are expected. Also, the relatively low observed column densities are consistent with models where **H_2O is dissociated**

References:
I. Bachiller, R., Martin-Pintado J., Tafalla M., et al. 1990, A&A, 23, 174
II. Flower D.R., & Pineau Des Forêts G. 2010, MNRAS, 406, 1745
III. Nisini B., Codella C., Giannini T., et al. 2007, A&A, 462, 163
IV. Van der Tak, F.F.S., Black, J.H., Schöier, F.L., et al. 2007, A&A 468, 627-635