The *Herschel*-WISH spectral line survey of shock regions in proto-stellar outflows: the case of L1448

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I. Introduction

As part of the WISH (Water In Star-forming regions with *Herschel*) key project, two shocked regions (R4 and B2) along the outflow driven by the L1448 low-luminosity (11 $L_\odot$) Class 0 proto-stellar system (in the Perseus cloud, d= 235 pc) have been observed with the HIFI and PACS instruments in a set of H_2O lines and several transitions of CO, OH and [OI].

The aim was to settle the conditions for water formation and understand its role in probing specific excitation regimes with respect to other shock tracers.

II. The HIFI line survey

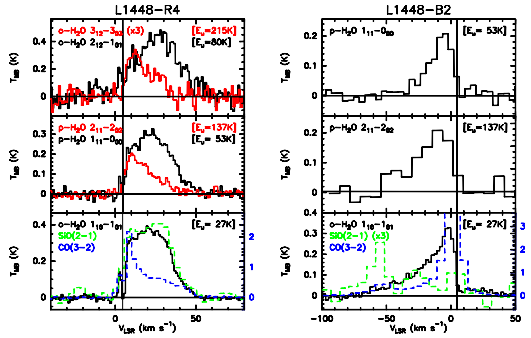


Fig.1. HIFI H_2O detected lines in R4 (*left*) and B2 (*right*) (Santangelo et al. 2012). In both cases, the lower panel shows the ortho-H_2O 1_{10}-1_{01} in black, overlaid on the IRAM-30m SiO(2-1) emission line in green (Nisini et al. 2007) and the JCMT CO(3-2) emission line in blue (Nisini et al. 2012, in prep.), respectively in the R4 (*left*) and B2 (*right*) positions.

R4:
- Excitation decreases with velocity
- Good overlap between SiO and H_2O

B2:
- Similar profiles for all detected lines
- Little overlap between SiO and H_2O, with SiO confined in the EHV gas

R4 & B2:
- **H_2O and low-J CO trace different gas components**
- A RADEX escape probability analysis (Van der Tak et al. 2007) indicates **a warm (T=400-600 K)** and **dense (n_{H_2}~10^6-10^7 cm^{-3}) gas** (Table 1)

Table 1. Summary of the best-fit models derived for each HIFI component. R4-LV and R4-HV indicate the low-velocity and high-velocity components in R4, respectively.

Comp.	Model	*o*/*p*	T_{kin} (K)	$n(H_2)$ (cm^{-3})	$N(H_2O)$ (cm^{-2})	Θ (arcsec)
R4-LV	LV-1	3	600	10^7	2 10^{13}	37
R4-HV	HV-2	3	650	10^6	4 10^{14}	13
B2	B2-2	3	450	10^6	5 10^{14}	17

III. The PACS line survey

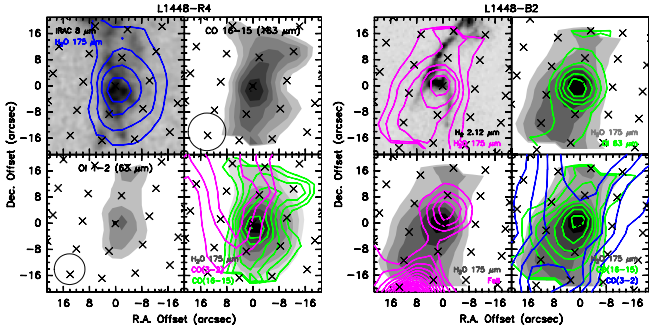
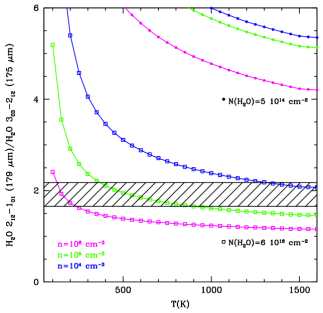


Fig.2. Overlay between PACS H_2O (175 μm), CO(16-15) and [OI] (63 μm) and other tracers in the R4 (*left*) and B2 (*right*) shocked spots in L1448. In particular, JCMT CO(3-2) from Nisini et al. (2012, in prep.), *Spitzer* [FeII] from Neufeld et al. (2009), IRAC 8 μm emission (Tobin et al. 2007, ApJ 659, 1404) and H_2 at 2.12 μm (Davis & Smith 1995, ApJ 443, 41) are shown.

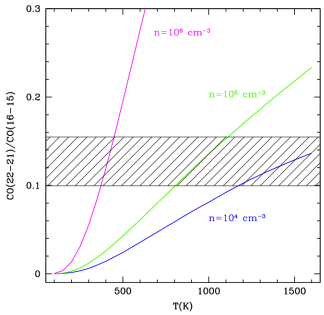
- At B2 the peak of the H_2O emission is at the apex of the bow-shock
- No shift is found at this angular resolution between PACS H_2O, CO and [OI]
- In both shocks, PACS H_2O and CO(16-15) peak at the same position, while there is a shift in respect to CO(3-2): **high-J CO and H_2O trace the same shocked gas, while low-J CO traces the ambient entrained gas**

IV. H_2O excitation at B2 from PACS



CONSTRAINTS ON H_2O COLUMN DENSITY:
- The low N(H_2O) (~5 10^{14} cm^{-2}) derived from HIFI H_2O does not reproduce the observed PACS (179/175)μm H_2O ratio
- Although the 179 μm H_2O line is contaminated by the gas component traced by HIFI, **N(H_2O)~ a few 10^{16} cm^{-2} is required to reproduce the PACS H_2O lines**
- **PACS traces an additional gas component with respect to HIFI**

Fig.3. Ratio between PACS H_2O 2_{12}-1_{01} (179 μm) and H_2O 3_{03}-2_{12} (175 μm) as a function of T for three n_{H2} (10^4, 10^5 and 10^6 cm^{-3}) and two N_{H2O} (5 10^{14} and 6 10^{16} cm^{-2}). The shadowed band indicates the observed ratio.

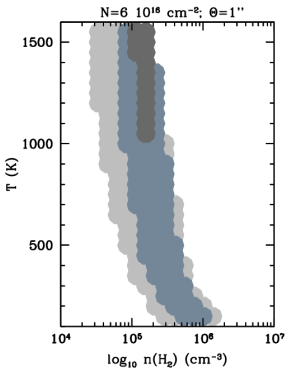


CONSTRAINTS ON T AND n_{H2} FROM CO:

PACS CO line ratios are degenerate with respect to the (n_{H2}T) product, however:
- n_{H2}~10^4 cm^{-3} (and T~1500 K) is not consistent with PACS H_2O (Fig.5) and with *Spitzer* H_2 (n_{H2}≥10^5 cm^{-3}, Giannini et al. 2011)
- n_{H2}~10^6 cm^{-3} and T~400 K is not consistent with Fig.3

→ **T~1000 K and n_{H2}~10^5 cm^{-3}**

Fig.4. Ratio between PACS CO(22-21) and CO(16-15) lines as a function of temperature for three H_2 densities (10^4, 10^5 and 10^6 cm^{-3}). The shadowed band indicates the observed ratio.



χ^2 DISTRIBUTION:

The best fit to the H_2O lines with E_u>190 K confirms that PACS H_2O emission in B2 traces an additional gas component with respect to HIFI H_2O observations: **a warmer (~1000 K), less dense (~10^5 cm^{-3}) gas with higher column density of a few 10^{16} cm^{-2}** (Fig.5).

Fig.5. χ^2 distribution at the B2 central spaxel versus T and n_{H2}, considering only PACS lines with E_u>190 K. Contours indicate 1.2×, 2×, 3×χ^2_{min}.

V. Conclusions

HIFI emission:
- **Strong differences** in the line profiles at the two shocked positions (R4 and B2) toward the L1448 outflow, with R4 showing **variations in the excitation conditions as a function of velocity**
- The observed emission is consistent with a **very dense** (n_{H2}~10^6-10^7 cm^{-3}) gas with T=400-600 K and **moderate H_2O column densities**, corresponding to H_2O/H_2~10^{-5}-10^{-6} (see also Vasta et al. 2012)

PACS emission:
- No shift is found between H_2O, CO and [OI]
- **High-J CO and H_2O trace the same shocked gas, while low-J CO traces the ambient entrained gas**
- PACS H_2O lines trace an additional gas component, which is warmer (T~1000 K), less dense (~10^5 cm^{-3}) and with higher column density (~ 10^{16} cm^{-2}) with respect to the gas traced by HIFI

References:
Davis & Smith 1995, ApJ 443, 41; *Giannini et a. 2011*, ApJ, 738, 80; *Neufeld et al. 2009*, ApJ, 706, 170; *Nisini et al. 2007*, A&A 462, 163; *Santangelo et al. 2012*, A&A, 538, A45; *Tobin et al. 2007*, ApJ 659, 1404; *Van der Tak et al. 2007*, A&A 468, 627-635; *Vasta et al. 2012*, A&A, 537, A98