The WISH outflow program in low mass protostars

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Description of the program

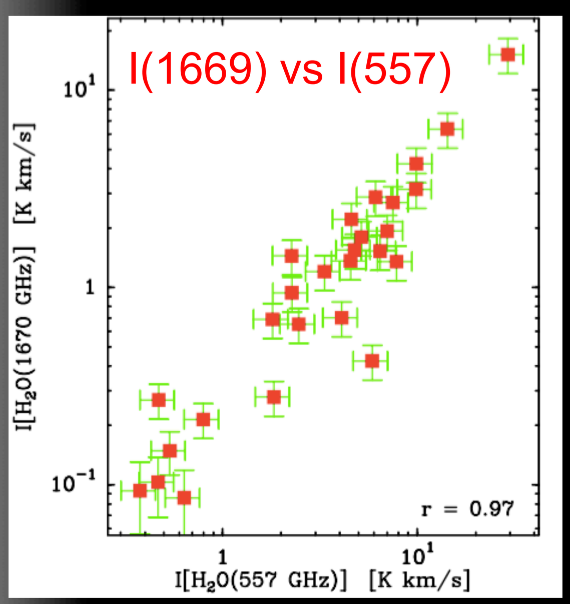
As part of the WISH Herschel Key Program (P.I. E.F. van Dishoeck), a sample of outflows from class 0 and class I protostars have been observed by Herschel with both the PACS and HIFI instruments.The WISH- outflow program consists of three parts:

- The **outflow survey**: shocks in 26 outflows from low mass stars observed in the H_2O 2_{21}-1_{10} 1669 GHz (PACS) and 1_{10}-1_{01} 557 GHz (HIFI) H_2O lines
- The **outflow maps**: the L1448-C, VLA1623 and L1157 outflows were mapped in the same two lines
- The **line survey**: selected shock positions on the same outflows were observed in several H_2O, CO, [OI],OH transitions with both HIFI and PACS

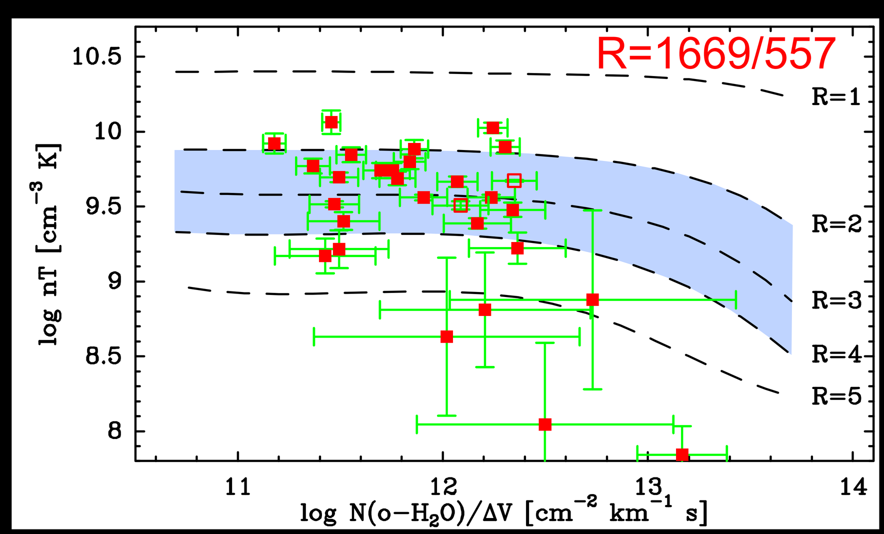
Here we summarize the main conclusions about water distribution, excitation and abundance in outflows.

Water excitation: 1) physical conditions for the 1_{10}-1_{01} 557 and 2_{21}-1_{10} 1669 GHz lines

Tafalla et al. 2013



The good correlation between the intensity of the 1669 GHz and 557 GHz lines indicates that they arise from the same outflow component.

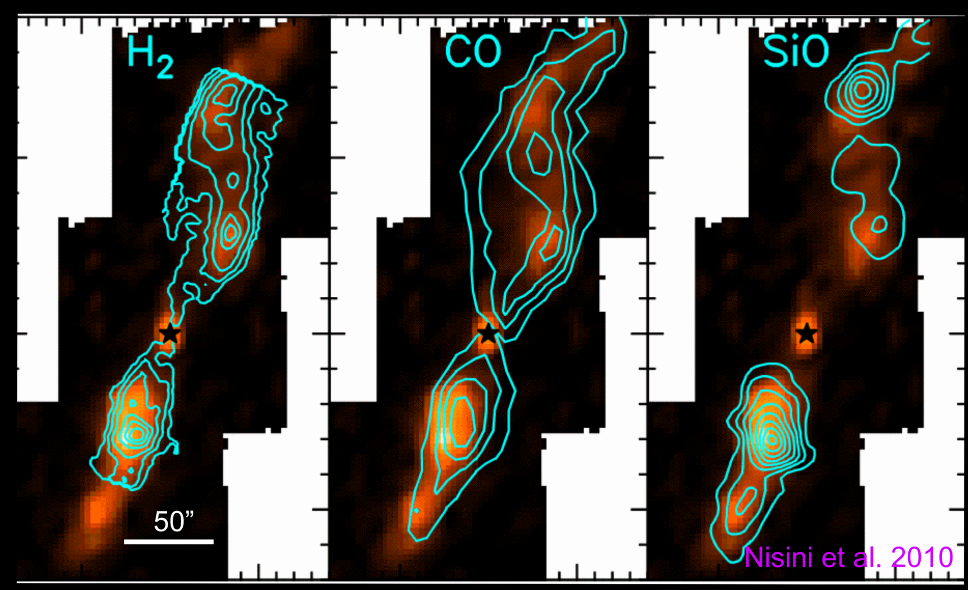


The observed 1669GHz/557GHz intensity ratio compared with LVG predictions. The range of observed ratios is consistent with excitation in a high pressured gas with *log(nT)* about 9.5 cm^{-3} K

→ The 557 and 1669 GHz lines in shocks originate from a gas over-pressured with respect to the ambient gas by a factor of about 10^4

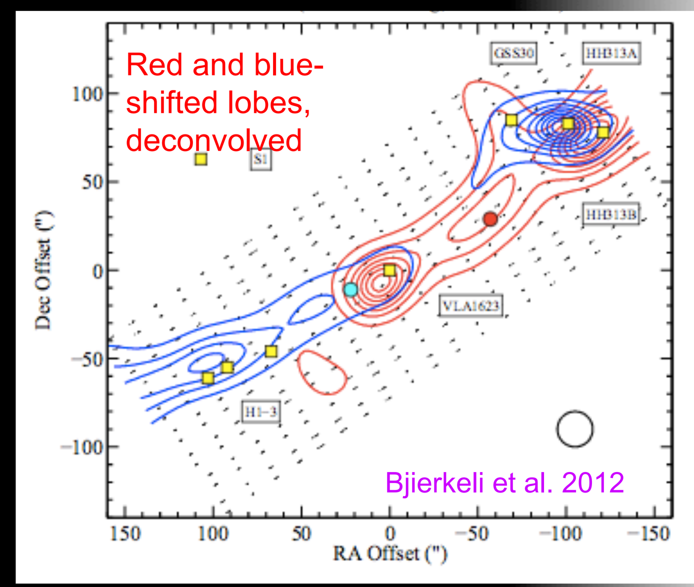
Water distribution and line profiles

L1157: PACS map of the H_2O 1669 GHz line



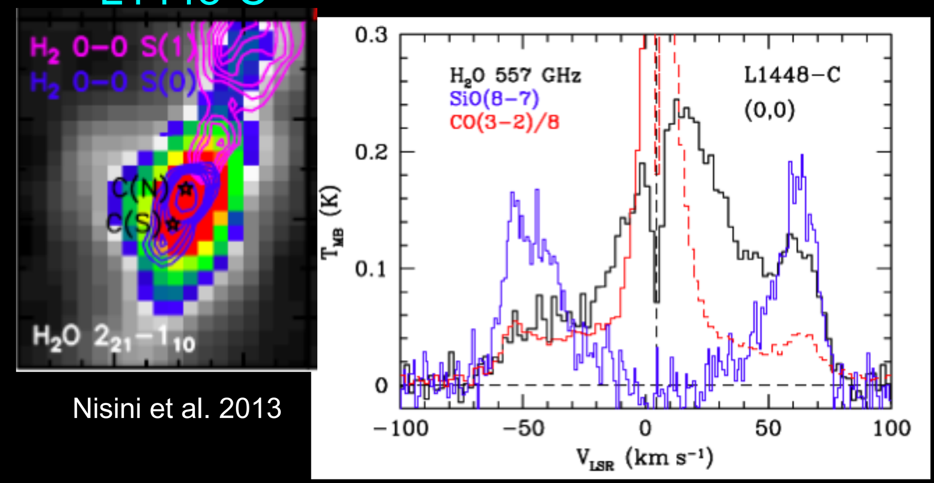
The PACS 1669GHz outflow map (image) is compared with the maps of H_2 0-0S(2) (Spitzer), CO 3-2 and SiO 5-4 (contours). The H_2O morphology better correlates with H_2 than with the other typical outflow tracers.

VLA1623: HIFI map of the H_2O 557 GHz line



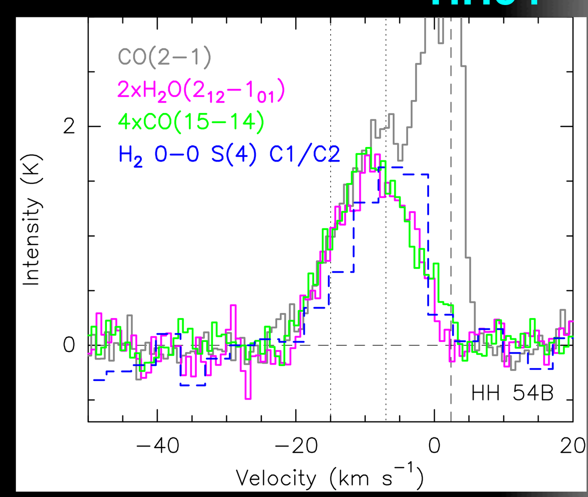
The 557GHz deconvolved line intensity in VLA1623, separately plotted for the blue- and red-shifted gas. Blue and red dots indicate CO peaks while yellow squares indicate the location of H2 near-IR peaks

L1448-C



Left: PACS 1669 GHz map of the central position of L1448-C with overlayed the H_2 S(0) and S(1) intensity distribution.
Right: HIFI 557 GHz spectrum centered on L1448-C. The water line profile is compared with the profiles of CO 3-2 and SiO 8-7. The broad water emission at velocities between -30 and +50 km/s is not observed in the other tracers.

HH54

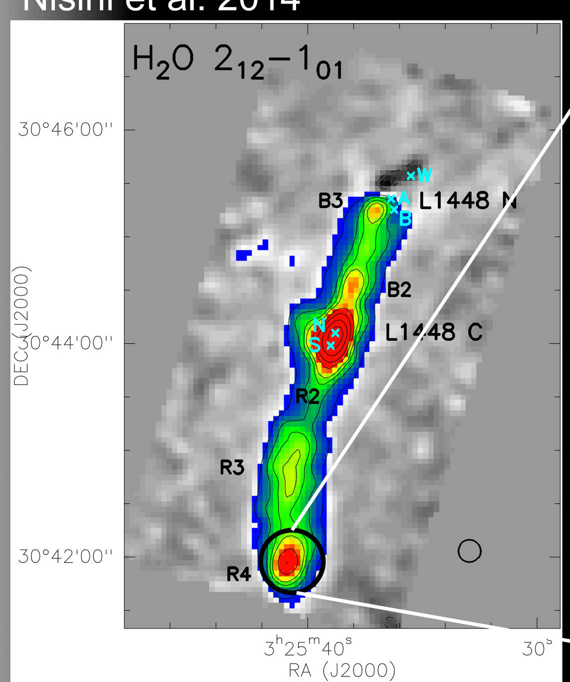


Profile of H_2O 557 GHz in the HH54 object is compared with CO 2-1 (APEX), CO 15-14 (HIFI) and H_2 0-0 S(4) (VISIR). The water profile follows the profiles of the lines at higher excitation.

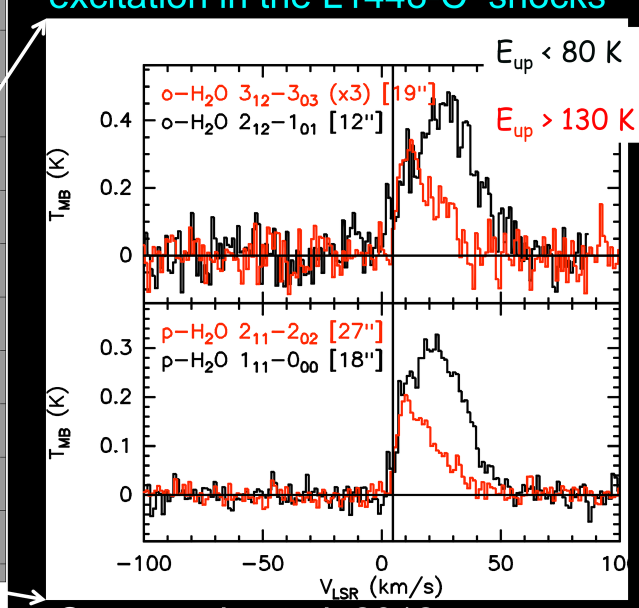
→ The morphology and line profiles of H_2O 557 and 1669 GHz indicate that water is associated with excited shocked gas along the outflow and not with entrained outflow gas.

Water excitation: 2) two physical components

Nisini et al. 2014

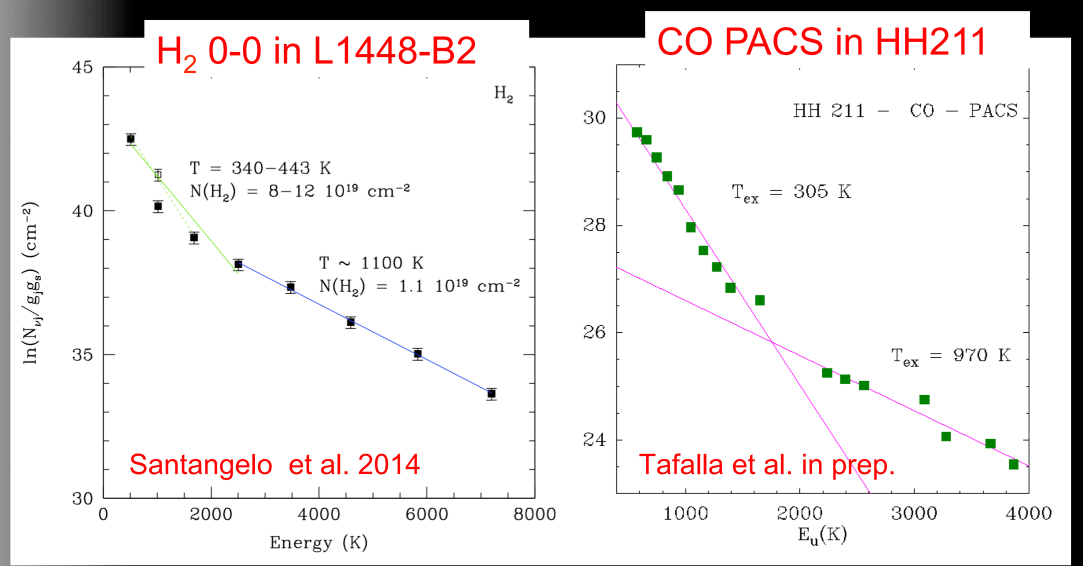


Profiles of H_2O lines at different excitation in the L1448-C shocks



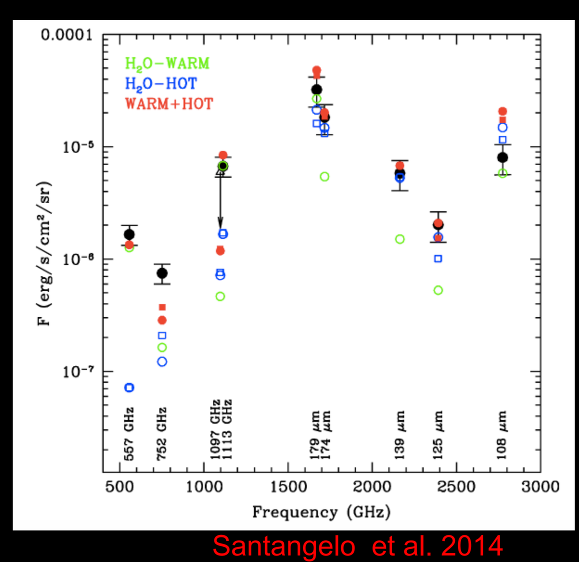
HIFI lines at different excitation show remarkably different profiles in some shock spots, and the low excited lines present an excess in emission at high velocity with respect to the lines at higher excitation. This can be interpreted in terms of density variations: the gas at low velocity is denser than the high velocity gas (a similar result is found also on L1157, Vasta et al. 2012)

Complementary tracers: Boltzmann diagrams of H_2 0-0 (Spitzer) and CO high-J (PACS)



The Boltzmann diagrams of molecules/lines tracing the same gas as the water lines (i.e. H_2 0-0 and CO high-J lines) show the presence of gas in two temperature regimes.

LVG analysis of multi-line HIFI and PACS observations



A two component fit is better able to reproduce the line intensity of H_2O lines at different excitation

→ **Outflow shock spots present at least two components: a compact hot component (T>1000 K, n=10^5-10^6 cm^{-3}) that may be associated with jets impacting on the ambient material, and a warm (T=300-500 K), denser (n=10^6-10^7 cm^{-3}), and more extended component originating from the compression of the ambient gas by the propagating flow.**

Water abundance in shocks

Water abundance is different in the warm and hot gas:

- Warm (T = 300-700 K): X(H_2O) = 10^{-7}-10^{-6}
- Hot (T>1000 K): X(H2O) = 10^{-5}-10^{-4}

→ Water abundances as high as 10^{-4}, as predicted by chemical models, are attained in shocks only in the high temperature gas at the shock front. The abundance decreases by two/three order of magnitudes in the dense post-shock cooling region.

Open questions

- Abundance determined with at least an order of magnitude uncertainty: degeneracy in parameters and choice of N(H_2)
- Why abundance so low in the dense post-shocked gas ?
- Need refinement of shock models to reproduce the variety of excitations, abundances and line profiles observed

Papers published by the WISH-outflow group

- Bjerkeli et al. 2011, A&A, 533, 80
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- Neufeld et al. 2014, ApJ 781, 102
- Nisini et al., 2010, A&A, 518, 120
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- Tafalla et al. 2013, A&A, 551, 116
- Vasta et al. 2012, A&A, 537, 98