The WISH outflow program in low mass protostars

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As part of the WISH Herschel Key Program (PI: 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 25 outflows from low mass stars observed in the H2O 0-0-0 S(2), 1669 GHz and 557 GHz lines indicate that they arise from the same outflow component.
• 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 H2O, CO [D] and OH transitions with both HIFI and PACS

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

Water distribution and line profiles

- 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 104
- The morphology and line profiles of H2O 557 and 1669 GHz indicate that water is associated with excited shocked gas along the outflow and not with entrained outflow gas.

Water abundance in shocks

Water abundance is different in the warm and hot gas:

• Warm (T ≃ 300-700 K): X(H2O) = 10^-4-10^-6
• Hot (T>1000 K): X(H2O) = 10^-4-10^-3

→ 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(H2)
- 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

- Nisini et al., 2010, A&A, 518, 120

Description of the program

Water excitation: 1) physical conditions for the 1_0-1_0, 557 and 2_1-1_0, 1669 GHz lines

The correlation between the intensity of the 1669 and 557 GHz lines indicates that they have similar physical conditions.

The observed 1669GHz/557GHz intensity ratio compared with LVG analysis of multi-line HIFI and PACS observations.

Water excitation: 2) two physical components

Profiles of H2O lines at different excitation: in L1488-C, HH154, and L1157. HIFI lines at different excitation show remarkably different profiles in some shock spots. The two excited lines present a clear separation of high velocity with respect to the lines at higher energy. This separation will be less clear 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. 2013).

The Boltzmann diagrams of molecules/lines tracing the same gas as the excited lines (in H2O and CO high-J PACS) show the presence of gas in two temperature regimes.

Outflow shock spots present at least two components: a compact hot component (T>1000 K, n=10^4-10^5 cm^-3) that may be associated with jets impacting on the ambient material, and a warm (T=300-500 K), denser component (n=10^2-10^3 cm^-3), and more extended component originating from the compression of the ambient gas by the propagating flow.