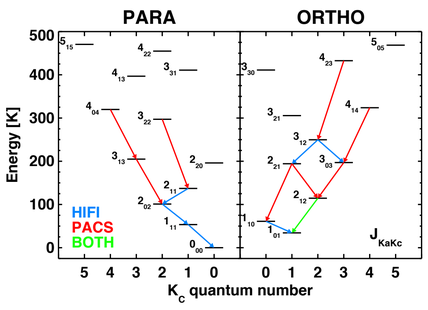
Water in Low-Mass Star-Forming Regions

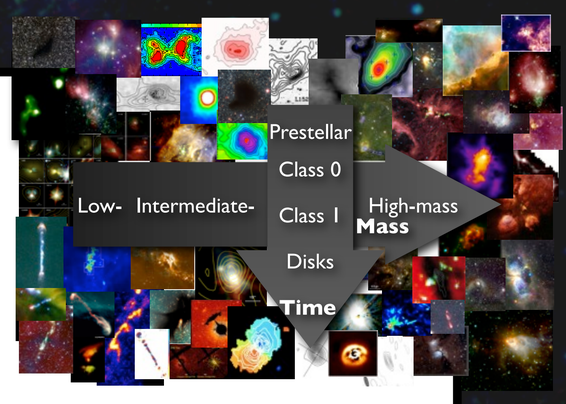
L.E. Kristensen[1], U.A. Yildiz[1], R. Visser[1], G. Herczeg[2], T.A. van Kempen[3], E.F. van Dishoeck[1,2], S.D. Doty[4], M.R. Hogerheijde[1], J.K. Jørgensen[5], S. Wampfler[6], S. Bruderer[6], A.O. Benz[6] and the WISH team*

(1) Leiden Observatory, NL (2) MPE Garching, DE (3) CfA, USA (4) Denison University, USA (5) StarPlan, Copenhagen, DK (6) ETH Zurich, CH

Water

- Key molecule for probing the physics and chemistry of star-forming regions
- Large abundance variations between warm/cold regions
- Capable of highlighting key episodes of stellar birth such as gravitational collapse, outflow injection, and stellar heating of envelopes and disk
- Chemical importance as one of the main oxygen reservoirs
- Direct association with life on Earth

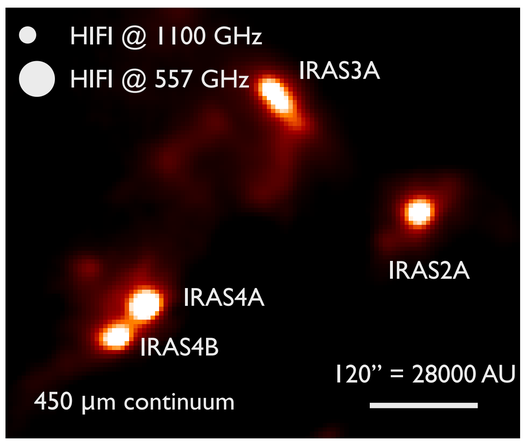




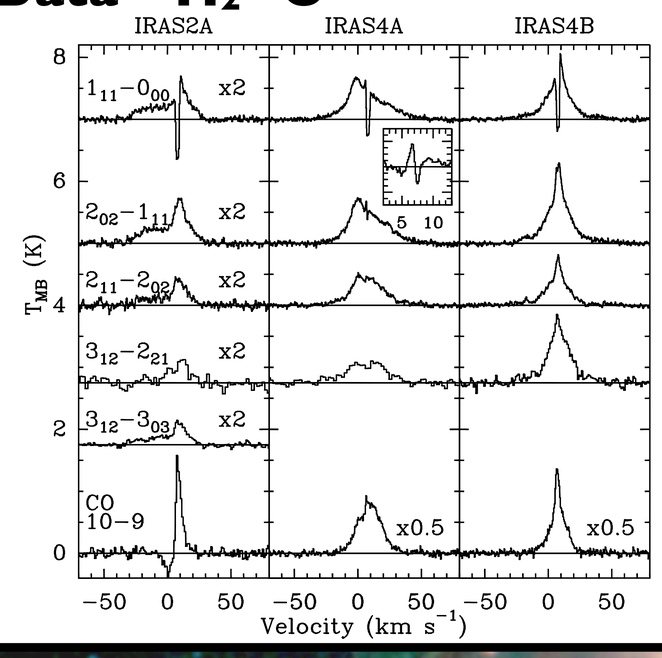
Water is a prime target for Herschel observations. The "Water in Star-Forming Regions with Herschel" (WISH) key programme uses HIFI and PACS to follow the water 'trail' from prestellar cores to planet-forming disks.

NGC1333

- Low-mass star-forming cluster in Perseus
  Four bright sub-mm sources: **IRAS2A**, IRAS3A, **IRAS4A** and **IRAS4B**; three observed with HIFI and PACS
- D ~ 235 pc
- Extensively surveyed from the ground and space
- Currently forming stars like the Sun



Data - $H_2{}^{16}O$



Results

Surprises:

- Multiple components: broad, even in $H_2{}^{18}O$ (~ 50 km s^{-1}), medium (~ 5-10 km s^{-1}), narrow (~ 1-2 km s^{-1}) and inverse P Cygni (IRAS4A)
- Line centers off-set with respect to v_{source}

Interpretation:

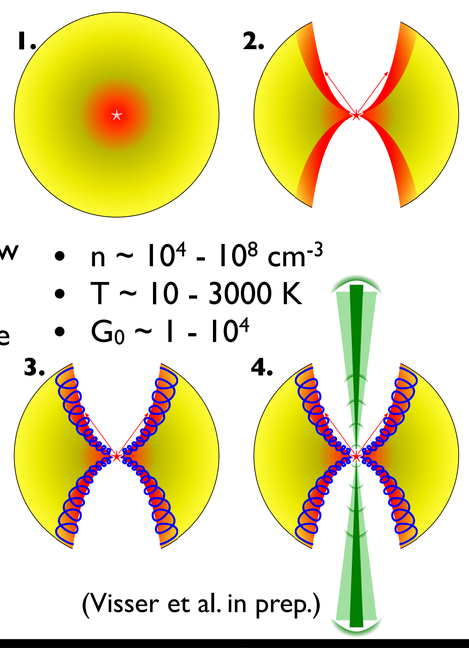
- Broad component originates in molecular jet; abundance measured to H_2O/CO ~ 0.1 - 1
- Medium component is caused by small-scale shocks in the envelope-outflow interface
- Narrow component caused by the cold envelope; H_2O/H_2 is 10^{-8} in the outer envelope, and < 10^{-5} in the inner envelope.

Take-home message:

- H_2O is one of the best dynamics tracers

Scenario

Components:
1. Passively heated envelope
2. UV-heated outflow cavity walls
3. Small-scale C-type shocks along walls
4. Jet responsible for outflow (atomic and molecular)
5. Protoplanetary disk

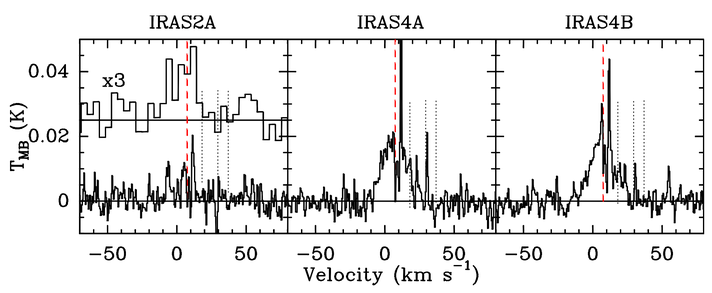


- $n \sim 10^4 - 10^8$ cm^{-3}
- $T \sim 10 - 3000$ K
- $G_0 \sim 1 - 10^4$

(Visser et al. in prep.)

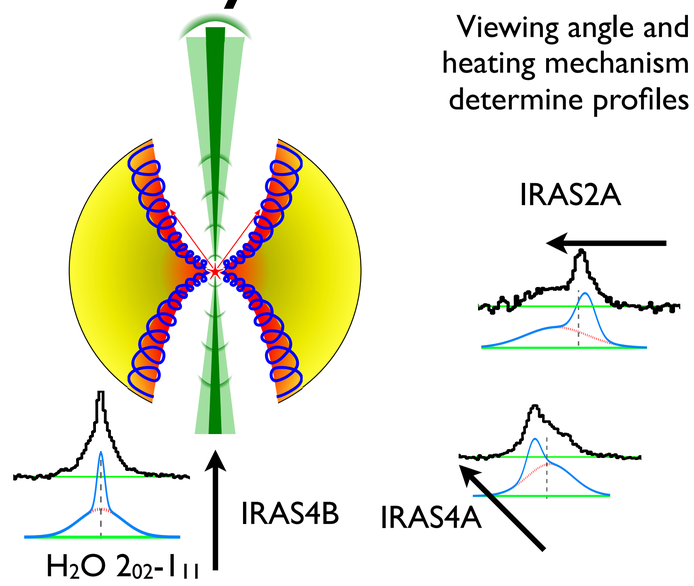
Data - $H_2{}^{18}O$

- $H_2{}^{18}O$ 1_{10}-1_{01} (and CH)
- Surprisingly broad profile (~ 25 km s^{-1}), comparable to that of $H_2{}^{16}O$



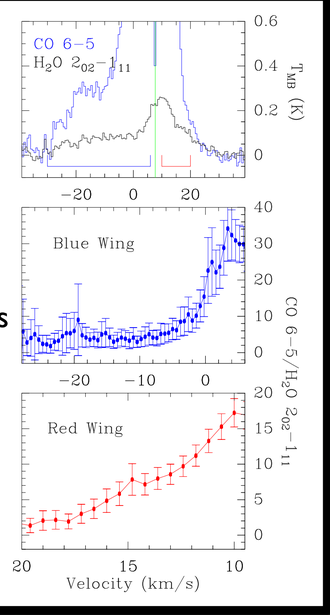
Geometry

Viewing angle and heating mechanism determine profiles



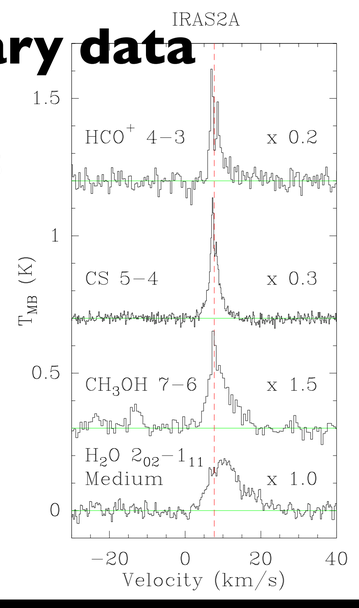
CO / H_2O

- Deep CO 6-5 spectrum obtained with APEX/CHAMP+ (Liu et al. in prep.) and CO 10-9 with HIFI (Yildiz et al. subm.)
- Similar profile to H_2O, but less prominent wings
- CO/H_2O abundance ratio varies from 1 - 10
- 5-10% of the gas is so hot that all available O is in H_2O



Complementary data

- H_2O much broader than high-density tracers, e.g., CS and HCO^+
- The medium component corresponds well to the CH_3OH profile
- Origin in same physical component: small-scale shocks in the envelope-outflow interface



Technical details

- Observations carried out on March 5-15, 2010 using HIFI in DBS mode. WBS spectra presented here.
- Linear baselines subtracted from all spectra.
- To be published in Kristensen et al. (2010)
- Similar results available for CO, ^{13}CO and $C^{18}O$ (Yildiz et al. subm.)
- See also: **http://www.strw.leidenuniv.nl/WISH/**

***WISH team:** **E.F. van Dishoeck**, Y. Aikawa, R. Bachiller, A. Baudry, M. Benedettini, A. Benz, E. Bergin, P. Bjerkeli, G. Blake, S. Bontemps, J. Braine, A. Brandeker, S. Bruderer, S. Cabrit, P. Caselli, J. Cernicharo, L. Chavarria, C. Codella, F. Daniel, C. Dedes, P. Encrenaz, A.M. di Giorgio, C. Dominik, S. Doty, H. Feuchtgruber, M. Fich, W. Frieswijk, A. Fuente, T. Giannini, J.R. Goicoechea, Th. De Graauw, F. Helmich, F. Herpin, G. Herczeg, M. Hogerheijde, T. Jacq, J. Jørgensen, D. Johnstone, A. Karska, M. Kaufman, E. Keto, L. Kristensen, B. Larsson, B. Lefloch, D. Lis, R. Liseau, M. Marseille, C. McCoey, G. Melnick, D. Neufeld, B. Nisini, M. Olberg, G. Olofsson, L. Pagani, O. Panić, B. Parise, J. Pearson, R. Plume, C. Risacher, D. Salter, N. Sakai, J. Santiago, P. Saraceno, R. Shipman, M. Tafalla, F. van der Tak, T. van Kempen, R. Visser, S. Viti, S. Wampfler, M. Walmsley, F. Wyrowski, S. Yamamoto, U.A. Yildiz