Synergy between Herschel and ALMA: Hot Gas in Low-Mass Protostars

Ruud Visser
University of Michigan

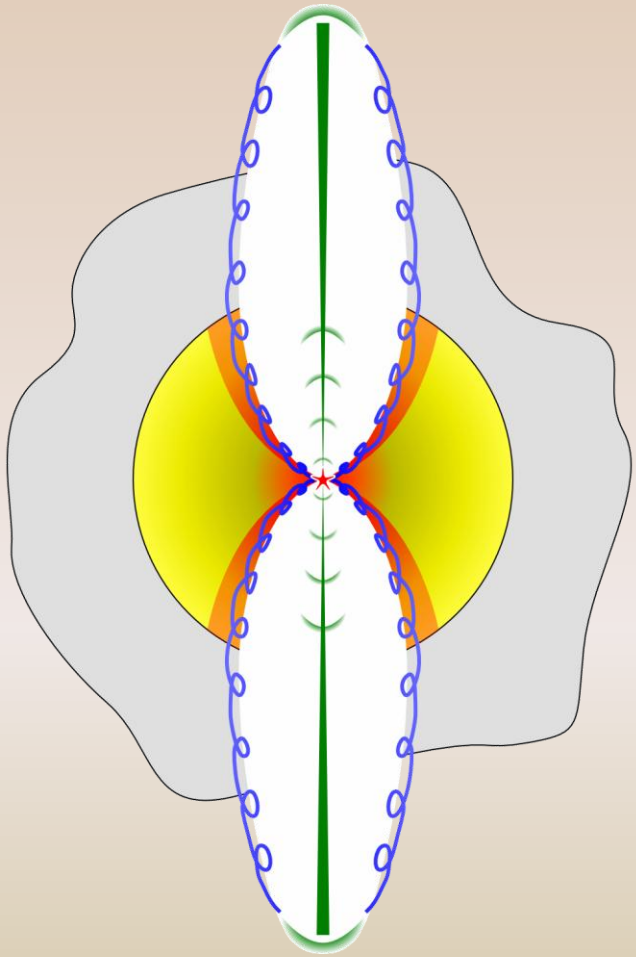
Lars Kristensen, Ewine van Dishoeck, Ted Bergin, Simon Bruderer, Greg Herczeg, Christian Brinch, Jes Jørgensen, Mark Wolfire, and the WISH and DIGIT teams

May 9, 2011

Low-mass embedded protostars

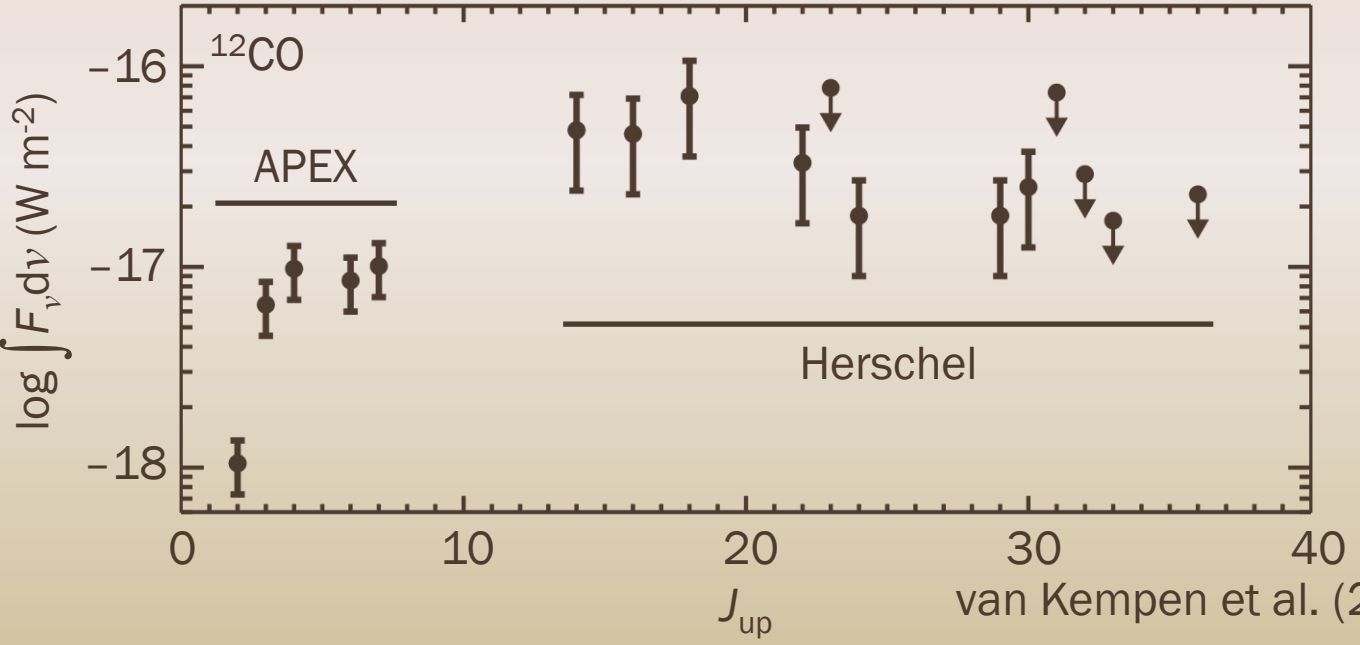
Open questions:

- Envelope structure on 100 AU scales
- Interaction between outflow and envelope



CO as a Swiss Army knife

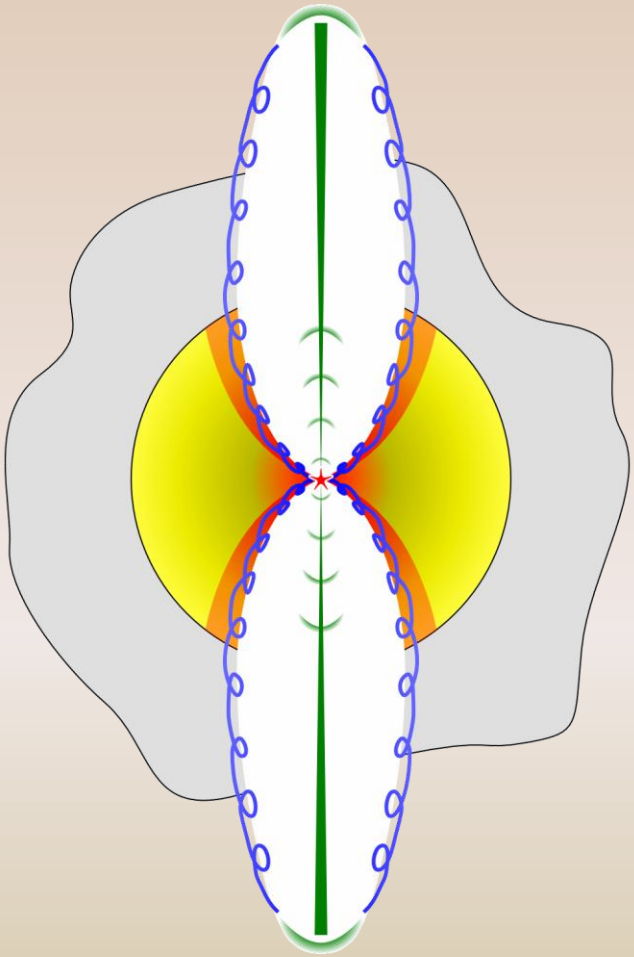
Isotopologue and transition	Sensitive to
$C^{18}O$, $C^{17}O$ $J = 2-1$ and $3-2$	bulk envelope mass
^{12}CO $J = 3-2$ line wings	cold outflow on 1000 AU scales
^{12}CO $J = 6-5$ and $7-6$	hot gas along outflow
^{12}CO $J = 10-9$ and higher	hot gas on 100 AU scales?



van Kempen et al. (2009-2010)

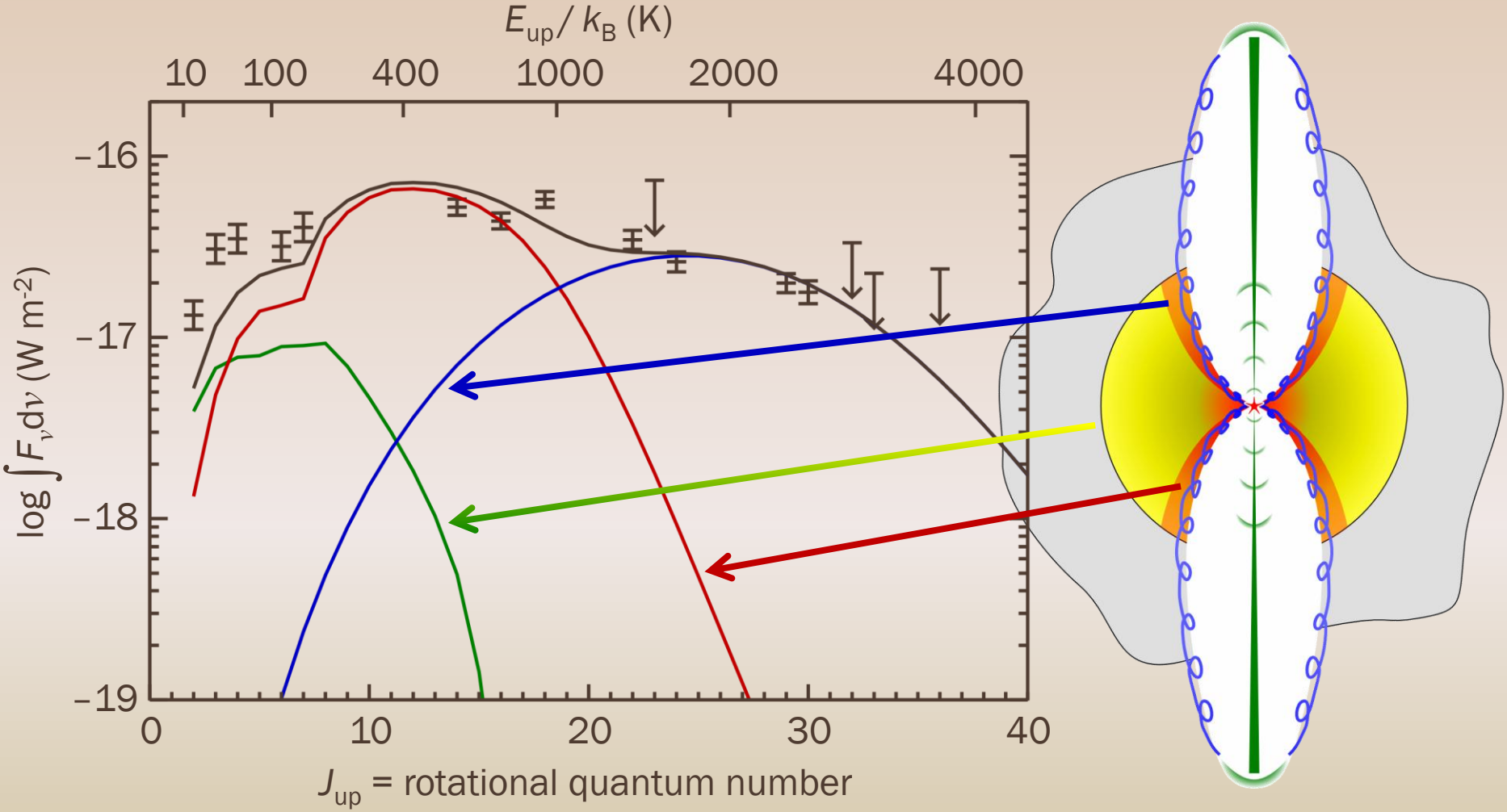
Origin of the Herschel emission?

- Three-component model:
  - Spherical envelope
  - UV-heated cavity walls
  - Shocks along cavity walls
- Compute line emission with radiative transfer code LIME



van Kempen, Kristensen et al. (2010), Visser et al. (in prep.)

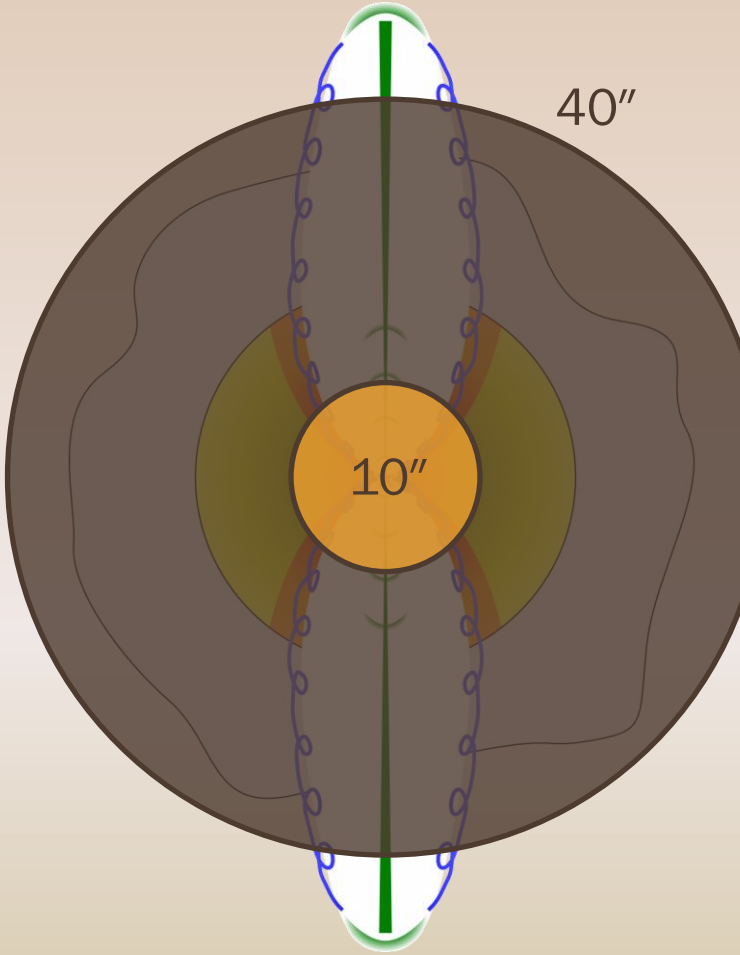
Origin of the Herschel emission?



van Kempen, Kristensen et al. (2010), Visser et al. (in prep.)

Origin of the Herschel emission?

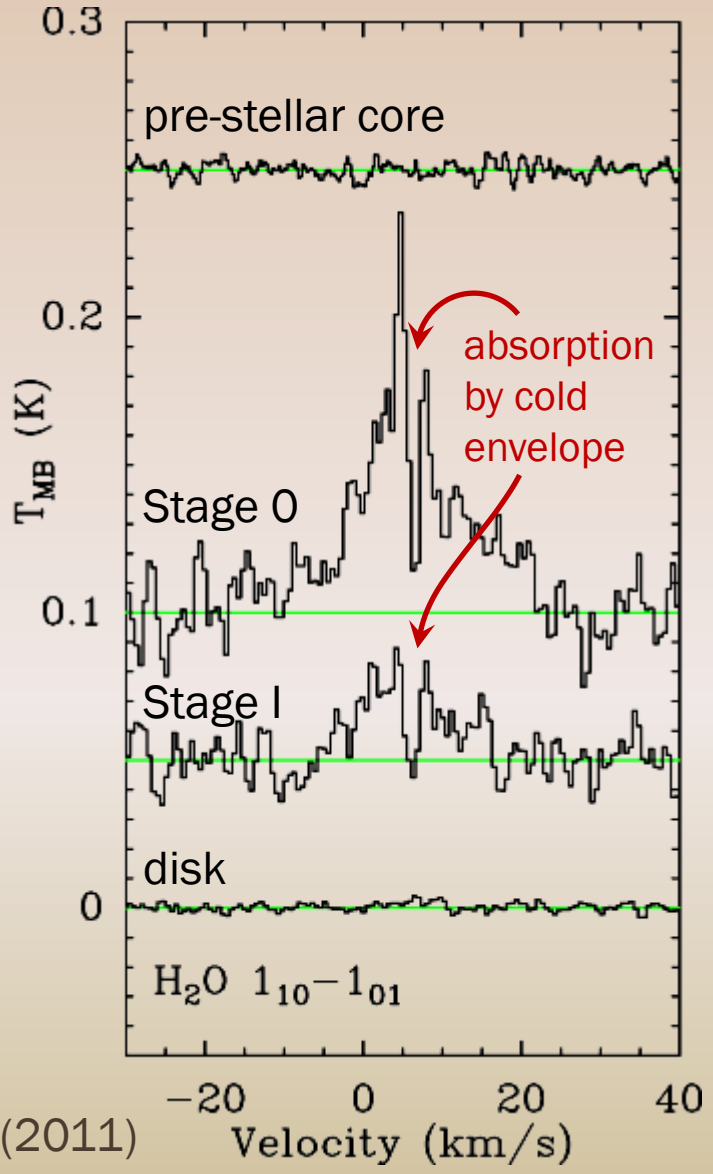
- Herschel beam is ~10–40″
- Spectral lines resolved only up to $J = 16–15$
  - Higher lines observed with PACS at lower spectral resolution
- ALMA: maps of $J = 6–5$ at sub-arcsec resolution



van Kempen, Kristensen et al. (2010), Visser et al. (in prep.)

Water in the inner envelope

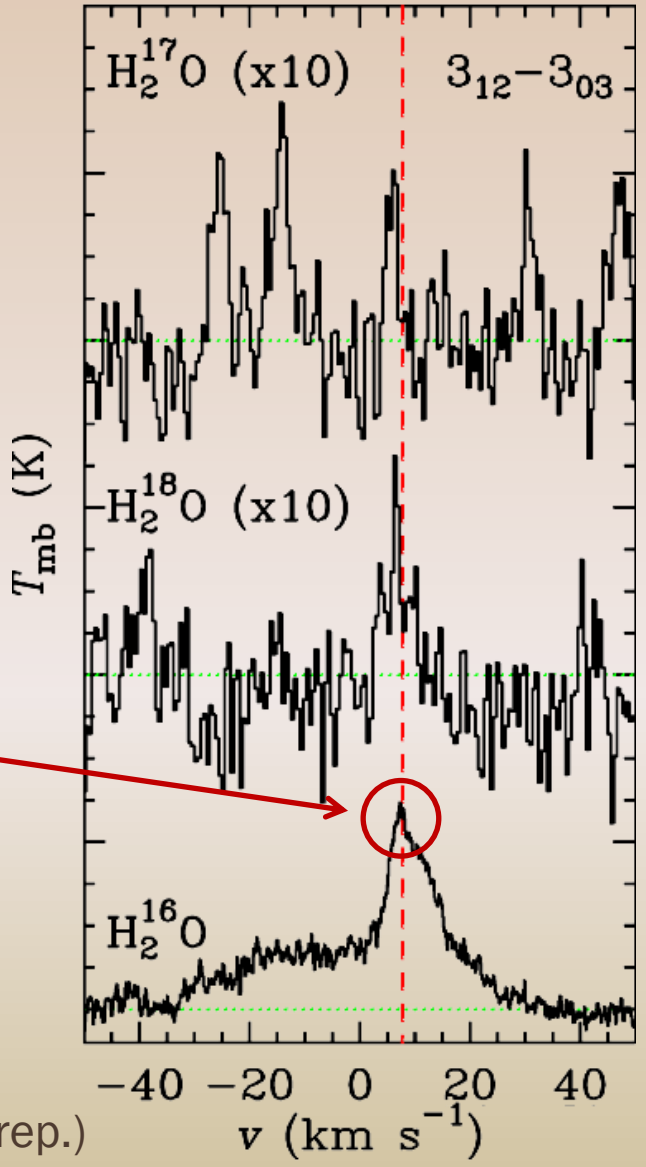
- Why water?
  - Dynamical probe: outflow, infall, quiescent…
  - Main reservoir of O, tracing gas-grain interactions
  - Important for life on Earth
- Herschel KP WISH: follow water trail during star formation
- Cold outer envelope clearly seen; what about hot inner part?



van Dishoeck et al. (2011)

Hot water in NGC1333 IRAS2A (Stage 0)

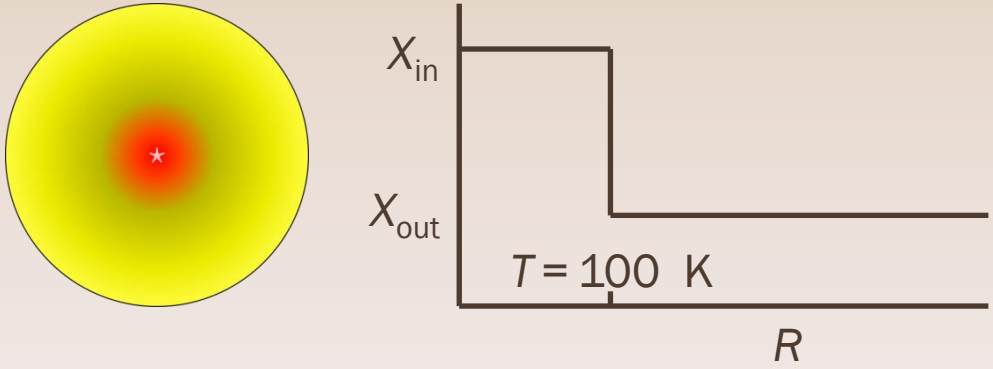
- 3_{12}–3_{03} rotational line
  - E_{up} = 249 K, ν = 1097 GHz
- 5-hr observation with HIFI on Herschel
  - 7 mK rms in 1 km/s bins
- The value of a deep integration:
  - Narrow component in $H_2^{16}O$
  - $H_2^{18}O$ clearly seen ($^{16}O/^{18}O = 550$)
  - $H_2^{17}O$ tentatively seen ($^{18}O/^{17}O = 4$)



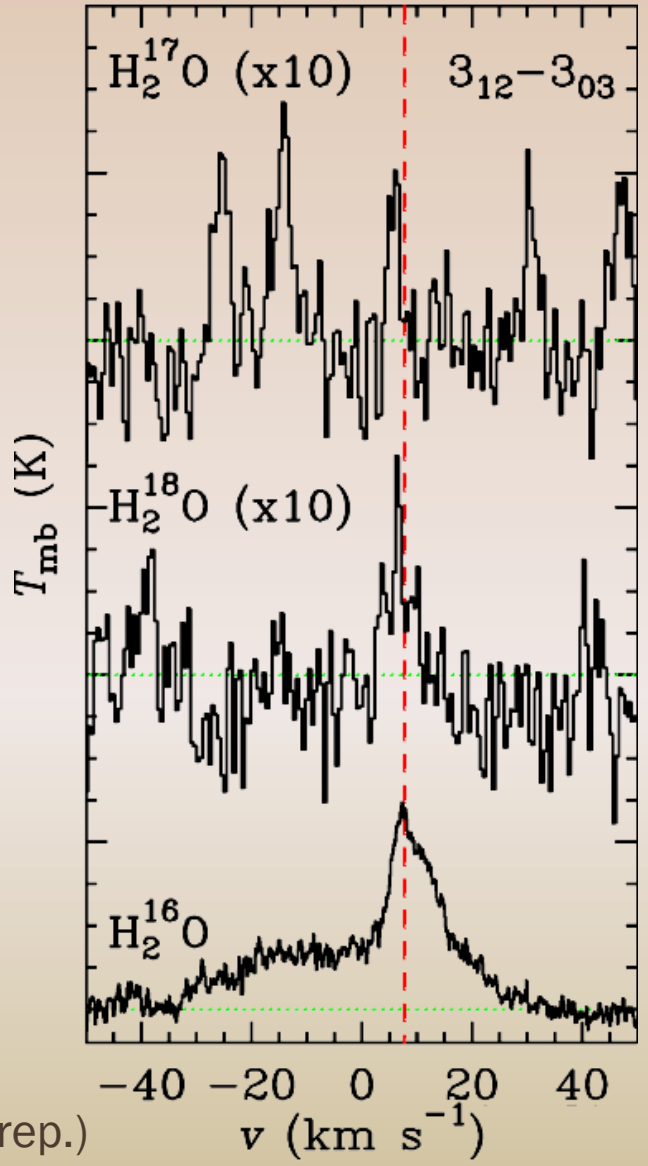
Visser et al. (in prep.)

Hot water in NGC1333 IRAS2A (Stage 0)

- Model: spherical envelope with jump abundance



- $H_2^{16}O$ sensitive to X_{out}, $H_2^{18}O$ and $H_2^{17}O$ to X_{in}
- Preliminary result: $X_{in} = 4\times10^{-6}$, $X_{out} = 1\times10^{-8}$



Visser et al. (in prep.)

Inner envelope structure

- Pseudo-disk likely on 100 AU scales:
  not spherical, no power-law density
- PdBI: $H_2^{18}O$ 3_{13}–2_{20} on 0.2″ scale in IRAS4B
  (Jørgensen & van Dishoeck 2010)
  - Physical extent of 25 AU
  - 1 km/s FWHM too narrow for shock or infalling envelope
  - Hint of rotation: disk?
- X_{in} of 4×10^{-6} in IRAS2A may be meaningless
- ALMA: observe $H_2^{18}O$ in more sources,
  use CO $J=6$–5 to constrain inner envelope

Conclusions

- Hot gas observed with Herschel
  - Highly rotationally excited CO
  - Water in inner envelope
- ALMA:
  - Resolve small-scale structure
  - Help identify origin of the Herschel observations