# High-pressure, low-abundance water in bipolar outflows
# Results from a Herschel-WISH survey

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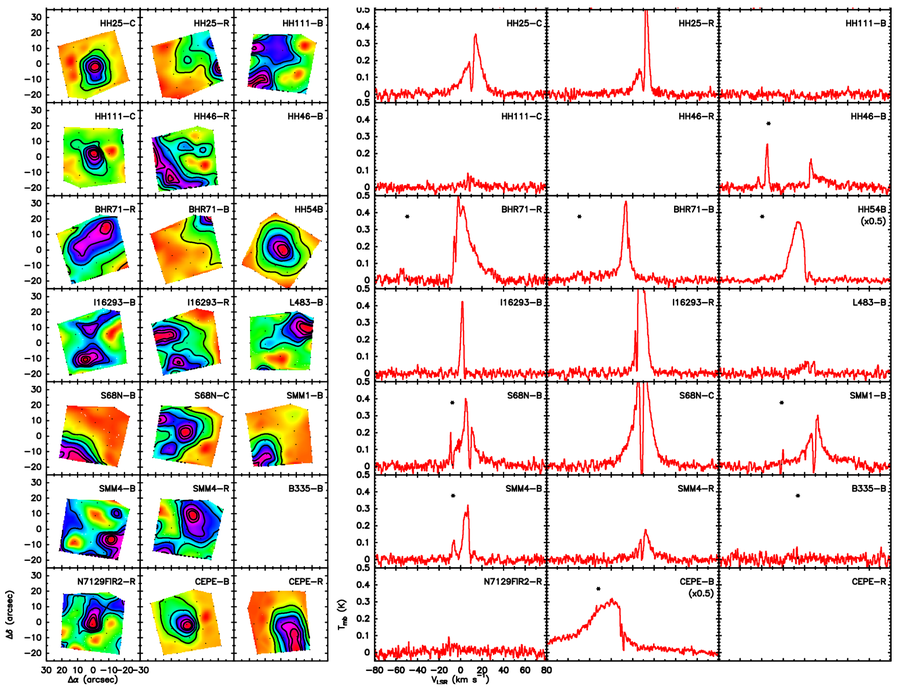
## 1. Our water outflow survey

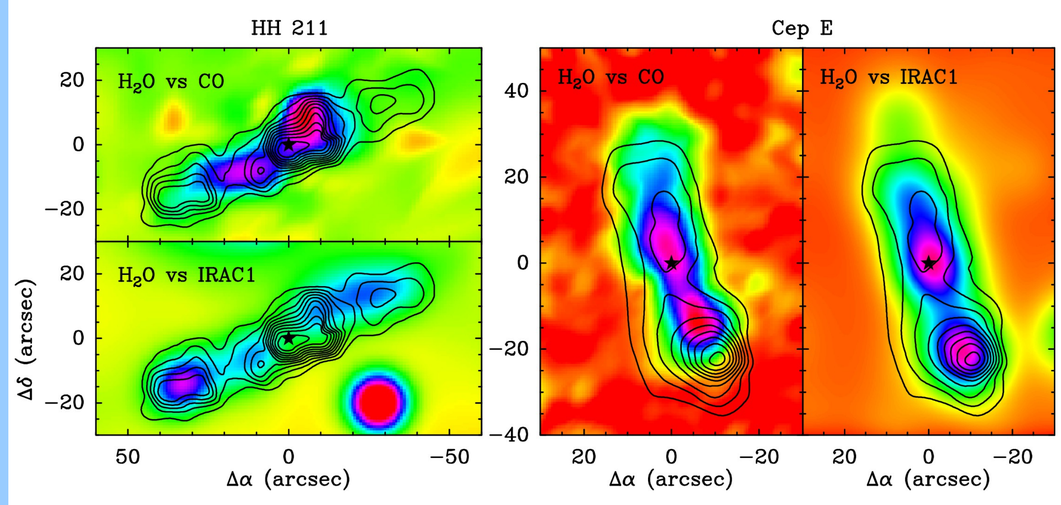
- We used **Herschel** to observe **$H_2O$** in more than **20 outflows**.
- In each outflow, 2 positions were observed, usually one in each lobe.
- In each position, **2 $H_2O$** lines were observed:
  - $H_2O(1_{10}\text{-}1_{01})$ at **557 GHz** with **HIFI.**
  - $H_2O(2_{12}\text{-}1_{01})$ at **1669 GHz** with **PACS.**
- The two lines are **complementary**: 557GHz-HIFI provides velocity resolution with 40” beam and 1669 GHz-PACS provides 13” angular resolution over 40” map.

## 2. The PACS maps and the HIFI spectra complement each other

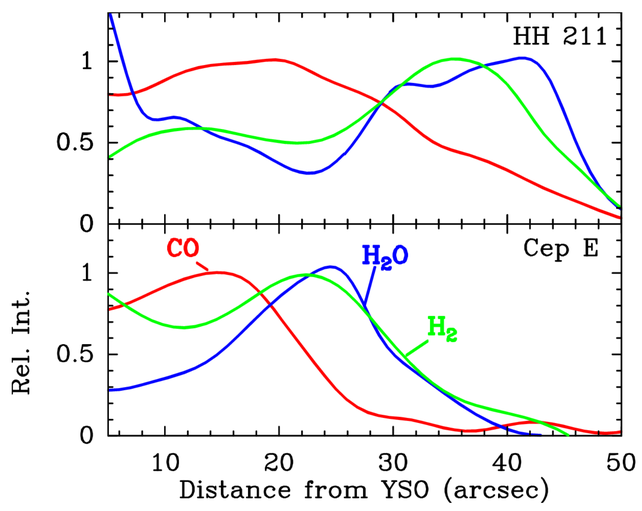



- **Left:** Sample of $H_2O(1669)$- PACS maps. Each map is a is 5x5 footprint. Note how the emission is compact but resolved.
- **Right**: Sample of $H_2O(557)$-HIFI spectra. (* mark $NH_3$ line from image band.) Note the outflow wings, about 10-40 km/s wide.
- The PACS maps resolve the emission inside the 40” HIFI beam.

## 3. $H_2O$ vs $H_2$ and CO(2-1) in the HH211 and Cepheus E outflows

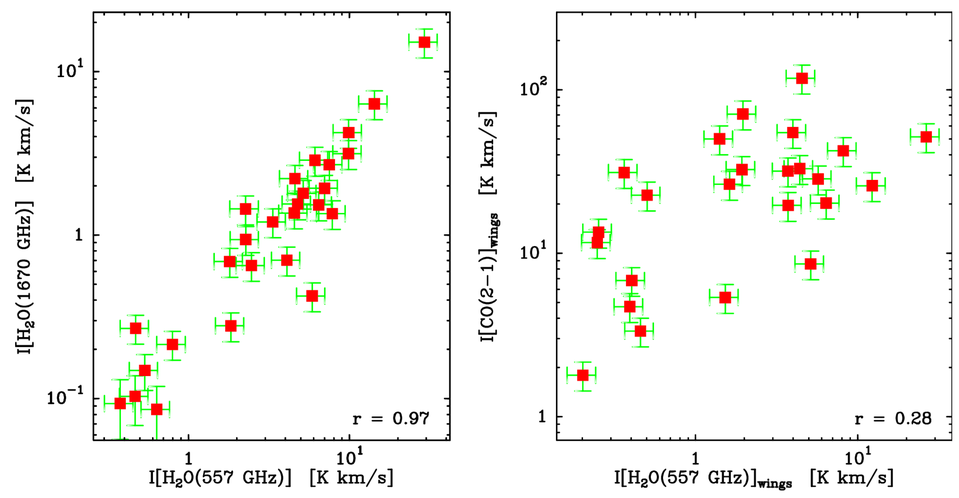



- For **HH211** and **Cepheus E**, our PACS data fully cover the outflow.
- As can be seen, the water emission (**contours**) differs from CO(2-1) emission but resembles the $H_2$-IRAC1 emission (**colors**).



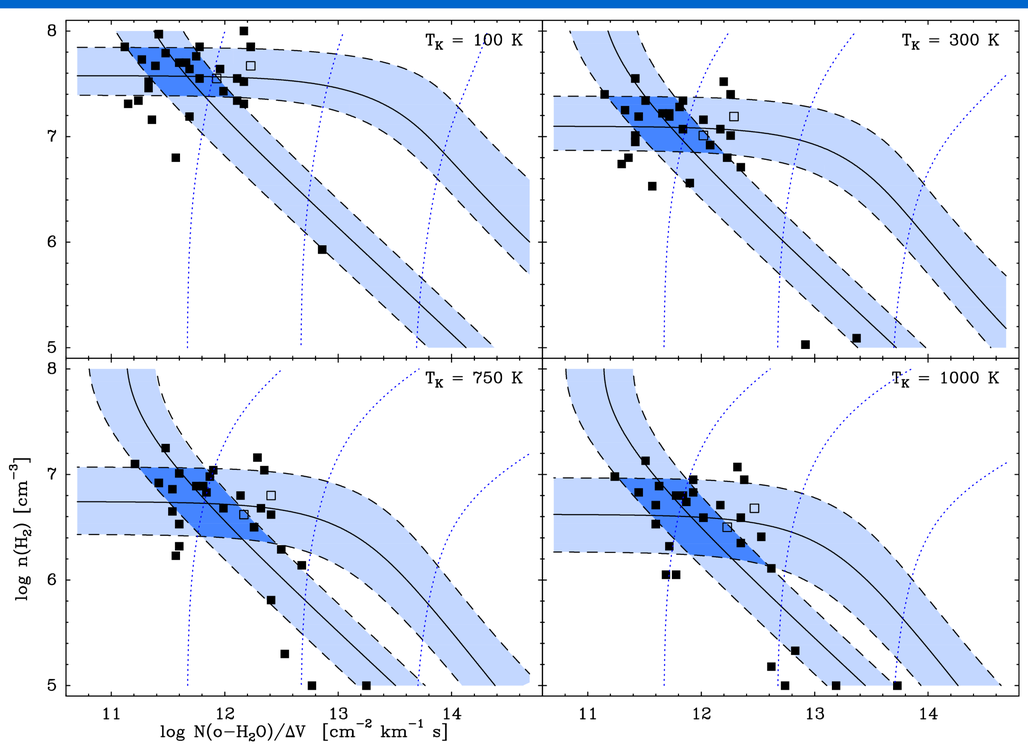

- The emission profiles for HH211-SE and CepE-SW lobes best illustrate the pattern.
- $H_2O$-CO mismatch.
- $H_2O$-$H_2$ good match.
- **$H_2O$ traces a warmer outflow component seen in $H_2$ but not in CO(2-1).**

## 4. Strong 557-1669 GHz correlation over the whole sample



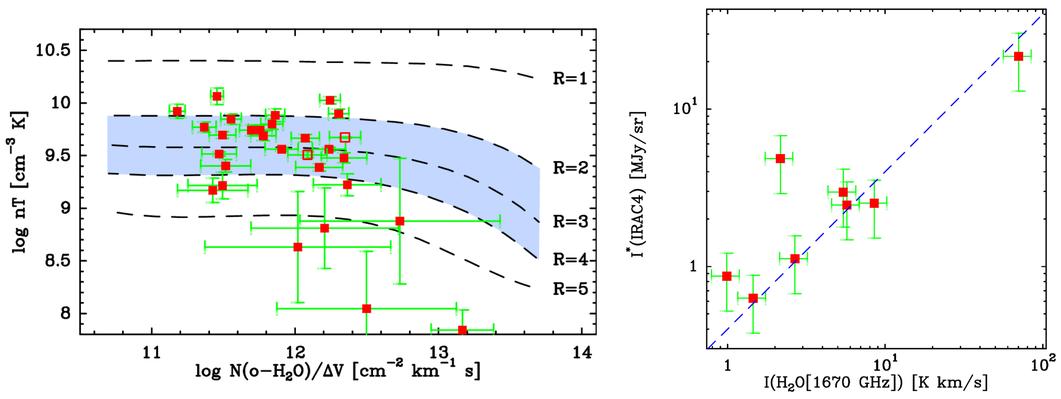

- **Left:** When convolved to the same angular resolution, the intensities of the 557 and 1669 GHz lines are **strongly correlated.**
- **Right**: As expected from the HH211 and Cepheus E maps, the $H_2O$(557GHz) emission is poorly correlated with CO(2-1).
- **A main constraint from the data is an almost constant $H_2O(557)/H_2O(1669)$ intensity ratio of 3.**
- **This suggests typical excitation temperatures around 25 K.**

## 5. LVG transfer: density-temperature ambiguity




- We use a **Large Velocity Gradient (LVG)** code to predict 557 and 1669 GHz line intensities as a function of **$n(H_2)$, $N(H_2O)$, and $T_k$.**
- With only two $H_2O$ transitions, we cannot constrain all 3 inputs.
- We explore solutions of fixed $T_k$.
- **Higher $T_k$ solutions require lower $n(H_2)$.**

## 6. High pressure and low abundance




- **Left:** While $n(H_2)$ and $T_k$ are poorly constrained, their product (**P=nT**) has little scatter thanks to constant 557/1669 line ratio R.
- $N(H_2O)$ is also well constrained from data.
- **Right:** From $H_2O$-$H_2$ correlation, we derive $H_2O$ abundance **~ $3\ 10^{-7}$**
- **Abundance is much lower than predicted by C-shock models.**