Water towards hot molecular cores

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Motivation

• Water unique in many respects:
  • Dominant ice constituent
  • Natural filter for warm/hot gas
  • Probes shocked outflowing gas
  • Controls chemistry of many other species

• Observations of water was one of the key science themes of the Herschel space mission.
Hot molecular cores
an early stage of high-mass star formation

- Water unique diagnostic of warm gas and energetic processes taking place during star formation.

- Hot cores:
  - Warm, dense gas around/close to young (forming) massive stars/clusters: $T>100K$, molecules evaporate from grain $\rightarrow$ rich chemistry $\rightarrow$ complex organic molecules
  - In hot cores water might rival CO in abundance and with its many lines of high excitation, will provide a new tool to study the inner workings of massive star forming regions
Fig. 1. Herschel/HIFI spectra of the $\text{H}_2\text{O} 1_{11} \rightarrow 0_{00}$ (top), $\text{H}_2\text{O} 2_{02} \rightarrow 1_{11}$ (middle) and $\text{H}_2^{18}\text{O} 1_{11} \rightarrow 0_{00}$ (bottom) lines. Dashed lines drawn at $V_{\text{LSR}}$.
Fig. 2. HIFI spectra of $^{13}$H$_2$O and $^{18}$H$_2$O (Left) and $^{16}$H$_2$O (Right) lines (in black) with continuum for NGC6334(N). The best-fit radiative transfer models are shown as red and blue lines over the spectra, respectively for constant parameters ($V_{\text{inf}} = -0.7$ and $V_{\text{shift}} = 2.5 \text{ km s}^{-1}$) and varying turbulent velocity. Vertical dotted lines indicate the $V_{\text{LSR}}$. The spectra have been smoothed to 0.2 km s$^{-1}$, and the continuum divided by a factor of two.

Fig. 8. Inner water abundance vs. the absolute value of the infall or expansion velocity as derived from our model (see Table 8). The filled square symbol is for W3IRS5 from Chavarria et al. (2010), and the arrow shows the abundance for W3IRS5 from van der Tak et al. (2006).
Main high-mass WISH results
e.g. van der Tak+2013, Herpin+2016

- Large variation in water abundance
  - from diffuse clouds on L.O.S (1e-9)
  - outer envelope (1e-9, freeze out)
  - Outflows (1e-7)
  - Inner envelope/hot core (1e-6 – 1e-4, evaporation)
- Sensitive kinematic probe due to mix of absorption and high optical depth emission
  - Infall, outflows, turbulence
- Evolutionary tracer
Ground based water observations

- **Menten 2009:** *Into Hot Water at the CSO and Elsewhere*

- \( \text{H}_2\text{O} \; ^{13}\text{O} \; ^{16}\text{O} \) \; \; 3_{13} - 2_{20} \; @ \; 183\text{GHz}, \; 205\text{K above ground,} \; \) (Waters et al. 1980, KAO)

- \( \text{H}_2\text{O} \; ^{15}\text{O} \; ^{16}\text{O} \) \; \; 5_{15} - 4_{22} \; @ \; 325\text{GHz}, \; 470\text{K above ground,} \; \) (Menten et al. 1990, CSO)
SEPIA Water Observations

- Science verification observations
- 12 hot cores/30min integrations
- 2x2x4GHz, PI-XFFTS
- $\text{H}_2\text{O}/\text{H}_2^{17}\text{O} 3\,_{13} - 2\,_{20}$ lines at 183.3/194.0 GHz
- $T_{\text{sys}}$: 300 – 1200 K
- Supporting FLASH $\text{H}_2\text{O} 5\,_{15} - 4\,_{22}$ at 325.1 GHz observed within 20 days after SEPIA observations
SEPIA water emission @ 183GHz
FLASH water emission @ 325GHz
HIFI water emission @ 752GHz
Time variability?

G34.26 H₂O 325 GHz

2011 Jun
2015 Jun

$T_a^*$ (K)

Velocity (km/s)
H$_2^{17}$O @ 194 GHz

Blend with CH$_3$O$^{13}$CHO?
Status

- **Preliminary findings:**
  - Higher occurrence of masers (and maser features) at 183GHz
  - Common maser features correlated between 183 & 325 GHz
  - Broad component better separated from masers at 325GHz
  - Broad component too bright for LTE, weak maser

- **Next steps:**
  - Add another epoch of 183 GHz observations to study variability
  - Look into more detailed excitation modeling
    - RATRAN/RADEX (Hogerheijde/van der Tak)
Strongest 183 GHz masers

PdBI $\text{H}_2^{18}\text{O}$ observed

ALMA $\text{H}_2^{18}\text{O}/\text{H}_2\text{O}$ to come
Water-18 transitions

203GHz line: see groundbreaking studies by Jacq+1988 and Gensheimer+1996
$\text{H}_2^{18}\text{O}$ rotational diagram of G34.26

- 3 APEX detections
- Herschel $3_{12}-3_{03}$ line optically thick?
- $\text{T}_{\text{rot}} = 200\text{K}$
- $\rightarrow 1.5''$ hot core (0.03pc)
- $N = 5\times10^{19} \text{ cm}^{-2}$
- Ratran: $X = 5\times10^{-5}$, confirms high optical depths of herschel line
PdBI $\text{H}_2^{18}\text{O}$ follow up

- $\text{H}_2^{18}\text{O}$ 203GHz: no ALMA yet $\rightarrow$ PdBI
- Sub-arcsec resolution to resolve hot water $\rightarrow$ B configuration
- 2 sources with strong $\text{H}_2^{18}\text{O}$ lines, G31.41, G34.26
Line emission after continuum subtraction

Source: G34.26
Line: H2180
Frequency: 203.40752 GHz
Beam: 1.1 x 0.48 PA 31°
Level step: 0.2 Jy/beam
11.26 K  ---  6.39 σ
Box marking: VELOCITY
Channels: [34,58]

wyrowski@alma
17–APR–2013 13:36:05
Gaume/Fey+ 1994

- J2000:
  - 18:53:18.618
  - +01:14:57.35

- Eastern $\text{H}_2^{18}\text{O}$ peak aligned with strongest water maser

- To the west, masers much weaker

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Fig. 6.—Spatial distribution of the $\text{H}_2\text{O}$ and OH masers toward the G34.3 + 0.2 H II regions superposed on contours of 2 cm continuum emission as in Fig. 1. Plus signs mark the positions of $\text{H}_2\text{O}$ masers; circles and squares respectively mark the positions of 1665 and 1667 MHz OH masers. Positions of the OH masers are from Gaume & Mutel (1987). The stippled region marks the position of the strongest OH and $\text{H}_2\text{O}$ maser emission. Contour levels of the continuum emission are 0.5, 1, 2, 4, 8, 15, 20, 30, 50, 70, and 90% of the peak flux density of 0.303 Jy beam$^{-1}$. Whereas the OH masers seem to be projected onto contours of the continuum emission of components B and C, most of the $\text{H}_2\text{O}$ masers are found projected onto the ultracompact molecular core.
Comparison 22 & 183 GHz masers

H$_2$O 22GHz, Fey+1994

63.9 km/s maser component 1".8 north
WEEDS fits to the hot cores
WEEDS fits to the hot cores (II)

East

Nmol = 2.5E17
Tkin = 100
Size = 0.5

West

Nmol = 2E18
Tkin = 300
Size = 0.25
G34.26 summary

- Hot core resolved, new secondary hot core with high water abundance discovered
- Temperatures of 100 and 300 K for the eastern and western hot core from CH$_3$CN
- Dimethyl ether is less abundant in the east, reducing the blend with water in this core \( \rightarrow \) chemical differentiation
- The two cores are shifted in velocity by 2 km/s
- The eastern core has a larger linewidth (6 vs. 4 km/s)
- Projected separation: 0.015 pc
Vibrationally excited Water

Figure 3: (a) Tentative detection of vibrationally excited water in G327 and IRAS17233 using the APEX/CHAMP+ receiver. (b) Rotational diagram of H$_2^{18}$O and vibrationally excited H$_2$O in the hot core G327 assuming H$_2$O/H$_2^{18}$O=500. Note the lowest energy H$_2^{18}$O observed by WISH/HIFI is already optically thick.
Water in hot cores with ALMA

• Cycle 4, priority A
• NGC6334I & IRAS17233 (track sharing)
• \( \text{H}_2^{18}\text{O} \ 4_{14} - 3_{21} \) @ 390.6 GHz
• \( \text{H}_2\text{O} \ v2, \ 1_{10} - 1_{01} \) @ 658.0 GHz
• 0”.15 angular resolution

• Cycle 5: Follow up SEPIA results to study origin of broad component

→ Stay tuned!