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H_2O isotopologues in extreme OH/IR stars

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Abstract. Using Herschel Space Observatory, we observed isotopologues of H_2O in extreme OH/IR stars. We detected strong $H_2^{16}O$ and $H_2^{17}O$ while the $H_2^{18}O$ lines are missing, contrary to the overall galactic oxygen abundane in the interstellar medium and the Sun that the ^{18}O is more abundant than ^{17}O. Theoretical stellar evolution suggests that ^{18}O is being destroyed during the hot-bottom burning. This implies that these OH/IR stars come from a population of intermediate-mass stars which have an initial mass ≥ 5 $M_\odot$.

1. Introduction

Extreme OH/IR stars are AGB stars which exhibit the silicate dust features at both 10 and 10 μm in absorption. This indicates that their circumstellar envelopes are highly optically thick. Estimated dust mass loss rates are relatively high $\sim$ 10^{-6} $M_\odot$ yr^{-1} (Justtanont et al. 2006). However, observations of the gas tracers like CO indicated that the gas mass loss rates are relatively low (Heske et al. 1990). To reconcile the dust and gas observations, it has been proposed that these stars have recently entered a superwind phase when mass loss rates increase by at least an order of magnitude in the past few hundred years (Justtanont et al. 1996; Delfosse et al. 1997; Justtanont et al. 2006).

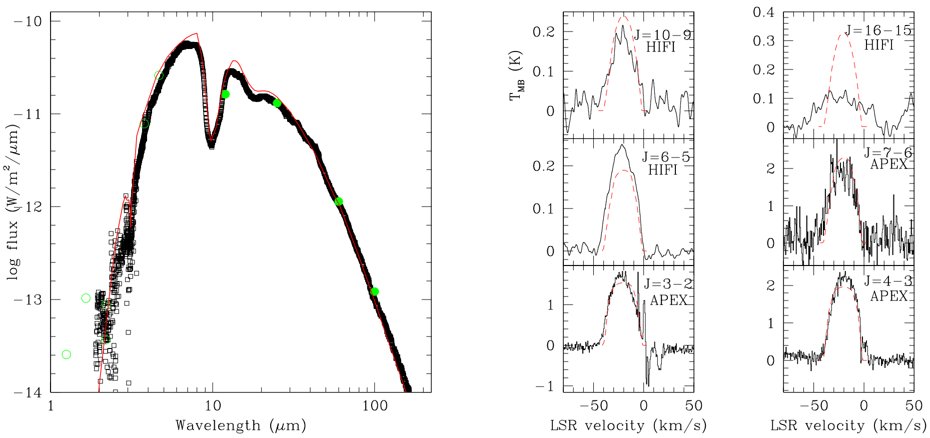
2. Observations

The Herschel Space Observatory (hereafter *Herschel*, Pilbratt et al. 2010) launched in 2009 has a heterodyne instrument for the far-infrared (HIFI, de Graauw et al. 2010) which has a spectral resolution of 0.66 km s^{-1} or higher for the wide-band spectrometer. We observed H_2O isotopologues using 2 frequency setting to cover the transitions $1_{11}-0_{00}$ (ground-state para-H_2O) and $3_{12}-3_{03}$ (ortho-H_2O) which are part of the guaranteed time key program, HIFISTARS, along with other H_2O transitions and CO in AFGL 5379 and OH 26.5+0.6. We obtained CO from the guaranteed time SUCCESS for two other extreme OH/IR stars. Using the dust and CO, we estimate the gas mass loss rates from the samples of our stars.

Table 1. The derived mass loss rate and the superwind radius for our sample stars.

source	$\dot{M}_{sw}$ [$M_\odot$ yr^{-1}]	r_{sw} [cm]
OH 127.8+0.0	9.2×10^{-4}	1.2×10^{16}
AFGL 5379	1.6×10^{-4}	1.0×10^{16}
OH 26.5+0.6	3.2×10^{-4}	0.9×10^{16}
OH 30.1-0.7	1.8×10^{-4}	2.5×10^{16}

Figure 1. A fit (solid line) to the spectral energy distribution of AFGL 5379 (left panel) to the ground-based observations and those from the spectrometers of the Infrared Space Observatory (ISO-SWS and LWS : open squares) and broad-band photometry (open and filled circles) Middle and right panels show the fits (dashed lines) to CO observations.



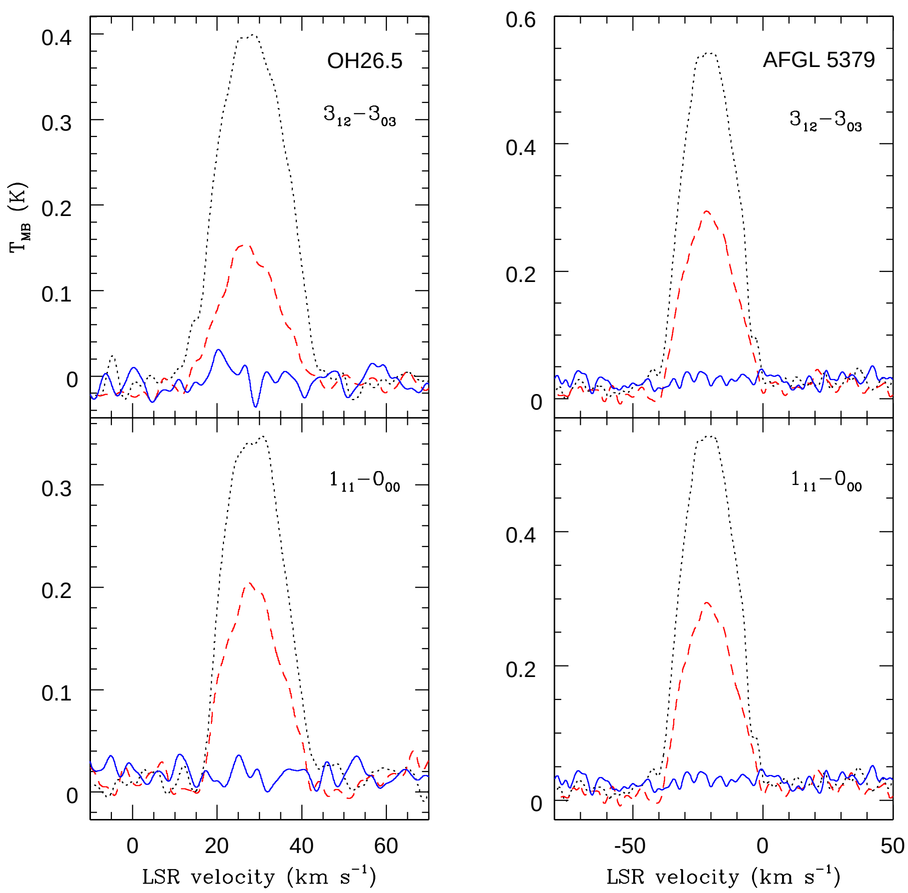
3. Superwind in extreme OH/IR stars

By modelling the spectral energy distributions, we derive dust mass loss rates for our sample stars of (1-2)$\times10^{-6}$ $M_\odot$ yr^{-1} (Justtanont et al. 2013). Using radiative transfer code to solve for the observed CO emission from ground-based observations and those from the *Herschel*-HIFI, we can put a limit on a superwind radius for each star which is of an order of $\leq 3 \times 10^{16}$ cm (Table 1). Fig. 1 shows fits to the observations of one of the stars in our sample, AFGL 5379.

4. H_2O isotopologues in extreme OH/IR stars

The observations of isotopologues of both para- and ortho-H_2O were observed as part of the HIFISTARS program. This yielded a surprising result. Both $H_2^{16}O$ and $H_2^{17}O$ were readily detected while the $H_2^{18}O$ were below the detection limit (Fig. 2). In the interstellar medium and in the Sun, the $^{18}O/^{17}O$ is between 3-5. For AFGL 5379 and OH 26.5+0.6, this ratio is approaching zero due to the non-detection of $H_2^{18}O$.

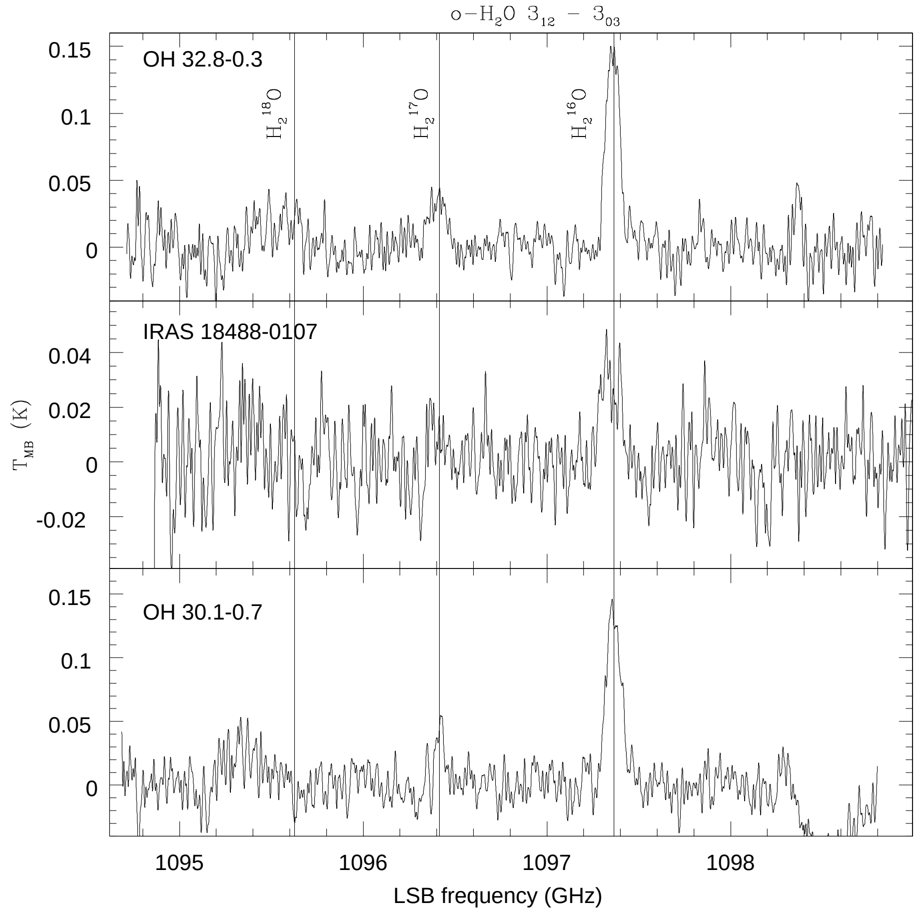
Figure 2. Ortho- and para-H_2O observations of OH26.5+0.6 (left) and AFGL 5379 (right) showing detection of $H_2^{16}O$ (dotted black line and $H_2^{17}O$ (red dashed line) while the $H_2^{18}O$ (blue solid line) remains in the noise limit.



The observations can be reconciled if the stars have entered a phase of hot-bottom burning where ^{18}O is preferentially destroyed in the reaction ^{18}O(p,α)^{15}N, leaving the other two isotopes essentially untouched (Lattanzio & Wood 2003). In order for hot-bottom burning to operate, the temperature at the base of the convective layer has to be in excess of 80×10^6 K. This implies that the stellar initial mass of these objects are at least 5 $M_\odot$ (Karakas & Lattanzio 2014).

Further observations of the ortho transition $3_{12} - 3_{03}$ were taken on 3 additional extreme OH/IR stars (Fig. 3) on April 29, 2010 – the last observations by *Herschel*. It can be seen that the $H_2^{16}O$ and $H_2^{17}O$ have been detected in OH 32.8-0.3, OH 30.7-0.3 and IRAS 18488-0107 (tentatively) but not the $H_2^{18}O$.

Figure 3. HIFI observations of additional extreme OH/IR stars. The vertical lines mark the expected positions of all three isotopologues.



From the observations of these extreme OH/IR stars, we conclude that the progenitors of these are intermediate-mass stars with an initial mass of $\geq$ 5 $M_\odot$. We will investigate other extreme OH/IR stars in the *Herschel* archive to see if this is a common phenomenon for this type of objects.

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