

Circumstellar H₂O in M-type AGB stars

Matthias Maercker¹, Fredrik L. Schöier², and Hans Olofsson²†

¹Stockholm Observatory, AlbaNova University Center, 106 91 Stockholm, Sweden
email: maercker@astro.su.se

²Onsala Space Observatory, 439 92 Onsala, Sweden
email: schoier@chalmers.se, hans.olofsson@chalmers.se

Abstract. Surprisingly high amounts of H₂O have recently been reported in the circumstellar envelope around the M-type AGB star W Hya. However, substantial uncertainties remain, as the required radiative transfer modelling is difficult due to high optical depths, sub-thermal excitation and the sensitivity to the combined radiation field from the central star and dust grains.

Keywords. Stars: AGB and post-AGB, circumstellar matter, mass loss

1. Introduction

We perform a detailed radiative transfer analysis and determine abundances of circumstellar H₂O in the envelopes around six M-type AGB stars (Maercker *et al.* 2008a). ISO LWS spectra are used to constrain the circumstellar abundance distribution of ortho-H₂O. We also make predictions for H₂O emission lines in the range of the upcoming Herschel/HIFI mission. The HIFI data will resolve the line profiles, providing valuable additional information. To investigate the constraints set by also fitting the line profile of spectrally resolved lines, we include spectrally resolved Odin data of the 557 GHz ($1_{10} - 1_{01}$) ortho-H₂O line for R Cas, R Dor and W Hya (Maercker *et al.* 2008b). Finally, the new models are used to adjust the predictions made for the HIFI lines.

2. Radiative transfer modelling

A ‘standard’ model with a spherically symmetric circumstellar envelope (CSE), formed by a constant mass-loss rate and expanding at a constant velocity is assumed, resulting in a density structure where $\rho \propto r^{-2}$. Amorphous silicate dust (Justtanont & Tielens 1992) is used, with a single grain size ($a_d = 0.05 \mu\text{m}$) and mass density ($\rho_d = 2.0 \text{ g cm}^{-3}$). The dust and CSE parameters were determined separately and used as an input for the water vapour models. The dust density profile, the dust temperature profile, and the dust optical depth are determined using Dusty (Ivezić *et al.* 1999), fitting the SEDs to 2MASS and IRAS fluxes. The mass-loss rates, gas expansion velocities, and kinetic temperature distributions of the CSEs are determined in a circumstellar CO excitation analysis using a non-LTE radiative transfer code based on the Monte Carlo method (Schöier & Olofsson 2001). The modelling of the circumstellar H₂O emission lines is done using the ALI (accelerated lambda iteration) method (Bergman, OSO internal report). The code is a detailed non-LTE, and non-local, radiative transfer code, including 45 energy levels in the ground state and 45 energy levels in the first excited vibrational state of ortho-H₂O. Collision rates within the ground state, the first excited vibrational state and between the two states are included. The radiation from the central star, the

† On behalf of the Odin team

Table 1. Results of the best-fit models from fitting the ISO data. The difference to the observed intensities is given in % for the ISO lines (average difference of all lines), and for the Odin line where data is available. For WX Psc and IK Tau the theoretical radius from Netzer & Knapp (1987) is used, as no constraints could be set on the radius in the models.

Source	\dot{M} [$10^{-6} M_{\odot} \text{ yr}^{-1}$]	v_{exp} [km s^{-1}]	r_e [10^{15} cm]	f_0 [10^{-4}]	δ_{Odin} %	δ_{ISO} %	χ_{red}^2
TX Cam	7.0	18.5	20.0	3.0	-	-7	0.6
R Cas	0.9	10.5	3.0	3.5	+3	-5	0.3
R Dor	0.2	6.0	1.1	3.0	+46	-1	0.6
W Hya	0.1	7.2	2.2	15.0	+67	-1	0.5
WX Psc	40	19.3	43.0	0.02	-	-7	2.7
IK Tau	10	19.0	17.0	3.5	-	-9	1.2

circumstellar dust, and the cosmic microwave background are included. The adjustable parameters in the modelling are the abundance of ortho- H_2O (relative to H_2 and assuming a Gaussian abundance distribution), and the size of the H_2O envelope. The outer radius of the H_2O envelope is defined by the e-folding radius (abundance decrease to 37%). A comparison to the radius given by theoretical models of photodissociation of water (Netzer & Knapp 1987) is done.

3. Results and conclusions

The results of the H_2O line modelling based on the ISO observations are presented in Table 1. For all sources the H_2O abundances are high with respect to expectations based on stellar atmosphere equilibrium calculations. An exception is WX Psc, possibly indicating processes that reduce the amount of observed water vapour (such as adsorption onto dust grains) in this source. The H_2O abundances are accurate to approx. $\pm 50\%$ within the adopted model (the absolute accuracy is within a factor of approximately 5). We find that the lines generally are subthermally excited and the emitting region to be excitation limited. The predictions for HIFI show that these lines are readily observable, with self-absorption and P-Cygni profiles apparent in the model spectra. In order to fit the spectrally resolved Odin line in R Cas, R Dor and W Hya, a reduction in expansion velocity compared to the CO models is needed (-19% , -33% , and -25% , respectively). Inclusion of the Odin line sets considerably tighter constraints on the envelope size for all three objects, and requires a reduction of the outer radius for W Hya by 32%. The fits to the spectrally resolved lines give information on the velocity field of the CSEs. In addition, the low-energy Odin line sets significantly stronger constraints on the size of the CSEs, as the line is excited throughout the envelope. The origin of the HIFI lines lies inside the region where the Odin line is formed, the resolved line profiles from these observations will likely set important constraints on the velocity structure of, and abundance distribution within the CSEs.

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