Direct Probe of the Water Gas-Ice Chemistry in Embedded Protostars

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Introduction

Water has long been speculated to be a key molecule in the chemistry and physics of starforming regions, but its actual role is only now starting to emerge thanks to Herschel. To fully understand the water and oxygen chemistry one has to know the abundance of water in the gas phase and on the grains. In the cold envelope, where thermal evaporation does not play a significant role, other mechanisms (e.g., UV and cosmic ray induced photodesorption) take over.

In this study we aim to determine the amount of cold water vapour in the protostellar envelopes of the three embedded low-mass sources Serpens SMM 4, IRAS 15398-3302, and Elias 29, for which direct observations of water ice areavailable from IR spectroscopy. Herschel observations show the presence of water vapour through absorption features in the lowest rotational transitions of ortho- and para-water. Measuring the column densities allows us to directly determine the gas/ice column and thus test the gas-grain chemistry.

Analysis

Water in the cold outer envelope does not emit significantly (Caselli et al., 2010). The equation of radiative transfer thus reduces to

$$I_\nu = I_{\nu,0}\,\mathrm{e}^{-\tau_\nu}$$

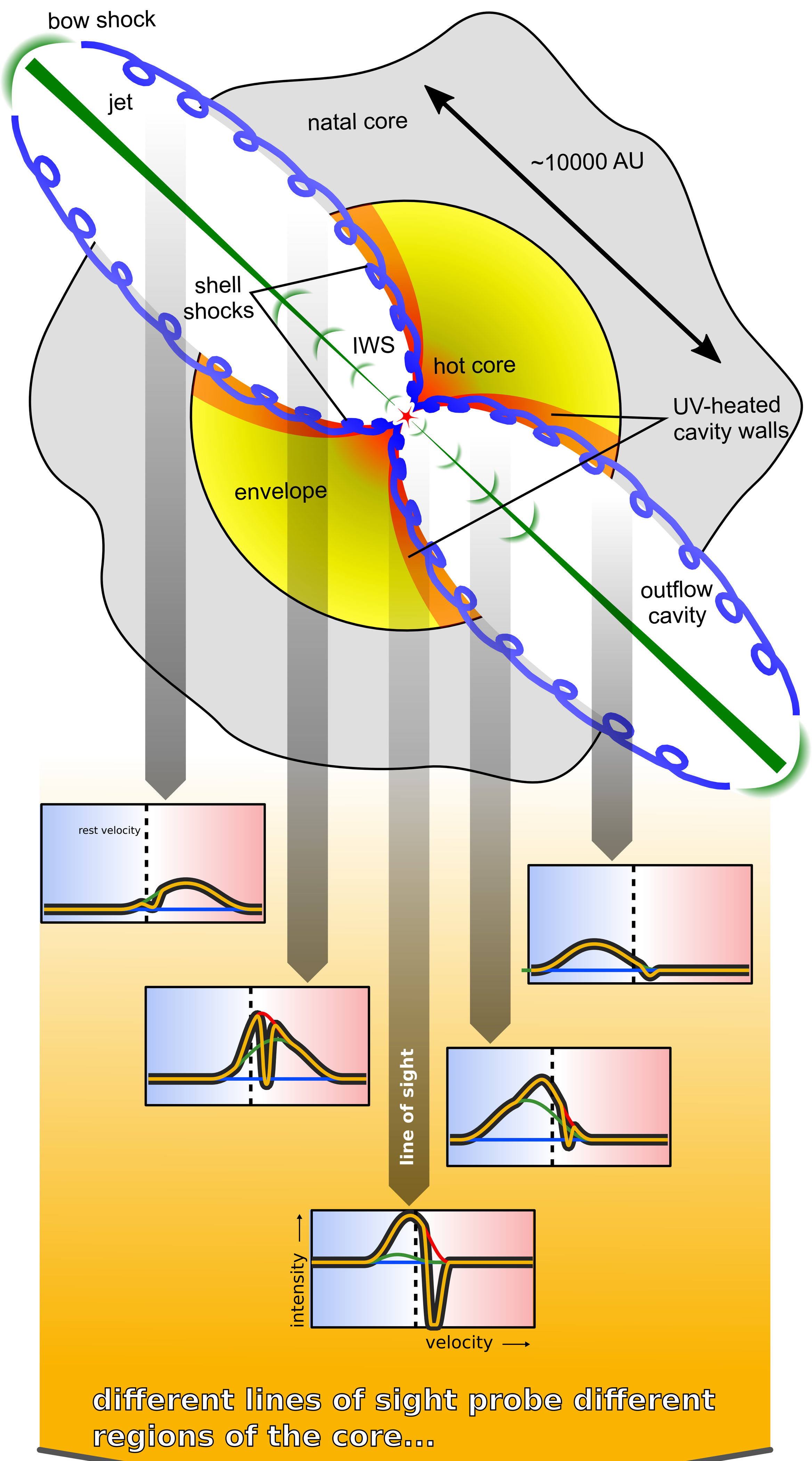
(measured intensity; background intensity; optical depth)

Many physical components are included in the Herschel beam (20-40"): the central warm region, UV-heated cavity walls and the outflow. Each of these are subject to a different absorbing column density. The observed spectrum is decomposed and takes the form

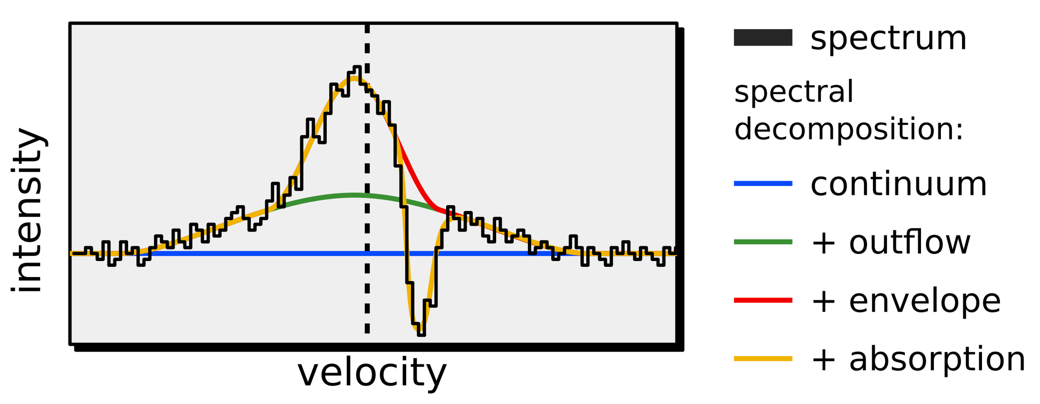
$$\mathrm{e}^{-\bar{\tau}_\nu} = f_{\nu,\mathrm{cont}}\,\mathrm{e}^{-\tau_{\nu,\mathrm{cont}}} + f_{\nu,\mathrm{env}}\,\mathrm{e}^{-\tau_{\nu,\mathrm{env}}} + f_{\nu,\mathrm{out}}\,\mathrm{e}^{-\tau_{\nu,\mathrm{out}}}$$

(measured optical depth; pencil beam optical depth; contributions from envelope, outflow; fraction of the total emission (sum up to unity))

The measured column density is a beam-averaged column density, and analysis of the different contributions yields the pencil beam optical depth, and thus the column density towards the core centre.

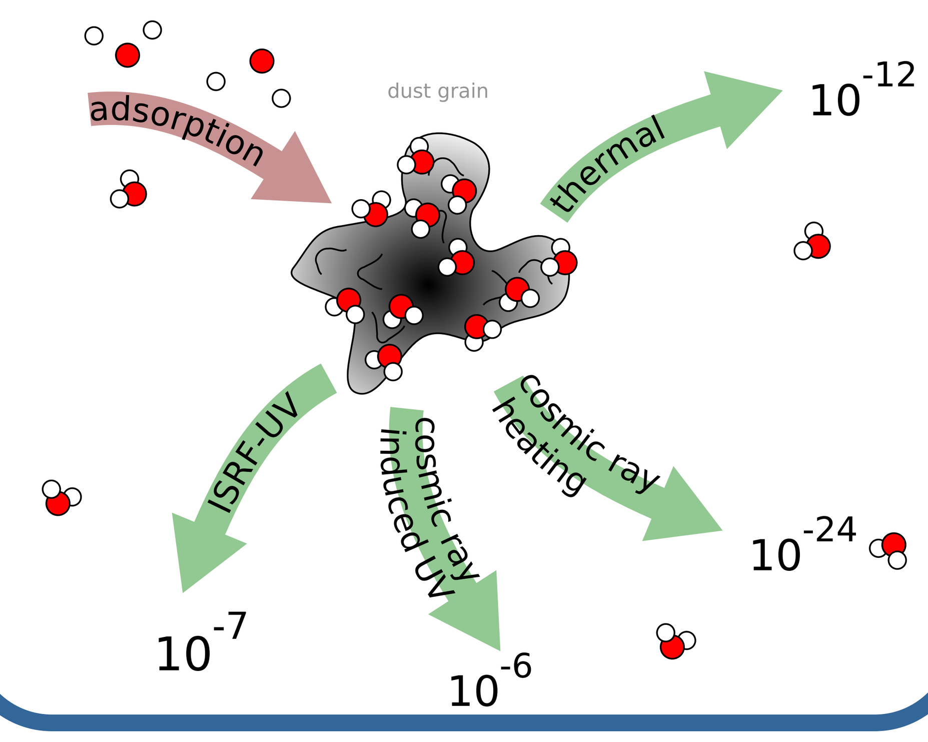


... but end all up in the same spectrum



Hop-on / Hop-off

Molecules that **freeze-out** on the dust grains have several ways of **desorbing** back into the gas phase. The numbers give an estimate for the desorption rates relative to adsorption in the envelope of protostellar cores (e.g. *Elias 29:* $n_{H2}=10^6 cm^{-3}$, T=60K, A_V=6mag)



Results

(water vapour column density; H_2 column density in regions with T<100K; water ice column density)

Source	$N(H_2O)_{gas}$ (10^{13} cm^{-2})	$N(H_2O)_{gas}/N(H_2)_{100K}$ (10^{-10})	$N(H_2O)_{gas}/N(H_2O)_{ice}$ (10^{-5})
Elias 29	1.3	10.5	0.42[a]
IRAS 15398	2.9	1.09	0.20[a]
Ser SMM4	4.2	0.83	0.42[b]

Notes.
[(a)] $N(H_2O)_{ice}$ from Boogert et al. (2008)
[(b)] using a abundance of $N(H_2O)_{ice}/N(H_2) = 9.0\,10^{-5}$ (Pontoppidan et al., 2004)

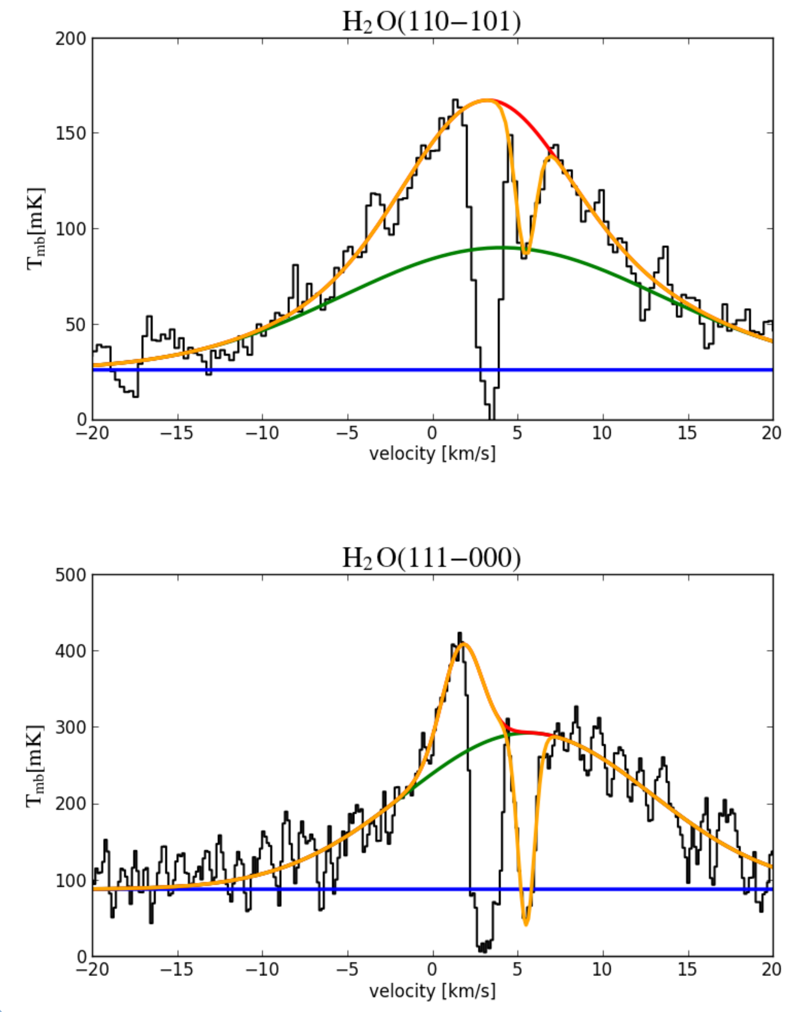
- The **abundances of water vapour** wrt. to hydrogen molecules are of the order of 10^{-10}, and therefore closely related to **prestellar cores** (Caselli et al., 2010).
- All protostellar cores show **gas-to-ice abundances** of the order of merely a few 10^{-6}.
- Additional modelling shows **ice-to-hydrogen abundances** of the order of 10^{-4}.

References

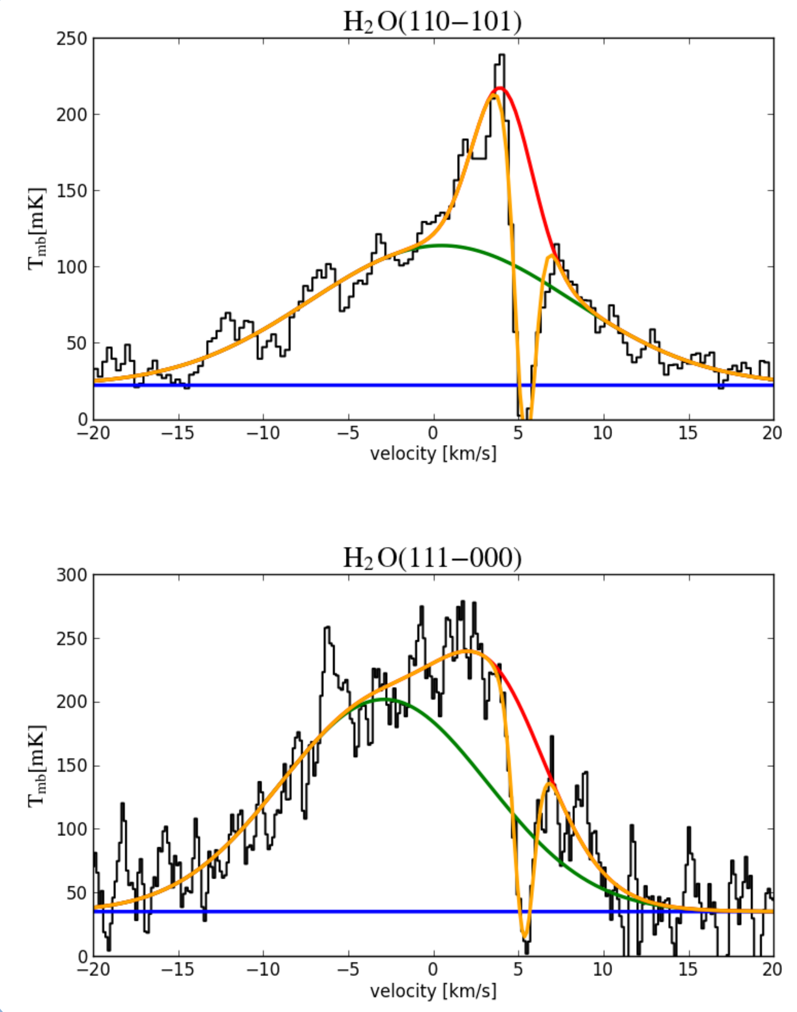
Boogert, A.C.A. et al. 2002, ApJ, 570, 708
Boogert, A.C.A., et al. 2008, ApJ, 678, 985
Caselli, P., et al. 2010, A&A, 521, L29
Pontoppidan, K.M., van Dishoeck, E.F., & Dartois, E. 2004, A&A, 426, 925

Protostellar Water Gallery

Elias 29



IRAS15398



Ser SMM4