Water Gas and Ice in Protostellar Envelopes

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Infrared-bright protostars form a unique class of sources for which both water gas and ice can be observed. We introduce a Simplified Water Network (SWaN) to model the data and test it against full gas-grain models as well as *Herschel*-HIFI spectra of a class 0 protostar. The combined *Herschel*-HIFI and *Spitzer*/VLT data on nine sources are then compared and analysed using SWaN, giving typical ice/gas ratios of 10^3 at the core edge and up to 10^7 deeper into the core. A quantification of the oxygen budget reveals that a large fraction of the oxygen is still unidentified.

▶ What is the *Simplified Water Network* SWaN?

Since chemical networks usually contain hundreds of species and thousands of reaction channels, smaller networks with a particular focus are developed (e.g., [1,2]). SWaN is a simplified network (depicted in the central Figure) that includes only reactions and species that are needed to reliably determine the abundance structure of water vapour and ice:

- ▶ **photodissociaton of water vapour** into atomic oxygen through *interstellar (ISRF)* or *cosmic-ray-induced (CR-induced)* UV photons,
- ▶ **freezeout of atomic oxygen** and immediate hydrogenation to form water ice,
- ▶ **freezeout of water vapour**, and
- ▶ **desorption of water ice** through grain heating or UV photons.

Figure 1 shows a collection of water vapour abundance profiles for a protostellar core. The profiles *V11*, *A13*, and *W13* result from sophisticated chemical models, and show good agreement with SWaN. The *drop* function is a phenomenological model to account for the ISRF UV photodesorption layer on the core edge (e.g., [3]).

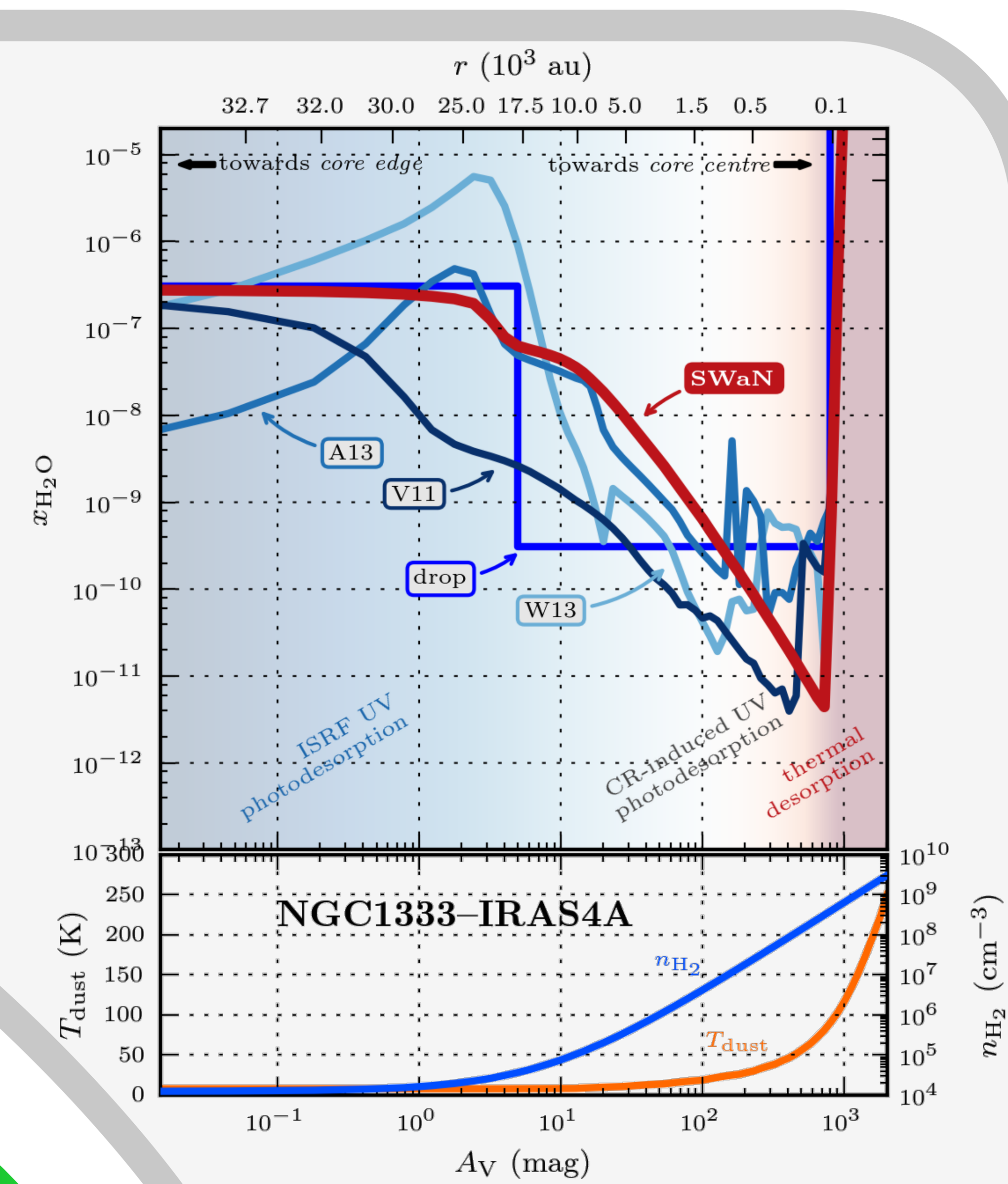
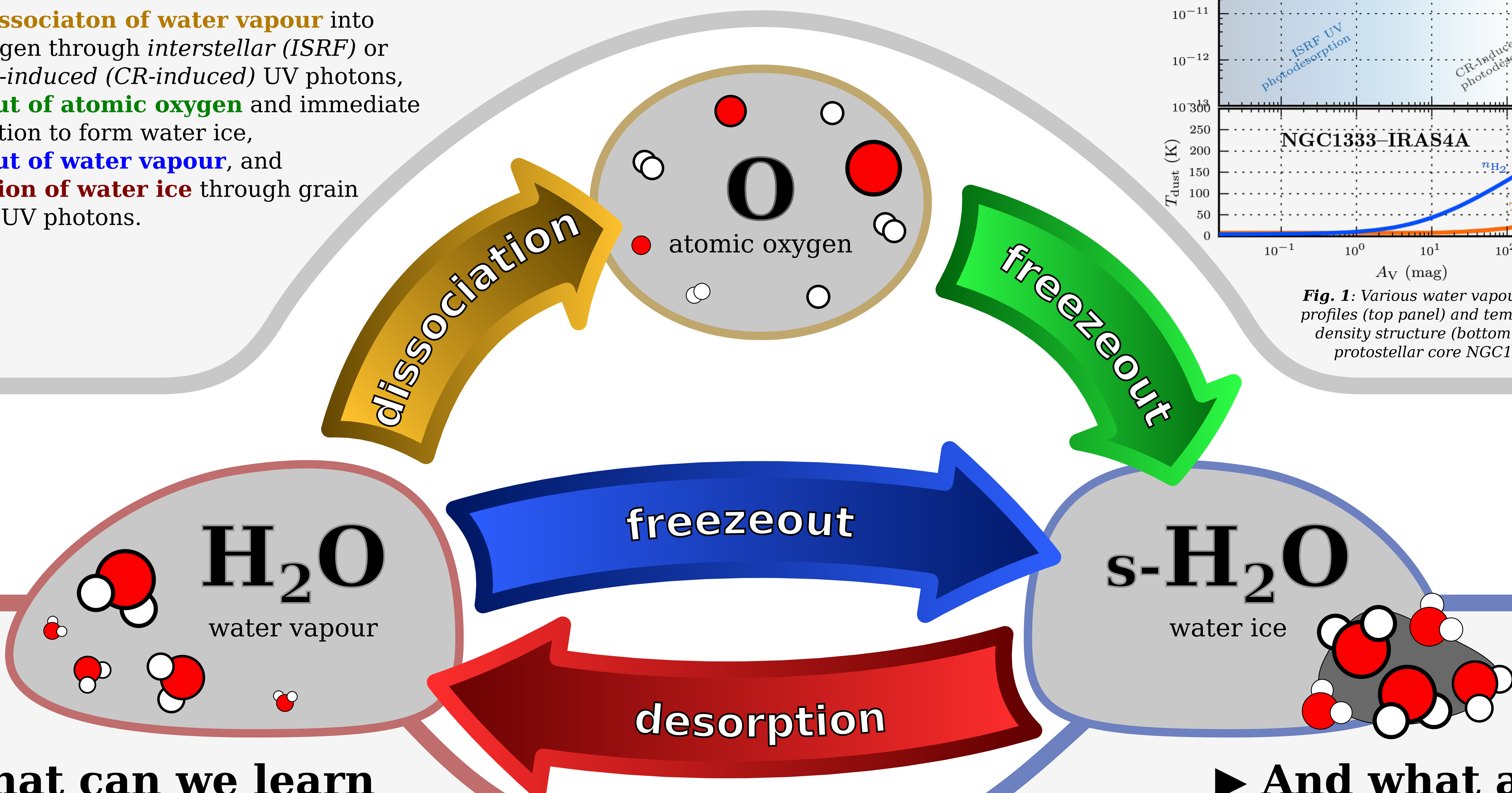


***Fig. 1**: Various water vapour abundance profiles (top panel) and temperature and density structure (bottom panel) of the protostellar core NGC1333–IRAS4A.*



▶ What can we learn about the water vapour?

Radiative transfer modelling shows that *drop abundance* profiles cannot fully reproduce certain water emission lines, whereas chemically modelled abundance profiles like SWaN return reliable results (Figure 2; [1,3]). Additionally, this allows us also to constrain and/or test physical parameters (CR-induced UV field, photodesorption yield, etc.).

As an example, the abundance profiles that are modelled with SWaN allow Mottram et al. (**Poster 1B083**) to follow the infall motion of water throughout protostellar envelopes.

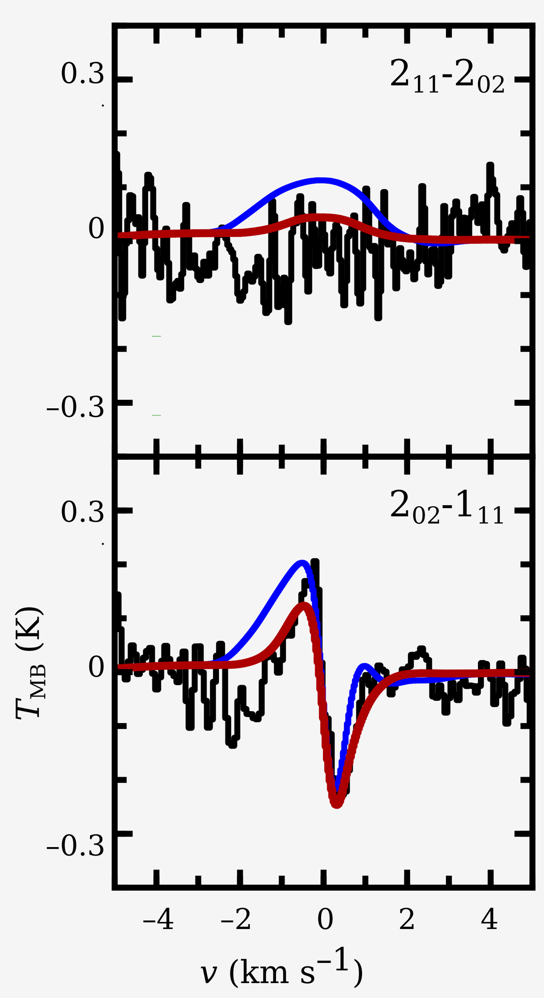


***Fig. 2**: Synthetic water emission spectra for a drop abundance profile (blue) and SWaN (red) compared to observed water spectra ([5]).*

▶ And what about water ice?

In the dense intracloud medium, the oxygen locked up in dust grains, ices, and CO gas can only account for a fraction of its elemental abundance (relative to H) of 575 ppm ([4,5]), whereas a large part is so-called "Unidentified Depleted Oxygen" (UDO, [6]). With SWaN we can estimate the amount of O, H_2O, and s-H_2O, which enables us to quantify the amount of UDO in protostellar cores (Figure 3). The simplicity of SWaN allows us to quickly probe the parameter space of different initial conditions and physical parameters to check the consistency of this first result, or if we can "identify" some of the UDO.

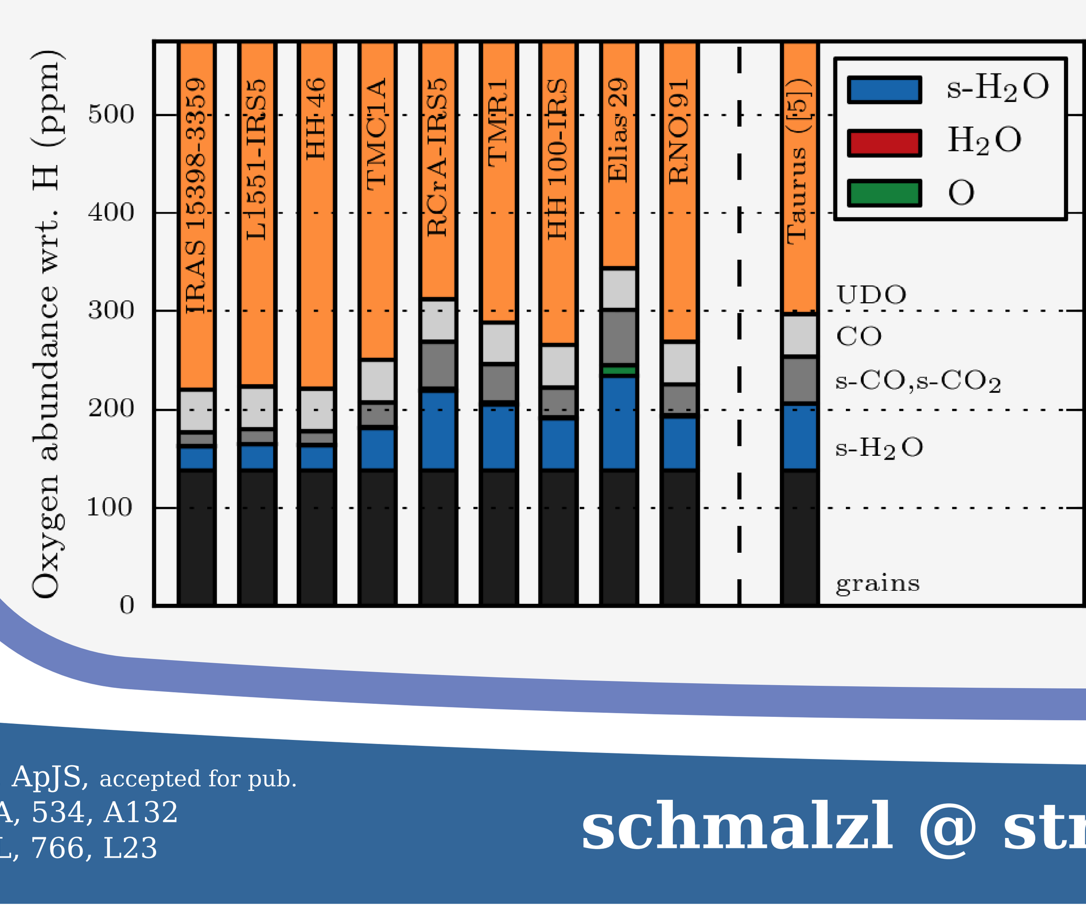


***Fig. 3**: The oxygen budget of a sample of nine protostellar cores compared to Taurus ([5]). SWaN models the abundance of O, H_2O and s-H_2O, using observations of water ice ([7,8]) to determine the overall oxygen abundance in the chemical network. The contributions from grains, s-CO, s-CO_2, and CO are estimated from [5,9].*

References:
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[V11] Visser et al. (2011), A&A, 534, A132
[W13] Walsh et al. (2013), ApJL, 766, L23

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