X-ray-induced chemistry of water and related molecules in low-mass protostellar envelopes

Shota Notsu,[1] Ewine F. van Dishoeck,[2,3] Catherine Walsh,[4] Arthur D. Bosman,[5] and Hideko Nomura[6]

[1]Star and Planet Formation Laboratory, RIKEN Cluster for Pioneering Research, Japan
[2]Leiden Observatory, Faculty of Science, Leiden University, The Netherlands
[3]Max-Planck-Institut für Extraterrestrische Physik (MPE), Germany
[4]School of Physics and Astronomy, University of Leeds, UK
[5]Department of Astronomy, University of Michigan, USA
[6]Division of Science, National Astronomical Observatory of Japan, Japan

Water is a key molecule in star and planet forming regions. Recent water line observations toward several low-mass protostars suggest low water gas fractional abundances (<10^-6) in the inner warm envelopes (r<100 au). Water destruction by X-ray radiation has been proposed to influence the water abundances in these regions, but the detailed chemistry, including the nature of alternative oxygen carriers, is not yet understood. In our study [1], we calculated the chemical composition of low-mass Class 0 protostar envelopes using a detailed gas-grain chemical reaction network including X-ray induced chemical reactions. We aimed to understand the impact of X-ray radiation on the composition of low-mass protostar envelopes, focusing specifically on water the related oxygen bearing species.

On the basis of our calculations [1], the protostar X-ray luminosity has a strong effect on the water gas abundances, both within and outside the water snowline (T<100K, r<100 au). Outside the water snowline, the water gas abundance increases with X-ray luminosities, due to X-ray-induced photodesorption of water ice. Inside the water snowline, water maintains a high abundance of 10^-4 for low X-ray luminosities, with water and CO dominant oxygen carriers. For high X-ray luminosities (>10^30 erg/s), the water gas abundances significantly decrease just inside the water snowline (down to ~10^-8–10^-7) and in the innermost regions with T >250K (~10^-6). For these cases, the fractional abundances of molecular and atomic oxygen gas reach <10^-4 within the water snowline, and they become the dominant oxygen carriers. In the presence of strong X-ray fields, gas-phase water molecules within the water snowline are mainly destroyed with ion-molecule reactions and X-ray-induced photo-dissociation. In addition, the fractional abundances of HCO+ and CH3OH, which have been considered to be tracers of the water snowline, significantly increase and decrease within the water snowline, respectively, as the X-ray fluxes become larger. These X-ray effects are larger in envelope models with lower number densities. Future molecular line observations for protostars (using e.g., ALMA, ngVLA) will access the regions around protostars where such X-ray induced chemistry is effective.

References

[1] Notsu. S., et al., 2021, A&A, 650, A180