Hot compressed ices in exoplanetary interiors

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Abstract

'Ices' of water, ammonia and methane (and mixture thereof) are major components of interstellar and planetary bodies, from comets to the icy moons of the Jovian planets or the thousands of newly discovered water/ice-rich exoplanets [1-3]. Current models of the internal structure of water-rich exoplanets assume the existence of thick ice mantle layers overlaying a rocky and/or metallic core [3]. Understanding the behaviour of hot compressed ice phases at relevant conditions (>50 GPa and 2000 K) is thus critical to model the internal structure and dynamics of large icy bodies from the growing number of remote geophysical observations [4,5]. Despite extensive investigation, experimental studies have largely focused on end-members, while the behaviour of more complex systems remains less well resolved.

Here I will discuss our recent results on the phase relations, chemical reactivity and thermal properties of HCNO ices achieved by static and dynamic compression approaches in diamond anvil cells coupled with X-ray diagnostics at PETRA III and the European XFEL. Specifically, I will present studies that show 1) chemical reactions in the H_2O-NH_3 system that stabilize ultra-water rich ammonia hydrates in the icy mantle layers of water/ice-rich exoplanets; 2) the effect of compression rates on the crystallization pathway and the stability of phases in the H_2O-NH_3 system; and 3) complexities in the phase relations of CH_4 at extreme conditions. Moreover, I will illustrate new opportunities for the study of the thermal conductivity of planetary ices that leverage the unique characteristics of the XFEL source to directly heat and probe samples with consecutive X-ray pulses. The picture that emerges from these studies is a large compositional and structural diversity in simple systems, and provides evidence for complex interactions between H_2O ice and volatiles at high pressure-high temperature conditions. The implications of these results to interior modelling of ice exoplanets will be discussed.

[1] Borucki et al. Science 327:977 (2010).

[2] Noack et al. *Space Sci. Rev.* 212, 877–898 (2017).

[3] Sotin et al. *Icarus* 191, 337–351 (2007)

[4] Nettelmann et al. *ApJ* 733, 2 (2011).

[5] Helled et al. *Exp. Astron.* 53, 323–356 (2022).