Exploring light C:H:N:O mixtures at conditions of ice giant interiors

The interiors of the ice giants Uranus and Neptune are largely composed of the light elements hydrogen, helium, carbon, nitrogen and oxygen (CHNO) at extreme pressures of several million atmospheres and temperatures of several thousand kelvins. These environments presumably allow the formation of unfamiliar structures, such as superionic states of water and ammonia, and exotic chemistry, e.g., the dissociation of hydrocarbons into diamond and metallic hydrogen. These processes are highly complex and, so far, cannot be modelled reliably with existing theory and simulation methods. At the same time, they are thought to significantly shape the internal structure and evolution of Uranus and Neptune and may be key to explain the unusual magnetic fields observed for both planets, and to elucidate their internal heat balance. Moreover, planets of similar size and probably composition, in particular so-called “sub-Neptunes”, are found to be highly abundant outside our Solar System. Thus, a better understanding of matter at conditions comparable to the interior of ice giants is required for both better models of our Solar System and a reliable classification of exoplanets from telescope data of mass and radius.

In the last years, the PHYHDEL group at the LULI laboratory at the Ecole Polytechnique in France started a scientific program focused on the characterisation of the properties of CHNO mixtures under high pressure and temperature conditions obtained with laser-generated shock compression. A DFG-ANR collaborative project, PROPICE, between PHYHDEL and the German team headed by Prof. D. Kraus, has lately been granted to pursue this research with focus on *in situ* microscopic probing. This PhD thesis fits into this context and it is funded by this project. It will build on the results previously obtained and enlarge their scope by leveraging on unique possibilities offered by high-power optical lasers and X-Ray Free Electron Lasers (XFEL) facilities based in Germany (EuropeanXFEL), USA (LCLS) and Japan (SACLA).

In this project the student will perform experiments to benchmark equations of state, melting curves and transport properties for new mixtures and over unexplored thermodynamic conditions. In particular, the candidate work will include water-ammonia mixtures with different concentrations, CH4 and various CHNO mixtures. At high pressures, calculations predict very peculiar properties that would highly impact interiors and dynamo models of ice giants and thus must be experimentally confirmed. These measurements will involve classical optical diagnostics.

In parallel, he/she will complement these results with microscopic data obtainable with X- ray diagnostics. This will allow a direct investigation of the physical and chemical processes into play. To this aim, the student will work in adapting the liquid samples of different ice mixtures to X-ray diagnostics implemented at current XFEL facilities. Direct characterization of super-ionic lattices, phase separation or polymerization will be obtained using x-ray diffraction, X-ray Thomson scattering and Small Angle Scattering diagnostics. The use of liquid samples gives enough freedom in changing H_2O/N/C stoichiometry so that N-H-O, C-H-O and more comprehensive C-H-N-O environments will be accessible. A comparison between various concentrations, including pure compounds, will underline the chemical processes associated with different specimens.

During this PhD project, the candidate will perform experiments on the most powerful lasers and XFEL facilities worldwide accessing unique data set that he/she will collect and analyze. The student will be based at the LULI laboratory, near Paros, but he/she will work in close collaboration with the German partner. He/She will profit from a fruitful environment benefiting from interactions and exchanges within both the French and German teams. Experiments will also be intermixed with discussion sessions on collected data with relevant experts from the ab-initio and planetary model communities.

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