Dense Plasma Chemistry of Hydrocarbons

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Carbon-hydrogen demixing and subsequent diamond precipitation has been predicted to strongly participate in shaping the internal structure and evolution of icy giant planets like Neptune and Uranus. The very same dense plasma chemistry is also a potential concern for CH plastic ablator materials in inertial confinement fusion (ICF) experiments where similar conditions are present during the first compression stage of the imploding capsule. Here, carbon-hydrogen demixing may enhance the hydrodynamic instabilities occurring in the following compression stages. First experiments applying dynamic compression and ultrafast in situ X-ray diffraction at SLAC's Linac Coherent Light Source demonstrated diamond formation from polystyrene (CH) at 150 GPa and 5000 K [1]. Very recent experiments have now investigated the influence of oxygen, which is highly abundant in icy giant planets on the phase separation process. Compressing PET ($C_5H_4O_2$) and PMMA ($C_5H_8O_2$) we find again diamond formation at pressures above ~150 GPa and temperatures of several thousand kelvins, showing no strong effect due to the presence of oxygen. Thus, diamond precipitation deep inside icy giant planets seems very likely. Moreover, small-angle X-ray scattering (SAXS) was added to the platform, which determines an upper limit for the diamond particle size, while the width of the diffraction features provides a lower limit. We find that diamond particles of several nanometers in size are formed on a nanosecond timescale. Finally, spectrally resolved X-ray scattering is used to absolutely scale amorphous diffraction signals and additionally allows for determining the amount of carbon-hydrogen demixing inside the compressed samples even if no crystalline diamond is formed. This whole set of diagnostics provides unprecedented insights into the nanosecond kinetics of dense plasma chemistry.

[1] D. Kraus et al., Nature Astronomy 1, 606-611 (2017).