Phase Separation in Giant Planet Interiors and Novel First-Principles Simulation of Plasmas

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Abstract

The Kepler satellite has detected over 2000 planets in distant solar systems. Starting with a brief overview over the search for such extrasolar planets, this talk will discuss the state of matter at high temperature and pressure conditions that prevail in the interiors of giant planets. We describe how data from the Galileo mission to Jupiter has been combined with first-principles simulations to demonstrate that hydrogen and helium phase-separate at high pressure causing helium rain to occur in the interior of this planet [1]. We then characterize the state of matter in the cores of giant planets. In particular, we focus on the question whether typical core materials like metals, rock, and ices are stable when they are exposed to metallic hydrogen at megabar pressures and temperatures exceeding 10,000 K. By combining Gibbs free energy calculations with density functional molecular dynamics simulations, we could show that water ice [2] and magnesium oxide [3] dissolve into the layers of metallic hydrogen that surround Jupiters core. This implies that the cores of Jupiter, Saturn, and many exoplanets have, at least partially, been eroded. Furthermore, we report simulation results from an all-electron path integral Monte Carlo (PIMC) method that we developed for the regime of warm dense matter and applied to study hot, dense water and carbon plasmas [4]. We extend PIMC simulations beyond hydrogen and helium to elements with core electrons. PIMC pressures, internal energies, and

pair-correlation functions compare well with density functional molecular dynamics at lower temperatures and enable the construction of a consistent equation of state over the pressure-temperature range of $1-50$ Mbar and $10^4 - 10^9$ K.

[1] H. F. Wilson and B. Militzer, "Sequestration of noble gases in giant planet interiors", Phys. Rev. Lett. 104 (2010) 121101

[2] H. F. Wilson, B. Militzer, " Rocky core solubility in Jupiter and giant exoplanets", Phys. Rev. Lett., in press (2012).

[3] H. F. Wilson, B. Militzer, "Solubility of water ice in metallic hydrogen: consequences for core erosion in gas giant planets", Astrophys. J. Lett. 745 (2012) 54.

[4] K. P. Driver, B. Militzer, "All-Electron Path Integral Monte Carlo Simulations of Warm Dense Matter: Application to Water and Carbon Plasmas", Phys. Rev. Lett., in press (2012).