Contribution ID: **10** Type: **not specified**

Matter Under Planetary Interior Conditions

Wednesday, 21 June 2017 09:15 (30 minutes)

The behaviour of warm dense matter (pressures up to the TPa region and temperatures up to several eV) is of paramount importance for understanding the interior, evolution, and magnetic field of solar and extrasolar planets. While the light elements H and He are the main components of gas giants like Jupiter, mixtures of C-N-O-H-He are relevant for Neptune-like planets, and minerals of the MgO-FeO-SiO2 complex are the building blocks of rocky planets (Earth, super-Earths). The high-pressure phase diagram of these elements and mixtures has to be known in order to develop corresponding models, see [1] for H/He. Of special interest in this context is the location of the melting line, e.g., of Fe [2], the occurrence of demixing effects, e.g., in H/He [1,3] and (Mg,Fe)SiO3 [4], and of metal-insulator transitions; for H/He see [1,5]. These high-pressure phenomena have a strong impact on interior, evolution, and dynamo models for planets and, simultaneously, constitute a major challenge to computational physics.
We used molecular dynamics simulations based on finite-temperature density functional theory to predict the equation of state, the high-pressure phase diagram, and the transport properties of warm dense matter for a wide range of densities and temperatures as typical for the interior of planets. Results were obtained for, e.g., H/He [6,7], H2O [8], NH3 [9], and MgO [10]. These data were benchmarked against DAC and shock-wave experiments and then applied to construct interior and evolution models for giant planets like Jupiter [11] and Uranus [12]. The treatment of more complex mixtures such as H/He, H2O-NH3, or MgO-FeO is in progress. Furthermore, new high-pressure techniques such as double-stage [13] and dynamic DACs [14] but also dynamic quasi-isentropic compression experiments will extend the pressure-temperature range studied at synchrotrons [15], free electron laser facilities [16], or with intense heavy ion beams [17]. These combined efforts will lead to a better understanding of the physics of warm dense matter and of planetary interiors.

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Session Classification: HED and Applications