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The proto-neutron star inner crust in a multi-component plasma approach

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Proto-neutron stars are born hot, with temperatures exceeding few 10^{10}K. In these conditions, the crust of the proto-neutron star is expected to be made of a Coulomb liquid and composed of an ensemble of different nuclear species. In this work, we perform a study of the beta-equilibrated proto-neutron-star crust in the liquid phase in a self-consistent multi-component approach, which also allowed for a consistent calculation of the impurity parameter, often taken as a free parameter in cooling simulations. To this aim, we developed a self-consistent multi-component approach at finite temperature using a compressible liquid-drop description of the ions, with surface parameters adjusted to reproduce experimental masses. The treatment of the motion of the ion centre of mass was included through a translational free-energy term accounting for in-medium effects. The results of the self-consistent calculations of the multi-component plasma are systematically compared with those performed in a perturbative treatment as well as in the one-component plasma approximation.

We show that the inclusion of non-linear mixing terms arising from the centre-of-mass motion leads to a breaking in the ensemble equivalence between the one-component and multi-component approach. Our findings also illustrate that the abundance of light nuclei becomes important, and eventually dominates the whole distribution, at higher density and temperature in the crust. This reflects in the impurity parameter, which, in turn, may have a potential impact on neutron-star cooling. For practical application to astrophysical simulations, we also provide a fitting formula for the impurity parameter in the proto-neutron star inner crust. Our results obtained within a self-consistent multi-component approach show important differences in the prediction of the proto-neutron star composition with respect to those obtained with a one-component or perturbative multi-component approximations, particularly in the deeper region of the crust. This highlights the importance of a full self-consistent multi-component plasma calculation for reliable predictions of the proto-neutron-star crust composition.

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