NUCLEAR PASTA: INHOMOGENEOUS NEUTRON-RICH MATTER IN NEUTRON STARS AND ASTROPHYSICAL IMPLICATIONS

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The condensation of spatial structure out of a homogeneous nuclear fluid as density and/or temperature is decreased below around saturation density and a few MeV respectively is mediated by a series of phases that has come to be referred to as “nuclear pasta”. Such phases are astrophysically relevant: they are predicted to exist in neutron stars from their birth through to their old age. We present detailed 3D quantum calculations of nuclear pasta in neutron star crusts and proto-neutron stars, focusing on how their properties depend on the equation of state of pure neutron matter at sub-saturation densities. We predict that over 50% of the mass and 15% of the thickness of a neutron star crust is taken up by nuclear pasta independent of uncertainties in the nuclear equation of state. We show that nuclear pasta likely co-exists with spherical nuclei at the lowest densities, and that multiple phases of pasta likely coexist at higher densities. We explore some possible observational implications of pasta: (1) as a proto-neutron star cools, neutrino scattering from nuclear pasta tends to keep the outer layers of the star hotter for longer, resulting in an observable imprint on the late-time neutrino signal from supernovae; (2) as a neutron star crust condenses, pasta likely forms microscopic domains characterized by different nuclear geometries, enhancing the disorder of the inner crust and contributing to an observable signal in the cooling of older accreting neutron stars in quiescence.

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