Density functional approach to superfluid phonon in inner crust of neutron stars

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Abstract: The inner crust of neutron stars is characteristic nuclear matter consisting of neutron superfluid with subnuclear density and a Coulomb lattice of neutron-rich nucleon clusters. Properties of the inner crust are governed by the superfluidity and the pair correlation of neutrons. The superfluid necessarily exhibits a collective mode of excitation, known as superfluid phonon. Recently the superfluid phonon mode has attracted attentions as it may influence thermal transport properties of transient phenomena of magnetized neutron stars, seismic oscillation of the crust, etc.

In the present work, we investigate collective excitations of inner crust in the framework of microscopic nuclear many-body method, i.e. by applying the density functional approach which has been proved very powerful in describing collective excitations of isolated nuclei. In contrast to macroscopic models adopted in the previous studies, which essentially assume uniform superfluid, we intend to clarify influences of the presence of nuclear clusters on the superfluid.

We apply the Skyrme-Hartree-Fock-Bolubobov model to find the pair correlated ground state of nucleons, and the quasi-particle random phase approximation to explore collective excitations. Numerical calculations are performed on the dipole mode under the Wigner-Seitz approximation assuming a spherical cell. We confirm universal emergence of the superfluid phonon mode, but more interestingly we found that the calculated superfluid phonon is found significantly influenced by the nuclear cluster: the phonon amplitude does not penetrate into inside of the cluster as if the superfluid phonon can takes place only outside the nuclear cluster. This find suggests possible large contribution of the superfluid phonon to the thermal conductivity.