SHEAR MODULUS OF NEUTRON STAR CRUST: HASHIN–SHTRIKMAN BOUNDS

Zemlyakov N.A.,* Chugunov A.I.

IPTI RAS, Saint-Petersburg, Russia

**zemlyakov@mail.ioffe.ru*

To explain various observational phenomena of neutron stars, a quantitative description of the elastic properties of their crust are essential. To describe response for shear deformations, an effective shear modulus is introduced, with the neutron star crust matter modeled as an isotropic polycrystalline material, composed of crystallites of sufficiently small size. To date, the elastic properties of individual crystallites are well understood. However, as it is well known for terrestrial materials, the elastic constants of a polycrystal cannot be directly derived from the elasticity tensor of individual crystallites. In neutron star crust physics, the Voigt method is commonly used; as noted in [Hill, 1952] it leads to an upper bound on the shear modulus of the polycrystal. The Reuss method provides a lower bound. In [Kobyakov & Pethick, 2015], an alternative estimate was proposed based on self-consistent theory [Kröner, 1958; Eshelby, 1961], which assumes that crystallites are spherical. However, as shown in a recent study [Yang Wu et al., 2023] on a similar problem for composites, the self-consistent estimate is significantly affected by the assumed shape of the crystallites.

This study presents new constraints on the effective shear modulus of the neutron star crust using the Hashin-Shtrikman variational approach, a method well-known in terrestrial material science. Applying this approach allowed us to establish Hashin-Shtrikman bounds, which reduce the possible range of the effective shear modulus of the crust by more than 15% compared to the previously used Voigt-Reuss bounds. Similar to the latter, the Hashin-Shtrikman bounds do not depend on the shape or size of the crystallites in the polycrystalline crust. However, unlike the Voigt-Reuss bounds, the Hashin-Shtrikman bounds are valid only if there are no correlations between crystallites. There are examples in the literature where these bounds are violated for polycrystals with ordered crystallite orientations.