Divergence of the isospin asymmetry expansion of the nuclear equation of state

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We have extracted [1] from realistic chiral nuclear interactions the quadratic, quartic, and sextic terms in the isospin-asymmetry expansion of the equation of state of nuclear matter at finite temperature,

\[
F(T, \rho, \delta) \approx \sum_{n=0}^{N} A_{2n}(T, \rho) \delta^{2n},
\]

(1)

from second-order many-body perturbation theory. In the bottom-right panel of Fig. 1, we observe that the quadratic coefficient \(A_2\) describes well the global isospin asymmetry dependence from symmetric nuclear matter to pure neutron matter by comparing to the symmetry energy \(F_{\text{sym}} = F(T, \rho, \delta = 1) - F(T, \rho, \delta = 0)\). The higher-order terms, however, are shown to be large and alternating in sign (see the top-right and bottom-left panels of Fig. 1) at low temperature and high density, indicating a divergent series incompatible with the traditional assumption in Eq. (1). In Ref. [2] it was shown that at zero temperature an S-wave contact interaction gives an additional logarithmic contribution to Eq. (1) when

\[
\text{FIG. 1. Coefficients of the Maclaurin expansion for the isospin-asymmetry dependence of the nuclear equation of state as a function of temperature and density from two chiral nuclear force models. The difference between the nuclear symmetry energy } F_{\text{sym}} \text{ and the } A_2 \text{ coefficient is shown in the bottom-right panel.}
\]
computed at second order in perturbation theory. Extracting this nonanalytic term leads to a significant improvement in the description of the free energy per particle at large isospin asymmetries. In future work these results will be used to study the crust-core transition density in neutron stars and the threshold density for the onset of direct URCA processes relevant for neutron star cooling.

[1] C. Wellenhofer, J.W. Holt, and N. Kaiser, Phys. Rev. C 93, 055802 (2016).
[2] N. Kaiser, Phys. Rev. C 91, 065201 (2015).