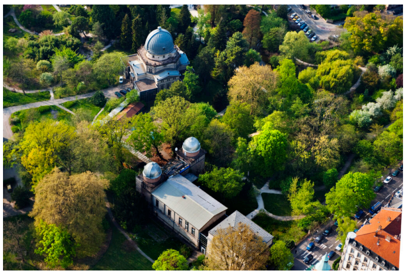

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The thermal index of neutron-star matter in the virial approximation

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We study the thermal index of low-density, high-temperature dense matter, using the virial expansion to account for nuclear interaction effects (G.R. et al 2025 ApJ 987 67). We focus on the region of validity of the expansion, which reaches 10^{-3} fm^{-3} at $T = 5$ MeV up to almost saturation density at $T = 50$ MeV.
In pure neutron matter, we find an analytical expression for the thermal index, and show that it is nearly density- and temperature-independent, within a fraction of a percent of the non-interacting, non-relativistic value of $\Gamma_{\rm th} \approx 5/3$.
When we incorporate protons, electrons and photons, we find that the density and temperature dependence of the thermal index changes significantly.
We predict a smooth transition between an electron-dominated regime with $\Gamma_{\rm th} \approx 4/3$ at low densities to a neutron-dominated region with $\Gamma_{\rm th} \approx 5/3$ at high densities. This behavior is by and large independent of proton fraction and is not affected by nuclear interactions in the region where the virial expansion converges.
We model this smooth transition analytically and provide a simple but accurate parametrization of the inflection point between these regimes. When compared to tabulated realistic models of the thermal index, we find an agreement that is of the order of 2% at high temperatures but remains commensurate, at the 5-10% level, for colder matter. The discrepancies can be attributed to the missing contributions of nuclear clusters.
The virial approximation provides a clear and physically intuitive framework for understanding the thermal properties of dense matter, offering a computationally efficient solution that makes it particularly well-suited for the regimes relevant to neutron star binary remnants.

Presenter: RIVIECCIO, Giuseppe