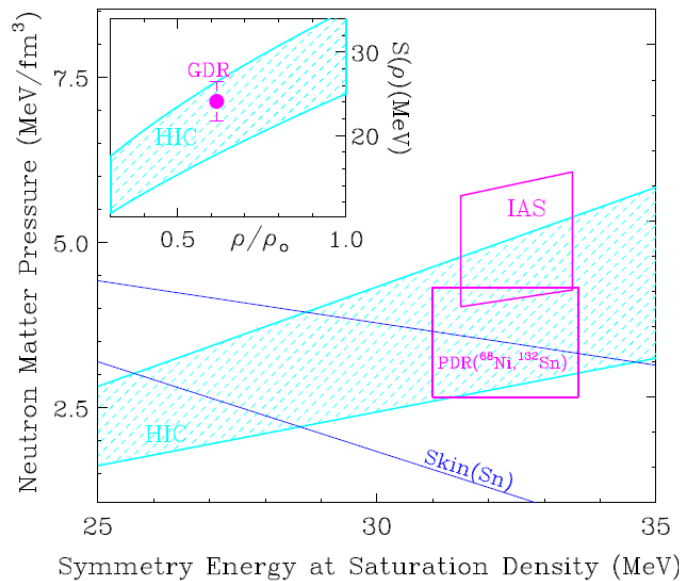


## Constraints the symmetry energy in the nuclear equation of state

The nuclear equation of state is a thermodynamic description of the average behavior of a large volume of nuclear matter in exact analogy to the equation of state of a gas or any other phase of matter. The nuclear symmetry energy is a component of the nuclear equation of state that describes the variation of the nuclear binding energy as a function of proton ( $Z$ ) and neutron ( $N$ ) numbers. While the range of neutron-to-proton number is relatively small in nuclei, neutron stars are thought to be close to pure neutron matter. In this case the nature and stability of phases within the star, the composition and the thickness of its inner crust, the frequencies of vibrations of the crust and its radius, among other properties, depend strongly on the symmetry energy and its density dependence.

JINA researchers and their colleagues at the National Superconducting Cyclotron Laboratory (NSCL) on the campus of Michigan State University have recently developed a consistent theoretical interpretation of a range of nucleus-nucleus collision data previously measured at the NSCL. The crosshatched region of the graph shows the allowed values for the symmetry energy and its contribution to pressure in pure neutron matter at saturation density. The inset shows what this analysis implies about the density dependence of the symmetry energy. These graphs also show comparison of these results to other attempts to extract the symmetry energy from the properties of individual nuclei. A value for the symmetry energy at around 0.4 normal nuclear matter density, extracted from Giant Dipole Resonance (GDR) data, is indicated by the symbol in the inset. The open region in the main figure labeled "IAS" indicates the constraints obtained from analyses of the excitation energies of Isobaric Analog states, (IAS). The region labeled "PDR", for Pygmy Dipole Resonance, results from analyses of low-lying electric dipole strength in neutron-rich nuclei. The region enclosed by the two diagonal lines labeled "Skin(Sn)" are the boundaries of recent constraints obtained from published skin thickness of tin nuclei. Some shifts in the boundaries of the constrained regions can be expected with improvements in the precision of the experimental data and with the evolution of the theory. Nevertheless, the consistency among the different probes of the symmetry energy and the possibility of probing higher densities with nucleus-nucleus collisions at higher energies suggests that the symmetry energy will soon be constrained over a range of densities.



Representation of the constraints on the symmetry energy for pressure in neutron matter as a function of the symmetry energy in neutron matter. Open rectangles were obtained from the properties of individual nuclei and the hatched area from recent analyses of nuclear collisions.