Probing the Nuclear Symmetry Energy and Neutron Skin Thickness in Collective Modes of Excitation

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Collective excitations in neutron rich nuclei contain valuable information which help to investigate the isospin dependence of the nuclear equation of state \cite{1}. By employing relativistic energy density functional (EDF) theory in describing both the nuclear matter properties and collective motion in finite nuclei, relevant observables related to isotropic dipole excitations can be identified by means of statistical equilibration analysis \cite{2}. With increasing isospin, the isotropic E1 excitation strength is expected to be a fragmentation pattern, giving rise to a low energy “pygmy” dipole strength (PDS), as opposed to the higher energy excitation of strong collective character, the giant dipole resonance (GDR).

Relativistic Energy Density Functional Theory

Dirac nucleons interacting via meson and photon exchange

Effective interaction - lifting of coupling constants

\[ B^2(E, J, l \to J') = \frac{1}{2} \sum_{\alpha=1}^{N} \sum_{\beta=1}^{N} M_{\alpha\beta}^{(2)} \]

\[ E_{\alpha\beta}(J, l) = \sum_{\gamma=1}^{N} M_{\alpha\beta}^{(1)} \]

Ground state \rightarrow Relativistic Hartree-Bogoliubov model (RHB)

Small amplitude vibrations limit \rightarrow Relativistic Quasiparticle RPA (QRPA)

Pygmy Dipole Strength in Neutron Rich Nuclei

Diagonalization of the QRPA equation system yields discrete energy excitation spectrum as eigenvalues. Each QRPA state is composed of various two-quasiparticle contributions, depending on the nature of the transition operator

- \( B^2(E, J, l \to J') \)
- \( E_{\alpha\beta}(J, l) \)

Two-quasiparticle (2qp) contributions in \( ^{100}\text{Sn} \) and \( ^{120}\text{Sn} \) most pronounced PDS and GDR QRPA states in the isotropic (upper right) and the same PDS energy states in the isoscalar channel (bottom left). Proton and neutron pairs with similar \( \Delta E \) contribute coherently in the case of an IVGDR state and cancel whenPDS transitions occur.

Calculations done using the DD-ME2 parametrization with pairing part adopted from the Gogny interaction.

E1 Isovector Strength Related Observables, Neutron Skin and the Symmetry Energy

Energy per nucleon of asymmetric nuclear matter

\[ E_{\alpha,\beta}(J, l) = \sum_{\gamma=1}^{N} M_{\alpha\beta}^{(1)} \]

Characteristics of the isotropic interaction channel

\[ E_{\alpha,\beta}(J, l) = \sum_{\gamma=1}^{N} M_{\alpha\beta}^{(1)} \]

\[ J = S\left(\frac{\omega}{c}\right) \]

\[ \text{symmetry energy at saturation density} \]

\[ S_{\alpha,\beta}(J, l) = \sum_{\gamma=1}^{N} M_{\alpha\beta}^{(1)} \]

\[ \Delta \left(\frac{\omega}{c}\right) \]

Neutron skin thickness \rightarrow strong linear correlation with \( J \), but difficult to measure in a model independent way. Observables related to E1 excitation channels \rightarrow GDR peak energy, strength distribution and moments \( m_{\lambda}(J, l) = \sum_{\gamma=1}^{N} M_{\alpha\beta}^{(1)} \).

Family of DD-ME2 interaction spans \( J=30, 32, 34, 36, 38 \).

Systematic Study of the Dipole Response for the Tin Isotope Chain - S412 Experiment at GSI

2. N. Paar, A. Horvat, EPJ Web of Conferences 66, 02078 (2014)