Study of Giant Monopole Resonance in SHN

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Flow of Talk

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- Formalism
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  - Correlation between observables
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Introduction: GMR

- The giant monopole resonance (GMR) measures the collective response of the nuclear density fluctuations.
- □T=0 Iso-scalar, □T=1 Iso-vector

- The giant monopole resonances(GMR) are high-frequency , small amplitude.
- Study of GMR of finite nuclei, able to constraint the incompressibility coefficient of the nuclear matter[1].
- The nuclear compressibility of the superheavy nuclei are predicted from the obtained breathing mode energy.
- It has indirect connection with nuclear matter properties like Symmetry energy, Equation of state etc…

[1]J. P. Blaizot, Phys. Rep. 64, 171 (1980).

Introduction:

Experimental Methods:

- **Inelastic alpha particle scattering:** Alpha particles at energies around 100 MeV/nucleon are scattered off target nuclei. The energy loss spectrum of scattered alpha particles includes peaks corresponding to different nuclear excitations, including the breathing mode.
- **Angular distribution analysis:** By measuring the differential cross sections at various scattering angles, the monopole resonance (breathing mode) can be distinguished due to its characteristic angular distribution.
- **Excitation energy determination:** The centroid energy of the isoscalar giant monopole resonance peak in the scattering cross-section spectrum corresponds to the breathing-mode energy.

Theoretical Method:

- Relativistic mean-field **(RMF)** theory
- Non-relativistic Hartree-Fock random-phase approximation **(HF+RPA)**

Formalism:

Lagrangian of the system:

$$\mathcal{L} = \overline{\psi_i}\{i\gamma^\mu\partial_\mu - M\}\psi_i + \frac{1}{2}\partial^\mu\sigma\partial_\mu\sigma - \frac{1}{2}m_\sigma^2\sigma^2 - \frac{1}{3}g_2\sigma^3 - \frac{1}{4}g_3\sigma^4 - g_s\overline{\psi_i}\psi_i\sigma$$
$$-\frac{1}{4}\Omega^{\mu\nu}\Omega_{\mu\nu} + \frac{1}{2}m_w^2V^\mu V_\mu + \frac{1}{4}c_3(V_\mu V^\mu)^2 - g_w\overline{\psi_i}\gamma^\mu\psi_i V_\mu - \frac{1}{4}\vec{B}^{\mu\nu}.\vec{B}_{\mu\nu}$$
$$+\frac{1}{2}m_\rho^2\vec{R}^\mu.\vec{R}_\mu - g_\rho\overline{\psi_i}\gamma^\mu\vec{\tau}\psi_i.\vec{R}^\mu - \frac{1}{4}F^{\mu\nu}F_{\mu\nu} - e\overline{\psi_i}\gamma^\mu\frac{(1-\tau_{3i})}{2}\psi_i A_\mu.$$

Degrees of freedom:

N	σ-meson	ω-meson	ρ-meson
Dirac nucleons	Attractive force	Repulsive force	Asymmetry

Formalism:

The scaled Hamiltonian is given as

$$\mathcal{H}_\lambda = \lambda^3\lambda\tilde{\mathcal{E}} + \frac{1}{2}g_s\phi_\lambda\tilde{\rho}_s^{eff} + \frac{1}{3}\frac{b}{\lambda^3}\phi_\lambda^3 + \frac{1}{4}\frac{c}{\lambda^3}\phi_\lambda{}^4 + \frac{1}{2}g_v V_\lambda\rho + \frac{1}{2}g_\rho R_\lambda\rho_3 + \frac{1}{2}eA_\lambda\rho_p$$

The scaled monopole excitation energy is defined as-

$$E^s = \sqrt{\frac{C_m}{B_m}},$$

$$B_m = \int dr U(\mathbf{r})^2\mathcal{H},$$

Where C_m = Restoring force and
B_m = mass parameter

$$U(\mathbf{r}) = \frac{1}{\rho(\mathbf{r})\mathbf{r}^2}\int d\mathbf{r}'\rho_T(\mathbf{r}')\mathbf{r}'^2,$$

$$C_m = \int dr\Big[-m\frac{\partial\tilde{\rho}_s}{\partial\lambda} + 3\Big(m_s{}^2\phi^2 + \frac{1}{3}b\phi^3 - m_v{}^2V^2 - m_\rho{}^2R^2\Big) - (2m_s{}^2\phi + b\phi^2)\frac{\partial\phi_\lambda}{\partial\lambda} + 2m_v{}^2V\frac{\partial V_\lambda}{\partial\lambda} + 2m_\rho{}^2R\frac{\partial R_\lambda}{\partial\lambda}\Big]_{\lambda=1}.$$

$$\rho_T(\mathbf{r}) = \frac{\partial\rho_\lambda(\mathbf{r})}{\partial\lambda}\Big|_{\lambda=1} = 3\rho(\mathbf{r}) + \mathbf{r}\frac{\partial\rho(\mathbf{r})}{\partial\mathbf{r}}.$$

Formalism:

The constraint functional equation:

$$\int dr\left[\mathcal{H}-\eta r^2\rho\right]=E(\eta)-\eta\int drr^2\rho.$$

The constraint incompressibility of a finite nucleus is defined as

$$K^c_A=1/AR_0^2\ (\partial^2E(\eta)/\partial\eta^2)\big|_{\eta=0}$$

Where η collective scaling parameter

The constrained energy E(η) can be expanded in a harmonic approximation as

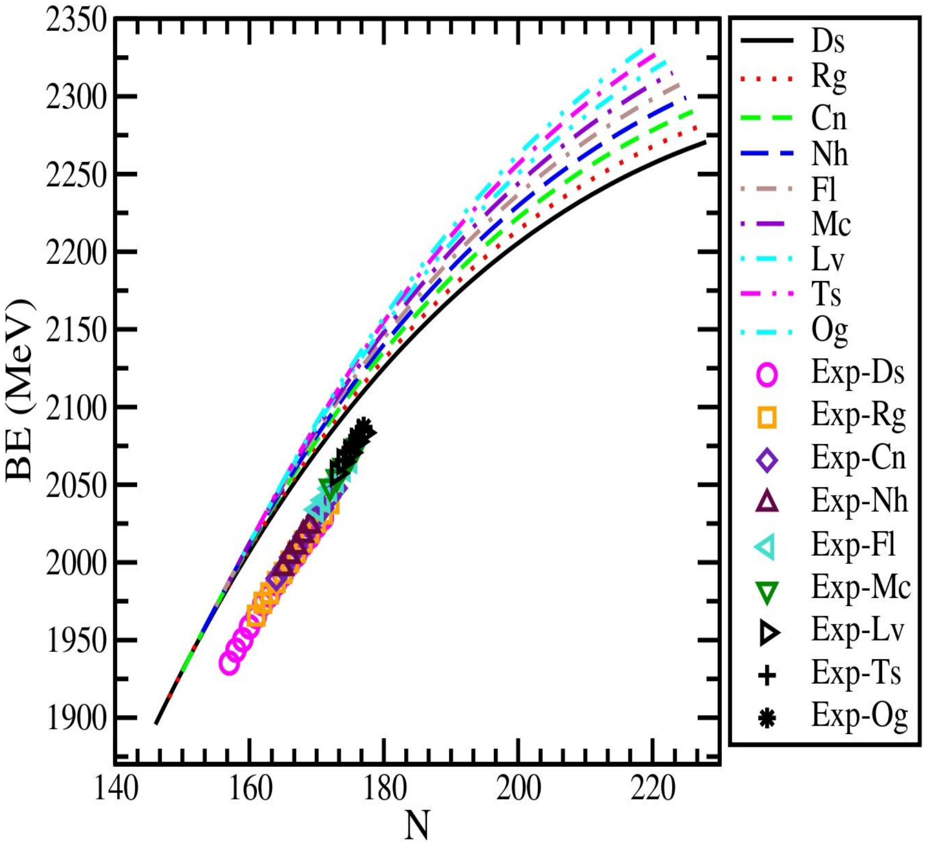
$$E(\eta)=E(0)+\frac{\partial E(\eta)}{\partial\eta}\Big|_{\eta=0}+\frac{\partial^2E(\eta)}{\partial\eta^2}\Big|_{\eta=0}.$$

Constrained monopole excitation energy E^c_x as

$$E_x{}^c=\sqrt{\frac{AK_A^c}{B_m^c}}.$$

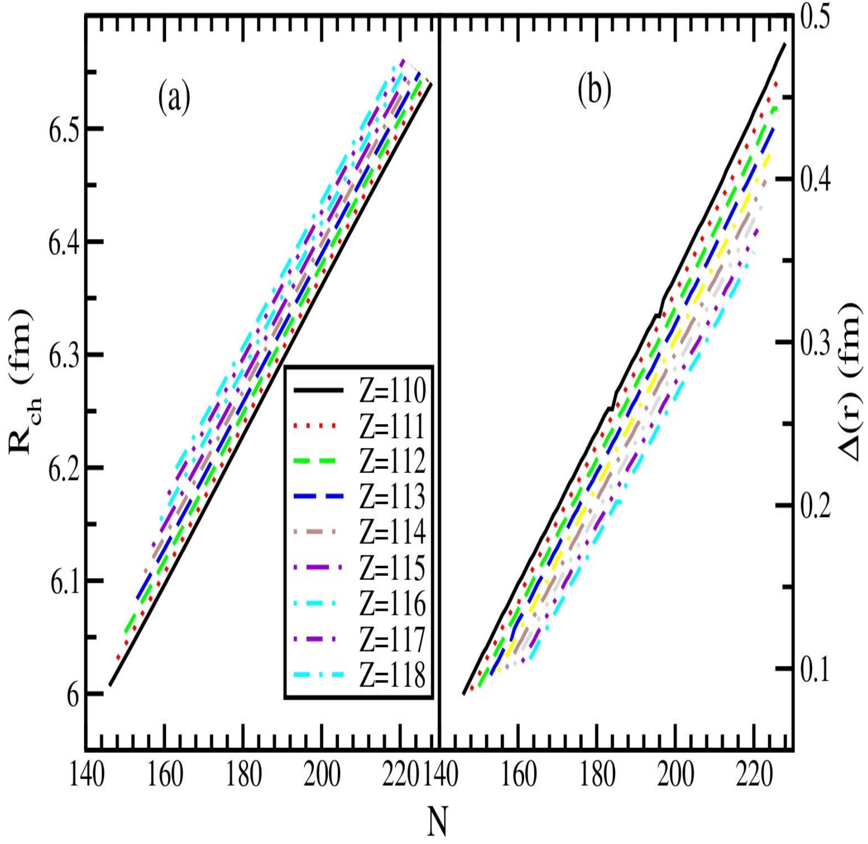
Results and Discussion: Binding Energy

- The most accurately measured quantity for finite nuclei.
- Binding energy in an isotopic chain indicates the energy needed to detach a neutron and serves as a representation of nuclear stability.
- The binding energy movements toward the neutron drip line in a series of isotopes increase steadily with neutron number.
- We achieve approximately 2% increased binding with the RETF formalism compared to the experimental data.
- BE(Exp) and BE(RETF) can be bridge with scaling factor f_s=1.024.



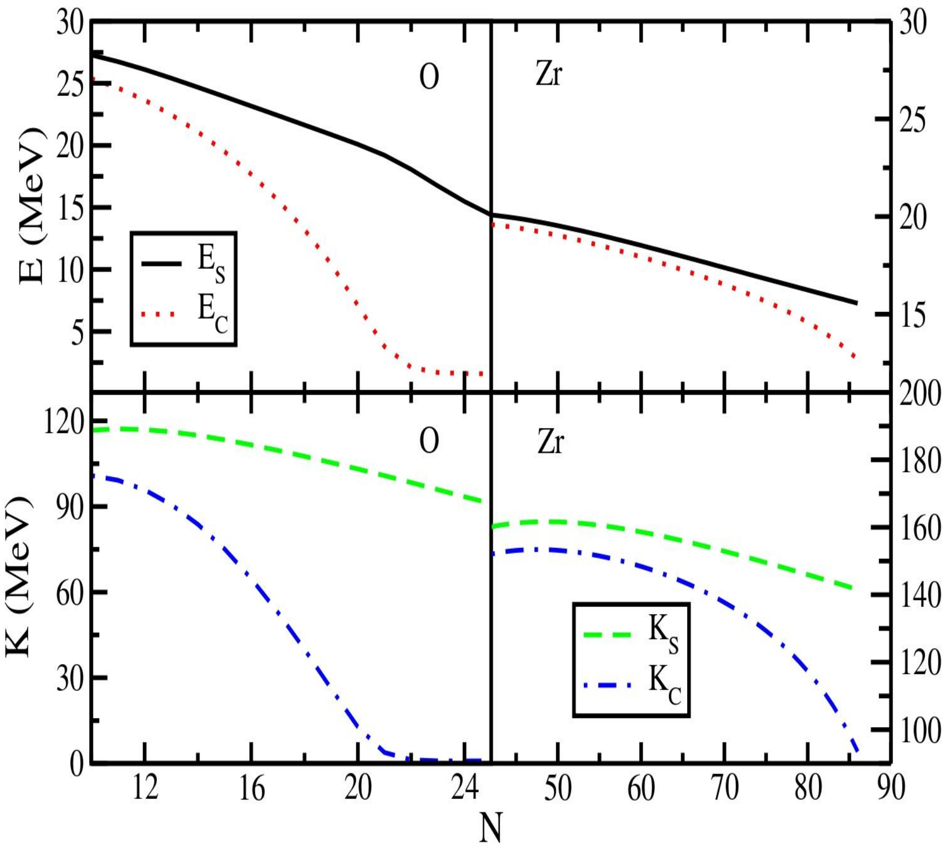
Results and Discussion: Charge radius skin thickness

- The nuclear charge radius is among the most utilized full observables that give insight into how effective interactions influence the nuclear structure and elucidate the nuclear shell framework.
- Charge radius and Neutron skin thickness both the observables increases monotonously with neutron number.



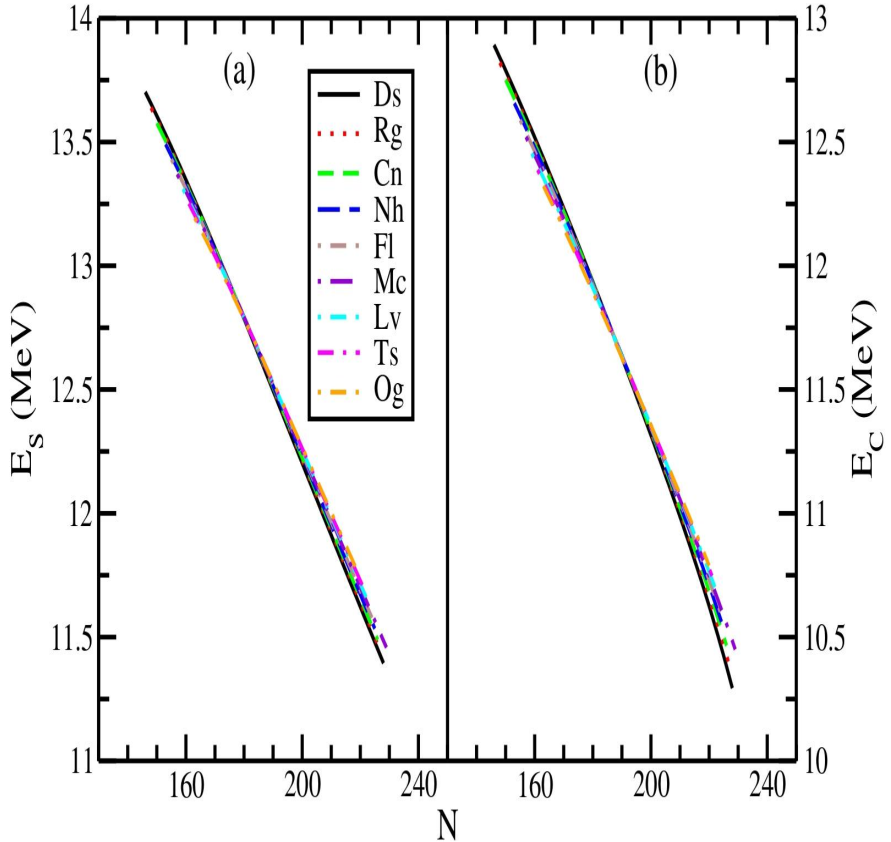
Results and Discussion: GMR Energy Lower Mass Region

- The obtained values of excitation energies for ^{16}O from the scaling and constrained calculations are 27.83 MeV and 25.97 MeV. E^x (Exp.) = 21.13 (+/- 0.49) MeV
- The Es and Ec energy for ^{80}Zr are 19.53 MeV and 19.03 MeV, E^x(Exp) = 17.89 (+/- 0.20) MeV
- Theoretical model gives the upper bound of the excitation energy.
- The K^A outcomes for both the Oxygen and Zirconium isotopes consistently diminish as the neutron number increases



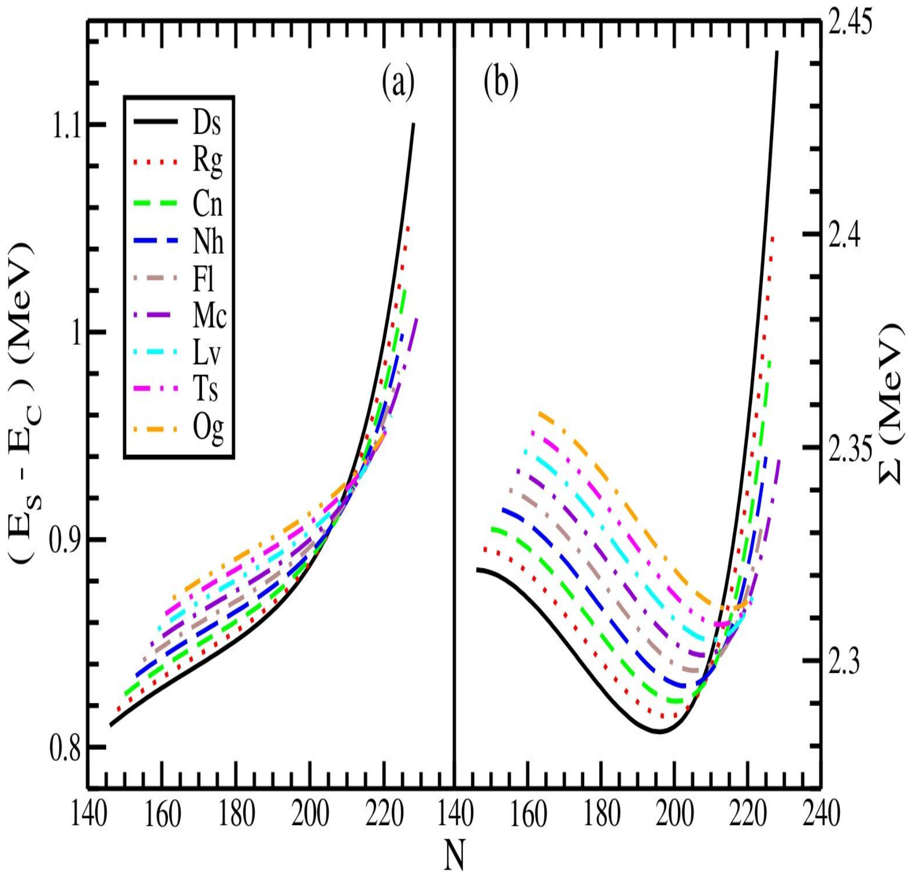
Results and Discussion: GMR E_x (MeV) Energy

- In our Calculations of Scaling and constraints monopole excitation energy is linearly decrease with increase in Neutron Number.
- At N=180 all the Nuclei have same Scaling monopole excitation energies, and the value be Es= 12.75 MeV.
- And N= 190 all the Nuclei have same Constraints excitation energy, and the value be Ec = 11.75MeV.



Excitation energy and Resonance width:

- In Super Heavy Region (Z=110-118) the Energy difference between the E_s and E_c is always less than 1 MeV.
- $\Sigma^2 = E^2_s - E^2_c$ (Resonance Width)
- The Σ as a function of neutron number is increasing slowly with N and most of the isotopes meet near N=210.
- We see Resonances Width First Decreases and a peak life structure observed and then resonance Width increases with increase in Neutron Number.



Results and Discussion: Correlation between Ex and skin thickness

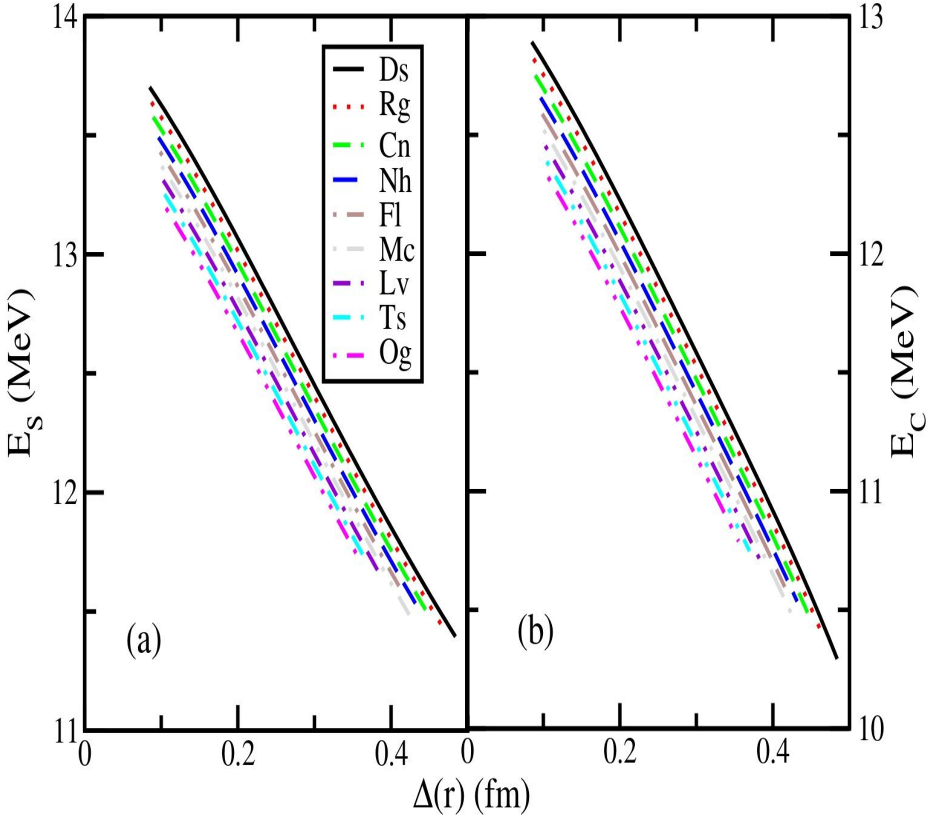
- Scaling energy and constraints energy of all the isotopes Z=110-118 decreases with increase in Neutron skin thickness.
- □r = r_n - r_p (fm)
- linear regression fitting for both the E_s and E_c separately and the fitting equations are given as

E_s = 14.044 − 5.9514 × □r

E_c = 13.25 − 6.3228 × □r

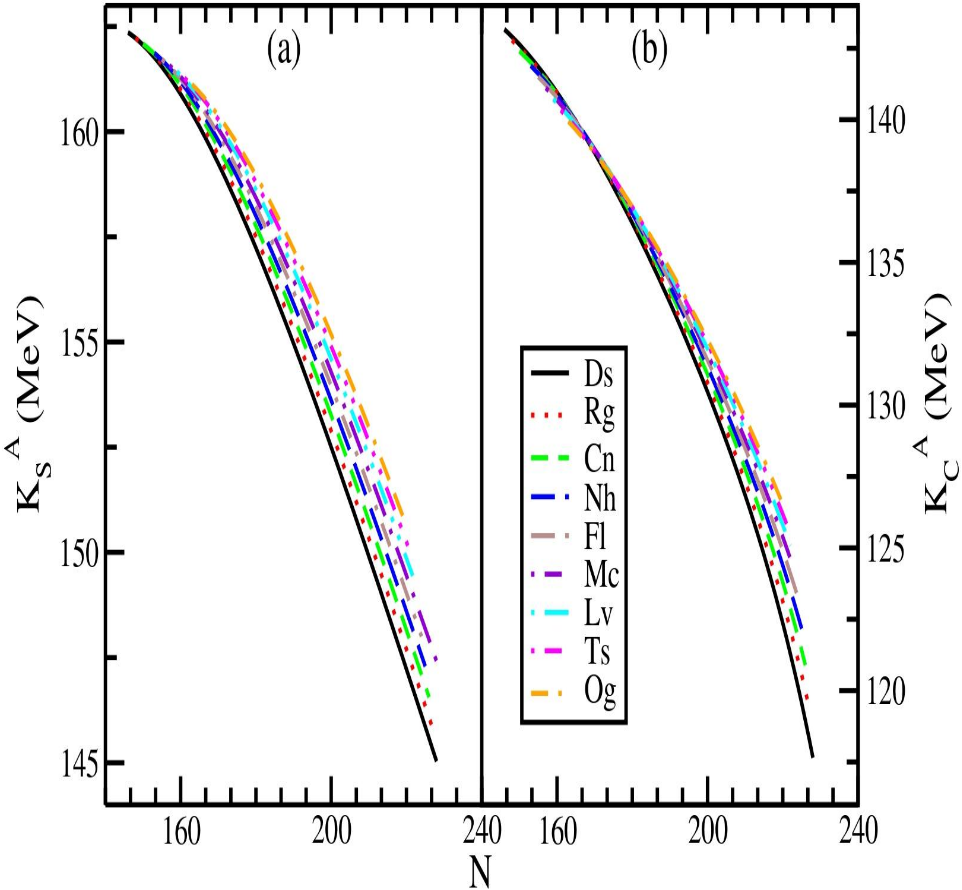
with a correlation coefficient

η =99.9999 for both the cases.



Results and Discussion: Nuclear Incompressibility

- One can easily constrained the nuclear matter incompressibility by analyzing the finite nuclei.
- It is clear that when we increases the number of neutrons then scaling incompressibility modulus and constrained incompressibility modulus monotonously decreases.
- The rate of change of scaling incompressibility modulus K_s is more than rate of change in constraint incompressibility modulus K_c with neutron number.



Conclusions:

- Excitation energy is a strong element to fix the nuclear incompressibility.
- One can constraint the neutron skin thickness with the proper measurement of the isoscalar giant monopole resonance.
- Our results motivate the future experiments.
- A connection with the measured neutron skin thicknesses is proposed as a possible way to obtain realistic estimations of the energy of ISGMR.

Collaboration:

1. Santosh Kumar, Patliputra University, Patna
2. Dr. J. A. Patnaik, SOA, BBSR
3. Dr. M. Bhuyan, IOP, BBSR
4. Dr. R. N. Panda, SOA, BBSR
5. Prof. S. K. Patra, SOA, BBSR

Thanks