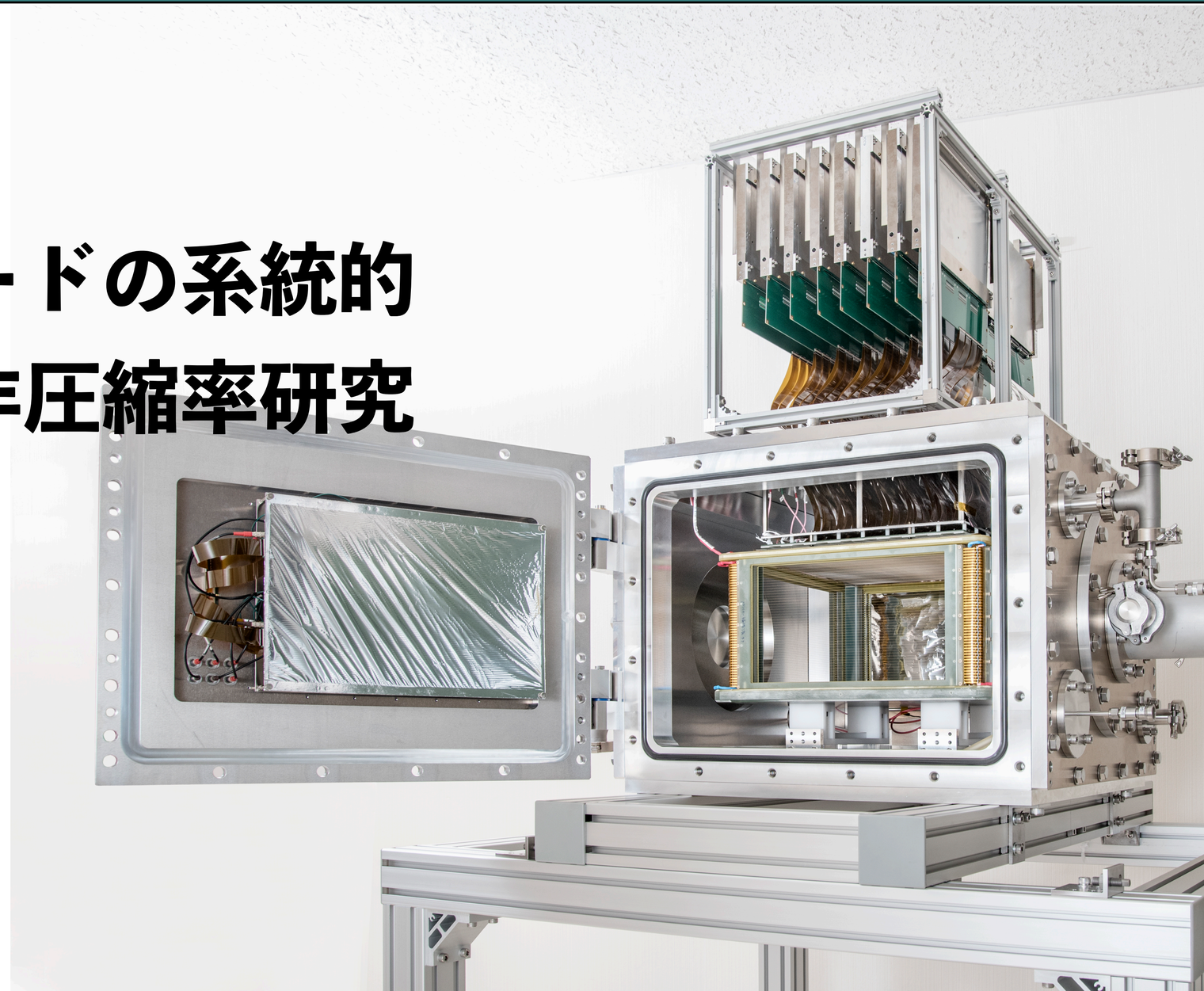
原子核の密度振動モードの系統的測定による核物質の非圧縮率研究



RIKEN Nishina Center
Fumitaka ENDO

This Research in a Nutshell - Introduction -

核物質の基礎物性『非圧縮率(硬さ)』を
原子核の膨張・収縮モードを通じて解き明かしたい

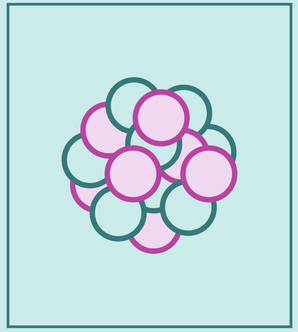
核物質

核子（中性子・陽子）からできている物質

中性子星

構成 : ほぼ中性子
半径 : 10 km程度

原子核

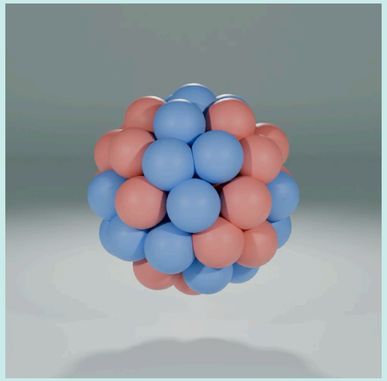


構成 : 中性子と陽子
半径 : $\approx 10^{-15}$ m

原子核の膨張・収縮モード

アイソスカラー型巨大単極共鳴 (ISGMR)

形状を保持したまま半径のみが変化する振動運動



振動を測定して硬さを調べる

例 :音

Nuclear Matter EoS - Research Background -

Nuclear Matter Equation of State (EOS)

Relationship between energy per nucleon and degrees of freedom (e.g., number density, asymmetry).

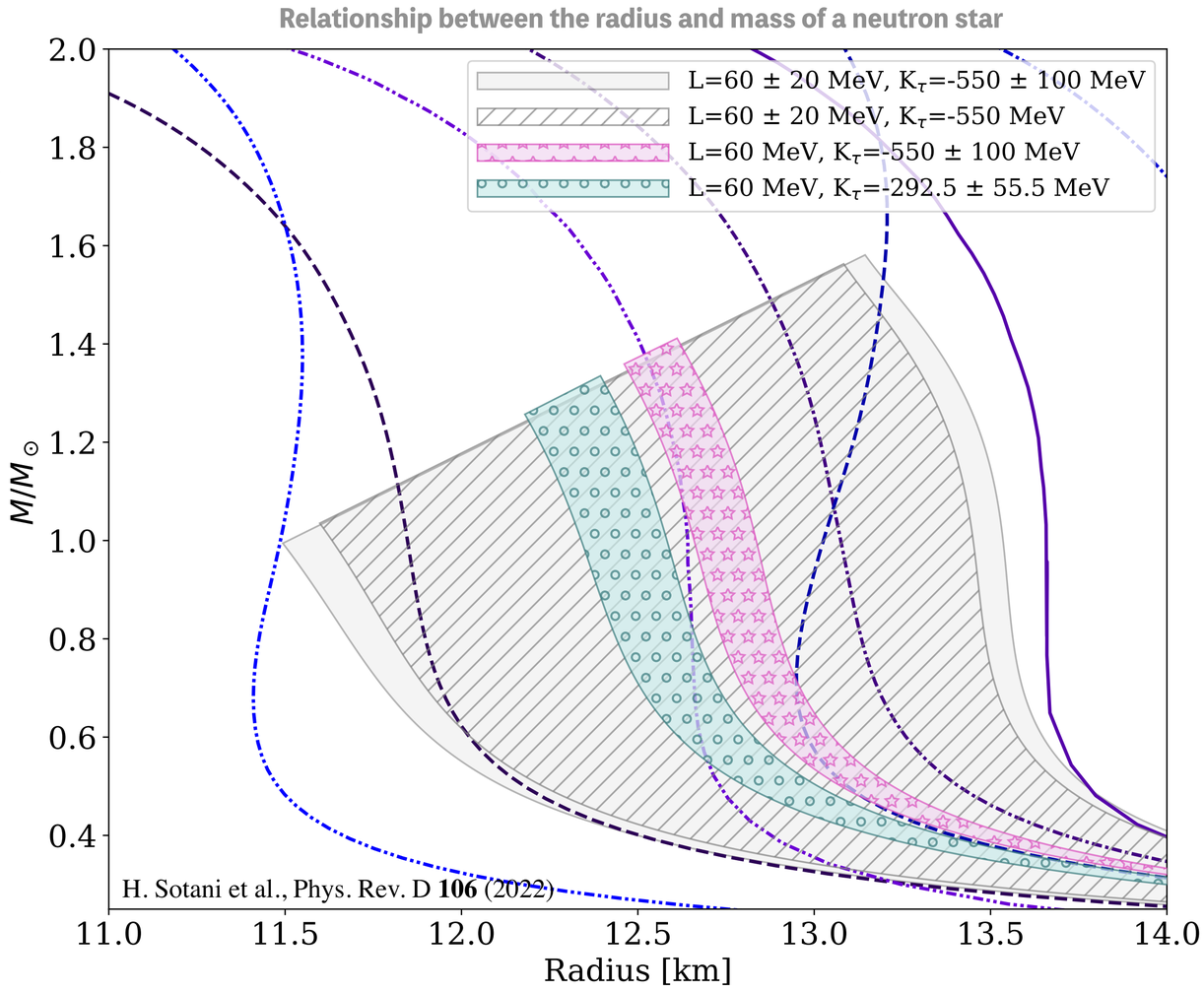
Leads to elucidation of the properties of neutron stars, astrophysical phenomena, nucleosynthesis, and etc...

EOS studies in Nuclear Experiments

$$\mathscr{E}(\rho,\alpha) = \epsilon_0 + J\alpha^2 + \frac{1}{2}\left[K_0^{\infty} + K_{\tau}^{\infty}\alpha^2\right]\bar{x}_0^2\cdots$$

Nuclear Incompressibility (Isospin-dependent term)

Nuclear experiments determine each coefficient from nuclear structure and reaction (J, K_0^{∞}, K_{τ}^{∞}…).



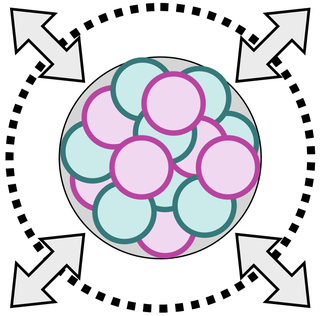
Precise & accurate measurement of K_{τ} is critical for EOS determination

非圧縮率 & ISGMR - Research Background -

原子核（膨張・収縮モード）

アイソスカラー型巨大単極共鳴 (ISGMR)

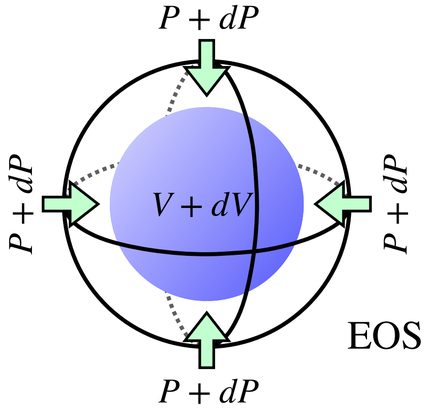
形状を保持したまま半径のみが変化する振動運動



$$E_{\mathrm{ISGMR}} = \hbar\sqrt{\frac{K_{\mathrm{A}}}{m\langle r^2\rangle}}$$

核物質（無限系）

無限系での非圧縮率



$$K = \rho^3 \frac{d^2 E/A}{d\rho^2}$$

EOS near saturation density

液滴モデルによる原子核非圧縮率

$$K_{\mathrm{A}} = K_0 + K_{\mathrm{s}}\mathrm{A}^{-1/3} + \left(K_\tau + K_{\tau\cdot\mathrm{s}}\mathrm{A}^{-1/3}\right)\alpha^2 + K_C Z^2 \mathrm{A}^{-4/3}$$

Surface Effect

Coulomb Term

飽和密度近傍でのEOSの冪展開公式

$$\mathscr{E}(\rho,\alpha) = \mathscr{E}(\rho,0) + \mathscr{S}(\rho)\alpha^2 + \cdots$$

Coefficient of second order (Symmetric nuclear matter)

Coefficient of second order (Asymmetric nuclear matter)

$$K_0 = 9\rho_0{}^2\frac{\partial^2\mathscr{E}}{\partial\rho^2} = \frac{9}{\rho_0}\chi^{-1} \qquad K_{\mathrm{sym}} = 9\rho_0{}^2\frac{\partial^2\mathscr{S}}{\partial\rho^2}$$

ISGMRから導出されるKAと液滴モデルよりKτを直接決定できる

Previous Studies - Research Background -

K_τ research based on droplet model :

Sn and Cd isotope Li(2010), Patel(2012) etc…

$K_\tau = -550 \pm 100$ MeV Li et al(2010)

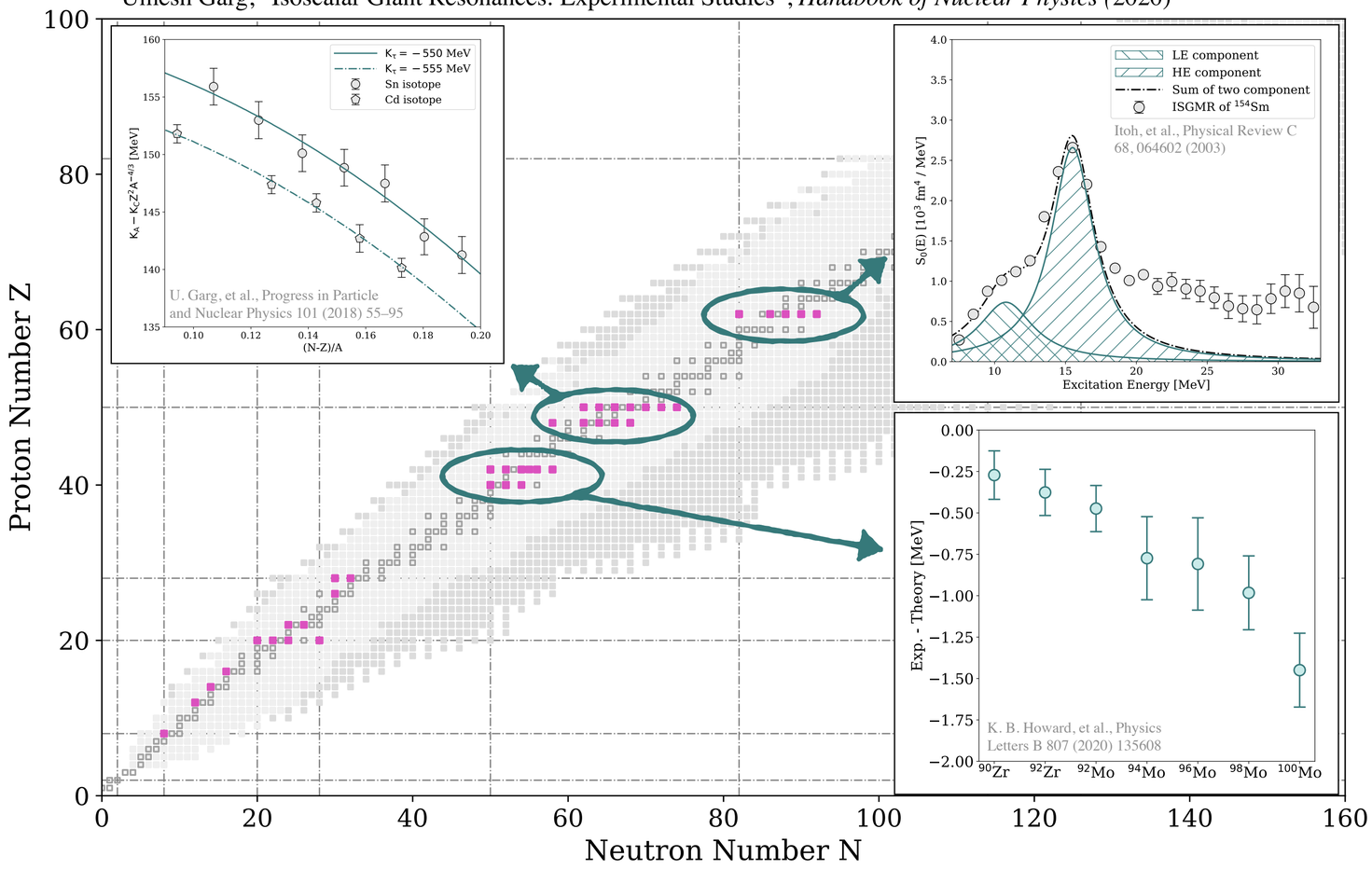
- **Limitation of measurable range** (**Stable nuclei**)
- **Assumptions of surface effects**

Challenge in K_τ studies through ISGMR

- <u>Deformation Effect</u> : Sm isotope Itoh(2003) etc…
  - ☞ What is the nuclear incompressibility when spectrum splits into 2 components?
- <u>Softness</u> : Mo isotope Howard(2020) etc…
  - ☞ Existing interactions fail to fully explain the observations.

Nuclides for which ISGMR has been measured up to now

Umesh Garg, "Isoscalar Giant Resonances: Experimental Studies", *Handbook of Nuclear Physics* (2020)



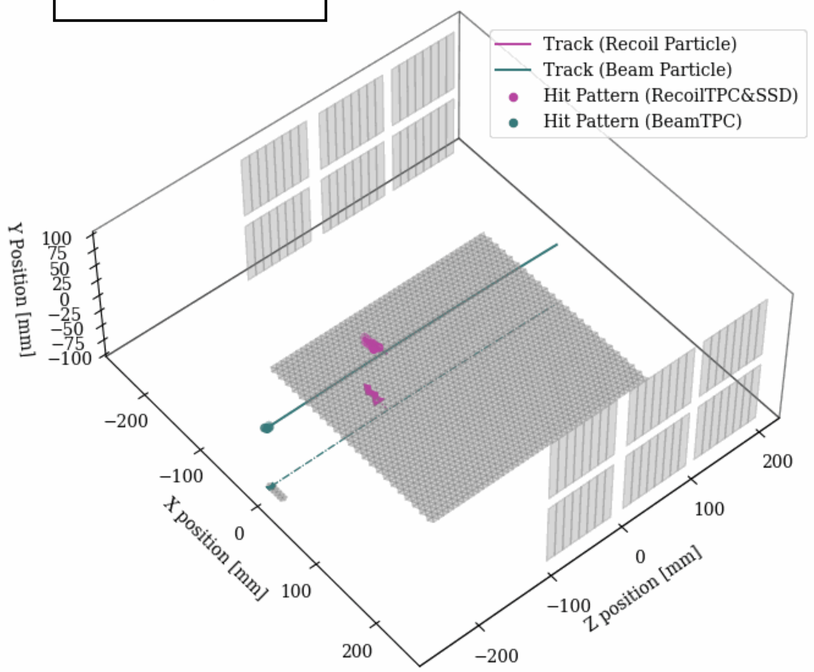
Understanding nuclear matter incompressibility requires systematic measurements of ISGMR including unstable nuclei

CNS Active Target (CAT-M) - Experiment -

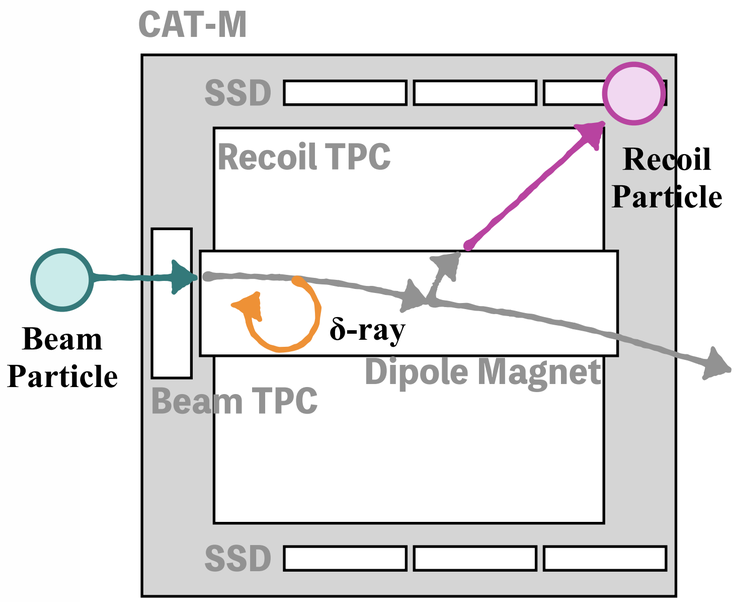
☑ Developed Active Target CAT-M for ISGMR measurements in unstable nuclei

（Active Target: A device where the reaction target itself functions as a detector）

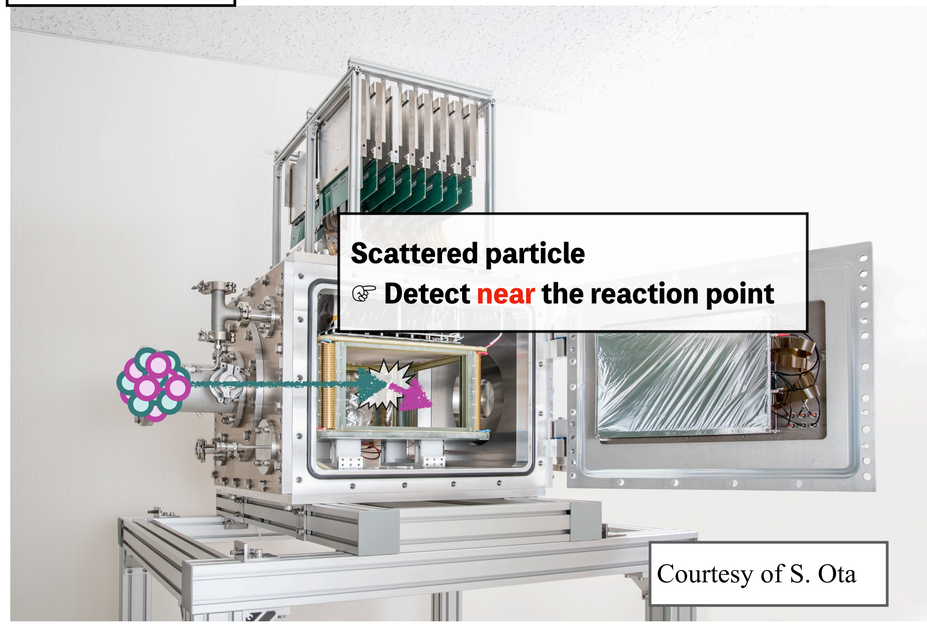
ヒットパターン



CAT-M模式図



CAT-M写真



Active target CAT-M that can be irradiated with high-intensity heavy ion beams, has been developed

Experimental setup - Experiment -

MDA & Double Differential Cross Section - Result -

Strength Function of ISGMR in ^{86}Kr - Result -

Derivation of Incompressibility using N=50 Isotones - Result -

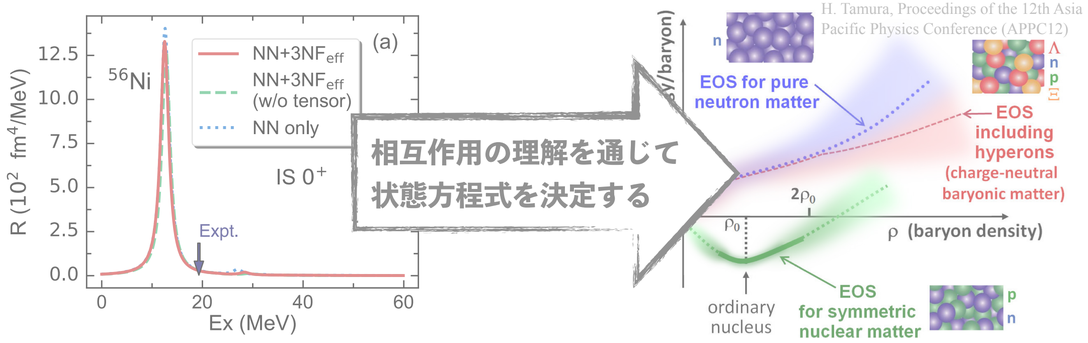
ISGMR Measurements of $^{104\text{-}108}$Sn isotopes - Future Plan -

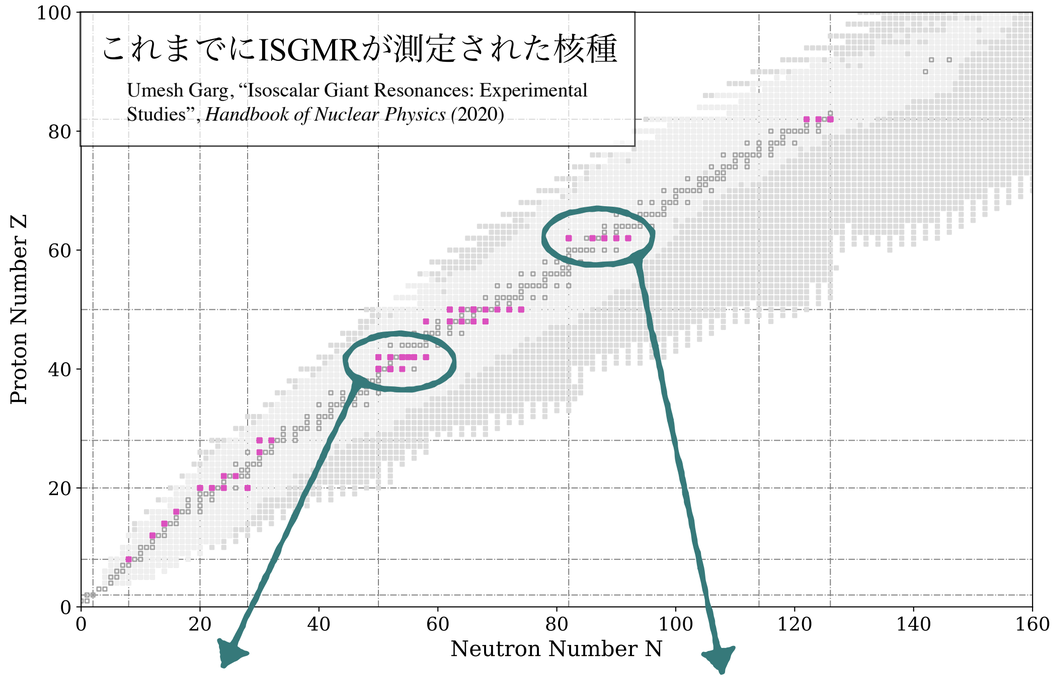
ISGMR系統的測定 - これからの研究 -

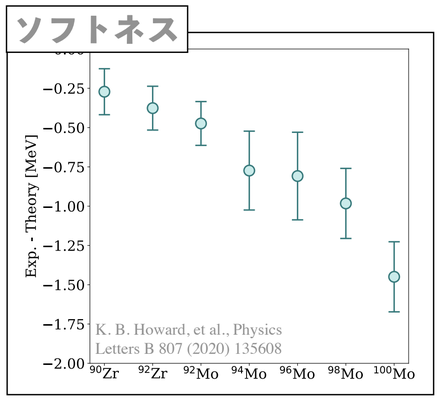
ISGMRによるK_τ研究の課題

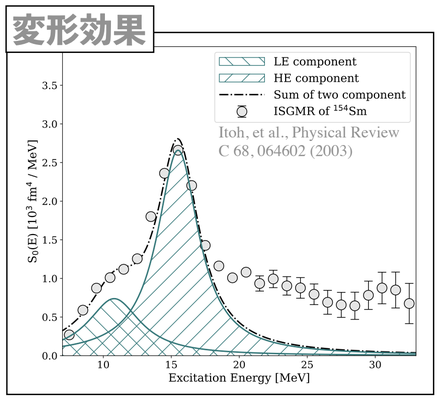
- 変形効果 : Sm同位体… Itoh(2003)など
  - ☞ 2成分に別れる時の原子核非圧縮率とは何か
- ソフトネス : Mo同位体… Howard(2020)など
  - ☞ 既存の相互作用では理解が不十分である

ISGMRの実験データが不十分（AME2020の1.5%）
ISGMRの強度関数から相互作用の検証が必要









非圧縮率の理解には不安定核を含むISGMRの系統的測定が必要である

Summary

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