The electric dipole polarizabily and the nuclear Equation of State

Xavier Roca-Maza

R3B Colloquium

July 23rd, 2024

On-line, GSI, Germany

Definitions, phenomenology & simple models

The Giant Dipole Resonance

→ Imagine to apply an uniform **electric field** to a nucleus in its **ground state**

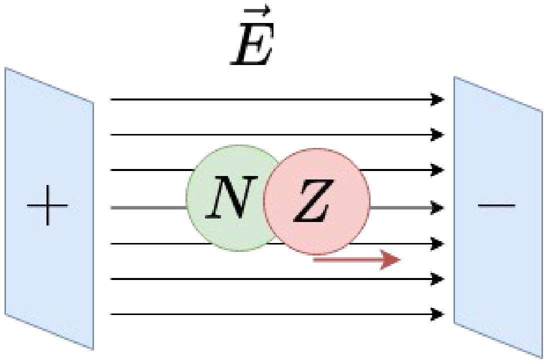
→ **Protons** will start **moving** to the right (**translation** due to **Coulomb force**)

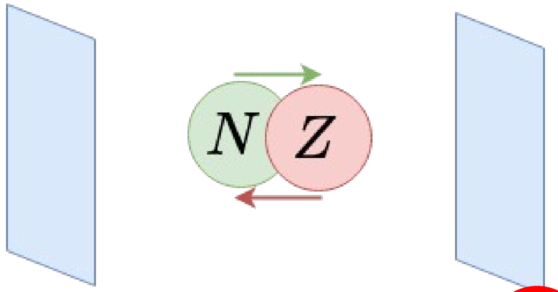
→ At (essentially) the same time, **neutrons will follow protons** (**nuclear force**) and start to **oscillate**.

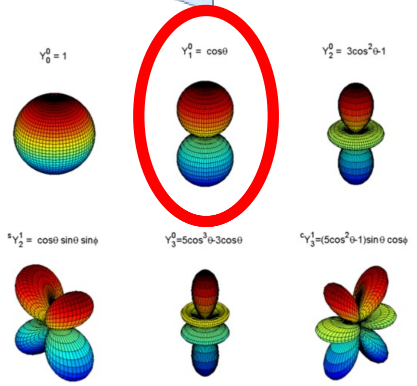
→ As a result one finds a translational motion of the whole nucleus plus an **oscillatory motion of neutrons against protons**. That is, $\rho_n(r,t) - \rho_p(r,t)$ oscillates (=isovector motion)

→ We are interested on the **oscillation frequency** since it must depend on the **attraction between neutrons and protons** (**restoring force**)

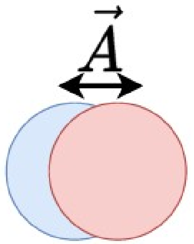
→ **Different multipolarities can contribute to this motion**, the **dominant** one will be the **dipole**







The Giant Dipole Resonance



→ The **Isovector Giant Dipole Resonance** was the first resonance measured in the atomic nucleus(**photo-absorption** experiments)

→ The **cross section** for the **excitation** of the nucleus to a **final state** $|\nu\rangle$ with energy $\mathbf{E_\nu}$ from the **ground state** $|0\rangle$ with energy $\mathbf{E_0}$ by a **photon** at a given energy **E** can be written as

Dominated by dipole

$$\sigma_\nu(E) = 4\pi^2\alpha(E_\nu - E_0)|\langle\nu|F_{\mathrm{dipole}}|0\rangle|^2\delta(E - E_\nu + E_0)$$

Convenient operator $[\sim r\, Y_{10}(\Omega)]$ produces dipole transitions and subtract CM motion

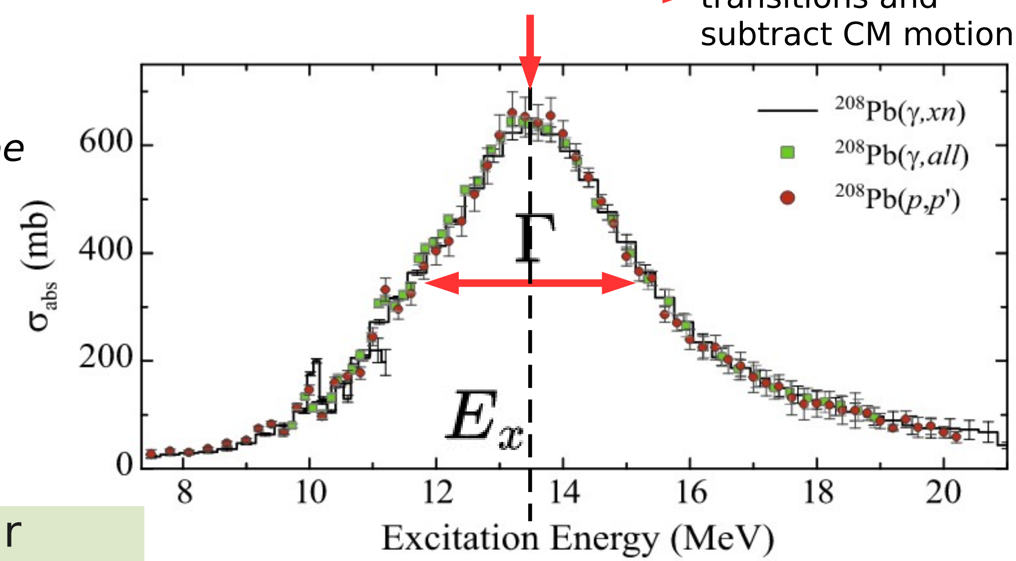
→ The **total cross-section** will be

$$\sigma_{\gamma-\mathrm{abs}} = 4\pi^2\alpha\sum_\nu(E_\nu - E_0)|\langle\nu|F_{\mathrm{dipole}}|0\rangle|^2$$

(EWSR see later)

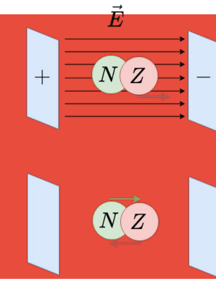
$$S(E) \equiv \sum_\nu |\langle\nu|F|0\rangle|^2\delta(E - E_\nu + E_0)$$

where **S(E)** is the so called **Strength function**



S(E) is used to **characterize** the nuclear **response** (experimentally, it is commonly parametrized as a **Lorentzian function** with energy $\mathbf{E_x}$ and width $\mathbf{\Gamma}$)

Electric Dipole Polarizability



The **electric dipole polarizability** measures the **tendency** of the nuclear **charge distribution** to be **distorted**

Macroscopically

$$\alpha = \frac{\text{electric dipole moment}}{\text{external electric field applied}}$$

Microscopically, it relates with the **photo-absorption cross-section**

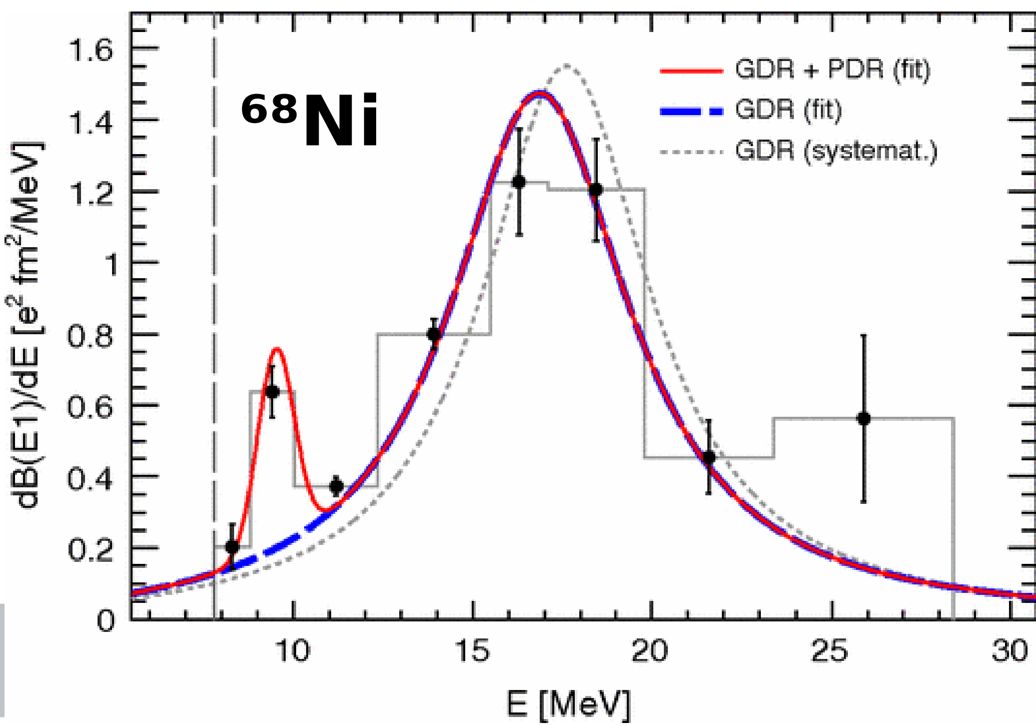
$$\alpha_D = \frac{\hbar c}{2\pi^2 e^2} \int_0^\infty dE \frac{\sigma_{\gamma-abs}}{E^2}$$

Integral from 0 to "infinity" → Full nuclear response known

In stable nuclei it has been measured, e.g., using polarized proton scattering at very forward angles (dominated by E1 and M1 well separated)

In unstable nuclei, such as ^{68}Ni, it has been measured using Coulomb excitation in inverse kinematics

(*<u>using the R3B−LAND setup</u>*)



Measurement of the Dipole Polarizability of the Unstable Neutron-Rich Nucleus ^{68}Ni

D. M. Rossi *et al.*
Phys. Rev. Lett. **111**, 242503 – Published 10 December 2013

Electric Dipole Polarizability

$$\alpha_D = \frac{\hbar c}{2\pi^2 e^2} \int_0^\infty dE \frac{\sigma_{\gamma-abs}}{E^2}$$

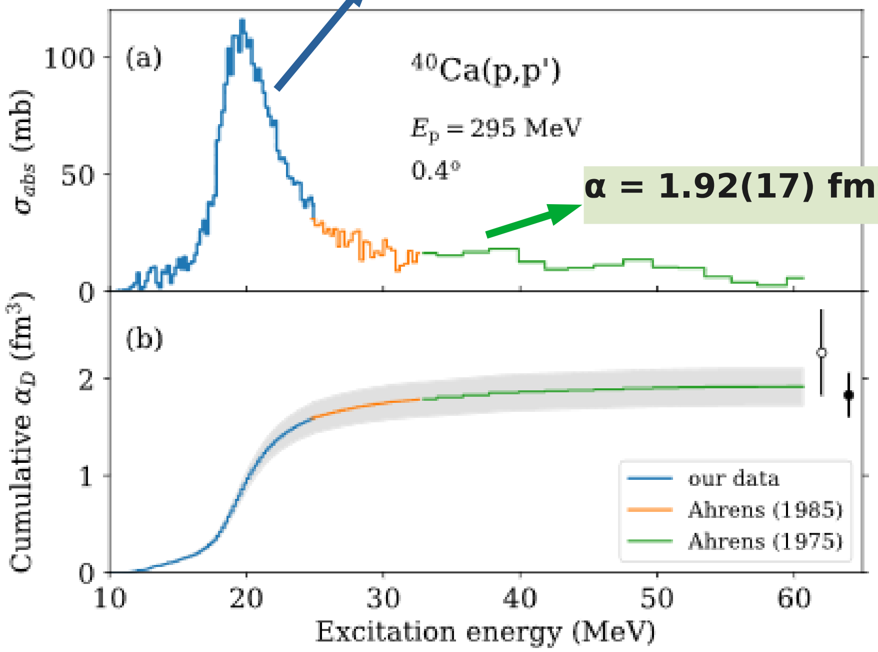
Integral from 0 to "infinity"
→ Full nuclear response must be known

→ **High energy tail** of the photo-absoption cross section need to be **measured**, **extrapolated** or taken from **theory**. It is, nevertheless, a **small contribution due to 1/E²**

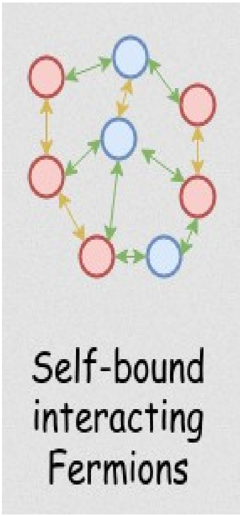
→ Discrete **states below the neutron separation energy** and **pygmy states** need to be **measured.** They constitute a **large contribution due to 1/E²**

α = 1.60(14) fm³

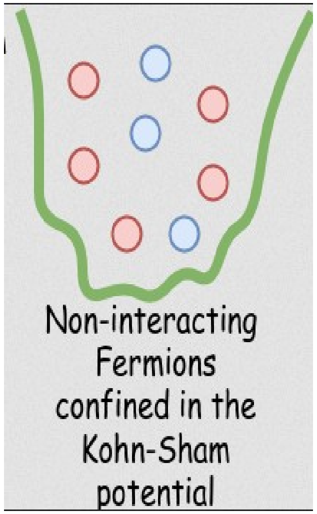
α = 1.92(17) fm³



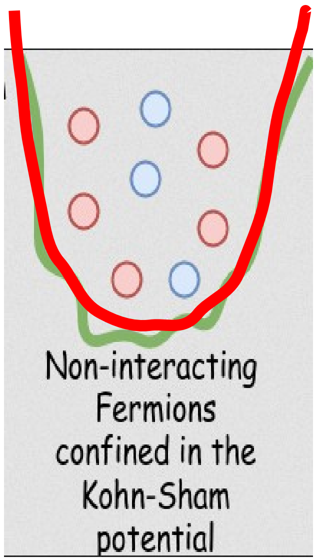
Giant Resonances from theory: Harmonic oscillator



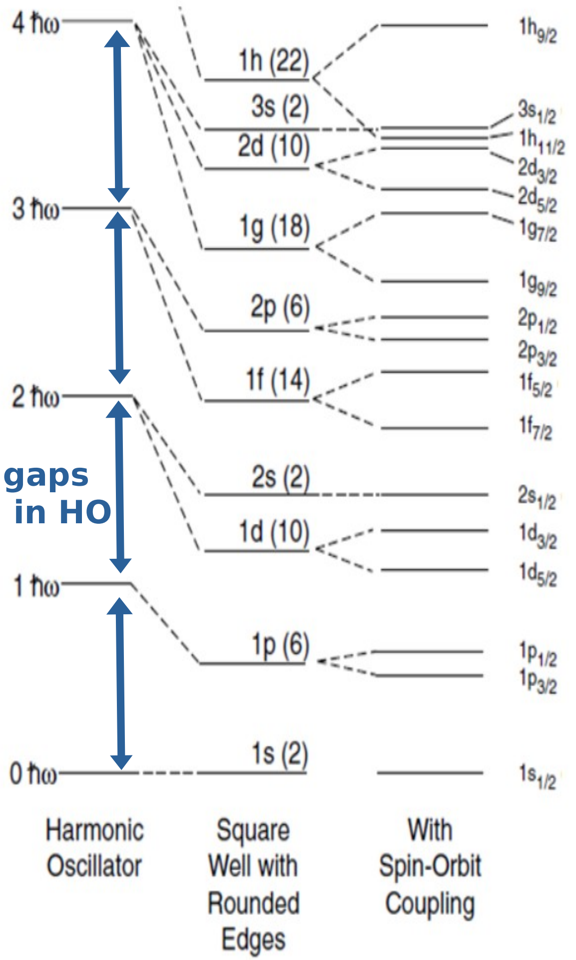
Equivalent (Density Functional Theory – Kohn Sham realization)



Approximated



U = ½ k x²



Shell gaps equal in HO

Assuming **nucleons** as **non-interacting** fermions confined in an **Harmonic Oscillator** (HO) trap with suitable **ħω₀** that **preserves** the main features of the g.s. **energy spectra**

$$E \sim \frac{1}{R} \sim A^{-1/3}$$

$$\hbar\omega_0 \sim A^{-1/3}$$

$$\hbar\omega_0 \approx 41 A^{-1/3}\ \mathrm{MeV}$$

Giant Resonances from theory: Harmonic oscillator

The **HO Hamiltonian**, in terms of the **conjugate variables α** (or *r* position) and **dα/dt** (or *v* velocity) and the ($C_0 \leftrightarrow m\omega^2$) and ($B_0 \leftrightarrow m$) parameters, could be written as (Bohr&Mottelson):

$$\mathcal{H}_0 = \frac{1}{2}B_0\dot{\alpha}^2 + \frac{1}{2}C_0\alpha^2 \rightarrow E_0 = \hbar\left(\frac{C_0}{B_0}\right)^{1/2} \longleftrightarrow E = \left(\frac{1}{B_0}\frac{\partial^2 U}{\partial \alpha^2}\right)^{1/2}$$

Assume harmonic perturbation (restoring force)

$$F = -\kappa\alpha \rightarrow V = \frac{1}{2}\kappa\alpha^2$$

$$\mathcal{H} = \mathcal{H}_0 + V \rightarrow \mathcal{H} = \frac{1}{2}B_0\dot{\alpha}^2 + \frac{1}{2}(C_0 + \kappa)\alpha^2$$

$$E = E_0\left(1 + \frac{\kappa}{C_0}\right)^{1/2}$$

Restoring force

Giant Resonances from theory: Harmonic oscillator

Generalized coordinate **α** will change with **$\delta=(\rho_n-\rho_p)/(\rho_n+\rho_p)$** in an **isovector oscillation** of **neutrons against protons**. Hence,

$$\mathcal{H}_0 = \frac{1}{2}B_0\dot{\alpha}^2 + \frac{1}{2}C_0\alpha^2 \rightarrow E_x^2 \propto \frac{\partial^2 e}{\partial \delta^2}$$

Where **$e=e(\rho_n,\rho_p,...)$** represents the **potential energy** of the system as a function of its variables. Assuming the **local density approximation** is valid:

It is **convenient** to write the **energy per nucleon** (e) as a **function** of the **total density** [$\rho=\rho_n+\rho_p$] and their **relative difference** [$\delta=(\rho_n+\rho_p)/\rho$].

→ Due to isospin symmetry only even powers of δ will appear

→ Stable nuclei have small values of δ

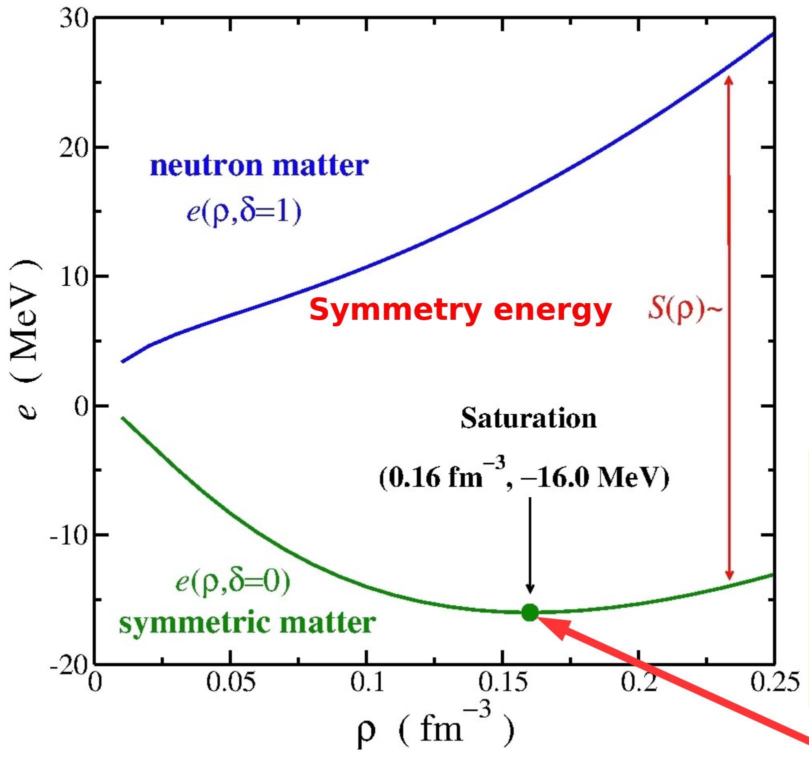
Taylor expansion for δ→ 0: $e(\rho,\delta) = e(\rho,0) + S(\rho)\delta^2 + \mathcal{O}[\delta^4]$

$$E_x^2 \propto \left.\frac{\partial^2 e}{\partial \delta^2}\right|_{\rho=\rho_{\mathrm{eq.}}} = S(\rho_{\mathrm{eq.}})$$

Symmetry energy

What is the symmetry energy? Nuclear Equation of State (EoS)

$$\boxed{e(\rho,\delta) = e(\rho,0) + S(\rho)\delta^2 + \mathcal{O}[\delta^4]}$$



It is customary to also **expand** e(ρ,0) and S(ρ) around nuclear **saturation density** $\rho_0 \sim 0.16$ fm^{-3}

$$e(\rho,0) = e(\rho_0,0) + \frac{1}{2}K_0 x^2 + \mathcal{O}[\rho^3] \text{ where } x = \frac{\rho-\rho_0}{3\rho_0}$$

$$S(\rho) = J + Lx + \frac{1}{2}K_{\mathrm{sym}}x^2 + \mathcal{O}[\rho^3,\delta^4]$$

K_0 → how **compressible** is symmetric matter at ρ_0

J (a_A) → **penalty energy** for converting all **protons into neutrons** in symmetric matter at ρ_0

L (a_S) → **neutron pressure** in neutron matter at ρ_0

$$P(\rho=\rho_0,\delta=0) = 0 \text{ MeV fm}^{-3}$$

Sum rules: m_1
Ground state gives access to excited state properties!!

→ **Sum Rules** or **moments** of the **strength function S(E):**

$$S(E) = \sum_\nu |\langle \nu || \hat{F}_J || \tilde{0} \rangle|^2 \delta(E - E_\nu + E_0)$$

k-moment of S(E): $m_k = \int dE\, E^k S(E) = \sum_\nu |\langle \nu || \hat{F}_J || \tilde{0} \rangle|^2 (E_\nu - E_0)^k$

Example: Energy Weighted Sum Rule (EWSR)

$$m_1 = \sum_\nu (E_\nu - E_0) |\langle \nu | F | 0 \rangle|^2 = \langle 0 | F^\dagger [\mathcal{H}, F] | 0 \rangle$$

Written in terms of a **commutator** with the **Hamiltonian** evaluated in the **G.S. !!**

→ [F,V]=0, if the excitation **operator** (F) **commutes** with the **interaction** (V) the **sum rule** will be **model independent!!**

$$\hat{F}_J^{(IS)} = \sum_{i=1}^{A} f_J(r_i) Y_{JM}(\hat{r}_i) \qquad m_1^{(IS)}(J) = \frac{\hbar^2}{2m} \frac{A}{4\pi} (2J+1) \langle g_J \rangle,$$

$$\langle g_J \rangle = \frac{1}{A} \int g_J(r) \rho(r) d^3r,$$

$$g_J(r) = \left(\frac{df_J}{dr} \right)^2 + J(J+1) \left(\frac{f_J}{r} \right)^2$$

→ [F,V] different form 0, if the excitation **operator does not commute** with the **interaction** the **sum rule** will be **model dependent** but still can be **used** to better **understand** nuclear **phenomenology**

Model dependent term

$$\hat{F}_J^{(IV)} = \sum_{i=1}^{A} f_J(r_i) Y_{JM}(\hat{r}_i) \tau_z(i) \qquad m_1^{(IV)}(J) = m_1^{(IS)}(J)(1 + \tilde{\kappa})$$

Sum rules: m_{-1}

Ground state gives access to excited state properties!!

Theoretically, the total **photo-absorption cross section**, can be written as

$$\sigma_{\gamma-\mathrm{abs}} = 4\pi^2\alpha \sum_\nu (E_\nu - E_0)|\langle\nu|F_{\mathrm{dipole}}|0\rangle|^2$$

Dipole operator subtract CM motion

$$\frac{eN}{A}\sum_{i=1}^{Z} r_i Y_{1M}(\hat{r}_i) - \frac{eZ}{A}\sum_{i=1}^{N} r_i Y_{1M}(\hat{r}_i)$$

And, thus,

$$\alpha_D = 2\sum_{\nu\neq 0}\frac{|\langle\nu|F_{\mathrm{dipole}}|0\rangle|^2}{E_\nu - E_0} \equiv 2m_{-1}$$

Considering the G.S. perturbed by an **external field** λF (with λ → 0). <H>=<H_0+λF_{dipole}> can be written as:

$$\delta\langle\mathcal{H}\rangle = \langle\mathcal{H}\rangle - \langle\mathcal{H}_0\rangle = \lambda^2\sum_{\nu\neq 0}\frac{|\langle\nu|F|0\rangle|^2}{E_\nu - E_0} + \mathcal{O}(\lambda^3) = \lambda^2 m_{-1} + \mathcal{O}(\lambda^3)$$

$$m_{-1} = \frac{1}{2}\frac{\partial^2\langle\mathcal{H}\rangle}{\partial\lambda^2}\Big|_{\lambda=0}$$

Dielectric Theorem

Dielectric theorem applied to the Droplet model Hamiltonian

→ Calculate the polarizability (α), **proportional to m_{-1}** from the **dielectric theorem** and **Droplet Model**

$$m_{-1} \approx \frac{A\langle r^2\rangle^{1/2}}{48J}\left(1+\frac{15}{4}\frac{J}{Q}A^{-1/3}\right)$$

J. Meyer, P. Quentin, and B. Jennings, Nucl. Phys. A **385**, 269

$$a_{sym}(A) = \frac{J}{1+x_A}, \quad \text{with} \quad x_A = \frac{9J}{4Q}A^{-1/3}. \qquad \Delta r_{np}^{DM} = \frac{2r_0}{3J}[J - a_{sym}(A)]A^{1/3}(I - I_C)$$

$$\alpha_D \approx \frac{A\langle r^2\rangle}{12J}\left[1+\frac{5}{2}\frac{\Delta r_{np}+\sqrt{\frac{3}{5}}\frac{e^2 Z}{70J}-\Delta r_{np}^{surface}}{\langle r^2\rangle^{1/2}(I-I_C)}\right]$$

Polarizability must increase with the mass (for the dipole $A^{5/3}$, for the quadrupole $A^{7/3}$ and so on) and **surface symmetry energy** (J/Q) and **decrease** with the **bulk symmetry energy** (J)

Density Funcitonal Theory:
a microscopic theory

DENSITY FUNCTIONAL THEORY
Hohenberg-Kohn theorems
P.Hohenberg, W. Kohn, Phys. Rev. 136, B864 (1964)

→ Assuming a system of **interacting fermions** in a confining **external potential**, there exist a **universal** functional **F[ρ]** of the fermion density **ρ**:

$$E[\rho] = \langle \Psi | T + V + V_{\text{ext}} | \Psi \rangle = F[\rho] + \int V_{\text{ext}}(r)\rho(r)d\vec{r}$$

→ and it can be shown that

$$\min_{\Psi} \langle \Psi | T + V + V_{\text{ext}} | \Psi \rangle = \min_{\rho} E[\rho]$$

so **E[ρ]** has a **minimum** for the **exact ground-state density** where it assumes the **exact energy** as a value.

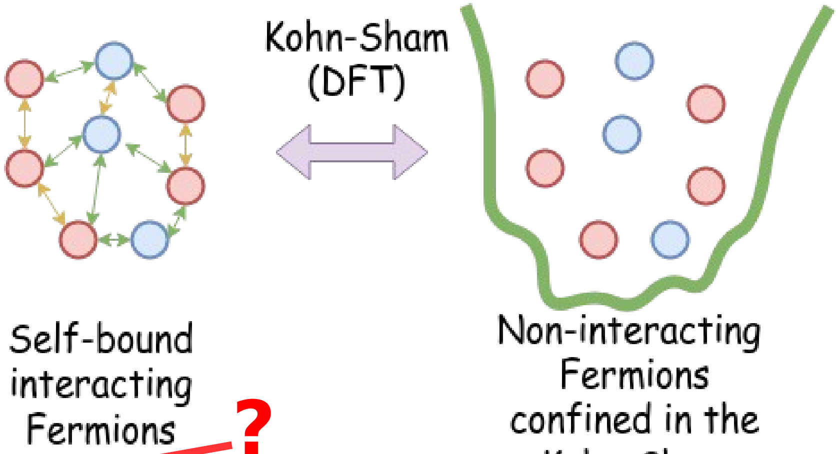
Kohn-Sham realization

$F[\rho] \rightarrow T_{\text{non-int.}}[\rho] + V_{KS}[\rho]$

In nuclei no need of external confining potential

For **any interacting system**, there exists a **<u>local</u> single-particle potential $V_{ks}(r)$**, such that the **exact ground-state** density of the **interacting system** equals the **ground-state density** of the **auxiliary non-interacting system**:

$$\rho_{\text{exact}}(\vec{r}) = \rho_{\text{KS}}(\vec{r}) = \sum_{i=1}^{A} |\phi(\vec{r})|^2$$



$$F[\rho] = \int d^3r \; f(\mathbf{r}, \rho, \nabla\rho, \ldots).$$

where φ are single-particle orbitals and the total wave-function correspond to a Slater determinant. The **E[ρ] is unique**

$$E[\rho] = T[\rho] + \int V_{\text{KS}}(\vec{r})\rho(\vec{r})d\vec{r}$$

where **T[ρ]** is the **kinetic energy of the non-interacting system** and for which the variational equation

$$0 = \frac{\delta E[\rho]}{\delta\rho} = \frac{\delta T[\rho]}{\delta\rho} + V_{\text{KS}}$$

yields to the **exact ground state density and energy**

Time dependent DFT for the study of GR

Linear Response Theory (Ring&Schuck)

Perturbing the initial static Hamiltonian H_0 with a small **time dependent operator F(t)**:

$$\mathcal{H} = \mathcal{H}_0 + F(t) \qquad F(t) = f \exp(-i\omega t) + f^\dagger \exp(i\omega t)$$

Will produce variations on the **static density ρ_0 linear with the external operator F(t)** in first approximation:

$$\delta\rho(t) = \delta\rho \exp(-i\omega t) + \delta\rho^\dagger \exp(i\omega t)$$

Writting the **Schroedinger equation using commutators**

$$\mathcal{H} = \sum_i h(i)$$

$$h\Psi(t) = i\hbar\dot{\Psi}(t) \rightarrow [h, \rho] = i\hbar\dot{\rho}$$

$$h_0\Psi = \varepsilon\Psi \rightarrow [h_0, \rho_0] = 0$$

$$[h_0 + F(t), \rho_0 + \delta\rho(t)] = i\hbar\delta\dot{\rho}$$

Time dependent DFT for the study of GR

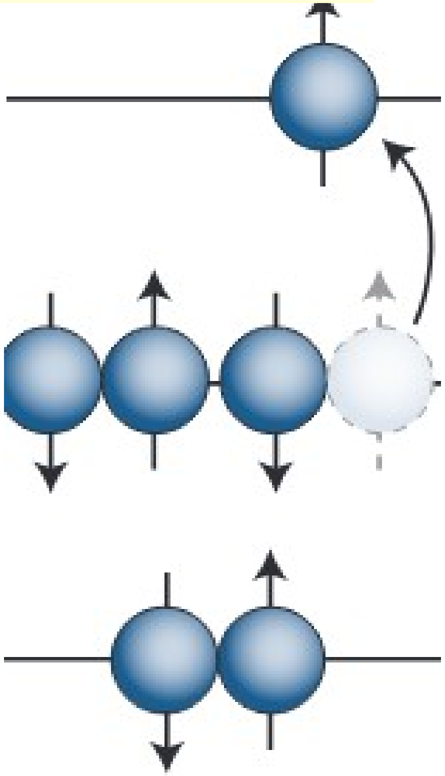
Linear Response Theory (Ring&Schuck)

Keeping the **linear terms** in the **perturbation** (F) and imposing that a Slater determinant (only for **particle-hole** or **hole-particle** excitations [**GR→ Many coherent ph excitations!**]) one could find:

$$(\omega - \epsilon_m + \epsilon_i)\delta\rho_{mi} \;=\; f_{mi} + \sum_{m'i'} V_{mi'im'}\delta\rho_{m'i'} + V_{mm'ii'}\delta\rho_{im'}$$

$$(\omega - \epsilon_i + \epsilon_m)\delta\rho_{im} \;=\; f_{im} + \sum_{m'i'} V_{imi'mm'}\delta\rho_{m'i'} + V_{im'mi'}\delta\rho_{im'}$$

$$V_{kl'lk'} \;=\; \sum_{kk'} \left.\frac{\partial h_{kl}}{\partial \rho_{k'l'}}\right|_{\rho^{(0)}} \;=\; \left.\frac{\partial^2 E}{\partial \rho_{lk}\partial \rho_{k'l'}}\right|_{\rho^{(0)}}$$



For **F→ 0** and solving the Eqs. for **δρ** one finds the **Random Phase Approximation** where the knowledge of **E[ρ] is suffient**, no need to impose H.

As a **result** one obtains the **excitation spectra** (energies and w.f.) and can build the **strength function S(E)**

Some selected results

Electric Dipole Polarizability: Do we understand it from theory?

Applying the **dielectric theorem** to the **Droplet Model** Hamiltonian (first Migdal and latter on Meyer et al. NPA385, 269) one can find (shown before)

$$\alpha_D \approx \frac{A\langle r^2\rangle}{12J}\left[1+\frac{5}{2}\frac{\Delta r_{np}+\sqrt{\frac{3}{5}\frac{e^2Z}{70J}}-\Delta r_{np}^{surface}}{\langle r^2\rangle^{1/2}(I-I_C)}\right]$$

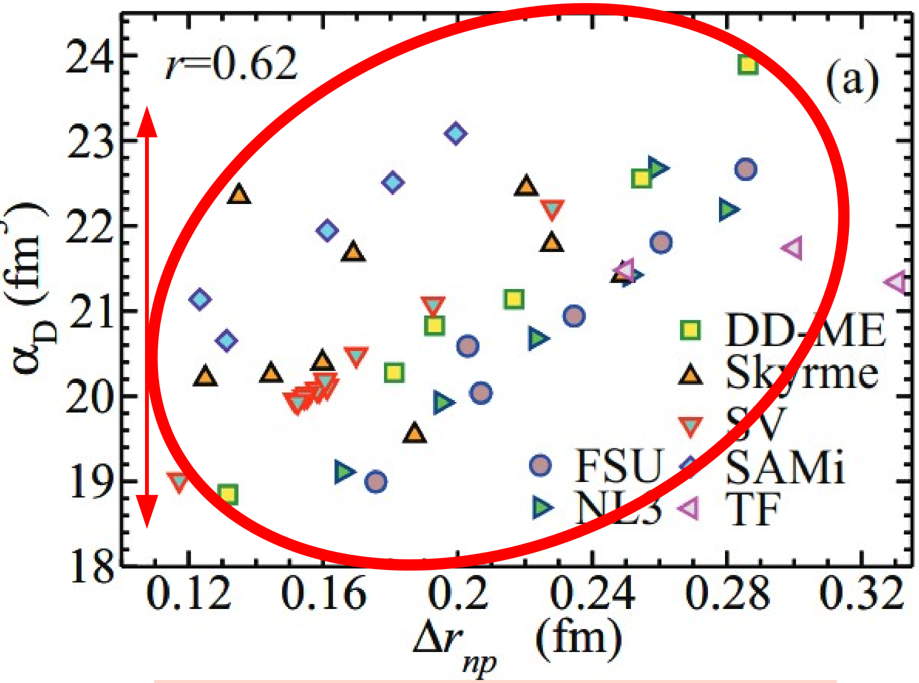
J = e(PNM)-e(SNM) → Symmetry energy at ρ_0

$\Delta r_{np} = \langle r_n^2\rangle^{1/2}-\langle r_p^2\rangle^{1/2}$ → Neutron skin thickness

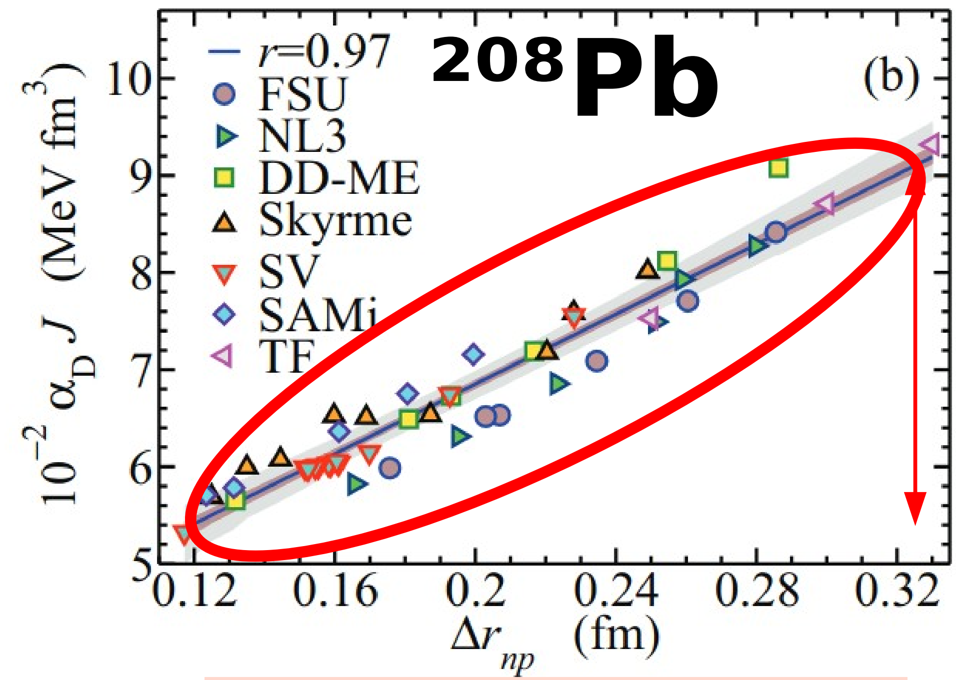
Using microscopic calculations

(Energy Density Functionals ↔ Hartree-Fock+Random Phase Approximation)

Model errors large



Correlation between models low



Model errors large

Correlation between models high

Electric Dipole Polarizability: Do we understand it from theory?

Applying the **dielectric theorem** to the **Droplet Model** Hamiltonian (first Migdal and latter on Meyer et al. NPA385, 269) one can find (shown before)

$\alpha_D \approx$

Using r

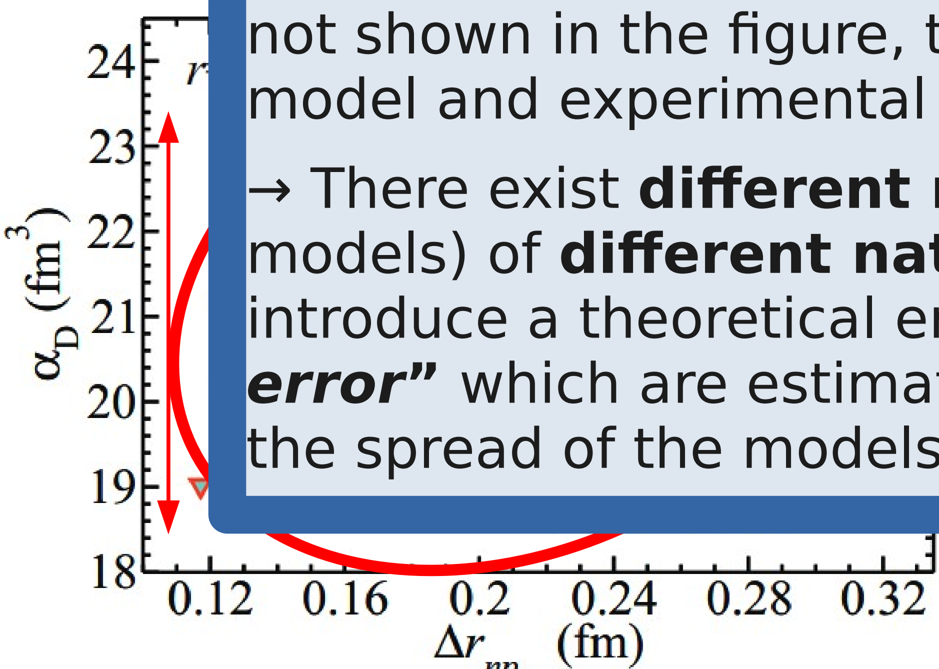
(Energy Den

WARNING: one must remember that (nowadays) **all nuclear models are effective models.**

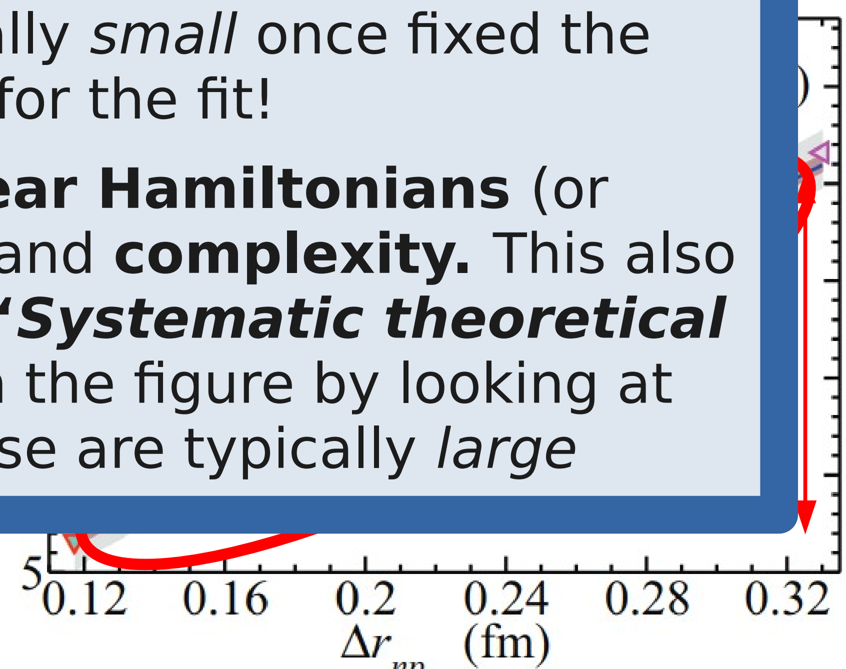
→ **Parameters of the model are not fundamental constants** but are **fitted** to reproduce some **experimental data** → "***Statistical theoretical***" errors not shown in the figure, typically *small* once fixed the model and experimental pool for the fit!

→ There exist **different nuclear Hamiltonians** (or models) of **different nature** and **complexity.** This also introduce a theoretical error: ***"Systematic theoretical error"*** which are estimated in the figure by looking at the spread of the models. Those are typically *large*

Model errors large



Correlation between models low

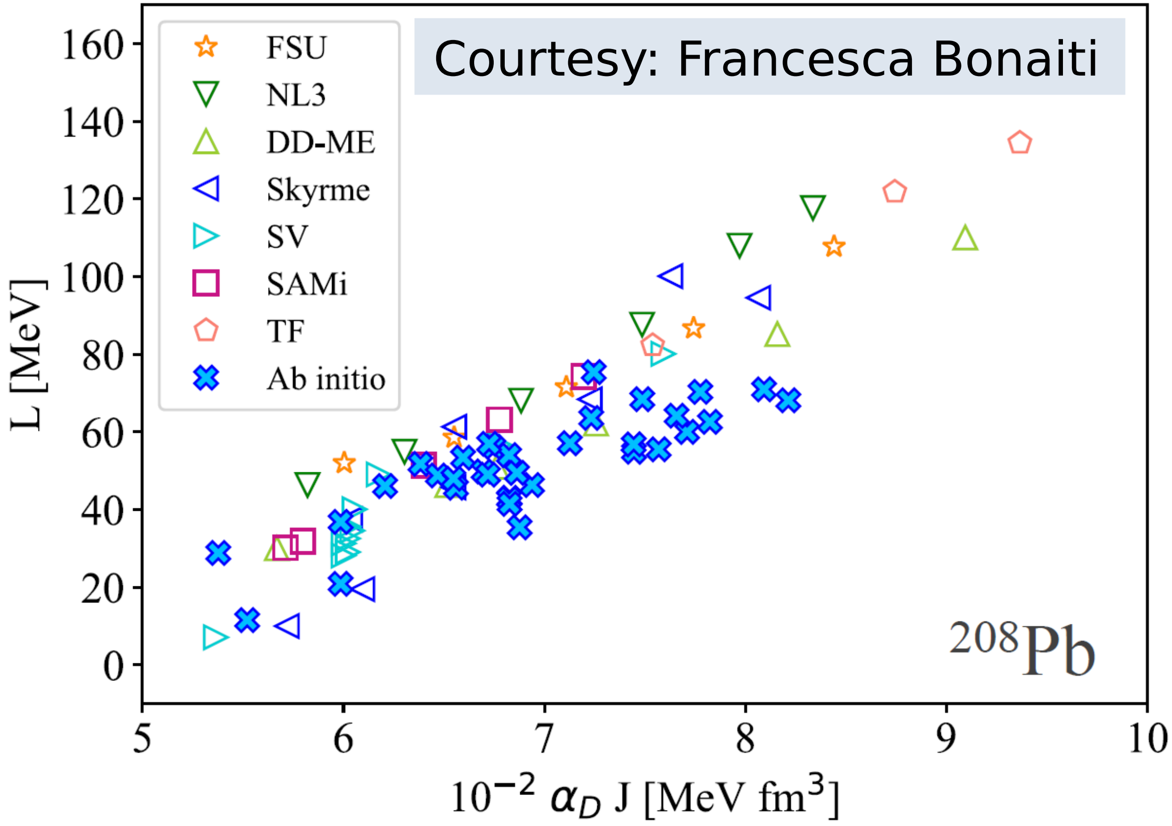


Correlation between models high

Model errors large

EDFs are consistent with Droplet Model
What about “ab initio” models?

What happens if we add to the previous results based on **DFT** from **χ-EFT**?



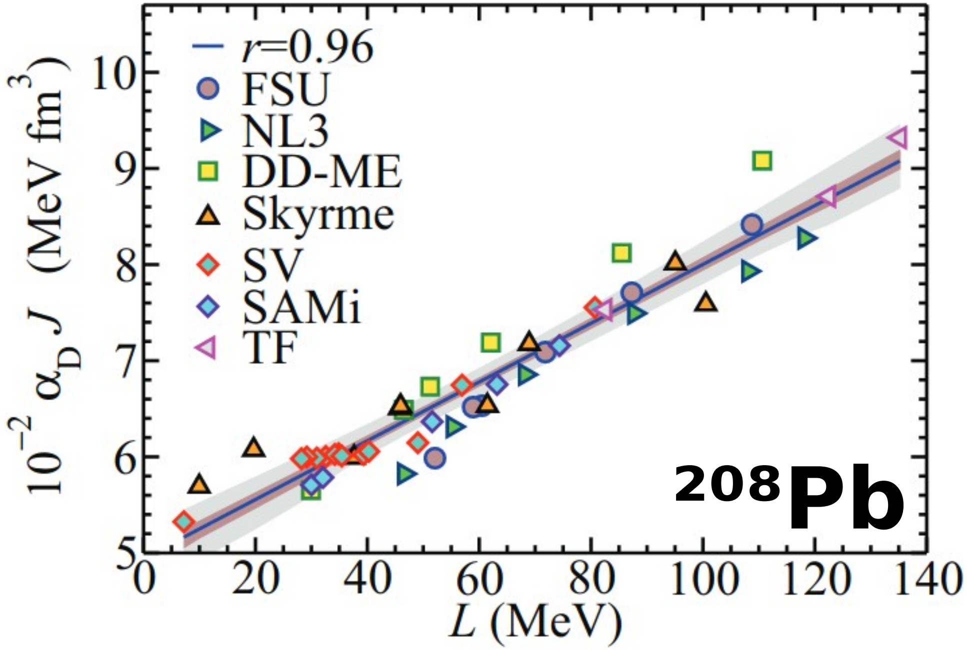
DFT data from:
Roca-Maza, Phys. Rev. C **88**, 024316 (2013)

Ab initio data from:
Hu, Nat. Phys. **18**, 1196-1200 (2022)

It looks consistent, may be we understood something

Now we are allowed to study the consequences of what we have learned on the EoS

Determination of the J vs L relation from experimental data according to EDFs



$$J = 25.0(2) + 0.19(2)L \quad \text{for } {}^{68}\text{Ni},$$
$$J = 25.4(1.1) + 0.17(1)L \quad \text{for } {}^{120}\text{Sn},$$
$$J = 24.5(8) + 0.17(1)L \quad \text{for } {}^{208}\text{Pb}.$$

Assuming Taylor expansion around ρ_0:

$$S(\langle\rho\rangle) \approx J - L\frac{\rho_0 - \langle\rho\rangle}{3\rho_0} \rightarrow J \approx S(\langle\rho\rangle) + \frac{\rho_0 - \langle\rho\rangle}{3\rho_0} L$$

one can qualitatively understand the result!!

$$S(\langle\rho\rangle \approx 0.08\ \text{fm}^{-3}) \approx 25\ \text{MeV}$$

X. Roca-Maza, M. Brenna, G. Colò, M. Centelles, X. Viñas, B. K. Agrawal, N. Paar, D. Vretenar, and J. Piekarewicz
Phys. Rev. C **88**, 024316 – Published 20 August 2013

X. Roca-Maza, X. Viñas, M. Centelles, B. K. Agrawal, G. Colò, N. Paar, J. Piekarewicz, and D. Vretenar
Phys. Rev. C **92**, 064304 – Published 8 December 2015

Current applications to the measurement or calculation of the nuclear polarizability

Polarizability is sensitive to the **neutron skin thickness** and **neutron distribution.** If accurately determined we can learn about **isospin symmetry breaking** effects in the nuclear medium ↔ **restoration of chiral symmetry?** And on the **weak charge of the nucleus** ↔ **weak mixing angle?**

Effects on **atomic energy levels** due to nuclear polarization (electronic or muonic atoms) ↔ help in accurate **determination** of electric **charge radii?**

Learning about **nuclear polarizability** could help understanding the **tidal deformability** (=quadrupole polarizability) in neutron stars

Collaborators

→ Gianluca **Colò** (University of Milan)

→ Hiroyuki **Sagawa** (University of Aizu & RIKEN)

→ Tomoya **Naito** (University of Tokyo & RIKEN)

→ Shihang **Shen** (Forschungszentrum Jülich)

→ Xavier **Vinyes** & Mario **Centelles** (University of Barcelona)

→ Jorge **Piekarewicz** (Florida State University)

→ Nils **Paar** & Dario **Vretenar** (University of Zagreb)

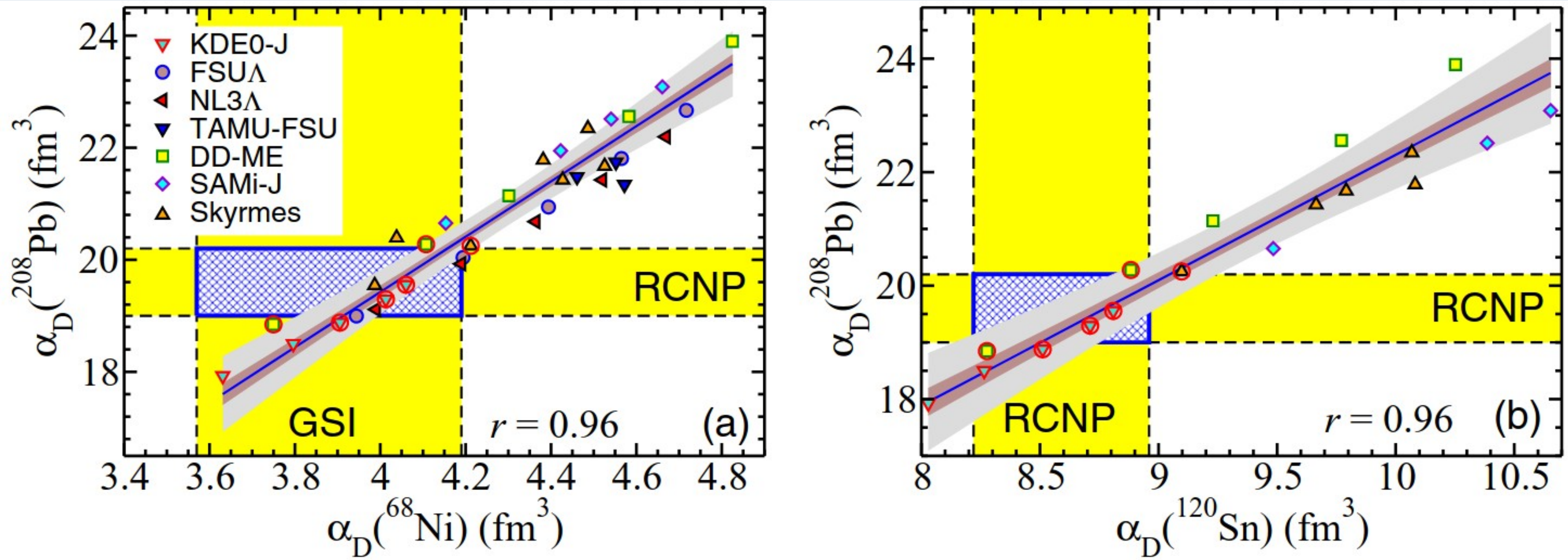
→ Bijay K. **Agrawal** (Saha Institute of Nuclear Physics)

→ P.-G. **Reinhard** (University of Erlangen-Nürnberg)

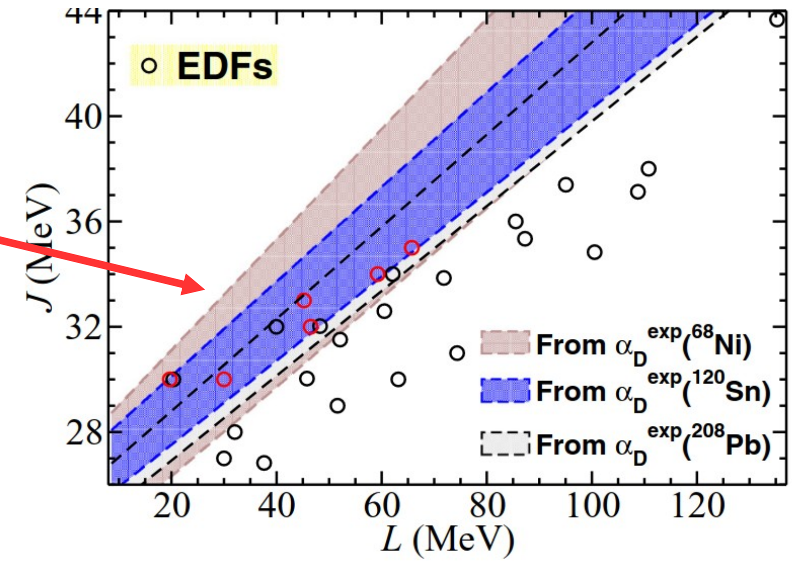
→ Witold **Nazarewicz** (FRIB and Michigan State University)

Are these results robust?

Selection of EDFs (red circles) compatible with experimental data



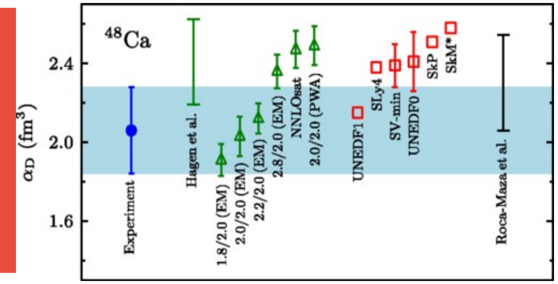
Warning: Some EDFs not compatible with experiment (black circles) are within bands, but most of them outside!



X. Roca-Maza, M. Brenna, G. Colò, M. Centelles, X. Viñas, B. K. Agrawal, N. Paar, D. Vretenar, and J. Piekarewicz
Phys. Rev. C **88**, 024316 – Published 20 August 2013

X. Roca-Maza, X. Viñas, M. Centelles, B. K. Agrawal, G. Colò, N. Paar, J. Piekarewicz, and D. Vretenar
Phys. Rev. C **92**, 064304 – Published 8 December 2015

Electric Dipole Polarizability:
but do we really really understand it?

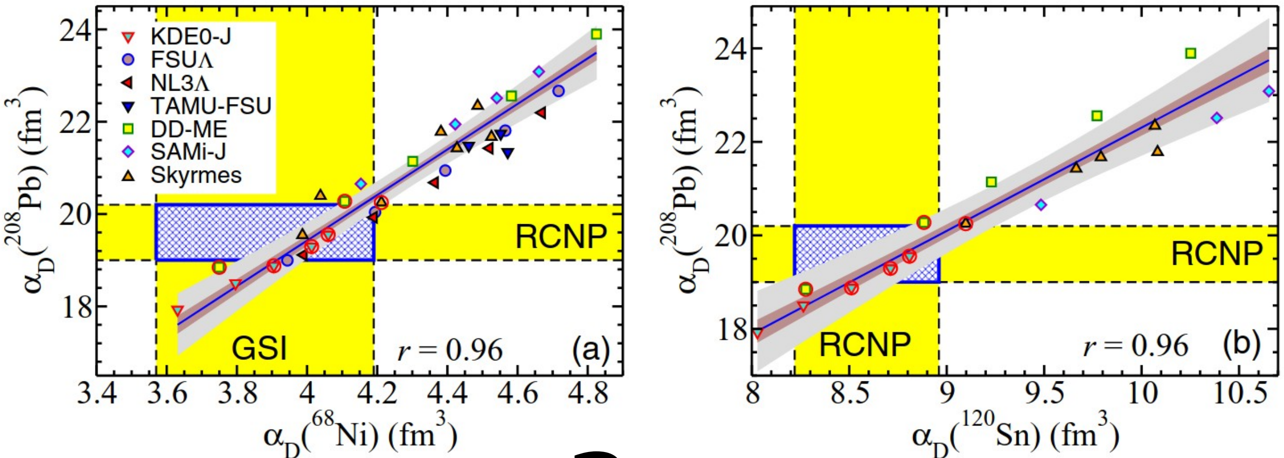


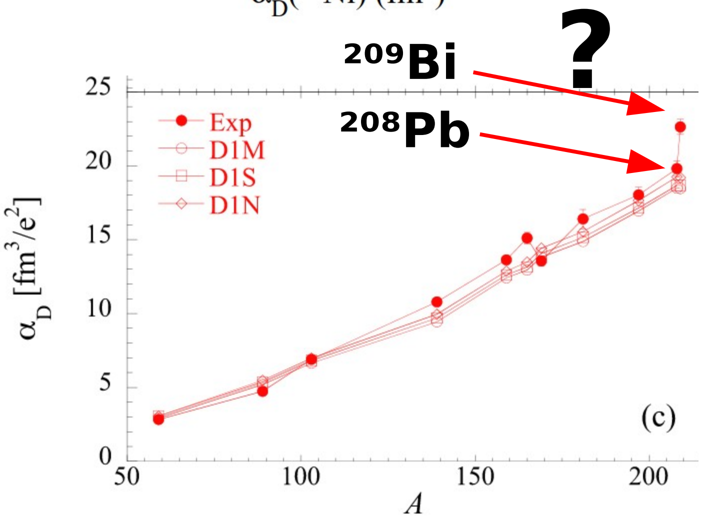
J. Birkhan, M. Miorelli, S. Bacca, S. Bassauer, C. A. Bertulani, G. Hagen, H. Matsubara, P. von Neumann-Cosel, T. Papenbrock, N. Pietralla, V. Yu. Ponomarev, A. Richter, A. Schwenk, and A. Tamii

Phys. Rev. Lett. **118**, 252501 – Published 23 June 2017

X. Roca-Maza, X. Viñas, M. Centelles, B. K. Agrawal, G. Colò, N. Paar, J. Piekarewicz, and D. Vretenar

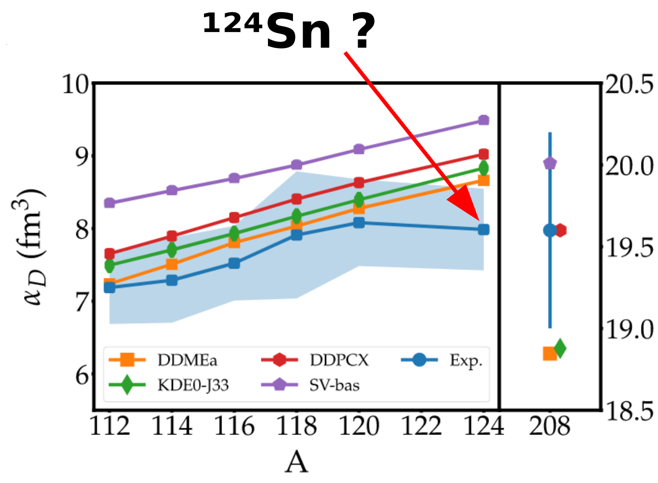
Phys. Rev. C **92**, 064304 – Published 8 December 2015





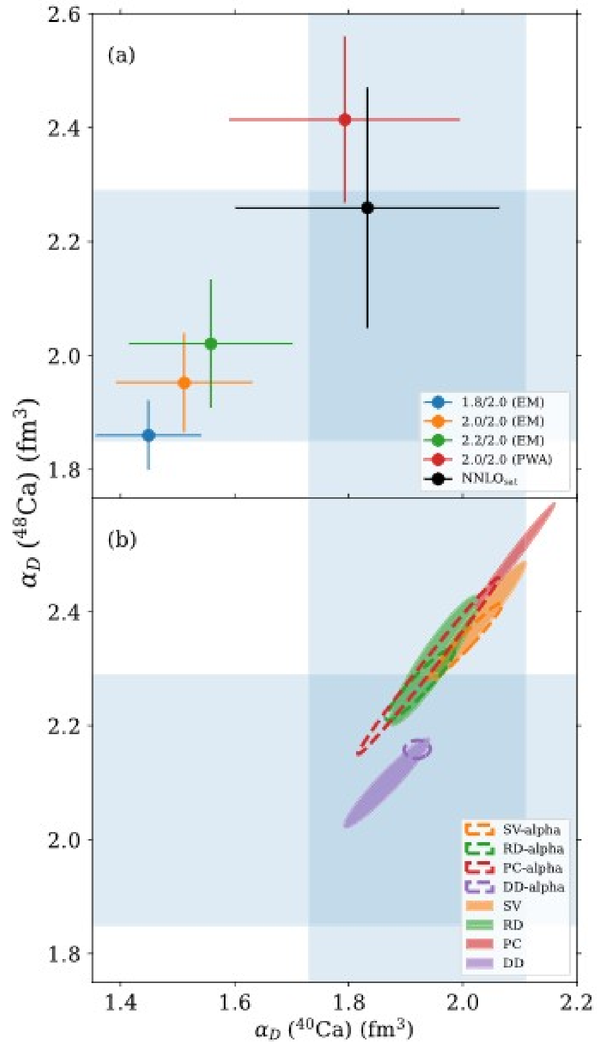
S. Goriely, S. Péru, G. Colò, X. Roca-Maza, I. Gheorghe, D. Filipescu, and H. Utsunomiya

Phys. Rev. C **102**, 064309 – Published 9 December 2020



S. Bassauer, P. von Neumann-Cosel, P.-G. Reinhard et al.

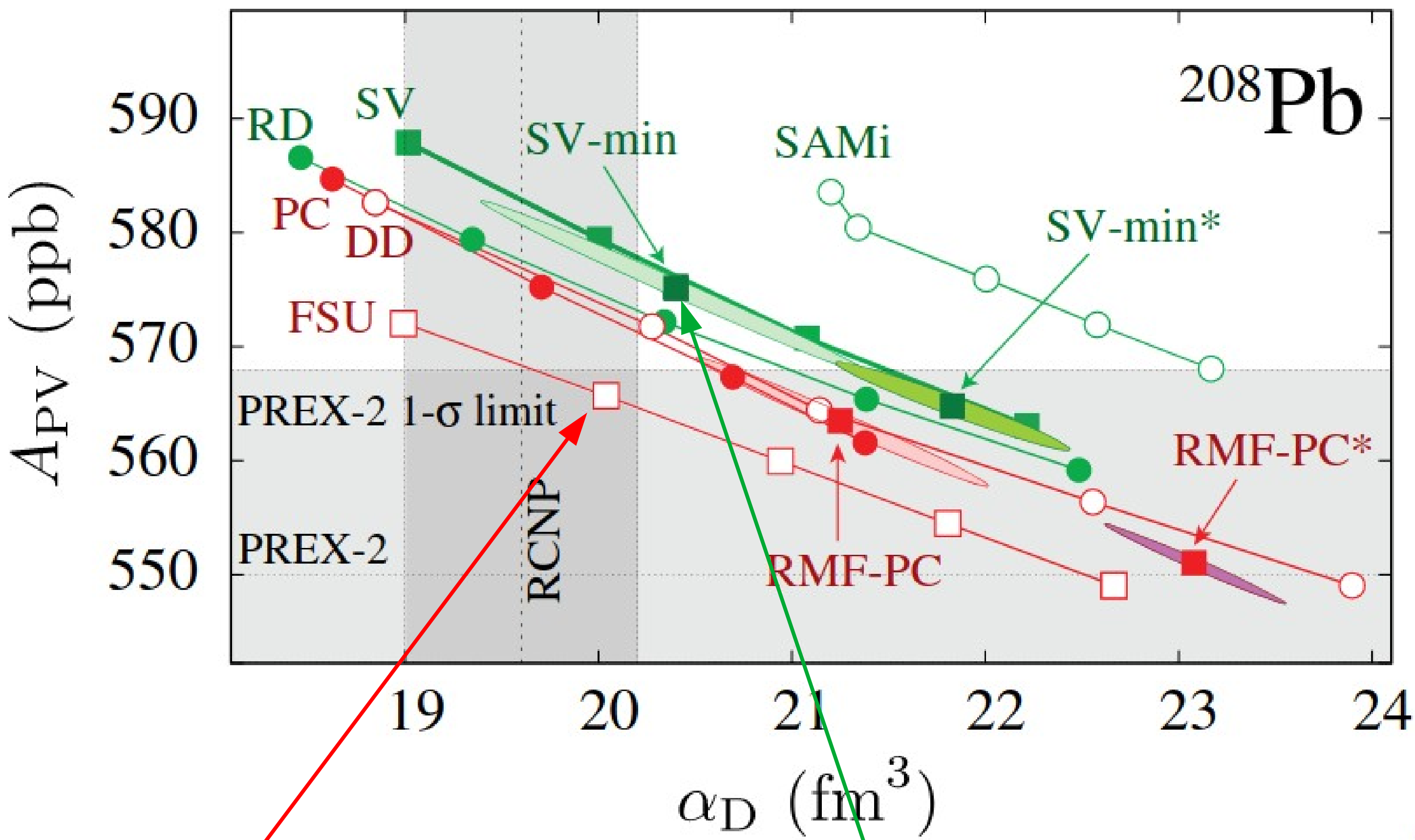
Physics Letters B 810 (2020) 135804



R. W. Fearick, P. von Neumann-Cosel, S. Bacca, J. Birkhan, F. Bonaiti, I. Brandherm, G. Hagen, H. Matsubara, W. Nazarewicz, N. Pietralla, V. Yu. Ponomarev, P.-G. Reinhard, X. Roca-Maza, A. Richter, A. Schwenk, J. Simonis, and A. Tamii

Phys. Rev. Research **5**, L022044 – Published 31 May 2023

And if we combine A_{PV} and α_D in ^{208}Pb?



Paul-Gerhard Reinhard, Xavier Roca-Maza, and Witold Nazarewicz
Phys. Rev. Lett. 127, 232501 (2021)

- Models with an * contain Apv in ^{208}Pb in the fitting protocol

- Models connected by lines: family

- SV, PC and RD models fitted to the same data

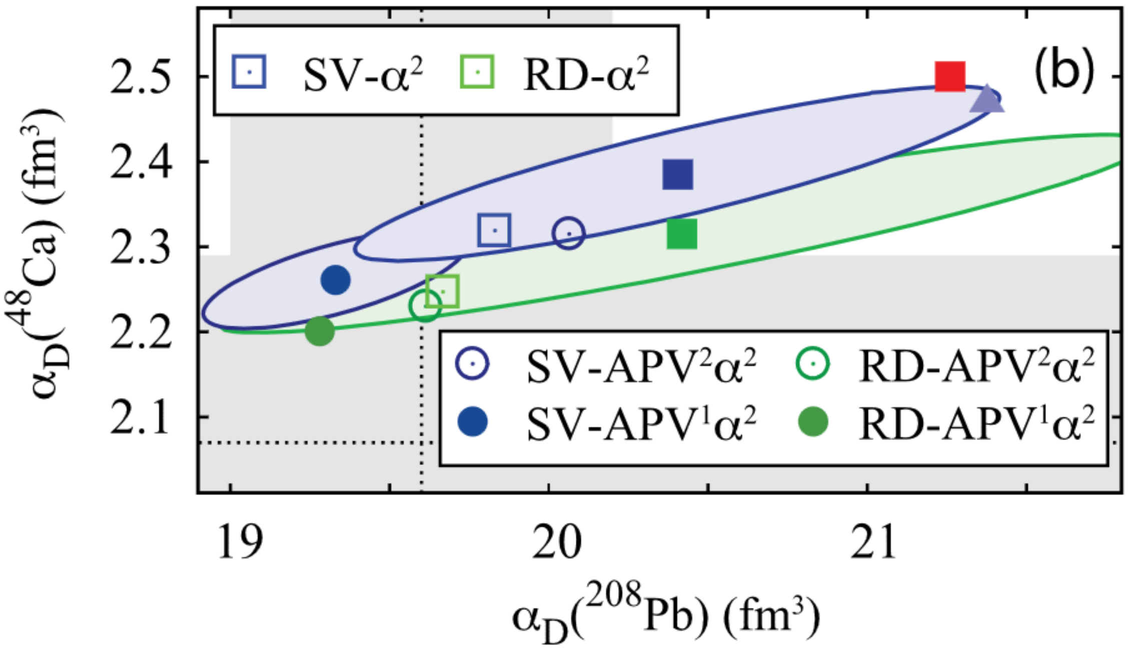
SV-min:

$$r_{\text{skin}} = 0.19 \pm 0.02 \text{ fm}$$
$$L = 54 \pm 8 \text{ MeV}$$

B and **Rch** away from "expected" EDF accuracy for B and Rch 

Theoretical and experimental 1σ errors overlap for SV-min
But not overlap both exp.

Summary: model performance A_{PV} (sensitive to Δr_{np}) and α_D (sensitive to J and Δr_{np}) in ^{48}Ca and ^{208}Pb

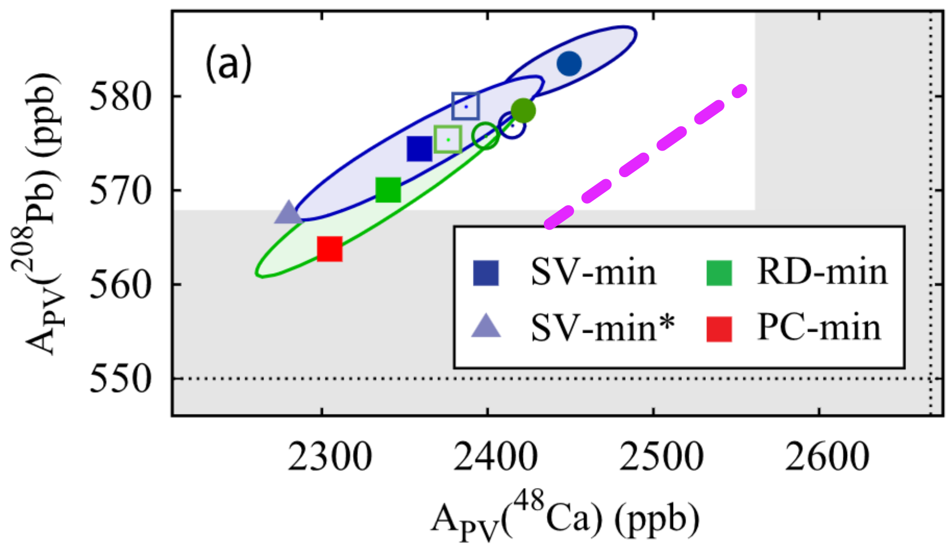


Simultaneous description of **dipole polarizabilities → point** to a **good understanding** of **symmetry energy (J)** and **neutron skins (Δr_{np})**

Ab-initio (B. Hu) Nature Physics (2022)

$\alpha_D(^{48}\mathrm{Ca})$	$2.30^{+0.31}_{-0.26}$
$\alpha_D(^{208}\mathrm{Pb})$	$22.6^{+2.1}_{-1.8}$

No simultaneous description of **parity violating asymmetries** (ground state observable) → point to a **deficient understanding** of **neutron skins**



Magenta dashed lines from extrapolated Δr_{np} given in G. Hagen et al. Nature Physics 12, 186–190 (2016) and H. Bu et al. Nature Physics (2022)

Combined Theoretical Analysis of the Parity-Violating Asymmetry for ^{48}Ca and ^{208}Pb
Paul-Gerhard Reinhard, Xavier Roca-Maza, and Witold Nazarewicz
Phys. Rev. Lett. **129**, 232501 – Published 2 December 2022