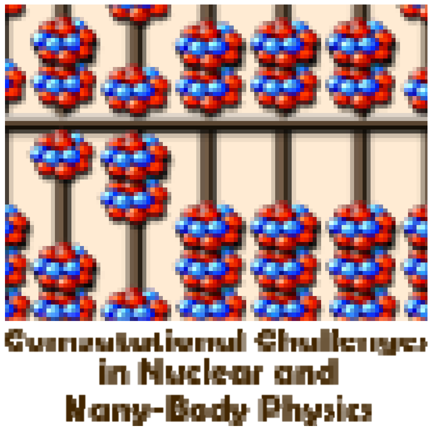
北京大學 PEKING UNIVERSITY

COMPUTATIONAL CHALLENGES IN NUCLEAR AND MANY-BODY PHYSICS

FROM 15 SEPTEMBER 2014 TO 10 OCTOBER 2014

NORDITA, STOCKHOLM

Highlight for Nuclear Structure in Covariant Density Functional Theory



Jie MENG（孟 杰）

School of Physics，Peking University

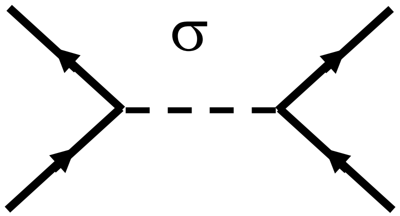
北京大学物理学院

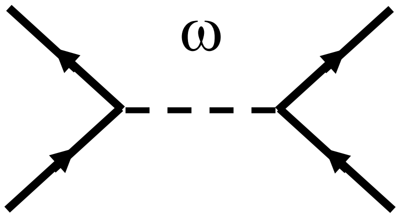
Outline

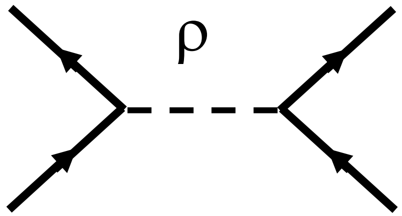
- Introduction
- Halo
- Clustering
- Hidden pseudospin and spin symmetries
- Nuclear barrier with triaxial and octupole shape
- Simultaneous shape phase transition
- Exotic rotation: magnetic and antimagnetic rotation MχD
- Nuclear β-decay half-lives
- Extending the nuclear landscape by continuum: from spherical to deformed
- Perspectives

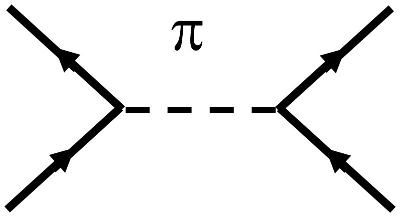
Starting point of CDFT

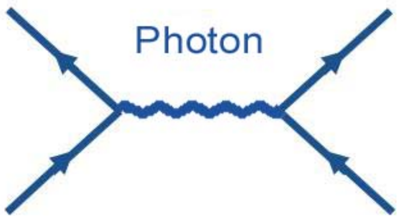
Nucleons are coupled by exchange of mesons via an effective Lagrangian with all relativistic symmetries, used in a mean field concept **and** no-sea approximation











meson	J^π	T
π	0^-	1
σ	0^+	0
ω	1^-	0
ρ	1^-	1

Free Space: Lorentz Invariant

Scalar(0) [Sigma] $L_\sigma = \frac{1}{2}\partial_\mu\sigma\partial^\mu\sigma - \frac{1}{2}m_\sigma^2\sigma^2$ ⇒ $\left[\Box + m^2\right]\sigma = 0$ **Klein-Gordon**

Vector(1) [E-M] $L_{em} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu}$ ⇒ $\partial^\mu F_{\mu\nu} = 0$

Spinor(1/2) [N] $L_\psi = \bar{\psi}\left(i\gamma_\mu\partial^\mu - m\right)\psi$ ⇒ $\left[i\gamma_\mu\partial^\mu - m\right]\psi = 0$ **Dirac**

Motivated by the empirically observed large Lorentz scalar and four-vector components in the N-N interaction:

Scalar(0) [Sigma] —— Scalar(0) [Sigma] $L = L_\sigma^{free} - g_2\sigma^3 - g_3\sigma^4$ $\lambda\phi^4$ **Theory**

Spinor(1/2) [N] —— Scalar(0) [Sigma] $L = L_\sigma^{free} + L_\psi^{free} - \bar{\psi}g_\sigma\sigma\psi$

Spinor(1/2) [N] —— Vector(1) [E-M] $L = L_\psi^{free} + L_{em}^{free} - eA^\mu\bar{\psi}\gamma_\mu\psi$ **Gauge symmetry**

Brief introduction of CDFT

Lagrangian:

$$L = \bar{\psi}[i\gamma^{\mu}\partial_{\mu} - M - g_{\sigma}\sigma - \gamma^{\mu}(g_{\omega}\omega_{\mu} + g_{\rho}\vec{\tau}\bullet\vec{\rho}_{\mu} + e\tfrac{1-\tau_3}{2}A_{\mu}) - \tfrac{f_{\pi}}{m_{\pi}}\gamma_5\gamma^{\mu}\partial_{\mu}\vec{\pi}\bullet\vec{\tau}]\psi$$

$$+\frac{1}{2}\partial^{\mu}\sigma\partial_{\mu}\sigma - \frac{1}{2}m_{\sigma}^2\sigma^2 - \frac{1}{4}\Omega^{\mu\nu}\Omega_{\mu\nu} + \frac{1}{2}m_{\omega}^2\omega_{\mu}\omega^{\mu} - \frac{1}{4}\vec{R}_{\mu\nu}\bullet\vec{R}^{\mu\nu}$$

$$+\frac{1}{2}m_{\rho}^2\vec{\rho}^{\mu}\cdot\vec{\rho}_{\mu} + \frac{1}{2}\partial_{\mu}\vec{\pi}\bullet\partial^{\mu}\vec{\pi} - \frac{1}{2}m_{\pi}^2\vec{\pi}\bullet\vec{\pi} - \frac{1}{4}F^{\mu\nu}F_{\mu\nu}$$

$$\Omega^{\mu\nu} = \partial^{\mu}\omega^{\nu} - \partial^{\nu}\omega^{\mu}$$

$$\vec{R}^{\mu\nu} = \partial^{\mu}\vec{\rho}^{\nu} - \partial^{\nu}\vec{\rho}^{\mu}$$

$$F^{\mu\nu} = \partial^{\mu}A^{\nu} - \partial^{\nu}A^{\mu}$$

Hamiltonian:

$$H = \bar{\psi}(-i\boldsymbol{\gamma}\bullet\nabla + M)\psi + \frac{1}{2}\int d^4y \sum_{i=\sigma,\omega,\rho,\pi,A} \bar{\psi}(x)\bar{\psi}(y)\Gamma_i D_i(x,y)\psi(y)\psi(x)$$

$$= T + V$$

$$\Gamma_{\sigma}(1,2) \equiv -g_{\sigma}(1)g_{\sigma}(2), \qquad \Gamma_{\rho}(1,2) \equiv +(g_{\rho}\gamma_{\mu}\vec{\tau})_1\cdot(g_{\rho}\gamma^{\mu}\vec{\tau})_2,$$

$$\Gamma_{\omega}(1,2) \equiv +(g_{\omega}\gamma_{\mu})_1(g_{\omega}\gamma_{\mu})_2, \; \Gamma_{\pi}(1,2) \equiv -(\tfrac{f_{\pi}}{m_{\pi}}\vec{\tau}\gamma_5\gamma_{\mu}\partial^{\mu})_1\cdot(\tfrac{f_{\pi}}{m_{\pi}}\vec{\tau}\gamma_5\gamma_{\nu}\partial^{\nu})_2$$

$$\Gamma_{\mathrm{em}}(1,2) \equiv +\frac{e^2}{4}(\gamma_{\mu}(1-\tau_3))_1(\gamma^{\mu}(1-\tau_3))_2$$

Brief introduction of CDFT

$$H = T + \sum_{i=\sigma,\omega,\rho,\pi,A} V_i$$

$$\psi(x) = \sum_i [f_i(\mathbf{x})e^{-i\varepsilon_i t}c_i + g_i(\mathbf{x})e^{i\varepsilon_i' t}d_i^\dagger]$$

$$\psi^\dagger(x) = \sum_i [f_i^\dagger(\mathbf{x})e^{i\varepsilon_i t}c_i^\dagger + g_i^\dagger(\mathbf{x})e^{-i\varepsilon_i' t}d_i]$$

$$T = \int d\mathbf{x} \sum_{\alpha\beta} \bar{f}_\alpha(-i\gamma\cdot\nabla + M) f_\beta c_\alpha^\dagger c_\beta,$$

Hartree

$$V_i = \frac{1}{2}\int d\mathbf{x}_1 d\mathbf{x}_2 \sum_{\alpha\beta;\alpha'\beta'} c_\alpha^\dagger c_\beta^\dagger c_{\beta'} c_{\alpha'} \bar{f}_\alpha(1)\bar{f}_\beta(2)\Gamma_i(1,2)D_i(1,2)f_{\beta'}(2)f_{\alpha'}(1)$$

Fock

Energy density functional:

$$|\Phi_0\rangle = \prod_\alpha c_\alpha^\dagger |0\rangle$$

$$E = \langle\Phi_0|H|\Phi_0\rangle = \langle\Phi_0|T|\Phi_0\rangle + \sum_{i=\sigma,\omega,\rho,\pi,A} \langle\Phi_0|V_i|\Phi_0\rangle$$

$$= E_k + E_\sigma^D + E_\sigma^E + E_\omega^D + E_\omega^E + E_\rho^D + E_\rho^E + E_\pi + E_{\rm em}^D + E_{\rm em}^E$$

Equations of motion

For system with time invariance:

$$\left[\alpha\cdot\boldsymbol{p}+V(\boldsymbol{r})+\beta\left(M+S(\boldsymbol{r})\right)\right]\psi_i=\varepsilon_i\psi_i$$

$$\begin{cases} V(\boldsymbol{r})=g_\omega\omega(\boldsymbol{r})+g_\rho\tau_3\rho(\boldsymbol{r})+e\dfrac{1-\tau_3}{2}A(\boldsymbol{r}) \\ S(r)=g_\sigma\sigma(\boldsymbol{r}) \end{cases}$$

Same footing for

- Deformation
- Rotation
- Pairing (RHB,BCS,SLAP)
- …

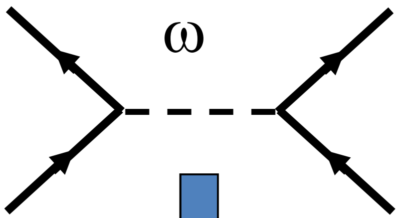
$$\left[-\Delta+m_\sigma^2\right]\sigma=-g_\sigma\rho_s-g_2\sigma^2-g_3\sigma^3$$

$$\left[-\Delta+m_\omega^2\right]\omega=g_\omega\rho_b-c_3\omega^3$$

$$\left[-\Delta+m_\rho^2\right]\rho=g_\rho\left[\rho_b^{(n)}-\rho_b^{(p)}\right]-d_3\rho^3$$

$$\begin{cases} \rho_s(\boldsymbol{r})=\sum_{i=1}^{A}\bar{\psi}_i(\boldsymbol{r})\psi_i(\boldsymbol{r}) \\ \rho_v(\boldsymbol{r})=\sum_{i=1}^{A}\psi_i^+(\boldsymbol{r})\psi_i(\boldsymbol{r}) \\ \rho_3(\boldsymbol{r})=\sum_{i=1}^{A}\psi_i^+(\boldsymbol{r})\tau_3\psi_i(\boldsymbol{r}) \\ \rho_c(\boldsymbol{r})=\sum_{i=1}^{A}\psi_i^+(\boldsymbol{r})\dfrac{1-\tau_3}{2}\psi_i(\boldsymbol{r}) \end{cases}$$

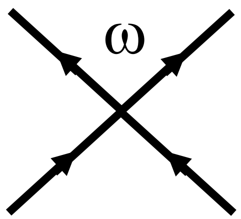
Effective Point-Coupling interaction



$$H=\bar{\psi}_i\left(-i\gamma\bullet\nabla+M\right)\psi_i+\frac{1}{4}F^{iv}F_{iv}$$
$$+\frac{1}{2}((\nabla\sigma)^2+m_\sigma^2\sigma^2)+g_\sigma\sigma\rho_s+\frac{1}{3}g_2\sigma^3+\frac{1}{4}g_3\sigma^4$$
$$+\frac{1}{2}g_\omega\omega_0\rho_v+\frac{1}{2}g_\rho\vec{\rho}_0\rho_3$$

$$g_\omega\omega=\frac{1}{1-\Delta/m_\omega^2}\frac{g_\omega^2}{m_\omega^2}\rho_v=\frac{g_\omega^2}{m_\omega^2}\rho_v+\frac{g_\omega^2}{m_\omega^4}\Delta\rho_v+\cdots\approx\alpha_v\rho_v+\delta_v\Delta\rho_v$$

$$H=\bar{\psi}_i\left(-i\gamma\square\nabla+M\right)\psi_i+\frac{1}{4}F^{iv}F_{iv}$$
$$+\frac{1}{2}\alpha_S\rho_S^2+\frac{1}{2}\delta_S\rho_S\Delta\rho_S+\frac{1}{3}\beta_S\rho_S^3+\frac{1}{4}\gamma_S\rho_S^4$$
$$+\frac{1}{2}\alpha_V\rho_V^2+\frac{1}{2}\delta_V\rho_V\Delta\rho_V+\frac{1}{2}\alpha_{TV}\rho_{TV}^2+\frac{1}{2}\delta_{TV}\rho_{TV}\Delta\rho_{TV}$$



Equations of motion

For system with time invariance:

$$\left[\alpha\cdot\boldsymbol{p}+V(\boldsymbol{r})+\beta\left(M+S(\boldsymbol{r})\right)\right]\psi_i=\varepsilon_i\psi_i$$

$$\begin{cases} V(\boldsymbol{r})=\alpha_V\rho_V(\boldsymbol{r})+\gamma_V\rho_V^3(\boldsymbol{r})+\delta_V\Delta\rho_V(\boldsymbol{r})+\alpha_{TV}\rho_{TV}(\boldsymbol{r})+\delta_{TV}\Delta\rho_{TV}(\boldsymbol{r})+e\dfrac{1-\tau_3}{2}A(\boldsymbol{r}) \\ S(r)=\alpha_S\rho_S+\beta_S\rho_S^2+\gamma_S\rho_S^3+\delta_S\Delta\rho_S \end{cases}$$

Without Klein-Gordon equation

$$\begin{cases} \rho_s(\boldsymbol{r})=\sum_{i=1}^{A}\bar{\psi}_i(\boldsymbol{r})\psi_i(\boldsymbol{r}) \\ \rho_v(\boldsymbol{r})=\sum_{i=1}^{A}\psi_i^+(\boldsymbol{r})\psi_i(\boldsymbol{r}) \\ \rho_3(\boldsymbol{r})=\sum_{i=1}^{A}\psi_i^+(\boldsymbol{r})\tau_3\psi_i(\boldsymbol{r}) \\ \rho_c(\boldsymbol{r})=\sum_{i=1}^{A}\psi_i^+(\boldsymbol{r})\dfrac{1-\tau_3}{2}\psi_i(\boldsymbol{r}) \end{cases}$$

$$(\bar{\psi}\, O\, \Gamma\, \psi),\ O \in \{1, \vec{\tau}\},\ \Gamma \in \{1, \gamma_\mu, \gamma_5, \gamma_5\gamma_\mu, \sigma_{\mu\nu}\}$$

ψ is the Dirac spinor field of the nucleon, τ is the isospin Pauli matrix, and generally denotes the 4 × 4 Dirac matrices. There are ten such building blocks characterized by their transformation characteristics in isospin and Minkowski space. In this paper, vectors in the isospin space are denoted by arrows and the space vectors by bold type. Greek indices μ and ν run over the Minkowski indices 0, 1, 2, and 3.

A general Lagrangian density: a power series in ($\bar{\psi} O \Gamma \psi$) and their derivatives.

$$\begin{aligned}
L &= \bar{\psi}(i\gamma_\mu \partial^\mu - m)\psi \\
&- \frac{1}{2}\alpha_S(\bar{\psi}\psi)(\bar{\psi}\psi) - \frac{1}{2}\alpha_V(\bar{\psi}\gamma_\mu\psi)(\bar{\psi}\gamma^\mu\psi) - \frac{1}{2}\alpha_{TV}(\bar{\psi}\vec{\tau}\gamma_\mu\psi)(\bar{\psi}\vec{\tau}\gamma^\mu\psi) \\
&- \frac{1}{3}\beta_S(\bar{\psi}\psi)^3 - \frac{1}{4}\gamma_S(\bar{\psi}\psi)^4 - \frac{1}{4}\gamma_V[(\bar{\psi}\gamma_\mu\psi)(\bar{\psi}\gamma^\mu\psi)]^2 \\
&- \frac{1}{2}\delta_S\partial_\nu(\bar{\psi}\psi)\partial^\nu(\bar{\psi}\psi) - \frac{1}{2}\delta_V\partial_\nu(\bar{\psi}\gamma_\mu\psi)\partial^\nu(\bar{\psi}\gamma^\mu\psi) - \frac{1}{2}\delta_{TV}\partial_\nu(\bar{\psi}\vec{\tau}\gamma_\mu\psi)\partial^\nu(\bar{\psi}\vec{\tau}\gamma_\mu\psi) \\
&- e\frac{1-\tau_3}{2}\bar{\psi}\gamma^\mu\psi A_\mu - \frac{1}{4}F^{\mu\nu}F_{\mu\nu}
\end{aligned}$$

parameterizations

Meson Exchange

Nonlinear parameterizations:

$$M, m_\sigma, m_\omega, m_\rho, g_\sigma, g_\omega, g_\rho, g_2, g_3, c_3, d_3$$

NL3, NLSH, TM1, TM2, PK1, …

Density dependent parameterizations:

$$M, m_\sigma, m_\omega, m_\rho, g_\sigma(\rho), g_\omega(\rho), g_\rho(\rho)$$

TW99, DD-ME1, DD-ME2, PKDD, …

Point Coupling

Nonlinear parameterizations:

$$M, \alpha_S, \alpha_V, \alpha_{TV}, \delta_S, \delta_V, \delta_{TV}, \beta_S, \gamma_S, \gamma_V$$

PC-LA, PC-F1, PC-PK1 …

Density dependent parameterizations:

$$M, \delta_S, \alpha_S(\rho), \alpha_V(\rho), \alpha_{TV}(\rho)$$

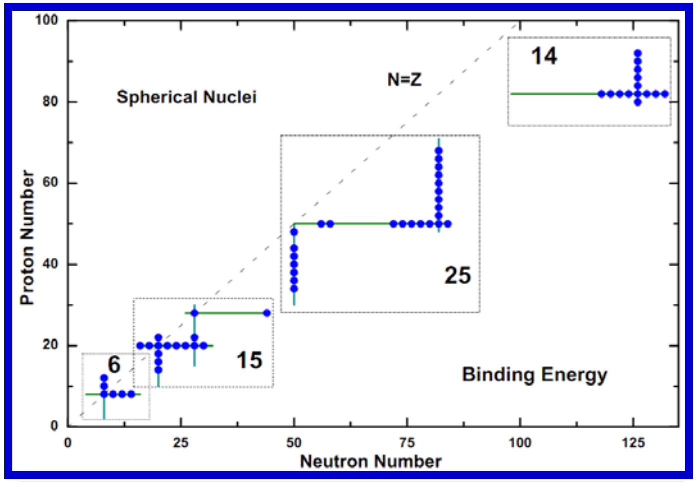
DD-PC1, …

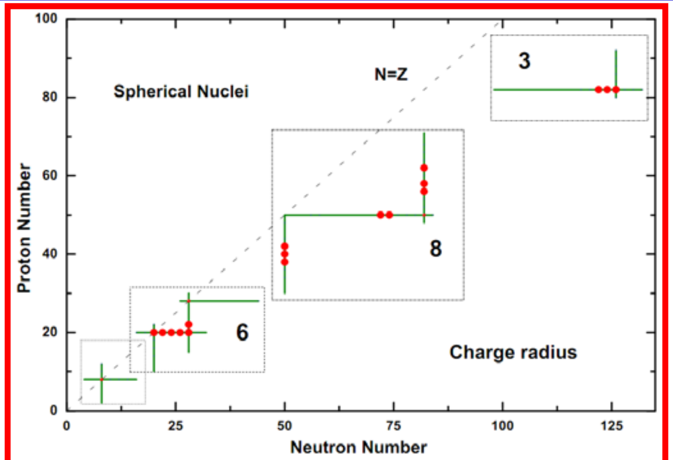
Parameterizations PC-PK1

P. W. Zhao (赵鹏巍), L. S. Song (宋凌霜), B. Sun (孙保华), H. Geissel, and J. Meng (孟杰)

Phys. Rev. C 86, 064324 (2012) [6 pages]

Crucial test for covariant density functional theory with new and accurate mass measurements from Sn to Pa



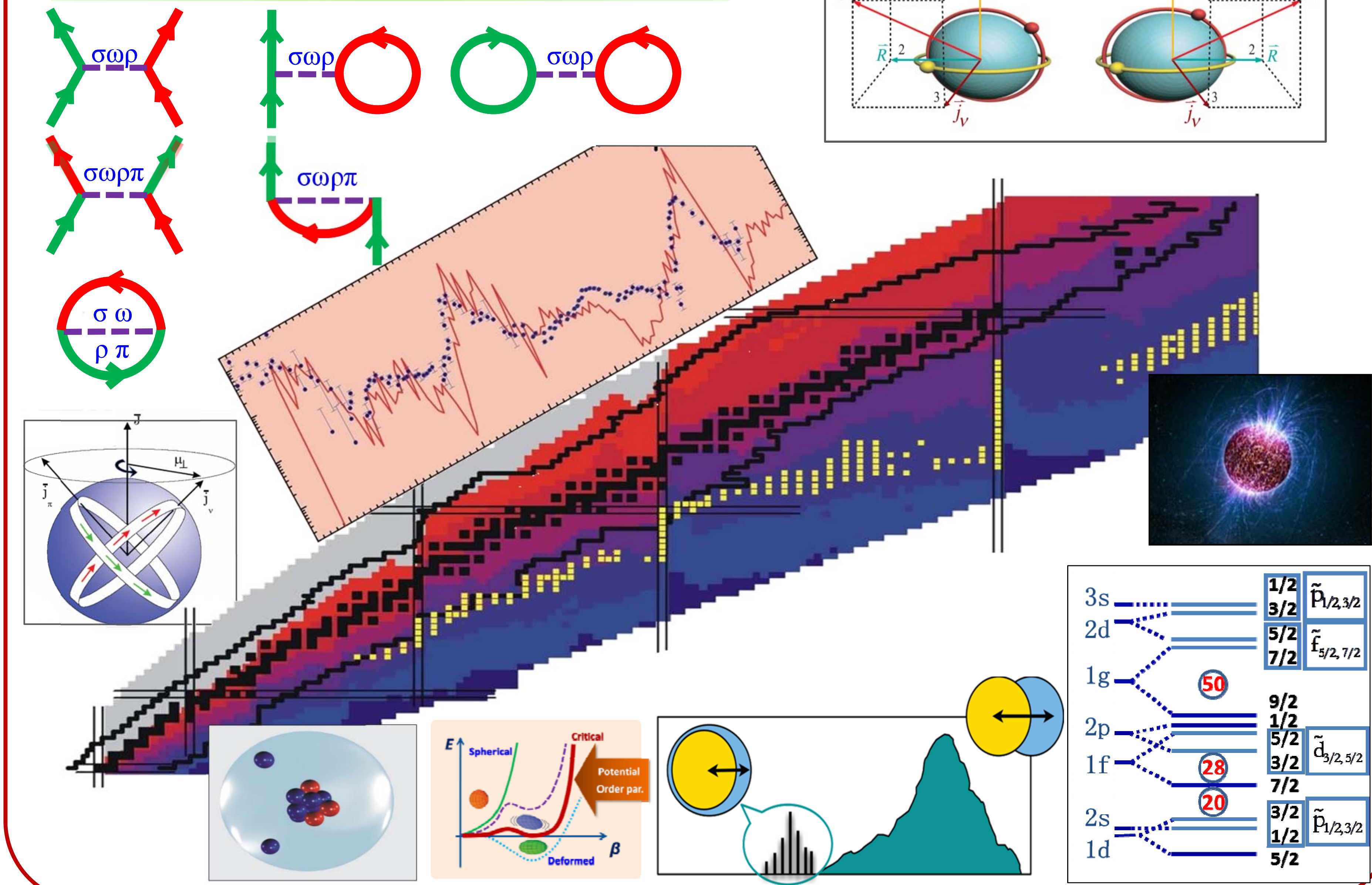


Coupl.	Cons.	PC-PK1	Dimension
α_S	$[10^{-4}]$	-3.96291	MeV^{-2}
β_S	$[10^{-11}]$	8.66530	MeV^{-5}
γ_S	$[10^{-17}]$	-3.80724	MeV^{-8}
δ_S	$[10^{-10}]$	-1.09108	MeV^{-4}
α_V	$[10^{-4}]$	2.69040	MeV^{-2}
γ_V	$[10^{-18}]$	-3.64219	MeV^{-8}
δ_V	$[10^{-10}]$	-4.32619	MeV^{-4}
α_{TV}	$[10^{-5}]$	2.95018	MeV^{-2}
δ_{TV}	$[10^{-10}]$	-4.11112	MeV^{-4}
V_n	$[10^{0}]$	-349.5	$\mathrm{MeV\ fm}^{3}$
V_p	$[10^{0}]$	-330	$\mathrm{MeV\ fm}^{3}$

Zhao, Li, Yao, Meng, PRC 82, 054319 (2010)

Covariant density functional

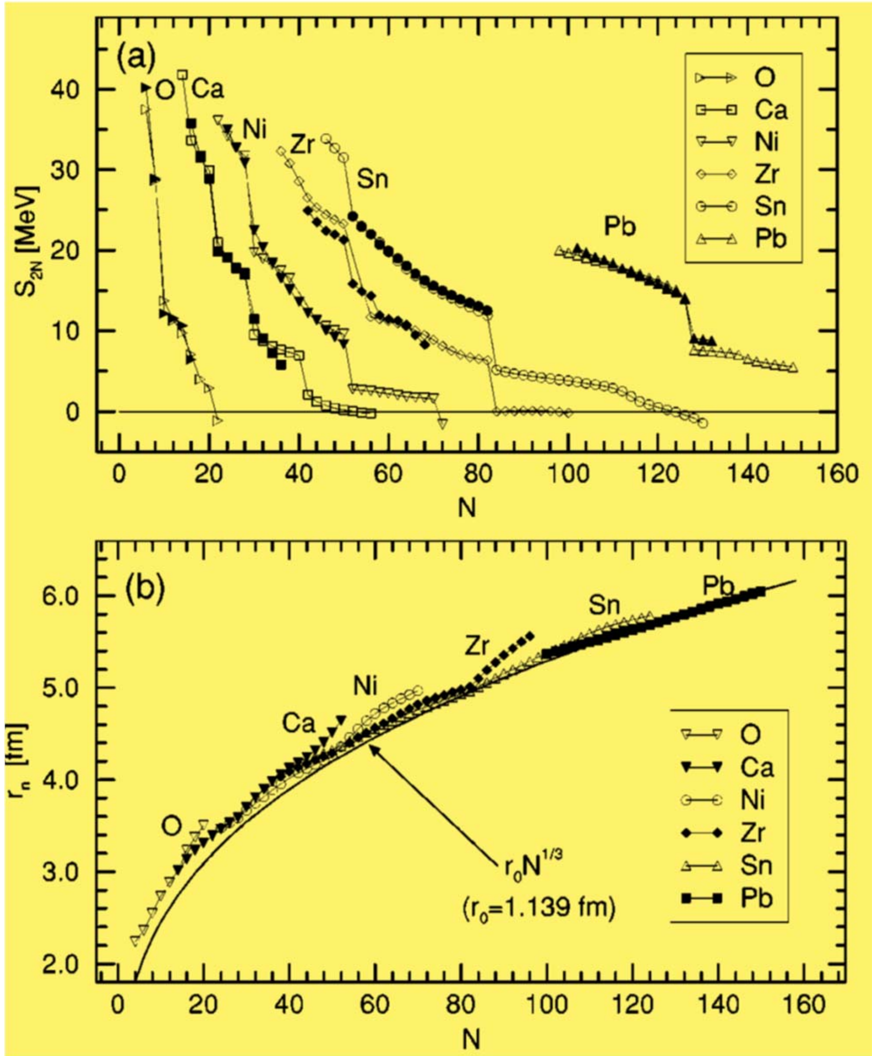
Progress in Physics. 31(2011)199-336.



Outline

- Introduction
- Halo
- Clustering
- Hidden pseudospin and spin symmetries
- Nuclear barrier with triaxial and octupole shape
- Simultaneous shape phase transition
- Exotic rotation: magnetic and antimagnetic rotation MχD
- Nuclear β-decay half-lives
- Extending the nuclear landscape by continuum: from spherical to deformed
- Perspectives

Halo in heavy nucleus: giant halo and deformed halo



Spherical nucleus: continuum & pairing
Meng & Ring, PRL77,3963 (96)
Meng & Ring, PRL80,460 (1998)
Meng, NPA 635, 3-42 (1998)
Meng, Tanihata & Yamaji, PLB 419, 1(1998)
Meng, Toki, Zeng, Zhang & Zhou, PRC65, 041302R

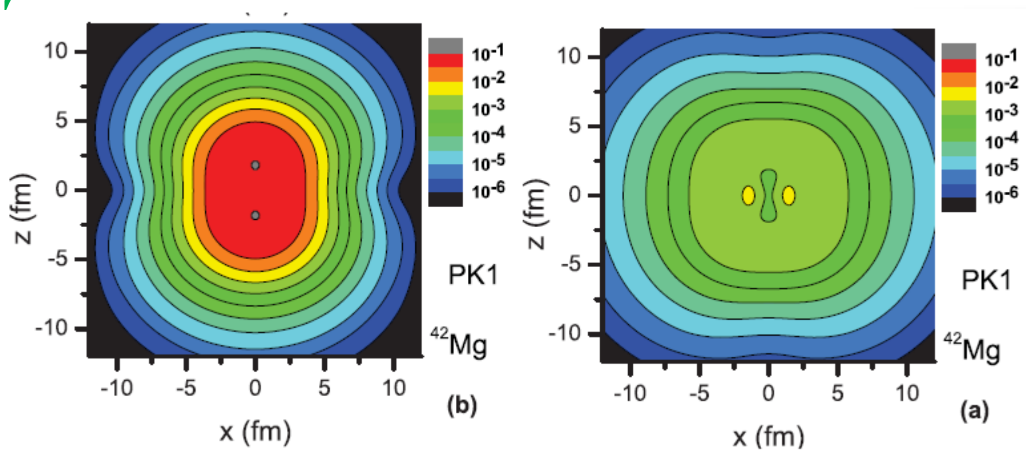
Spherical nucleus but in DDRHFB: Fock term
Long, Ring, Meng & Van Giai, PRC81 , 031302
Wang, Dong, Long, PRC 87, 047301(2013).
Lu, Sun, Long, PRC 87, 034311 (2013).

Deformed nucleus: deformation & blocking
Zhou, Meng, Ring & Zhao, Phys. Rev. C 82, 011301 (R)(2010)
Li, Meng, Ring, Zhao & Zhou, Phys. Rev. C 85, 024312 (2012)
Chen, Li, Liang & Meng, Phys. Rev. C 85, 067301 (2012)
Li, Meng, Ring, Zhao & Zhou, Chin. Phys. Lett. 29, 042101 (2012).

Reviews:
Meng,Toki, Zhou, Zhang, Long & Geng, PPNP 57. 460 (2006)

Zhang, Matsuo, Meng, PRC83:054301,2011; PRC86: 054318, 2012

Deformed RHB (DRHB) theory in continuum

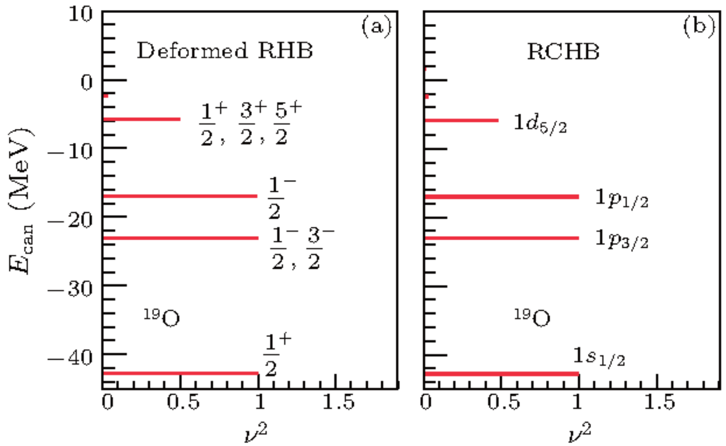


- Describe bound states, continuum, and the coupling between them, as well as asymptotical density and deformation effect in a self-consistent and proper way.
- Predicte shape decoupling between the core and halo in ^{42}Mg .

Zhou, Meng, Ring & Zhao, PRC 82, 011301R (2010)

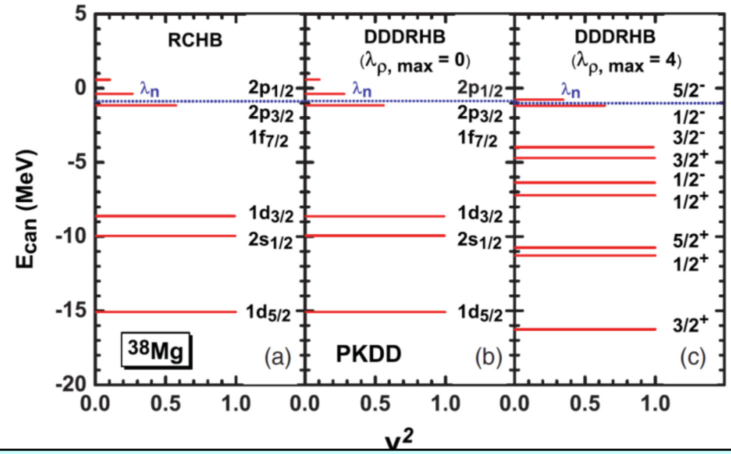
Li, Meng, Ring, Zhao, Zhou, PRC 85, 024312 (2012)

- Blocking effect incorporated to treat odd-A or odd-odd exotic nuclei



Li, Meng, Ring, Zhao, Zhou, Chin. Phys. Lett. 29, 042101 (2012)

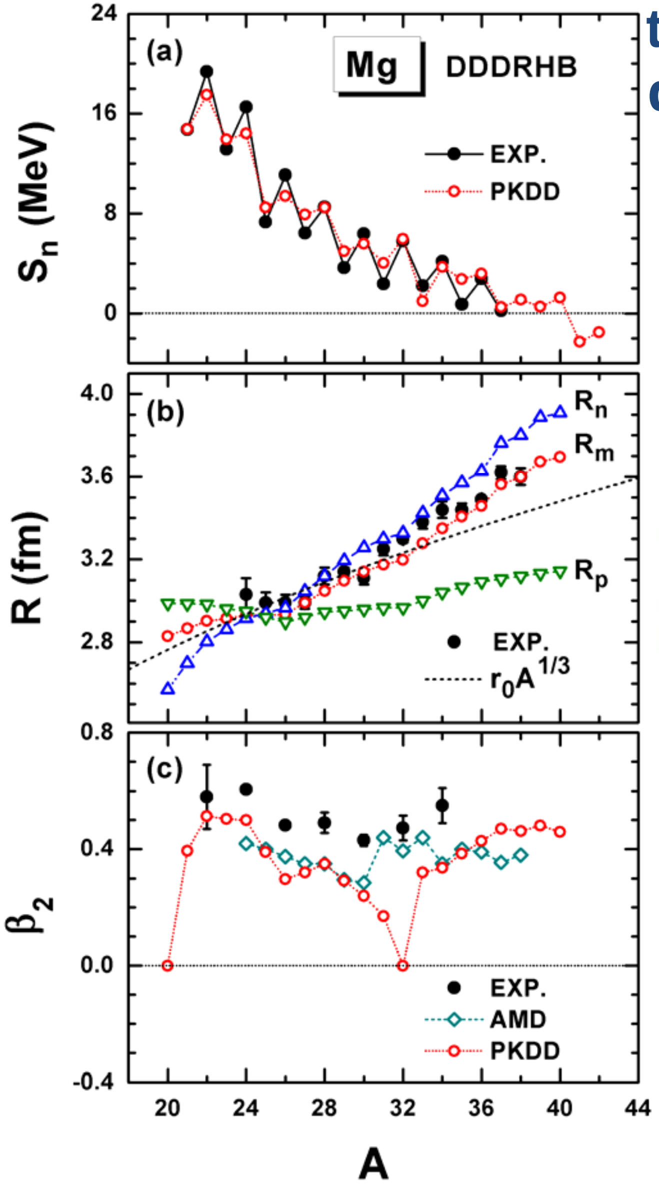
- DDDRHB: Generalized to density dependent meson-nucleon couplings

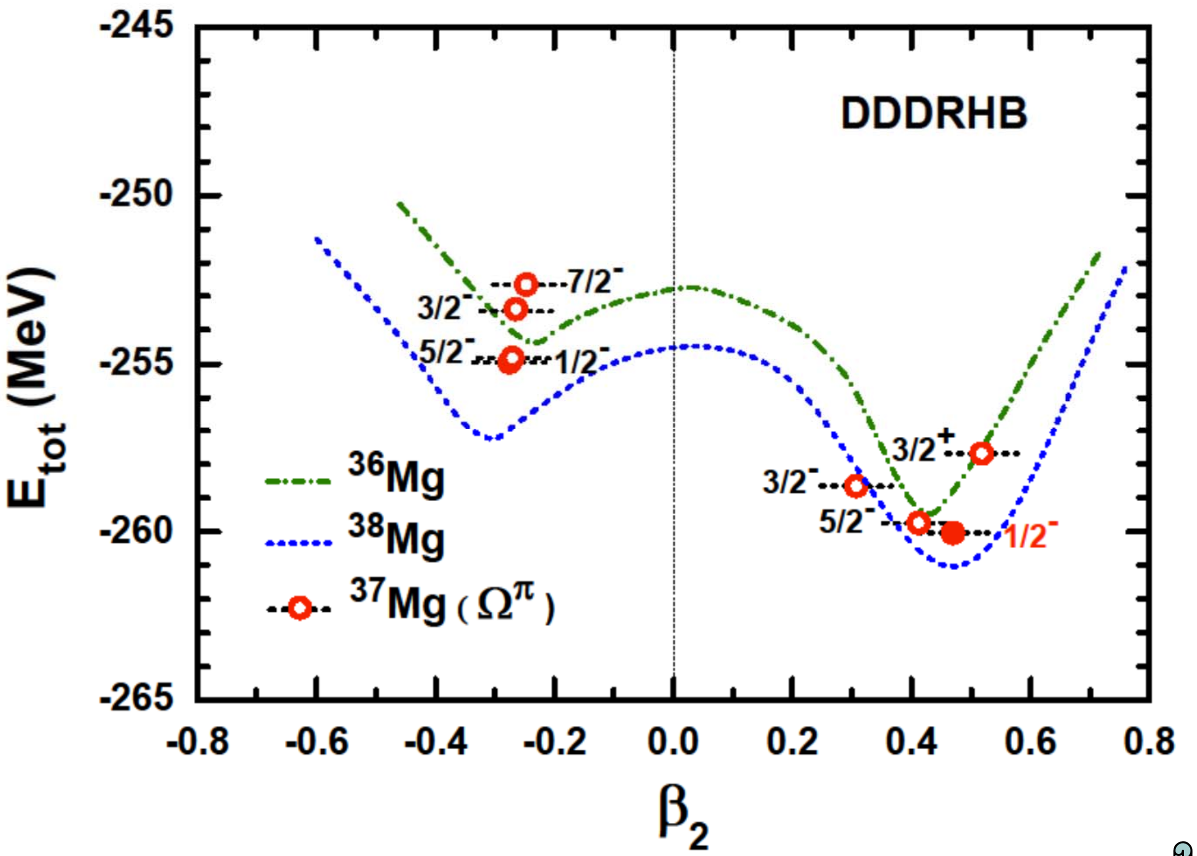


Chen, Li, Liang, Meng, PRC 85, 067301 (2012)

Deformed halo in ^{37}Mg and ^{38}Mg:

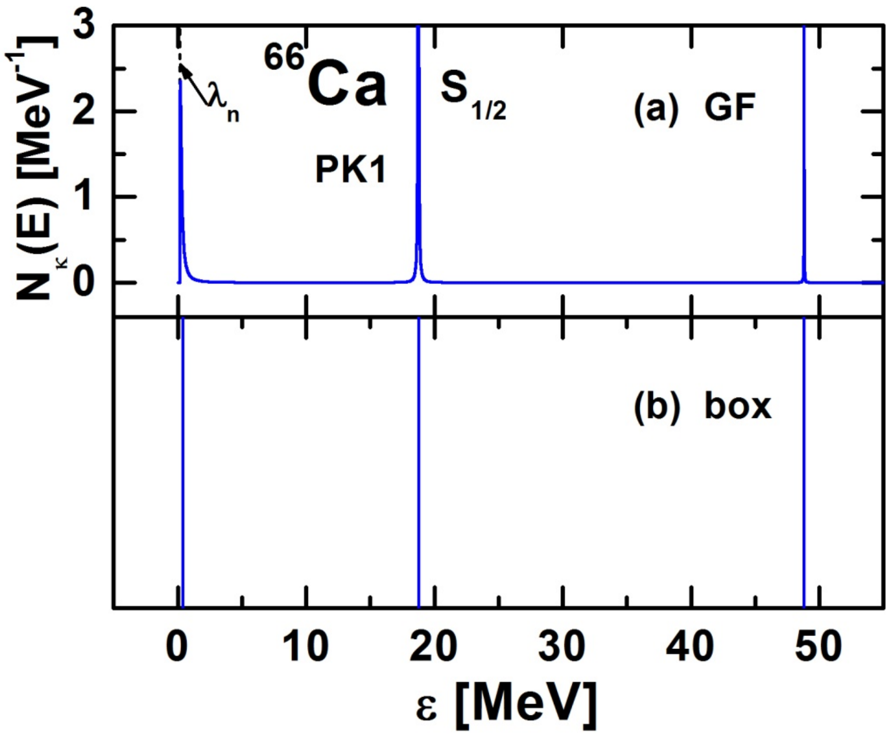
deformed relativistic Hartree-Bogoliubov theory in continuum with blocking and quadruple deformation constrained





Chen, et al, to be published

Density of states



Neutron occupation number density by the GF and discretized method with box boundary for $s_{1/2}$ block in ^{66}Ca.

	$E_{\rm GF}(\Gamma)$	$E_{\rm box}$
	0.188(0.291)	0.391
$S_{1/2}$	18.755(0.001)	18.755
	48.801 (<0.001)	48.801

Same quasiparticle energies for the deeply bound s1/2 states are obtained

Outline

- Introduction
- Halo
- Clustering
- Hidden pseudospin and spin symmetries
- Nuclear barrier with triaxial and octupole shape
- Simultaneous shape phase transition
- Exotic rotation: magnetic and antimagnetic rotation MχD
- Nuclear β-decay half-lives
- Extending the nuclear landscape by continuum: from spherical to deformed
- Perspectives

Cluster structures

Studies have shown that the nucleons are prone to form cluster structure in the nuclear system with

- high excitation energy and high spin with large deformation

  W. Zhang, H.-Z. Liang, S.-Q. Zhang, and J. Meng, Chin. Phys. Lett. 27, 102103 (2010).

  T. Ichikawa, J. A. Maruhn, N. Itagaki, and S. Ohkubo, Phys. Rev. Lett. 107, 112501 (2011).

- deep confining nuclear potential

  J.-P. Ebran, E. Khan, T. Niksic, and D. Vretenar, Nature 487, 341 (2012).

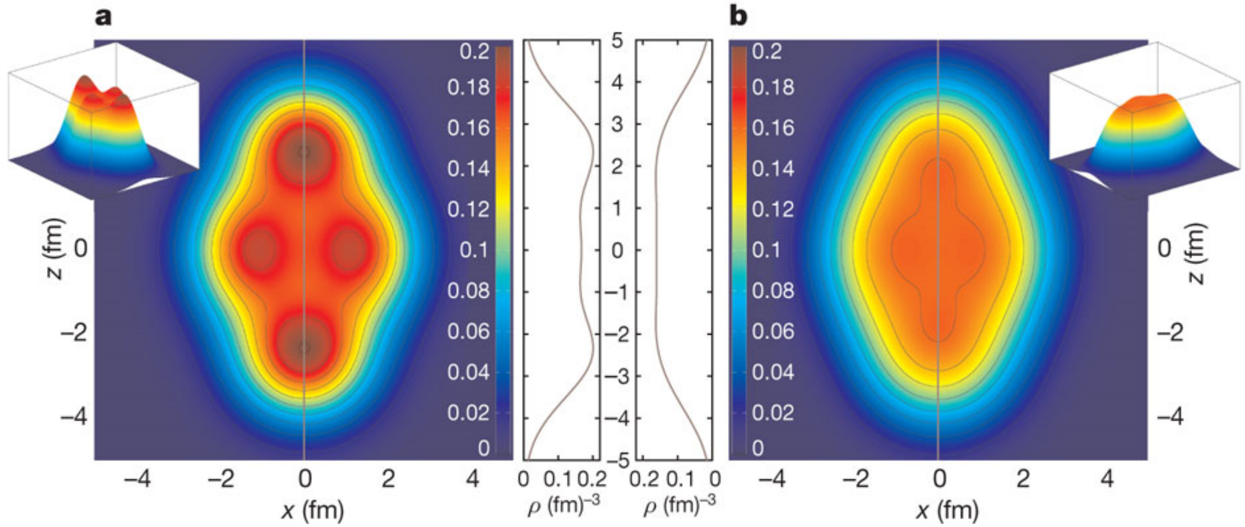
  J.-P. Ebran, E. Khan, T. Niksic, and D. Vretenar, Phys. Rev. C 87, 044307 (2013).

- or expansion with low density

  M. Girod and P. Schuck, Phys. Rev. Lett. 111, 132503 (2013).

Self-consistent ground-state densities of ^{20}Ne.

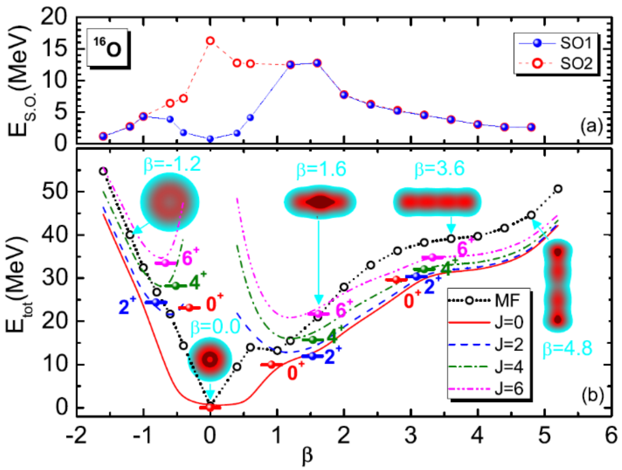
A localized equilibrium density and the formation of cluster structures are visible in (a) DD-ME2 but not in (b) Skyrme SLy4

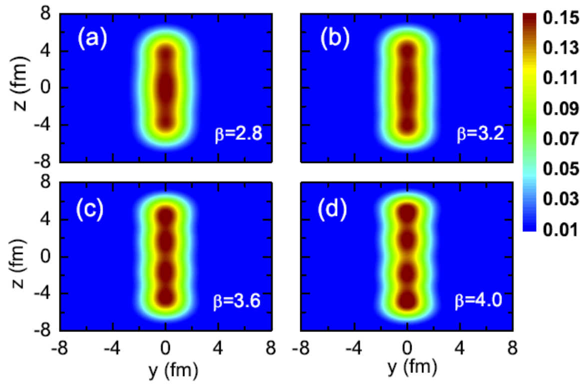


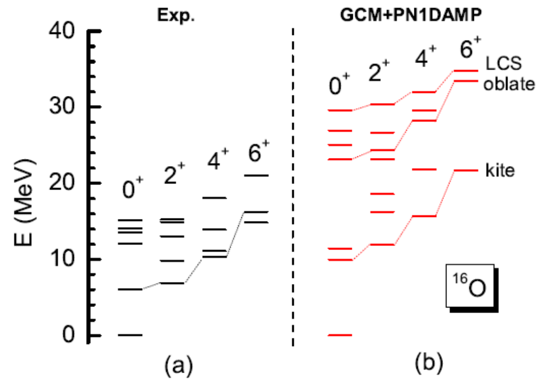
J-P Ebran et al. Nature **487**, 341-344 (2012) doi:10.1038/nature11246

Using the framework of nuclear energy density functional, the conditions for single nucleon localization and formation of cluster structures in finite nuclei are examined.

CDFT+GCM: clustering in light nuclei







- The Linear-Chain-Structure (LCS) in the low-spin GCM states with moment of inertia around 0.11 MeV is found.
- The 4 alpha clusters stay along a common axis and nucleons occupy the deformed states in a nonlocal way.
- The spin and orbital angular momenta of all nucleons are parallel in the LCS states.
- The fully microscopic GCM calculation has reproduced the excitation energies and B(E2) values rather well for the rotational band built on the second 0^+ state.

J. M. Yao, N. Itagaki, J.Meng, arXiv:1403.7940v1 [nucl-th] (2014)

Outline

- Introduction
- Halo
- Clustering
- Hidden pseudospin and spin symmetries
- Nuclear barrier with triaxial and octupole shape
- Simultaneous shape phase transition
- Exotic rotation: magnetic and antimagnetic rotation MχD
- Nuclear β-decay half-lives
- Extending the nuclear landscape by continuum: from spherical to deformed
- Perspectives

Pseudo-spin symmetry

北京大學 PEKING UNIVERSITY

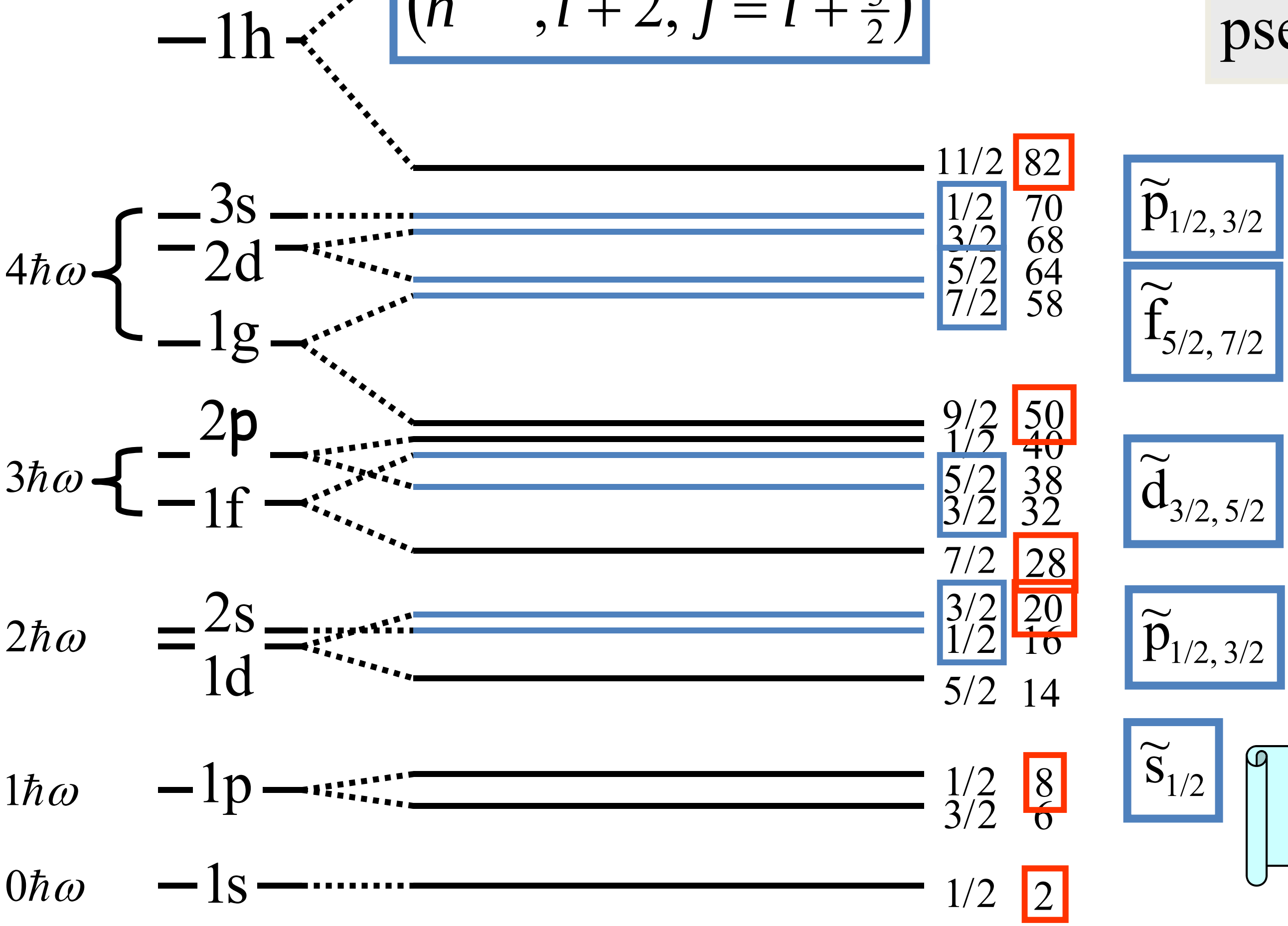
Woods-Saxon

$\kappa \vec{l} \cdot \vec{s}$

$$(n+1, l \quad , j = l + \tfrac{1}{2})$$
$$(n \quad , l+2, j = l + \tfrac{3}{2})$$

pseudo − orbit : $\tilde{l} = l + 1$

pseudo − spin : $\tilde{s} = 1/2$



Hecht & Adler
NPA137(1969)129

Arima, Harvey & Shimizu
PLB30(1969)517

Origin of PS symmetry: Ginocchio, PRL78(97)436

PSS in resonances

- There are discrete bound states and continuum / resonant states
- PSS in single particle resonant states is exact with the same condition for the PSS of bound states

By examining the zeros of Jost functions corresponding to the small components of Dirac wave functions and phase shifts of continuum states, it has been verified that the PSS in single particle resonant states is conserved when the scalar and vector potentials have the same magnitude but opposite sign.

Lu, Zhao, Zhou, PRL 109, 072501 (2012)
Lu, Zhao, Zhou, PRC 88, 024323 (2013)

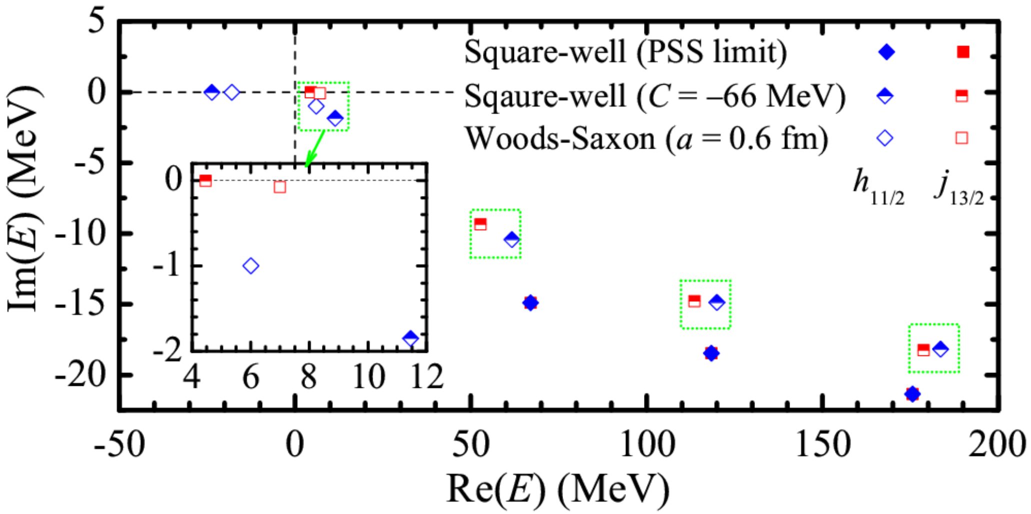


Figure: Conservation & breaking of PSS in resonances by examining the zeros of Jost functions corresponding to the small components of Dirac wave functions

PSS and SS in deformed system: Similarity renormalization group

Dirac Hamiltonian

$$H = \beta M + \vec{\alpha} \cdot \vec{p} + (\beta S + V)$$

Introducing a unitary transformation by similarity renormalization group

$$H(l) = U(l) H U^{\dagger}(l)$$

H is diagonlized to the form

$$H_D = \begin{pmatrix} H_P + M & 0 \\ 0 & -H_P^C - M \end{pmatrix}$$

H_P describing Dirac particle

H_P^C describes Dirac anti-particle, the charge-conjugation of H_P

Hp can be decomposed to be these components:

$$H_n = \Sigma + \frac{p^2}{2M},$$

$$H_d = -\frac{1}{2M^2}(Sp^2 - \nabla S \cdot \nabla) + \frac{S}{2M^3}(Sp^2 - 2\nabla S \cdot \nabla)$$

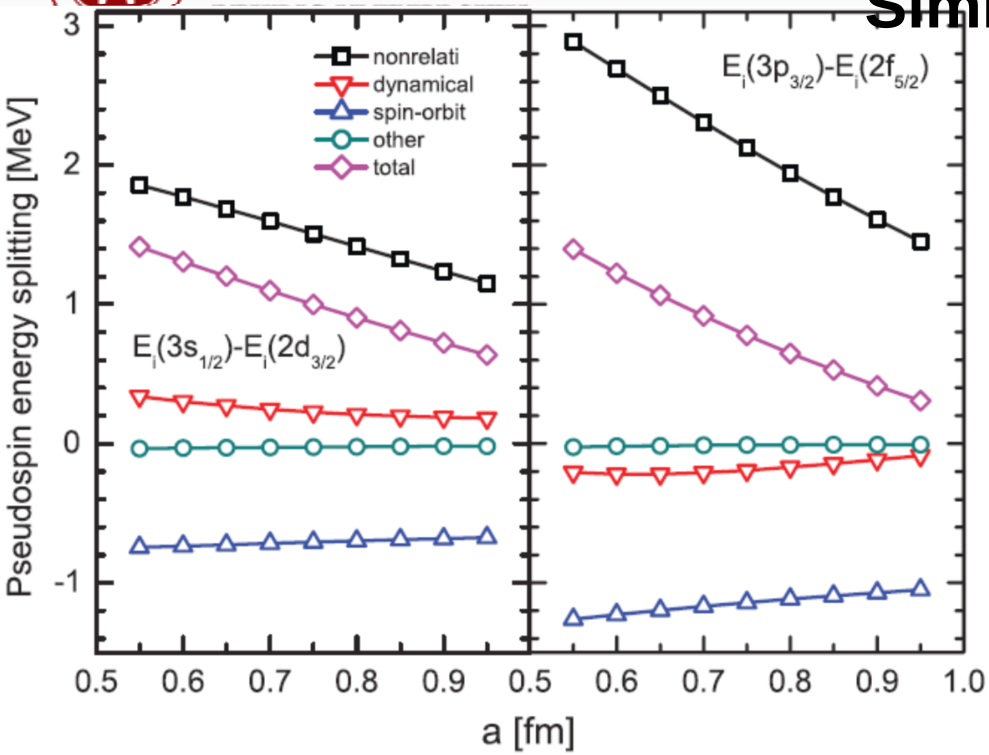
$$H_c = \frac{1}{4M^2}\left(1 - \frac{2S}{M}\right)\vec{\sigma} \cdot (\nabla \Delta \times \vec{p}),$$

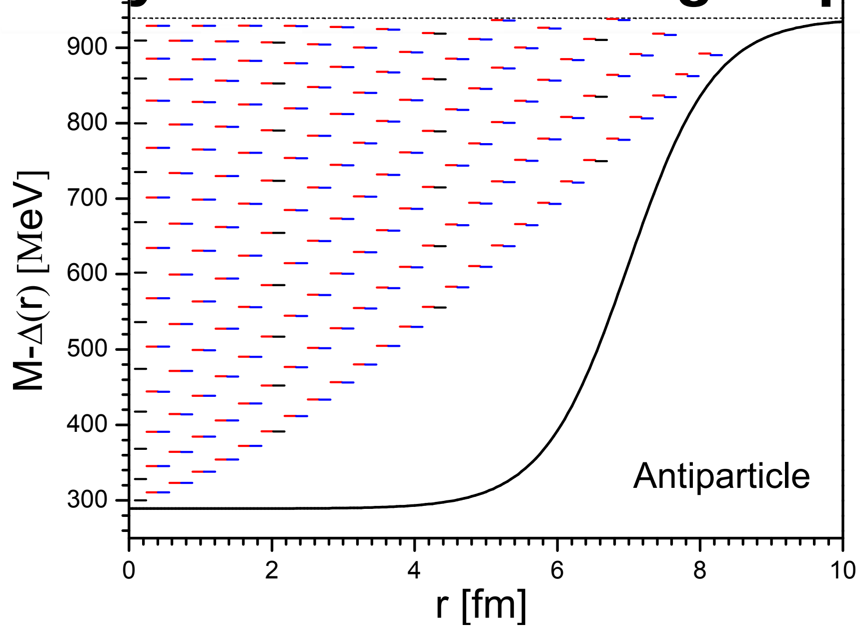
$$H_k = -\frac{p^4}{8M^3},$$

$$H_w = \frac{1}{16M^3}[2(M - 2S)\nabla^2 \Sigma + (\nabla \Sigma)^2 + 2\nabla \Sigma \cdot \nabla \Delta].$$

- The singularity disappears in every component.
- Every component in ***Hp*** is Hermitian.
- There is no coupling between the energy ***E*** and the operator ***Hp***.

PSS and SS in deformed system: Similarity renormalization group



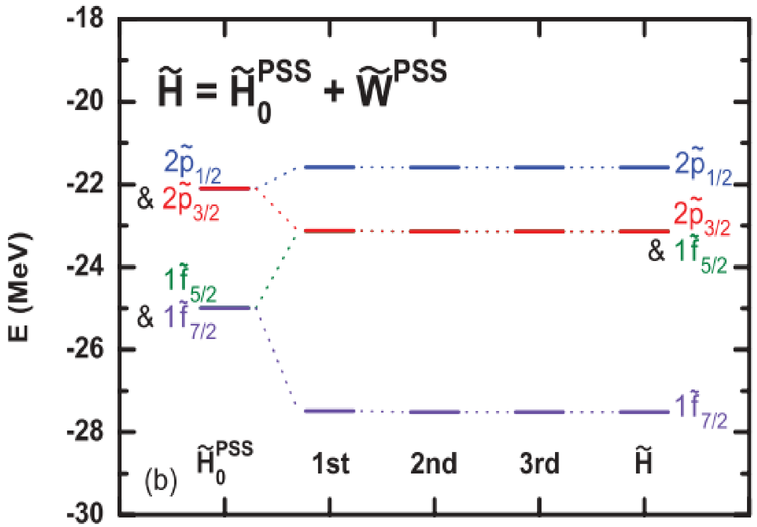


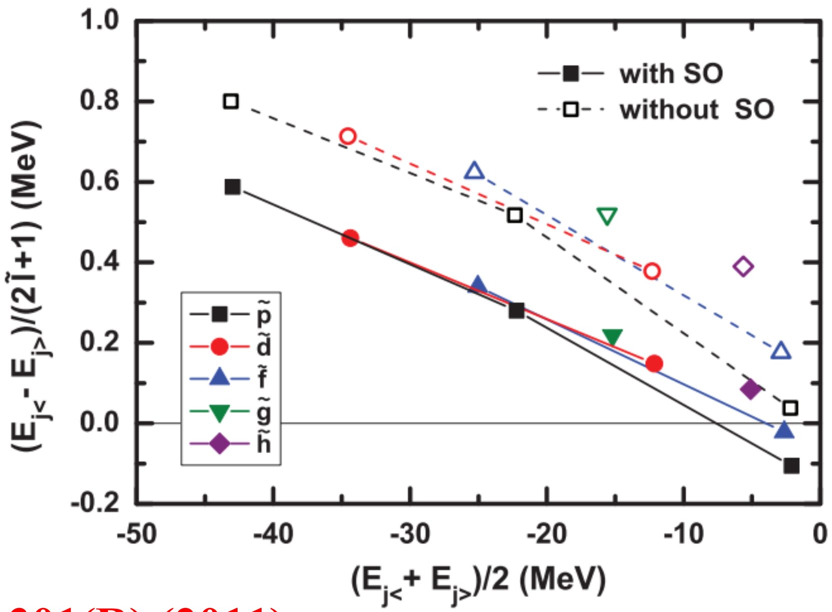
- Similarity renormalization group can be extended to deformed system
- The quality of PSS versus the shape of potentials can be investigated
- The dynamic term and spin-orbit coupling play key role in the PSS
- SS in anti-nucleon spectrum is better than PSS in nucleon spectrum

Guo et al., PRL 112, 062502 (2014)
Chen et al., PRC 85, 054312 (2012)
Guo et al., PRC 85, 021302(R) (2012)
Li et al., PRC 87, 044311 (2013)

Pseudospin symmetry in SUSY

- The origin of pseudospin symmetry and its breaking mechanism are explored by combining SUSY, perturbation theory, and the similarity renormalization group.
- Pseudospin-orbit (PSO) splitting becomes smaller with single-particle energies.
- After including the spin-orbit term the PSO splittings can even reverse with increasing single-particle energies.





Liang, Zhao, Zhang, Meng, Giai, PRC 83, 041301(R) (2011).

Liang, Shen, Zhao, Meng Phys. Rev. C 87, 014334 (2013)

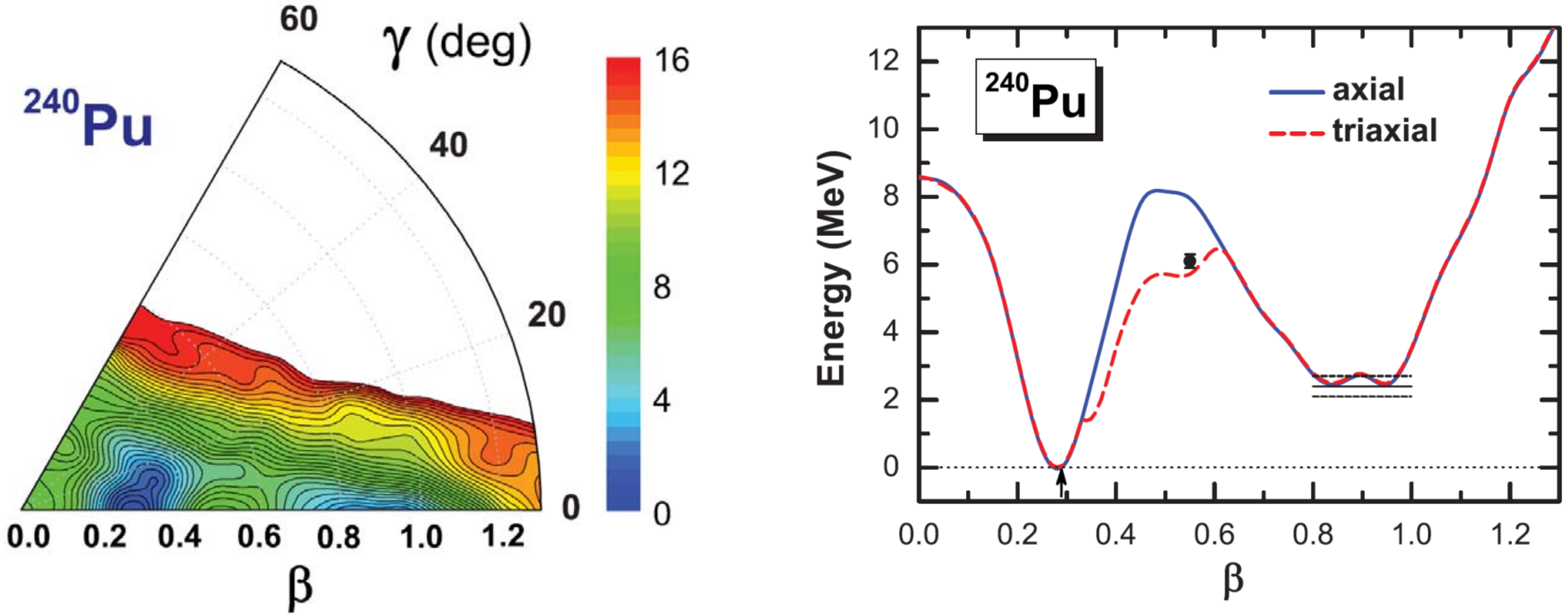
Shen, Liang, Zhao, Zhang, Meng Phys. Rev. C 88, 024311 (2013)

Outline

- Introduction
- Halo
- Clustering
- Hidden pseudospin and spin symmetries
- Nuclear barrier with triaxial and octupole shape
- Simultaneous shape phase transition
- Exotic rotation: magnetic and antimagnetic rotation MχD
- Nuclear β-decay half-lives
- Extending the nuclear landscape by continuum: from spherical to deformed
- Perspectives

Fission barrier in actinides

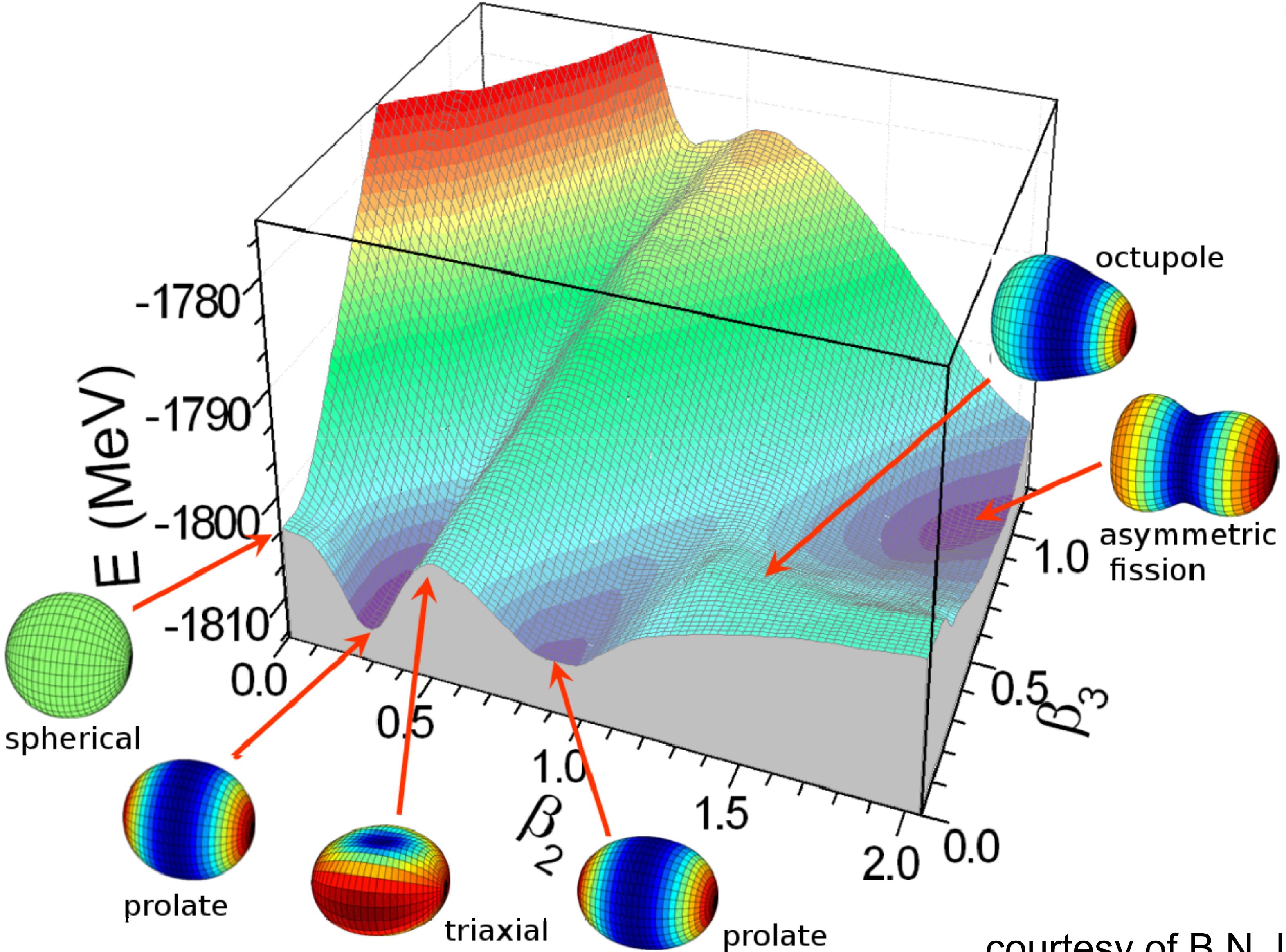
The structure of ^{240}Pu and its double-humped fission barrier:
a standard benchmark for self-consistent mean-field models



- ✓ The deformation of the ground state and the excited energy of the fission isomer are reproduced well;
- ✓ The inclusion of triaxial shapes lowers the inner barrier by ≈2 MeV, much closer to the available data.

Li, Niksic, Vretenar, Ring, Meng, *Phys*.Rev.C**81**, 064321 (2010)
Abusara, Afanasjev, Ring PRC 85, 024314 (2012)

Deformation map of ^{240}Pu



courtesy of B.N. LU

Multidimentionally constrained CDFT

- MDC-CDFT: all $\beta_{\lambda\mu}$ with even μ included
- Triaxial & octupole shapes both crucial around the outer barrier

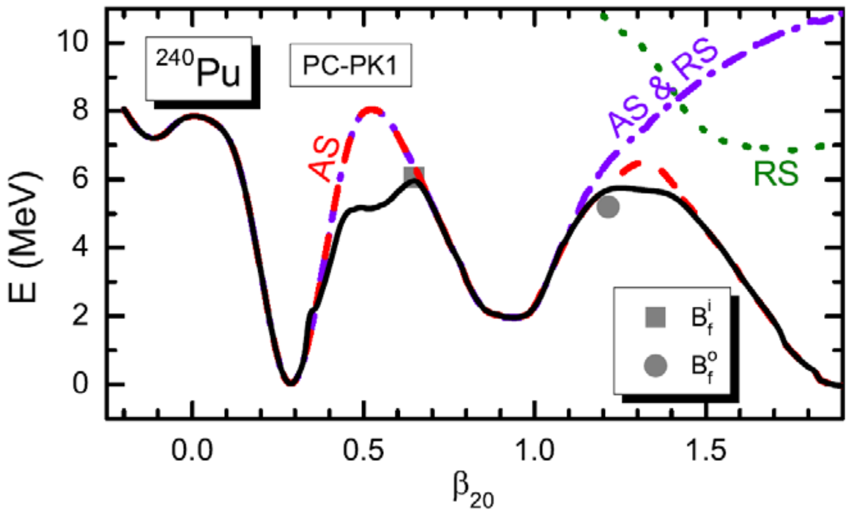


Figure: Potential energy curve of ^{240}Pu

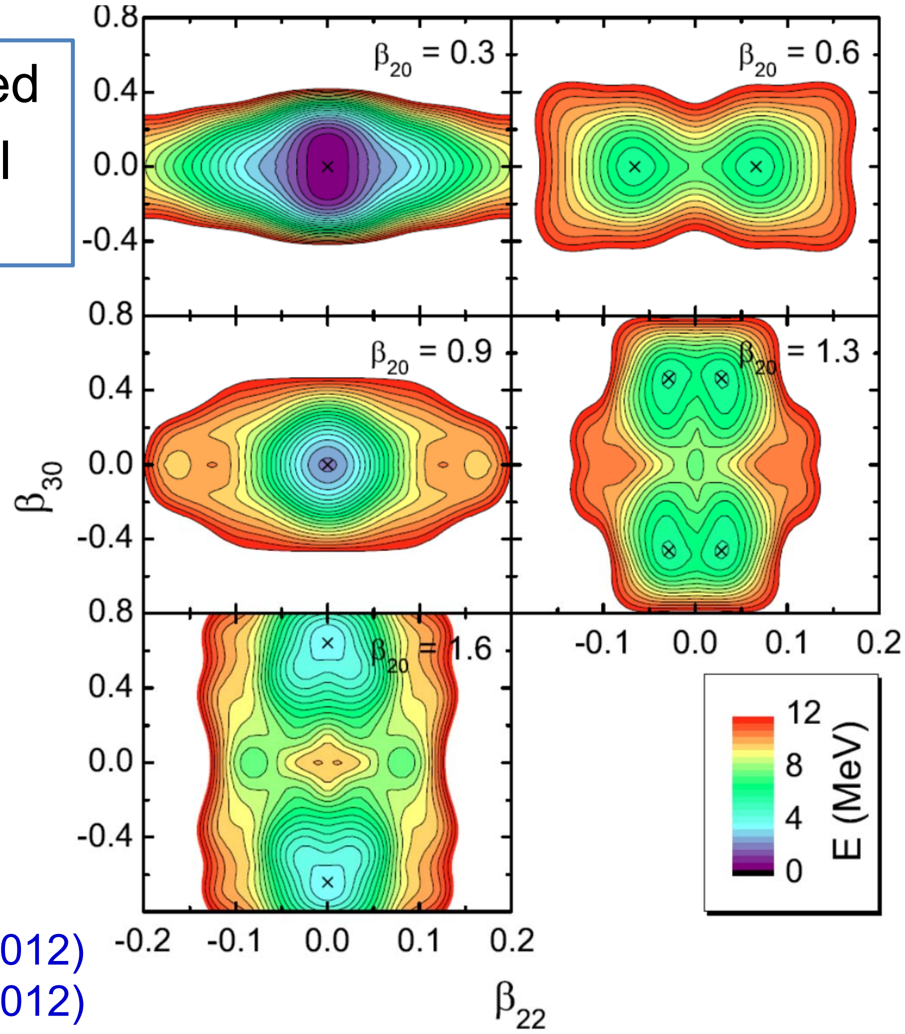


Figure: 3D PES of ^{240}Pu

Lu, Zhao, Zhou, PRC 85, 011301 (2012)
Zhao, Lu, Zhao, Zhou, PRC 86, 057304 (2012)
Lu, Zhao, Zhao, Zhou, PRC 89, 014323 (2014)
Zhao, Lu, Vretenar, Zhao, Zhou, arXiv:1404.5466 (2014)

Superdeformed hypernuclei

Lu, Zhao, Zhou, PRC 84, 014328 (2011)
Lu, Hiyama, Sagawa, Zhou, PRC 89, 044307 (2014)

- Different from other model predictions, the Λ separation energy S_Λ in the superdeformed (SD) state is larger than that in the ground state
- The localization of the nucleon density in SD state results in a larger overlap between Λ and nucleons, thus leading to a larger S_Λ

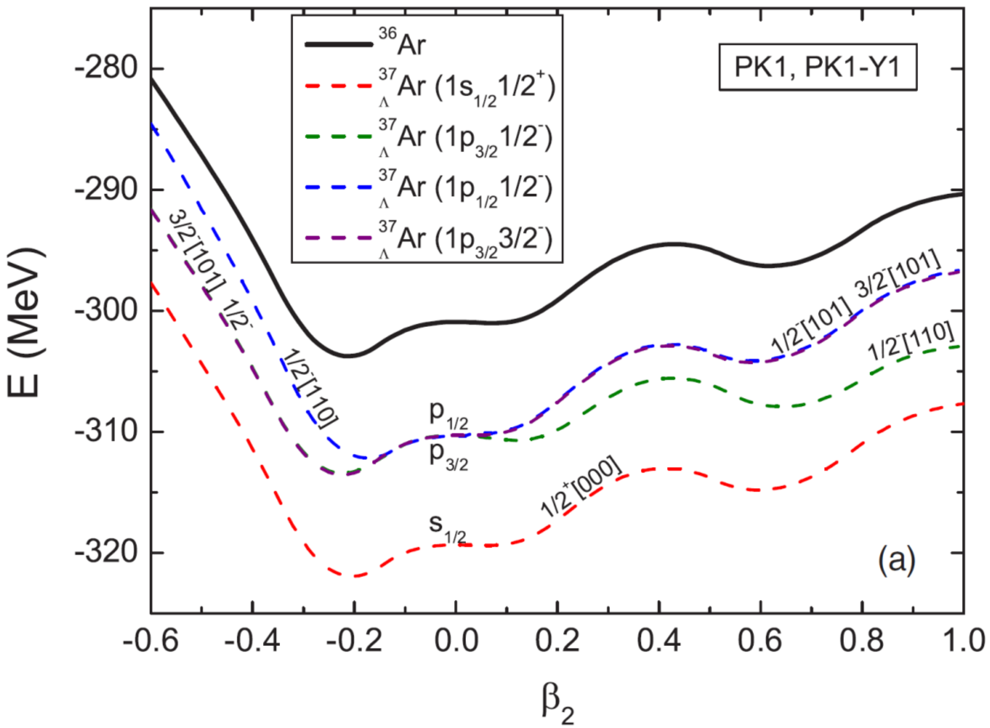
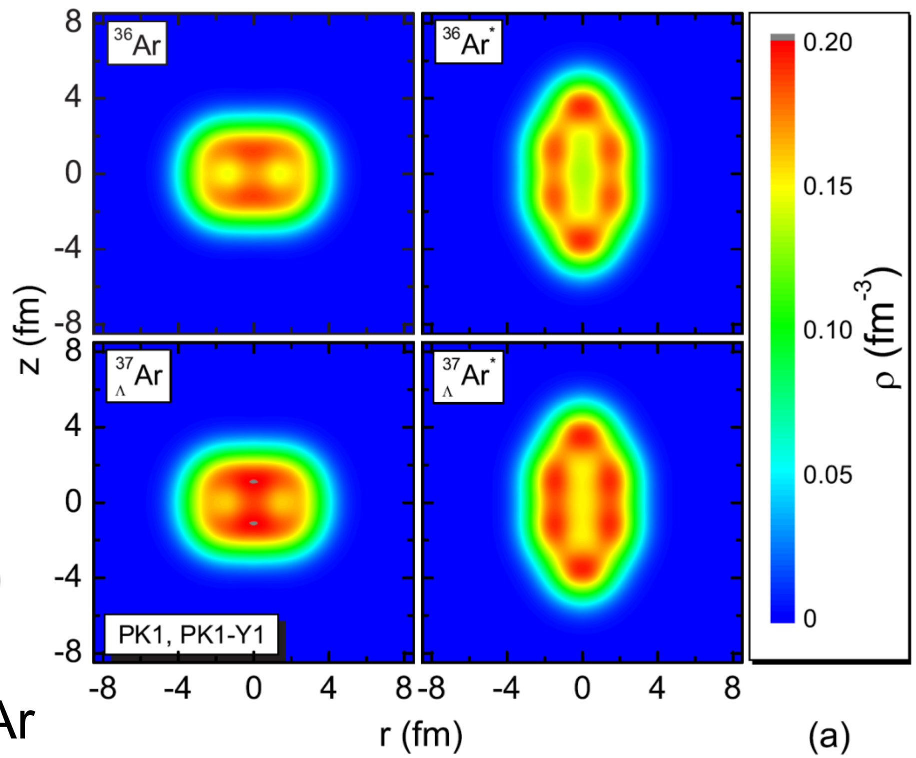


Figure: Potential energy curves of ^{36}Ar & $^{37}{}_{\Lambda}$Ar

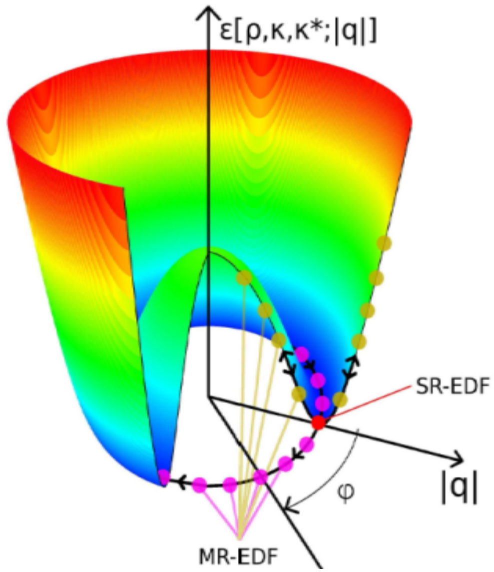
Figure: Density profiles of ^{36}Ar & $^{37}{}_{\Lambda}$Ar



Outline

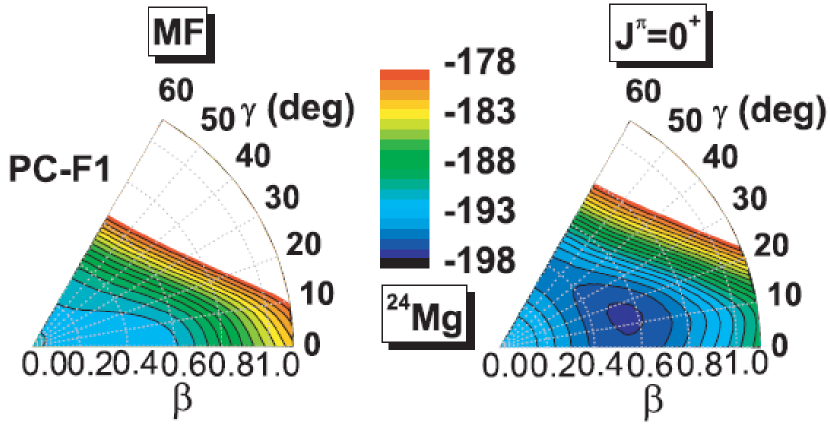
- Introduction
- Halo
- Clustering
- Hidden pseudospin and spin symmetries
- Nuclear barrier with triaxial and octupole shape
- Simultaneous shape phase transition
- Exotic rotation: magnetic and antimagnetic rotation MχD
- Nuclear β-decay half-lives
- Extending the nuclear landscape by continuum: from spherical to deformed
- Perspectives

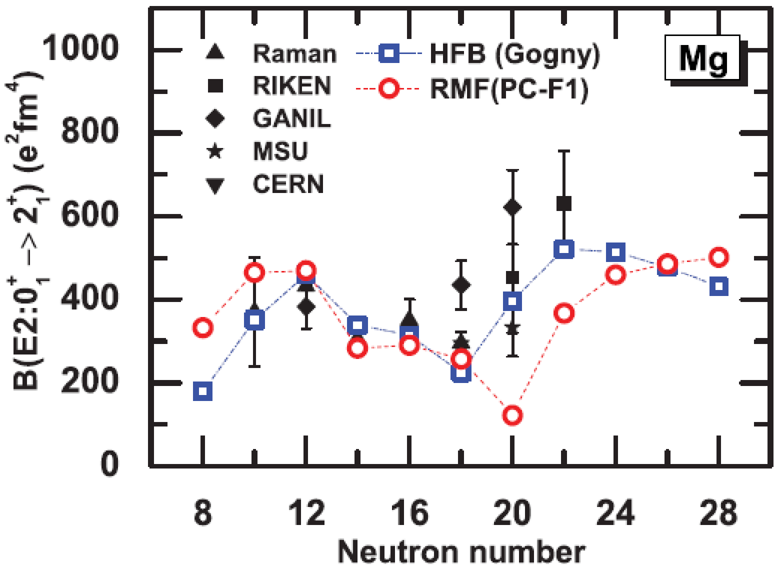
Nuclear collective low-lying Spectroscopy



A beyond Mean Field model:

- symmetry restoration via 3DAM projection
- configuration mixing via GCM
- advantage: spectroscopy of transitional nuclei, large amplitude collective motion



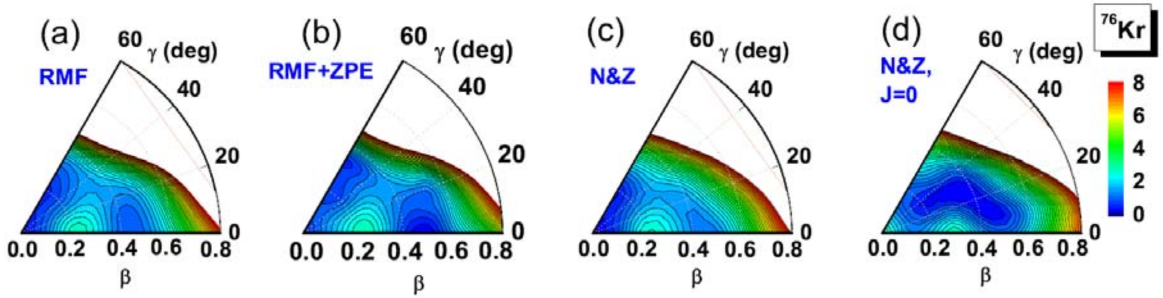


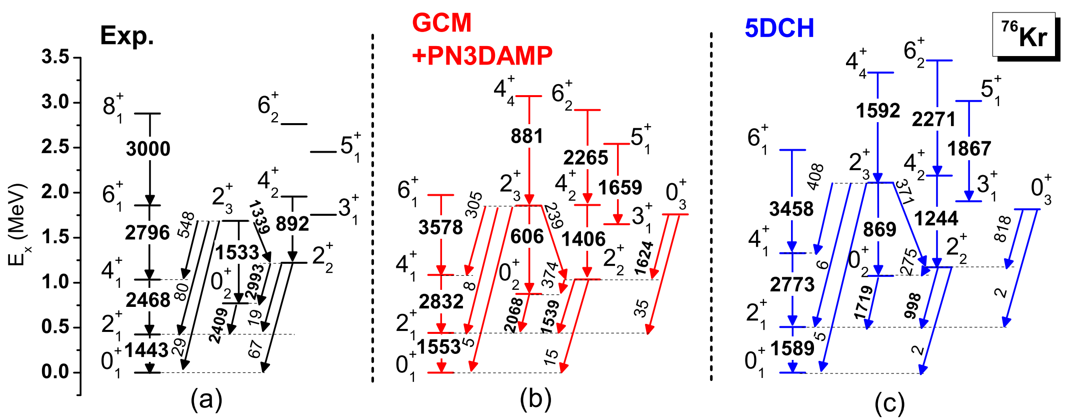
Yao, Meng, Ring, Vretenar, PRC 81, 044311 (2010);

Yao, Mei, Chen, Meng, Ring, Vretenar, PRC 83, 014308 (2011)

Nuclear low-lying states: CDFT+GCM+PN3DAMP

seven-dimensional generator coordinate calculation in the two deformation parameters together with projection on three-dimensional angular momentum and two particle numbers for the low-lying states





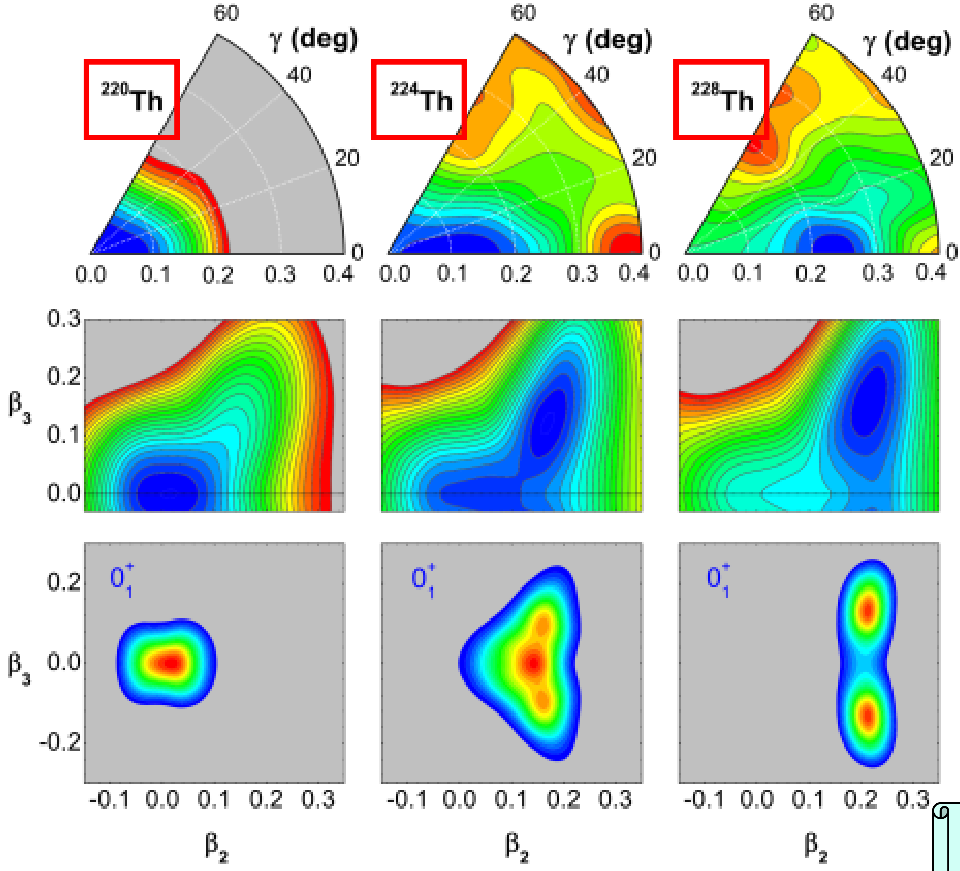
- The low-energy spectrum of ^{76}Kr are well reproduced after including triaxiality in the full microscopic GCM+ PN3DAMP calculation based on the CDFT using the PC-PK1 force.
- This study answers the important question of dynamic correlations and triaxiality in shape-coexistence nucleus ^{76}Kr and provides the first benchmark for the EDF based collective Hamiltonian method.

Yao, Hagino, Li, Meng, Ring, Phys. Rev. C 89, 054306 (2014)

Benchmark for the collective Hamiltonian in five dimensions

Simultaneous shape phase transition

➢ **Calculations with collective Hamiltonians based on CDFT indicate a simultaneous quantum shape phase transition between spherical and quadrupole deformed prolate shapes, and between non-octupole and octupole deformed shapes.**



triaxial quadrupole energy surfaces

axially-symmetric quadrupole–octupole energy surfaces

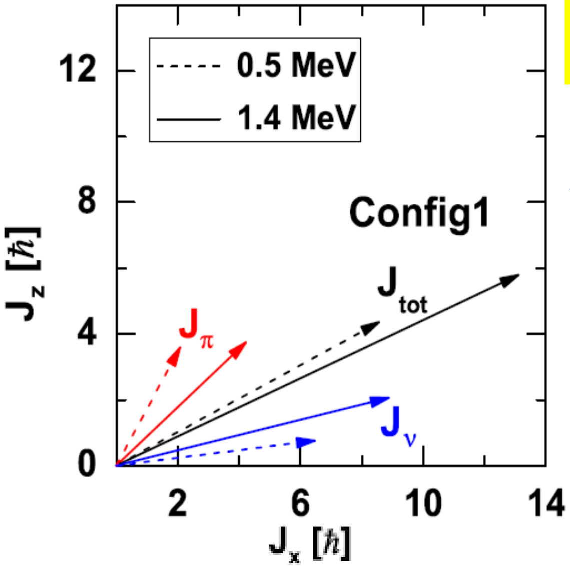
probability density distributions for the ground states

Li, Song, Yao, Vretenar, and Meng, Phys. Lett. B 726 (2013) 866

Outline

- Introduction
- Halo
- Clustering
- Hidden pseudospin and spin symmetries
- Nuclear barrier with triaxial and octupole shape
- Simultaneous shape phase transition
- Exotic rotation: magnetic and antimagnetic rotation MχD
- Nuclear β-decay half-lives
- Extending the nuclear landscape by continuum: from spherical to deformed
- Perspectives

Magnetic and Antimagnetic Rotation



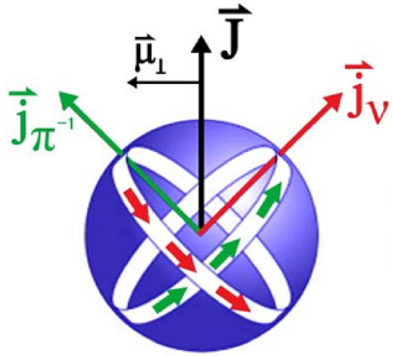
^{60}Ni: MR

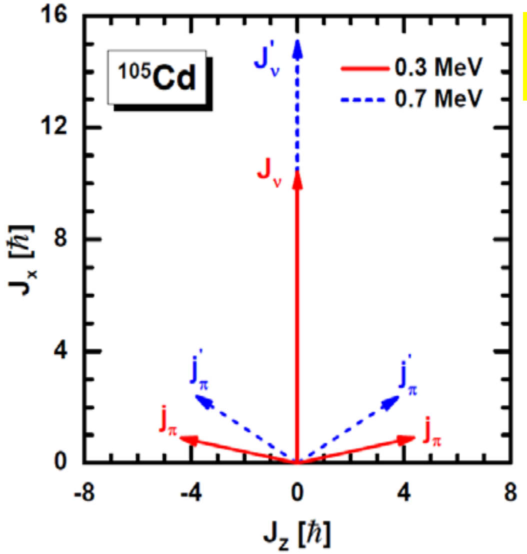
Zhao, Zhang, Peng, Liang, Ring, Meng, PLB 699, 181 (2011)

Yu, Zhao, Zhang, Ring, Meng, PRC 85, 024318 (2012)

Self-consistent and microscopic description :

- pictures: **"shears-like"**
- energy, spin, B(M1), B(E2)
- electric rotation to MR





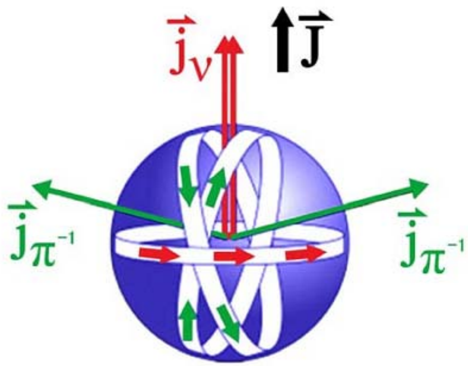
^{105}Cd: AMR

Zhao, Peng, Liang, Ring, Meng,

PRL 107, 122501 (2011)

Self-consistent and microscopic description :

- pictures: **two "shears-like"**
- energy, spin, B(E2)
- core polarization effects



Multiple chiral doublets (MχD) predicted in 2006

PHYSICAL REVIEW C **73**, 037303 (2006)

Possible existence of multiple chiral doublets in ^{106}Rh

J. Meng,[1,2,3,*] J. Peng,[1] S. Q. Zhang,[1] and S.-G. Zhou[2,3]
[1]*School of Physics, Peking University, Beijing 100871, China*
[2]*Institute of Theoretical Physics, Chinese Academy of Science, Beijing 100080, China*
[3]*Center of Theoretical Nuclear Physics, National Laboratory of Heavy Ion Accelerator, Lanzhou 730000, China*
(Received 30 March 2005; published 15 March 2006)

Adiabatic and configuration-fixed constrained triaxial relativistic mean field (RMF) approaches are developed for the first time. A new phenomenon, the existence of multiple chiral doublets (MχD), i.e., more than one pair of chiral doublet bands in one single nucleus, is suggested for ^{106}Rh based on the triaxial deformations and their corresponding proton and neutron configurations.

DOI: 10.1103/PhysRevC.73.037303 PACS number(s): 21.10.Re, 21.60.Jz, 21.10.Pc, 27.60.+j

The investigation followed by:

- ***Prediction for other odd-odd Rh isotopes:*** **J. Peng et al., PRC77, 024309 (2008)**
- ***Confirmed with time-odd fields included:*** **J. M. Yao et al., PRC79, 067302 (2009)**
- ***Prediction for the odd-A Rh isotopes:*** **J. Li et al., PRC83, 037301 (2011)**

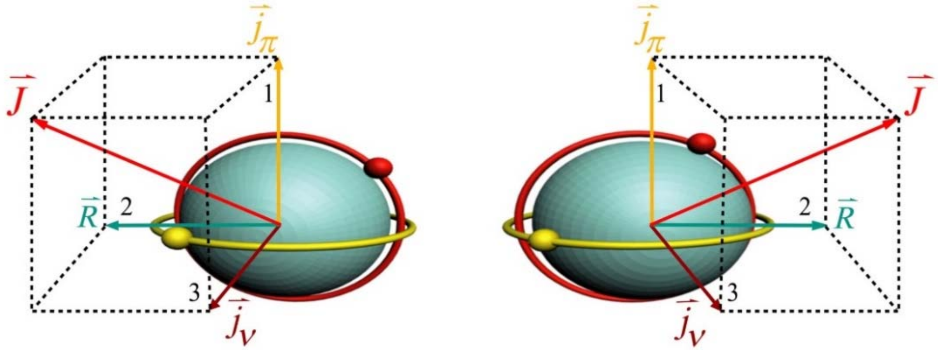
Originally suggested in 1997: chiral doublet bands

ELSEVIER
NUCLEAR PHYSICS A
Nuclear Physics A 617 (1997) 131–147

Tilted rotation of triaxial nuclei

S. Frauendorf, Jie Meng [1]
Institut für Kern- und Hadronenphysik, Forschungszentrum Rossendorf e.V
PF 510119, 01314 Dresden, Germany

Received 14 November 1996



Firstly Observed in 2001

VOLUME 86, NUMBER 6 PHYSICAL REVIEW LETTERS 5 FEBRUARY 2001

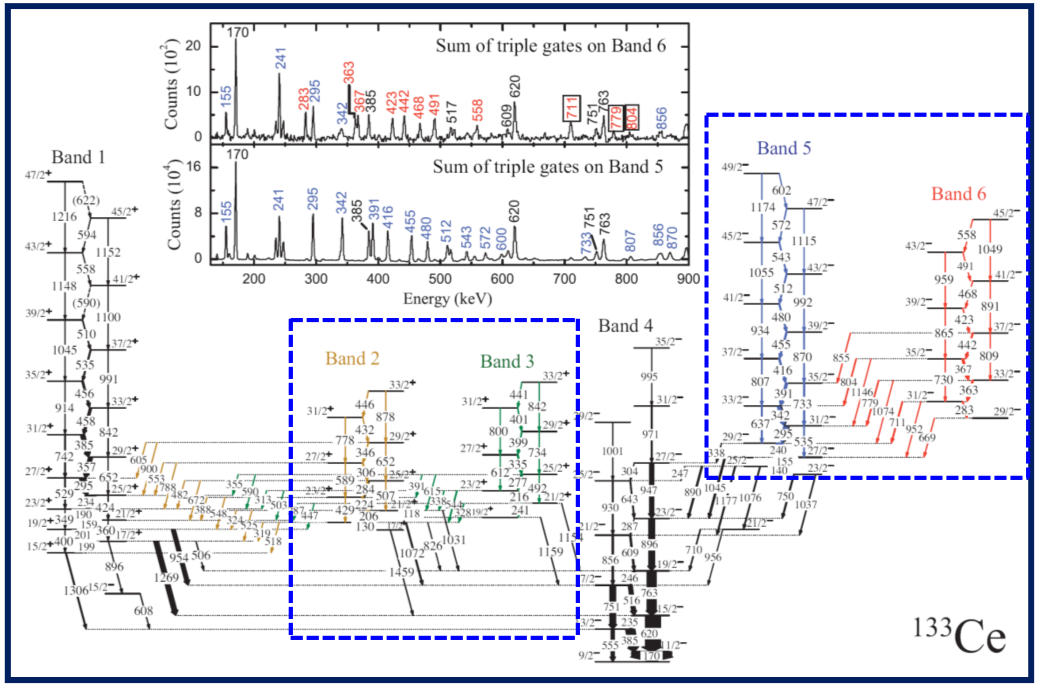
Chiral Doublet Structures in Odd-Odd $N = 75$ Isotones: Chiral Vibrations

K. Starosta,[1,*] T. Koike,[1] C. J. Chiara,[1] D. B. Fossan,[1] D. R. LaFosse,[1] A. A. Hecht,[2] C. W. Beausang,[2] M. A. Caprio,[2] J. R. Cooper,[2] R. Krücken,[2] J. R. Novak,[2] N. V. Zamfir,[2,†] K. E. Zyromski,[2] D. J. Hartley,[3] D. L. Balabanski,[3,‡] Jing-ye Zhang,[3] S. Frauendorf,[4] and V. I. Dimitrov[4,‡]
[1]*Department of Physics and Astronomy, SUNY at Stony Brook, Stony Brook, New York 11794*
[2]*Wright Nuclear Structure Laboratory, Yale University, New Haven, Connecticut 06520*
[3]*Department of Physics and Astronomy, University of Tennessee, Knoxville, Tennessee 37996*
[4]*Department of Physics, University of Notre Dame, Notre Dame, Indiana 46556*
and Institute for Nuclear and Hadronic Physics, Research Center Rossendorf, 01314 Dresden, Germany
(Received 24 July 2000)

Experimental confirmation of the MχD bands

PEKING UNIVERSITY

Level Scheme



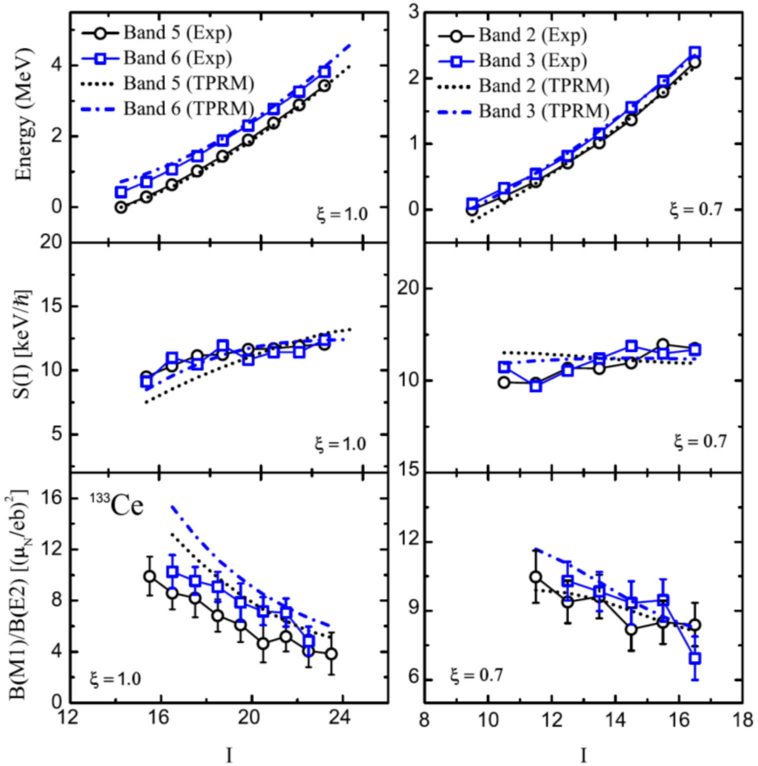
PRL **110**, 172504 (2013) PHYSICAL REVIEW LETTERS week ending 26 APRIL 2013

Evidence for Multiple Chiral Doublet Bands in ^{133}Ce

A. D. Ayangeakaa,[1] U. Garg,[1] M. D. Anthony,[1] S. Frauendorf,[1] J. T. Matta,[1] B. K. Nayak,[1,*] D. Patel,[1] Q. B. Chen (陈启博),[2] S. Q. Zhang (张双全),[2] P. W. Zhao (赵鹏巍),[2] B. Qi (亓斌),[3] J. Meng (孟杰),[2,4,5] R. V. F. Janssens,[6] M. P. Carpenter,[6] C. J. Chiara,[6,7] F. G. Kondev,[8] T. Lauritsen,[6] D. Seweryniak,[6] S. Zhu,[6] S. S. Ghugre,[9] and R. Palit[10,11]

[1]*Department of Physics, University of Notre Dame, Notre Dame, Indiana 46556, USA*
[2]*State Key Laboratory of Nuclear Physics and Technology, School of Physics, Peking University, Beijing 100871, China*
[3]*School of Space Science and Physics, Shandong University at Weihai, Weihai 264209, China*
[4]*School of Physics and Nuclear Energy Engineering, Beihang University, Beijing 100191, China*
[5]*Department of Physics, University of Stellenbosch, Matieland 7602, Stellenbosch, South Africa*
[6]*Physics Division, Argonne National Laboratory, Argonne, Illinois 60439, USA*
[7]*Department of Chemistry and Biochemistry, University of Maryland, College Park, Maryland 20742, USA*
[8]*Nuclear Engineering Division, Argonne National Laboratory, Argonne, Illinois 60439, USA*
[9]*UGC-DAE Consortium for Science Research, Kolkata 700 098, India*
[10]*Tata Institute of Fundamental Research, Mumbai 400 005, India*
[11]*The Joint Institute for Nuclear Astrophysics, University of Notre Dame, Notre Dame, Indiana 46556, USA*
(Received 31 January 2013; published 24 April 2013)

Theoretical description



FIRST EVIDENCE OF MULTIPLE CHIRAL DOUBLET BANDS

A.D. Ayangeakaa *et al.*, PRL 110, 172504 (2013)

PRL **110,** 172504 (2013) PHYSICAL REVIEW LETTERS week ending 26 APRIL 2013

Evidence for Multiple Chiral Doublet Bands in ^{133}Ce

A. D. Ayangeakaa,[1] U. Garg,[1] M. D. Anthony,[1] S. Frauendorf,[1] J. T. Matta,[1] B. K. Nayak,[1,*] D. Patel,[1]
Q. B. Chen (陈启博),[2] S. Q. Zhang (张双全),[2] P. W. Zhao (赵鹏巍),[2] B. Qi (亓斌),[3] J. Meng (孟杰),[2,4,5]
R. V. F. Janssens,[6] M. P. Carpenter,[6] C. J. Chiara,[6,7] F. G. Kondev,[8] T. Lauritsen,[6] D. Seweryniak,[6] S. Zhu,[6]
S. S. Ghugre,[9] and R. Palit[10,11]

[1]*Department of Physics, University of Notre Dame, Notre Dame, Indiana 46556, USA*
[2]*State Key Laboratory of Nuclear Physics and Technology, School of Physics, Peking University, Beijing 100871, China*
[3]*School of Space Science and Physics, Shandong University at Weihai, Weihai 264209, China*
[4]*School of Physics and Nuclear Energy Engineering, Beihang University, Beijing 100191, China*
[5]*Department of Physics, University of Stellenbosch, Matieland 7602, Stellenbosch, South Africa*
[6]*Physics Division, Argonne National Laboratory, Argonne, Illinois 60439, USA*
[7]*Department of Chemistry and Biochemistry, University of Maryland, College Park, Maryland 20742, USA*
[8]*Nuclear Engineering Division, Argonne National Laboratory, Argonne, Illinois 60439, USA*
[9]*UGC-DAE Consortium for Science Research, Kolkata 700 098, India*
[10]*Tata Institute of Fundamental Research, Mumbai 400 005, India*
[11]*The Joint Institute for Nuclear Astrophysics, University of Notre Dame, Notre Dame, Indiana 46556, USA*

(Received 31 January 2013; published 24 April 2013)

北京大学
PEKING UNIVERSITY

PRL 112, 202502 (2014) PHYSICAL REVIEW LETTERS week ending 23 MAY 2014

Resolution of Chiral Conundrum in ^{106}Ag: Doppler-Shift Lifetime Investigation

E. O. Lieder,[1,2] R. M. Lieder,[1,*] R. A. Bark,[1] Q. B. Chen,[3] S. Q. Zhang,[3] J. Meng,[3,4,5] E. A. Lawrie,[1] J. J. Lawrie,[1] S. P. Bvumbi,[1] N. Y. Kheswa,[1] S. S. Ntshangase,[1] T. E. Madiba,[1] P. L. Masiteng,[1] S. M. Mullins,[1] S. Murray,[1] P. Papka,[1] D. G. Roux,[6] O. Shirinda,[1] Z. H. Zhang,[3] P. W. Zhao,[3] Z. P. Li,[7] J. Peng,[8] B. Qi,[9] S. Y. Wang,[9] Z. G. Xiao,[10,11] and C. Xu[3]

[1]*iThemba LABS, P.O. Box 722, Somerset West 7129, South Africa*
[2]*Fraunhofer Gesellschaft, Institut für Naturwissenschaftlich-Technische Trendanalysen, D-53881 Euskirchen, Germany*
[3]*State Key Laboratory of Nuclear Physics and Technology, School of Physics, Peking University, Beijing 100871, China*
[4]*School of Physics and Nuclear Energy Engineering, Beihang University, Beijing 100191, China*
[5]*Department of Physics, University of Stellenbosch, Stellenbosch 7602, South Africa*
[6]*Department of Physics and Electronics, Rhodes University, Grahamstown 6410, South Africa*
[7]*School of Physical Science and Technology, Southwest University, Chongqing 400715, China*
[8]*Department of Physics, Beijing Normal University, Beijing 100875, China*
[9]*Shandong Provincial Key Laboratory of Optical Astronomy and Solar-Terrestrial Environment, School of Space Science and Physics, Shandong University, Weihai 264209, China*
[10]*Department of Physics, Tsinghua University, Beijing 100084, China*
[11]*Collaborative Innovation Center of Quantum Matter, Beijing 100084, China*

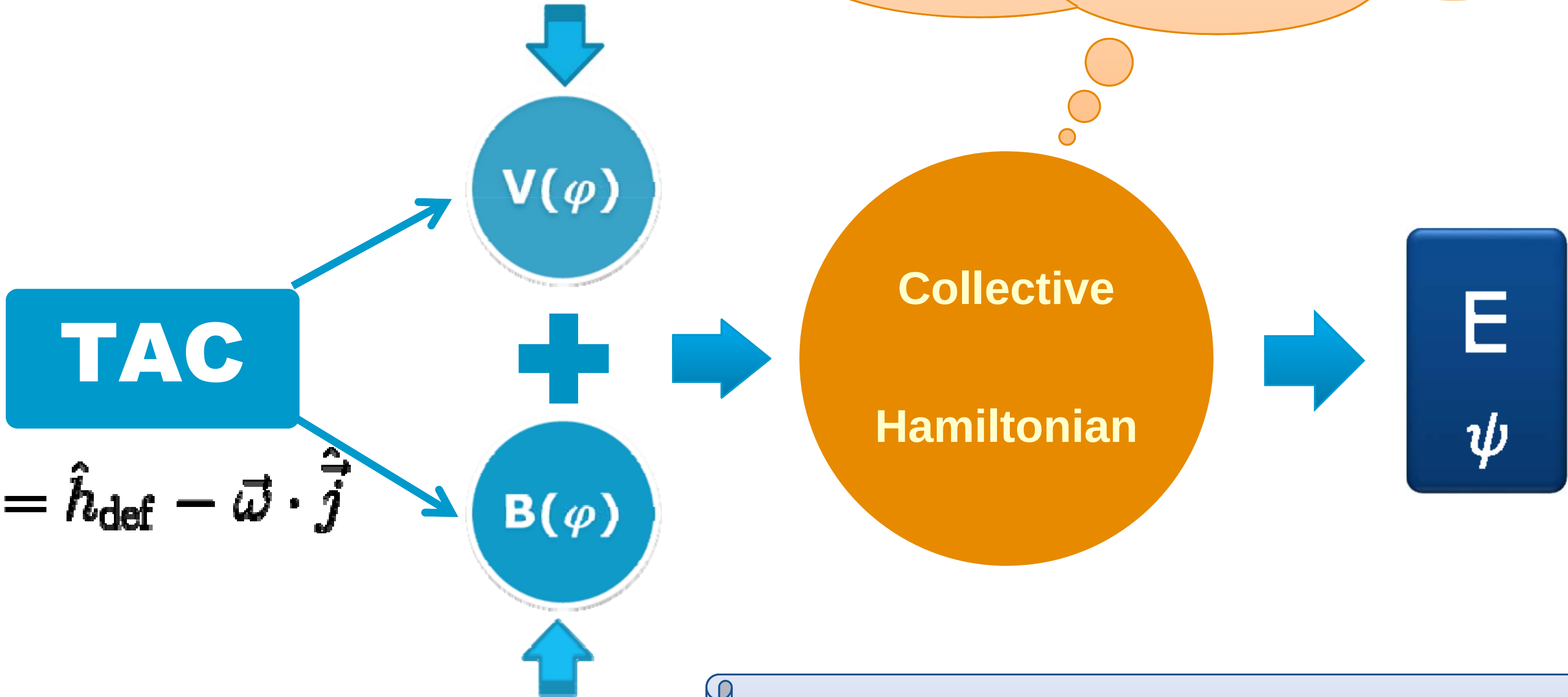
(Received 26 December 2013; revised manuscript received 11 March 2014; published 20 May 2014)

Collective Hamiltonian for Chiral Modes

$$\hat{H}_{\rm coll} = -\frac{\hbar^2}{2\sqrt{B(\varphi)}}\frac{\partial}{\partial\varphi}\frac{1}{\sqrt{B(\varphi)}}\frac{\partial}{\partial\varphi} + V(\varphi)$$

minimize

$$E' = \langle h' \rangle - \frac{1}{2}\sum_{k=1}^{3}\mathcal{J}_k\omega_k^2$$



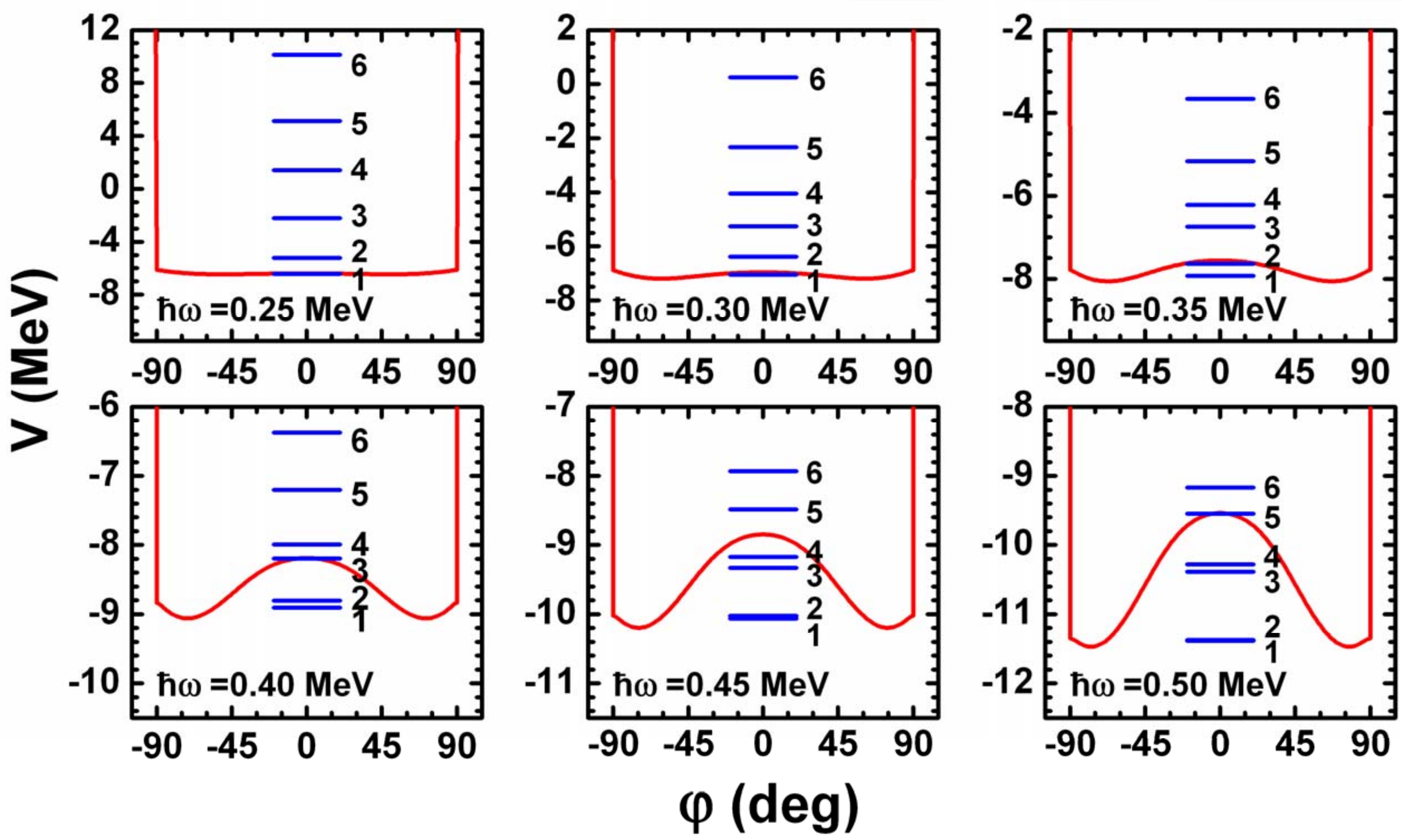
$$\hat{h}' = \hat{h}_{\rm def} - \vec{\omega}\cdot\hat{\vec{j}}$$

$$B = 2\hbar^2\sum_{l\neq 0}\frac{(E_l - E_0)\left|\frac{\partial\vec{\omega}}{\partial\varphi}\langle l|\hat{\vec{j}}|0\rangle\right|^2}{\left[(E_l - E_0)^2 - \hbar^2\Omega^2\right]^2}$$

Q. B. Chen, S. Q. Zhang, P. W. Zhao, R. V. Jolos, J. Meng

Phys. Rev. C87, 024314 (2013).

Energy levels



With the increasing frequency, the energy difference between levels 1 and 2 decreases.

北京大學 PEKING UNIVERSITY

Multiple chiral doublet bands of identical configuration in ^{103}Rh

PRL 113, 032501 (2014) PHYSICAL REVIEW LETTERS week ending 18 JULY 2014

Multiple Chiral Doublet Bands of Identical Configuration in ^{103}Rh

I. Kuti,[1] Q. B. Chen,[2] J. Timár,[1] D. Sohler,[1] S. Q. Zhang,[2] Z. H. Zhang,[2] P. W. Zhao,[2] J. Meng,[2] K. Starosta,[3] T. Koike,[4] E. S. Paul,[5] D. B. Fossan,[6] and C. Vaman[6]

[1]*Institute for Nuclear Research, Hungarian Academy of Sciences, Pf. 51, 4001 Debrecen, Hungary*
[2]*State Key Laboratory of Physics and Technology, School of Physics, Peking University, Beijing 100871, China*
[3]*Department of Chemistry, Simon Fraser University, Burnaby, British Columbia V5A 1S6, Canada*
[4]*Graduate School of Science, Tohoku University, Sendai 980-8578, Japan*
[5]*Oliver Lodge Laboratory, University of Liverpool, Liverpool L69 7ZE, United Kingdom*
[6]*Department of Physics and Astronomy, State University of New York, Stony Brook, New York 11794-3800, USA*

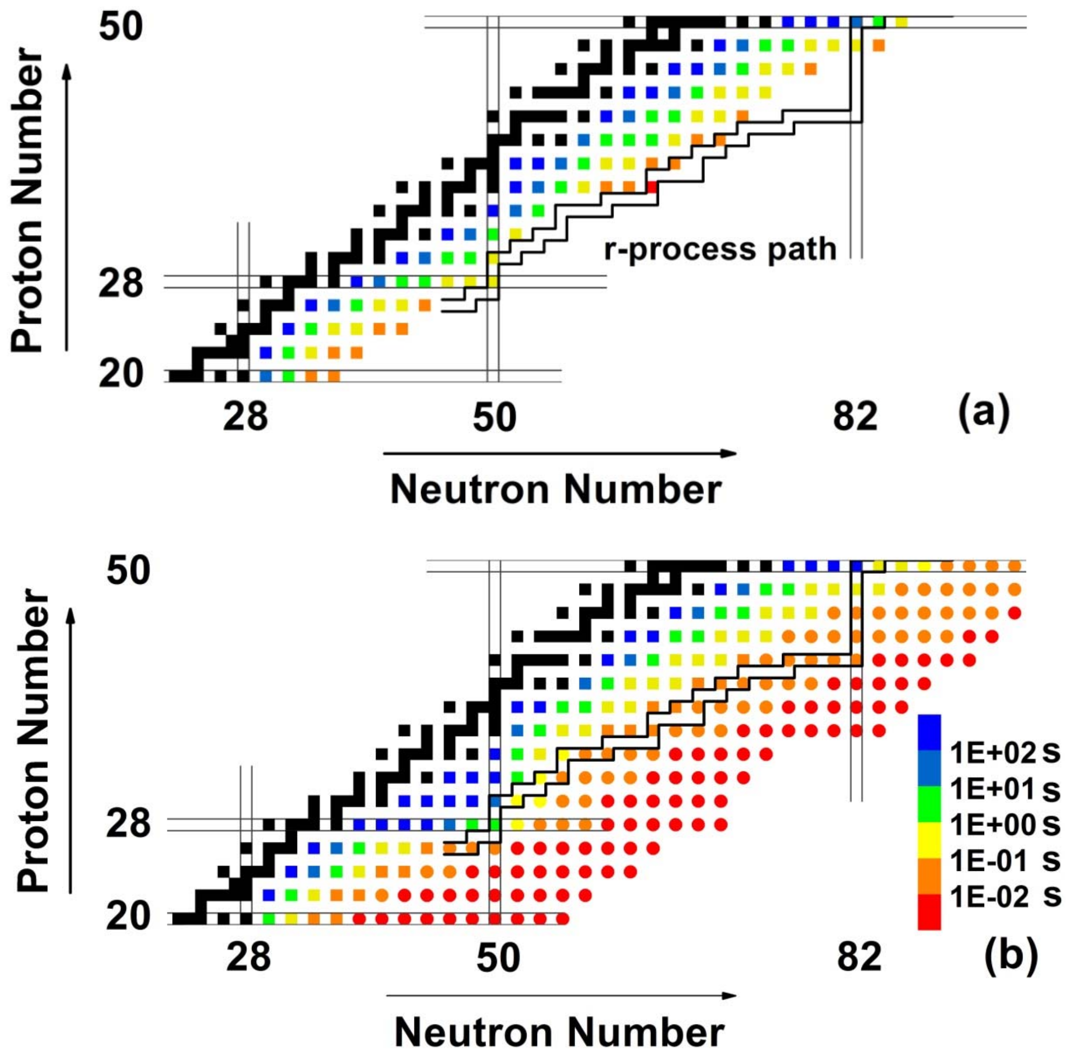
(Received 23 April 2014; published 14 July 2014)

Three sets of chiral doublet band structures have been identified in the ^{103}Rh nucleus. The properties of the observed chiral doublet bands are in good agreement with theoretical results obtained using constrained covariant density functional theory and particle rotor model calculations. Two of them belong to an identical configuration and provide the first experimental evidence for a novel type of multiple chiral doublets, where an "excited" chiral doublet of a configuration is seen together with the "yrast" one. This observation shows that the chiral geometry in nuclei can be robust against the increase of the intrinsic excitation energy.

Outline

- Introduction
- Halo
- Clustering
- Hidden pseudospin and spin symmetries
- Nuclear barrier with triaxial and octupole shape
- Simultaneous shape phase transition
- Exotic rotation: magnetic and antimagnetic rotation MχD
- Nuclear β-decay half-lives
- Extending the nuclear landscape by continuum: from spherical to deformed
- Perspectives

RHFB+QRPA: Nuclear β⁻-decay half-lives



- Available data are well reproduced by including an isospin-dependent proton-neutron pairing interaction in the isoscalar channel of the RHFB+QRPA model.

$$V_{T=0}(1,2) = -V_0 \sum_{j=1}^{2} g_j e^{-r_{12}^2/\mu_j^2} \hat{\Pi}_{S=1,T=0},$$

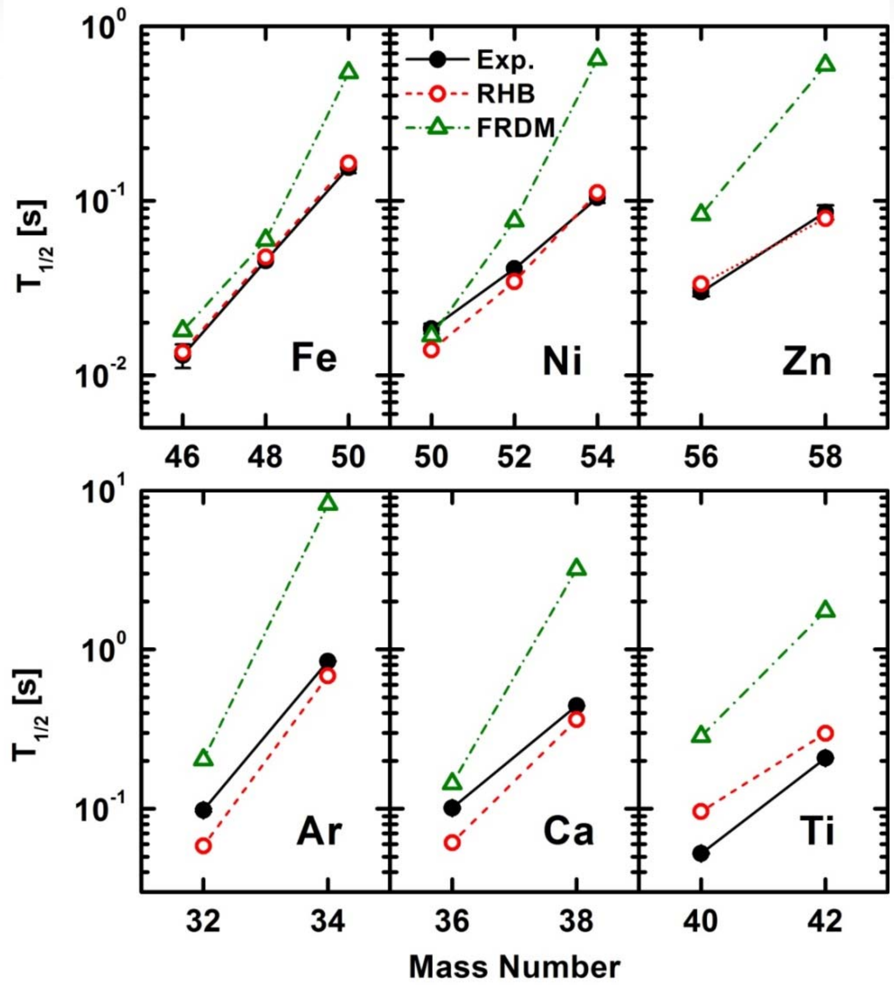
$$V_0 = V_1 + \frac{V_2}{1+e^{a+b(N-Z)}},$$

Niu et al., PLB 723, 172 (2013)

RHB+QRPA: Nuclear β⁺/EC-decay half-lives

- RHB+QRPA: well reproduces the experimental half-lives for neutron-deficient Ar, Ca, Ti, Fe, Ni, and Zn isotopes by a universal *T*=0 pairing strength.

- FRDM+QRPA: systematically overestimates the nuclear half-lives ← the pp residual interactions in the *T*=0 channel are not considered.



Nuclear β^+/EC-decay half-lives calculated in RHB+QRPA model with the PC-PK1 parameter set.

Niu et al., PRC 87, 051303(R) (2013)

Outline

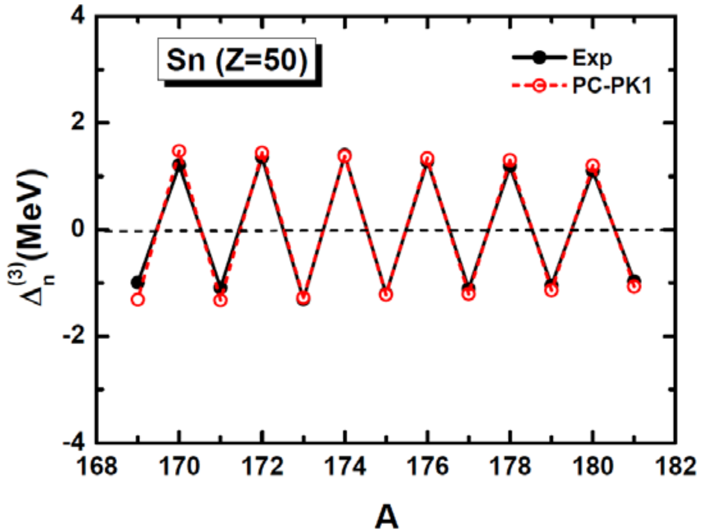
- Introduction
- Halo
- Clustering
- Hidden pseudospin and spin symmetries
- Nuclear barrier with triaxial and octupole shape
- Simultaneous shape phase transition
- Exotic rotation: magnetic and antimagnetic rotation MχD
- Nuclear β-decay half-lives
- Extending the nuclear landscape by continuum: from spherical to deformed
- Perspectives

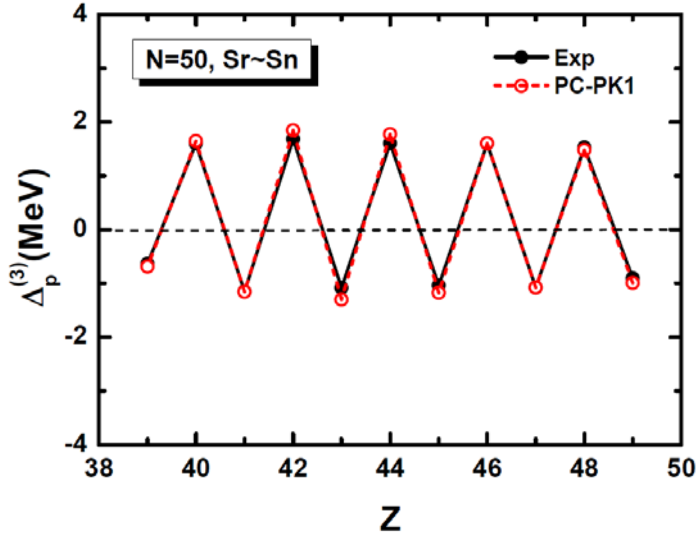
Relativistic Continuum Hartree-Bogoliubov theory

- PC-PK1: for nucleus with Z=8 to Z=130
- Box size: 20 fm; mesh size: 0.1 fm
- J_{max}=19/2, E_{cut}=100 MeV
- Density-dependent delta pairing force

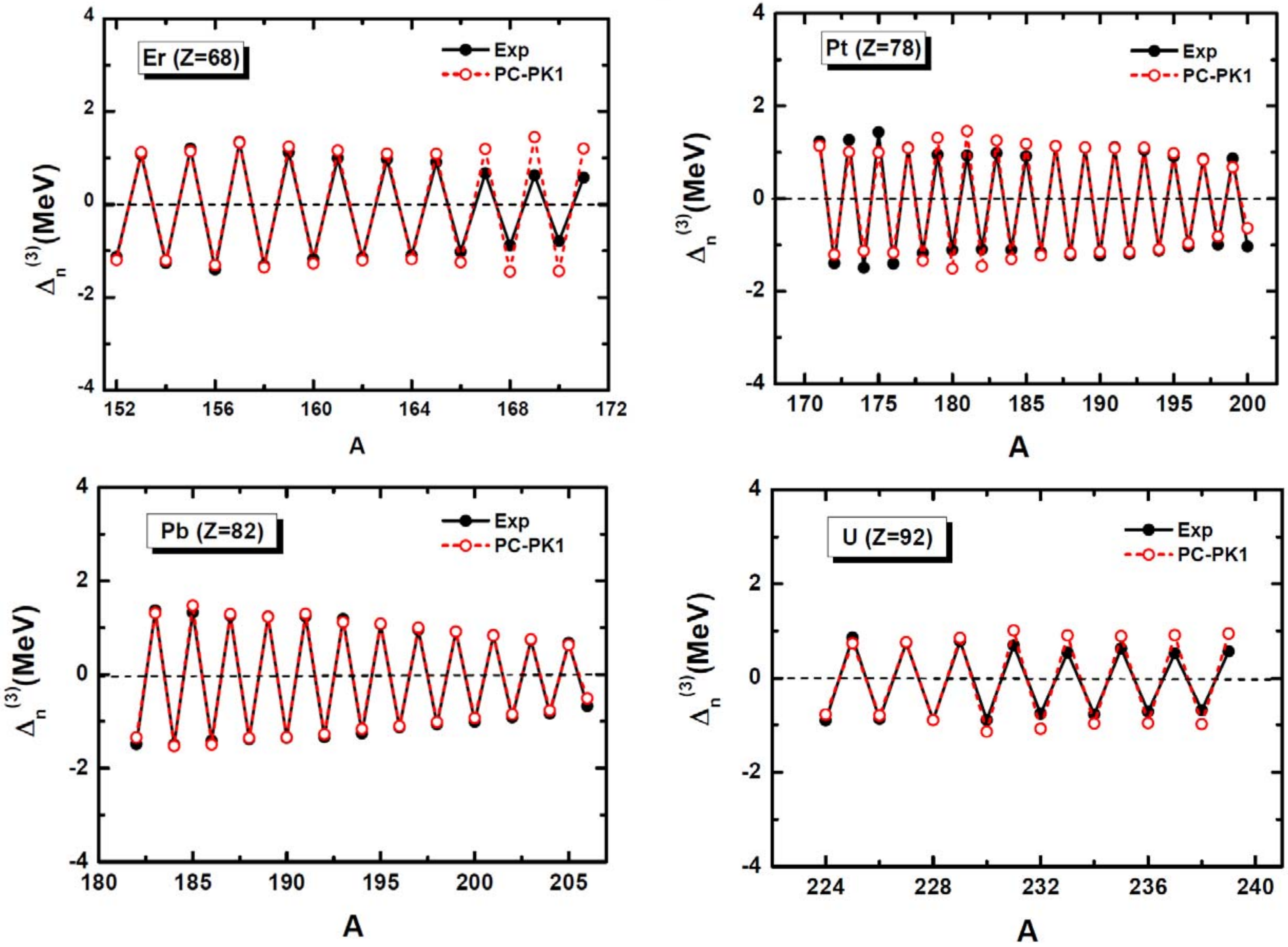
$$V^{pp}(\boldsymbol{r},\boldsymbol{r}') = \frac{V_0}{4}(1-P^\sigma)\delta(\boldsymbol{r}-\boldsymbol{r}')(1-\frac{\rho(\boldsymbol{r})}{\rho_{sat}})$$

with the saturation density $\rho_{sat} = 0.152\ \mathrm{fm}^{-3}$, and the pairing force strength $V_0 = 685.0\ \mathrm{MeV}\cdot\mathrm{fm}^{-3}$





Pairing force and odd-even staggering



Drip-lines in variant models

The number of bound nuclides with between 2 and 120 protons is around 7,000 28 JUNE 2012 | VOL 486 | NATURE | 509

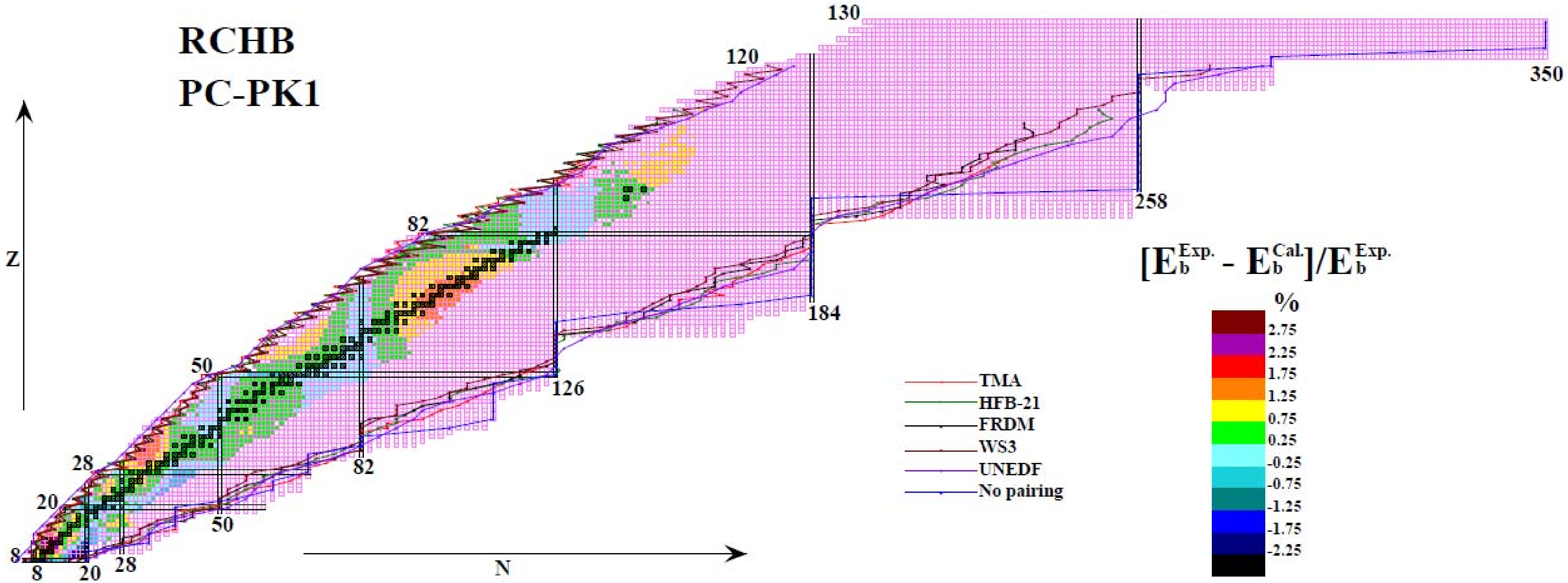


Figure: 10532 bound nuclei from Z=8 to Z=130 predicted by RCHB theory with PC-PK1. For 2227 nuclei with data, binding energy differences between data and calculated results are shown in different color. The nucleon drip-lines predicted TMA, HFB-21, WS3, FRDM , UNEDF and without pairing correlation are plotted for comparison.

Continuum contributions

Afanasjev et al PhysicsLettersB726(2013)680–684

Particle-bound e-e Z<120 nuclei is respectively 2040, 2050, 2057 and 2216 for DD-PC1, DD-ME2, DD-Meδ and NL3*

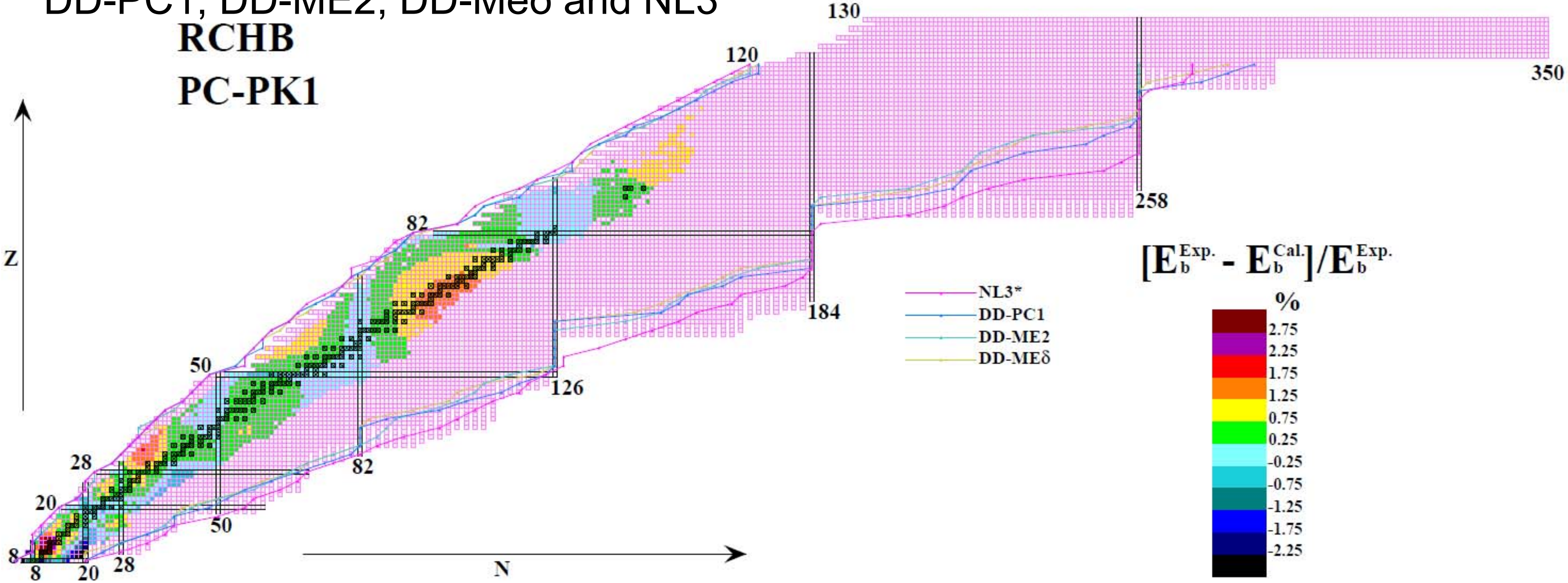
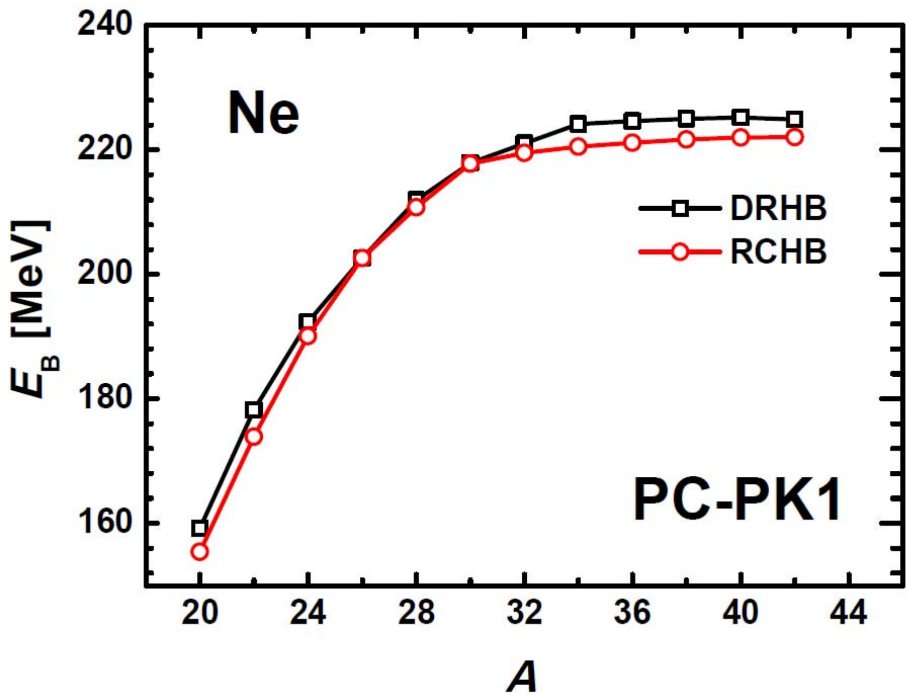
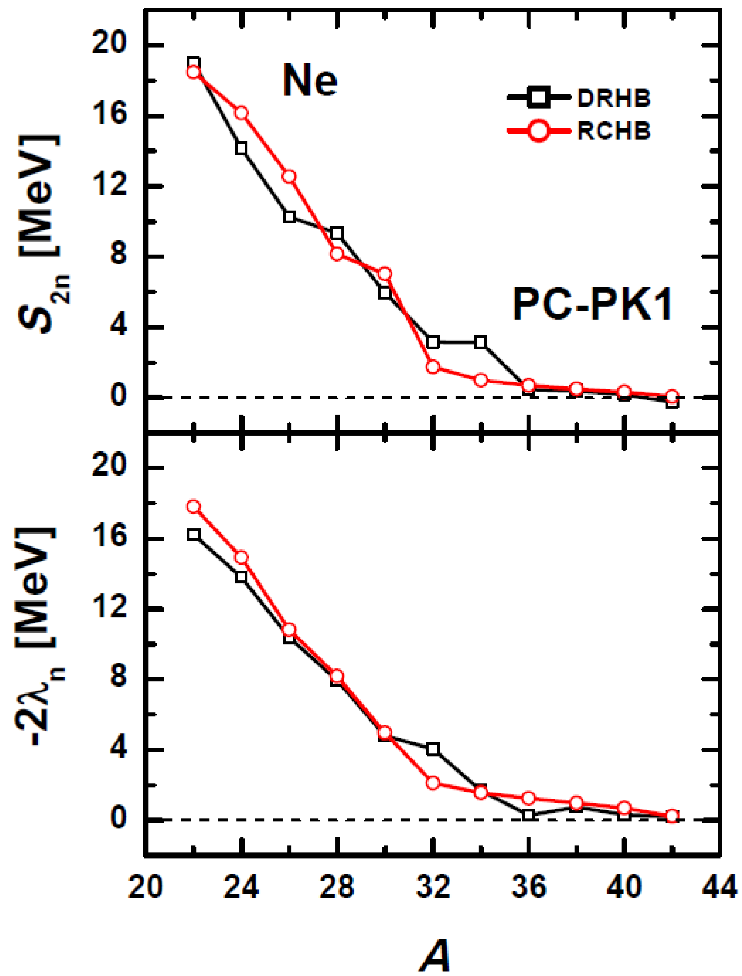


Figure: 10532 bound nuclei from Z=8 to Z=130 predicted by RCHB theory with PC-PK1. For 2227 nuclei with data, binding energy differences between data and calculated results are shown in different color. The nucleon drip-lines predicted without pairing correlation are plotted for comparison.

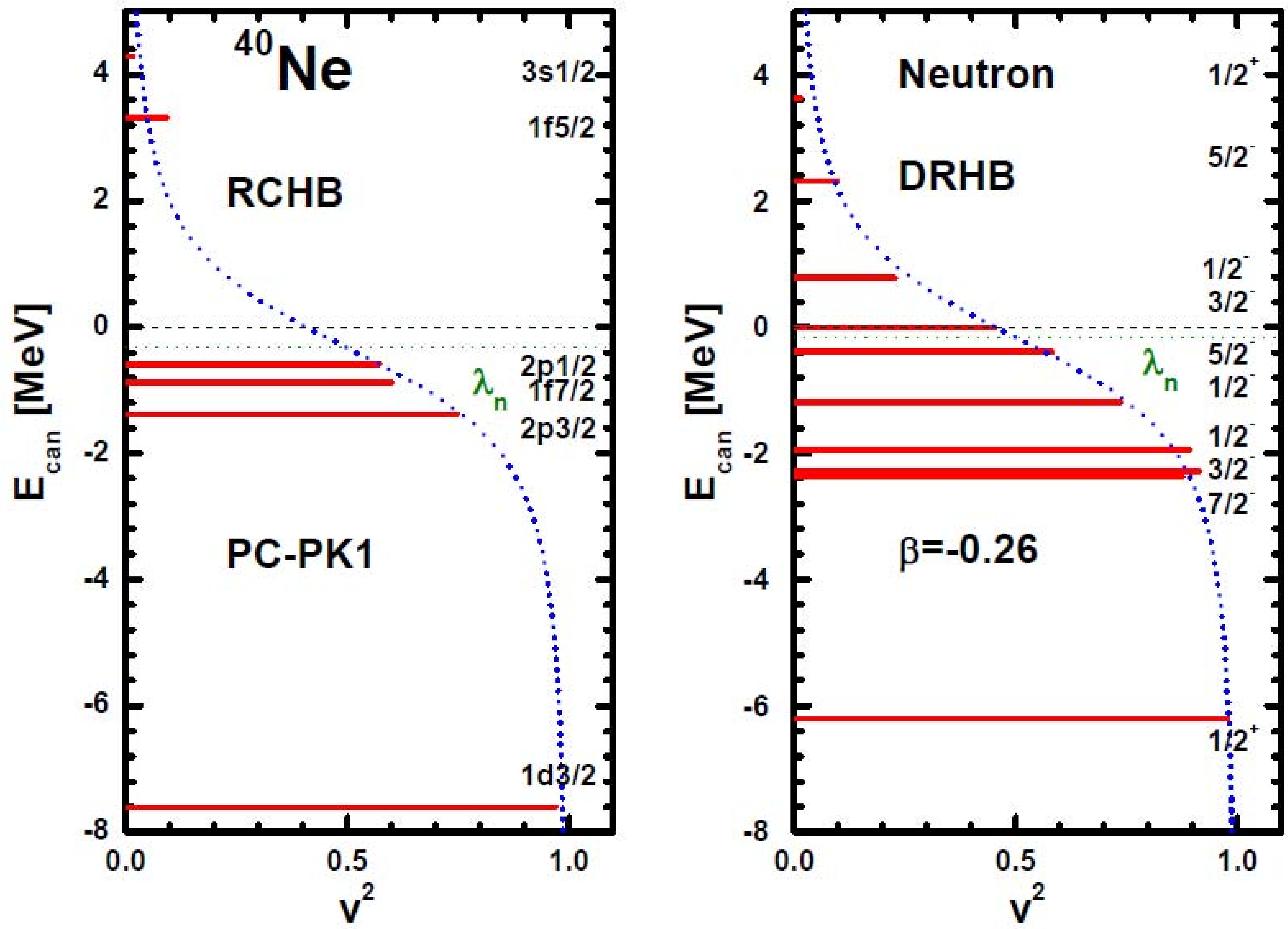
Deformation: Binding energy





Binding energy and two-neutron separation energy of Ne isotopes calculated with PC-PK1.

Single Neutron Levels in ^{40}Ne in comparison



Weizsäcker-Skyrme formula

Inspired by the Skyrme energy-density functional, Wang et al proposed a macroscopic-microscopic mass formula, Weizsäcker-Skyrme (WS) formula, with an rms deviation of 336 keV with respect to the 2149 measured masses in 2003 Atomic Mass Evaluation.

N. Wang, M. Liu and X. Z. Wu, Phys. Rev. C 81, 044322 (2010).
N. Wang, Z. Y. Liang, M. Liu and X. Z. Wu, Phys. Rev. C 82, 044304 (2010).
[M. Liu, N. Wang, Y. G. Deng, and X. Z. Wu, Phys. Rev. C 84, 014333 (2011).

How good is the WS formula ?

波兰科学院院士、波兰艺术与科学院院士 Sobiczewski 的评价

PHYSICAL REVIEW C 89, 024311 (2014)

Accuracy of theoretical descriptions of nuclear masses

Adam Sobiczewski*
National Centre for Nuclear Research, Hoża 69, 00-681 Warsaw, Poland;
GSI Helmholtzzentrum für Schwerionenforschung GmbH, 64291 Darmstadt, Germany;
and Helmholtz Institute Mainz, 55099 Mainz, Germany

Yuri A. Litvinov†
GSI Helmholtzzentrum für Schwerionenforschung GmbH, 64291 Darmstadt, Germany

(Received 30 December 2013; published 21 February 2014)

The
kinds
of oth
recent
the de
appro
develo
strong
a reali

DOI:

2014-03-08 (周六) 16:05
Adam.Sobiczewski@fuw.edu.pl
article
收件人 Jie Meng
答复此邮件的时间为 2014-03-10 8:23。
已删除此邮件多余的换行符。

Dear Jie,

attached, I send you a copy of our analysis of the accuracy of the description of nuclear masses by various models. You can see that the models by Dr. Ning Wang and cowerkers are really good. Thanks for the discussion and suggestions.

Best regards, Adam

超重核理论先驱者之一，经典工作
Phys. Lett. 22 [1966] 500
提出下一个双幻核为 **Z = 114** 及 **N = 184**

北京大学
PEKING UNIVERSITY

2014-03-13 (周四) 3:28
Adam.Sobiczewski@fuw.edu.pl
Re: 答复: article
收件人　Jie MENG
此邮件有多余的换行符。

Dear Jie,
thanks for the kind mail. It is very good that Ning still improves his model, which is really promising. Probably you encourage him to do this, which is nice and clever.
Best regards,　　　Adam

2014-03-10 (周一) 8:24
Jie MENG <mengj@pku.edu.cn>
答复: article
收件人　'Adam.Sobiczewski@fuw.edu.pl'
抄送　'wangning'
已删除此邮件多余的换行符。

Dear Adam,

Thank you for your mail and congratulation for your nice paper. It is quite helpful for the community.

By the way, recently by taking into account the isospin dependence of the mean field potential, Ning has further improved his mass model. The average deviation is below 300 Kev now.

I will ask him to send you the manuscript once it is ready.

With best regards,

Jie
==

Physics Letters B 734 (2014) 215–219

Contents lists available at ScienceDirect

Physics Letters B

www.elsevier.com/locate/physletb

Surface diffuseness correction in global mass formula

Ning Wang [a,*], Min Liu [a], Xizhen Wu [b], Jie Meng [c,d]

[a] Department of Physics, Guangxi Normal University, Guilin 541004, PR China
[b] China Institute of Atomic Energy, Beijing 102413, PR China
[c] State Key Laboratory of Nuclear Physics and Technology, School of Physics, Peking University, Beijing 100871, PR China
[d] School of Physics and Nuclear Energy Engineering, Beihang University, Beijing 100191, PR China

ARTICLE INFO

Article history:
Received 25 February 2014
Received in revised form 28 April 2014
Accepted 5 May 2014
Available online 20 May 2014
Editor: W. Haxton

ABSTRACT

By taking into account the surface diffuseness correction for unstable nuclei, the accuracy of the macroscopic–microscopic mass formula is further improved. The rms deviation with respect to essentially all the available mass data falls to 298 keV, crossing the 0.3 MeV accuracy threshold for the first time within the mean-field framework. Considering the surface effect of the symmetry potential which plays an important role in the evolution of the "neutron skin" toward the "neutron halo" of nuclei approaching the neutron drip line, we obtain an optimal value of the symmetry energy coefficient $J = 30.16$ MeV. With an accuracy of 258 keV for all the available neutron separation energies and of 237 keV for the α-decay Q-values of super-heavy nuclei, the proposed mass formula is particularly important not only for the reliable description of the r process of nucleosynthesis but also for the study of the synthesis of super-heavy nuclei.

PEKING UNIVERSITY

Dear Dr. Ning Wang and Jie,

We made here some tests of your WS models. Their accuracy is really good, especially of your recent WS4+RBF model.

For your information, I send you four detailed maps of the discrepancies between the calculated and experimental masses obtained with your 4 models for the region of heavy nuclei.

For a comparison, I also add 3 maps obtained with FRDM, HFB21 and DZ. You can see how much your models are more accurate.

Best regards,
Adam Sobiczewski

2014-06-29 (周日) 2:02
Adam.Sobiczewski@fuw.edu.pl
Re: nuclear mass formula WS4

收件人 wangning

抄送 mengj@pku.edu.cn

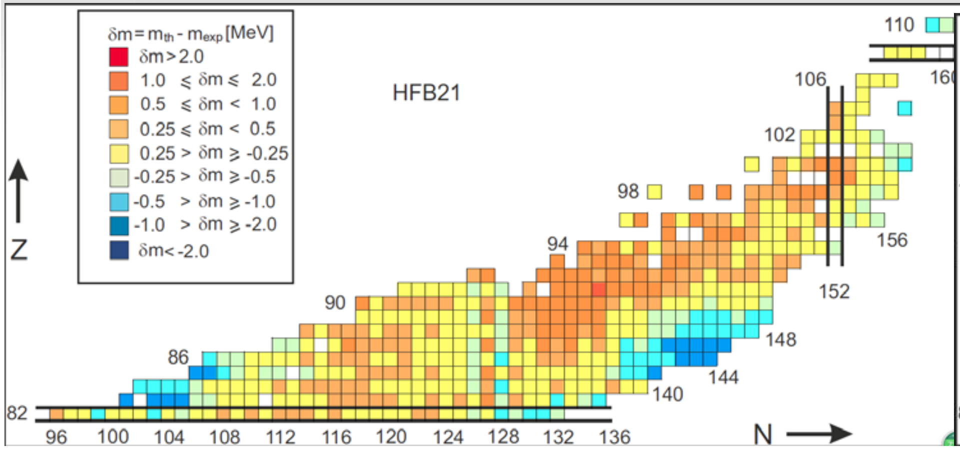
答复此邮件的时间为 2014-06-29 14:46。
已删除此邮件多余的换行符。

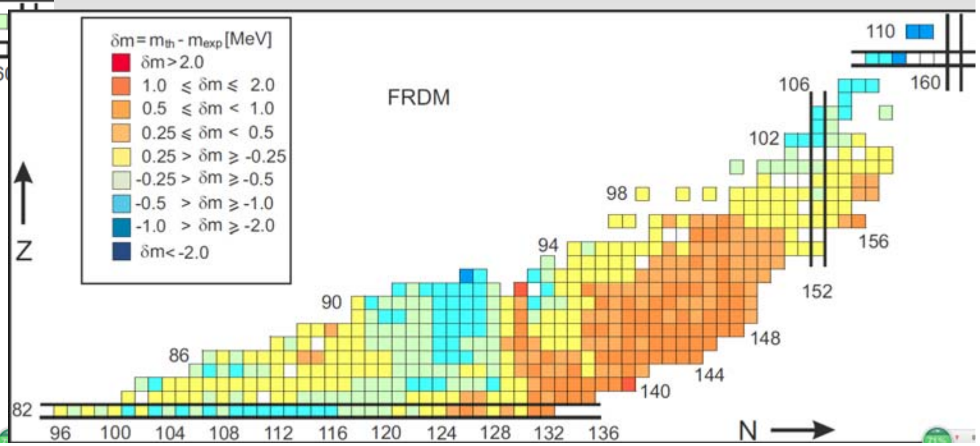
邮件 7 maps-obsz4(Ning+Jie).zip (120 KB)

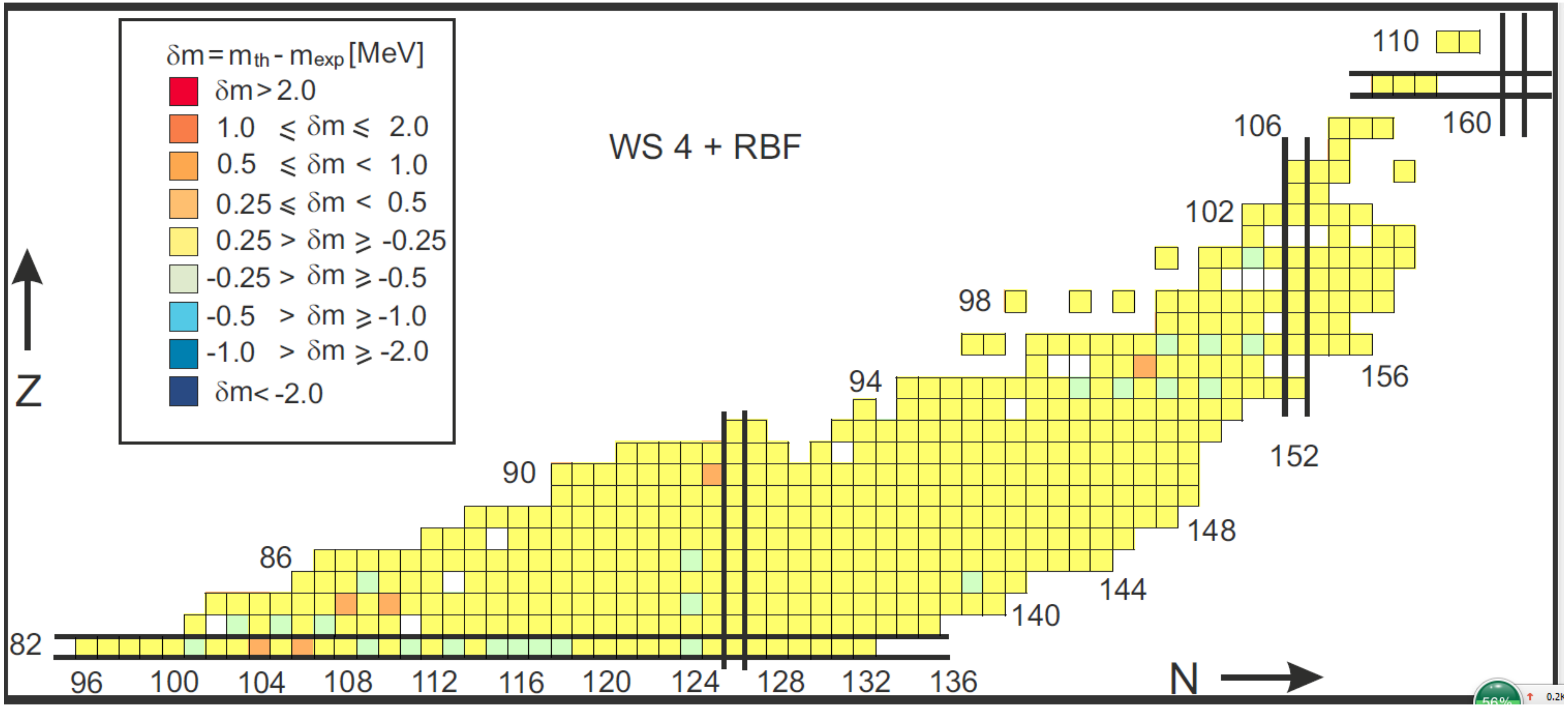
Dear Dr. Ning Wang and Jie,

We made here some tests of your WS models. Their accuracy is really good, especially of your recent WS4+RBF model.
For your information, I send you four detailed maps of the discrepancies between the calculated and experimental masses obtained with your 4 models for the region of heavy nuclei.
For a comparison, I also add 3 maps obtained with FRDM, HFB21 and DZ.
You can see how much your models are more accurate.

Best regards,
Adam Sobiczewski







courtesy of Adam Sobiczewski

PEKING UNIVERSITY

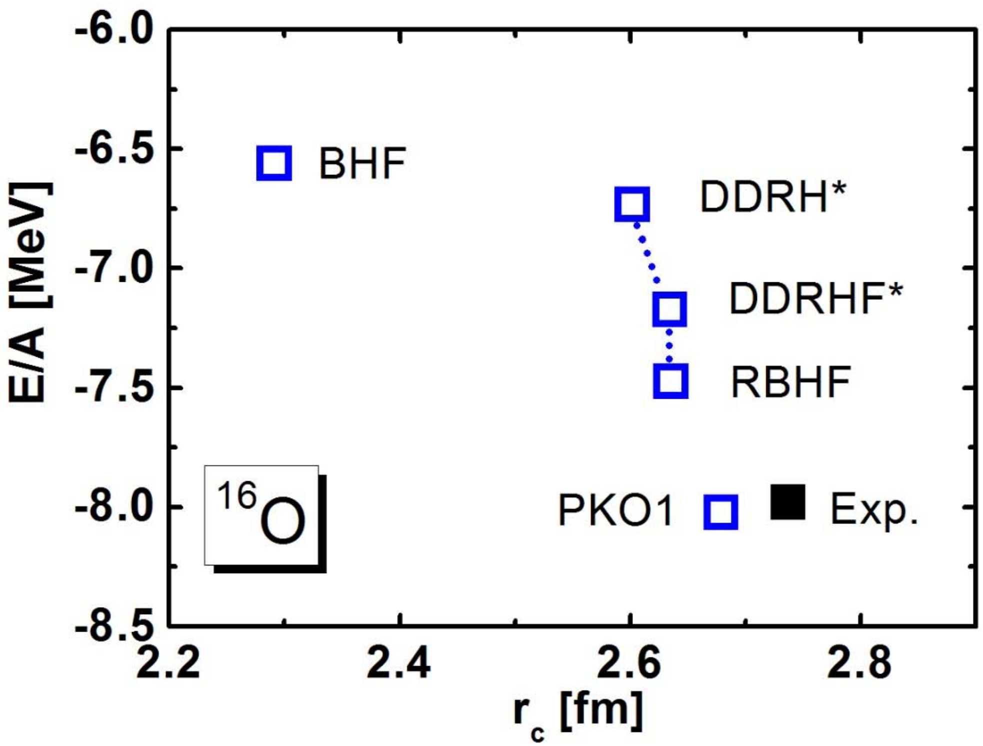
Outline

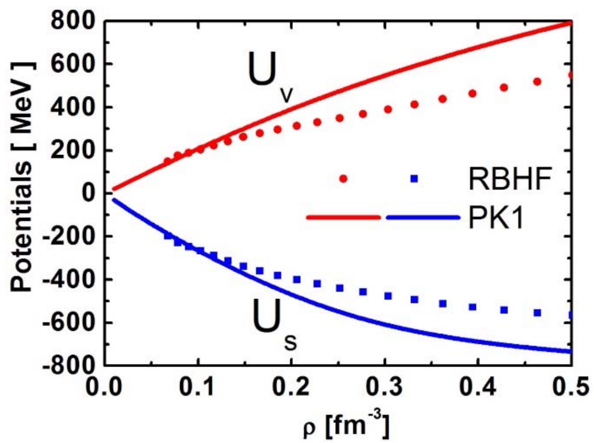
- Introduction
- Halo
- Clustering
- Hidden pseudospin and spin symmetries
- Nuclear barrier with triaxial and octupole shape
- Simultaneous shape phase transition
- Exotic rotation: magnetic and antimagnetic rotation MχD
- Nuclear β-decay half-lives
- Extending the nuclear landscape by continuum: from spherical to deformed
- Perspectives

Future: *ab initio* CDFT

Binding energy and radii of ^{16}O

- **Full Relativistic Brueckner Hartree-Fock calculation for finite nucleus with expansion in Harmonics Oscillator basis**
- **NN interaction: Brueckner G-matrix in HO basis**
- **Solve RBHF equation in HO basis with the G-matrix in HO basis**





Hu, Meng, Ring, *to be published.*

Thank you!