Gogny interactions with tensor terms

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Work in colaboration with

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Outline

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Motivation

- Tensor force is usually neglected in mean-field methods.
- Shell evolution cannot be studied without tensor force (nuclei far from the stability line).
- Crucial in the study of properties of spin and spin-isospin states (Gamow-Teller and spin-dipole excitations).
- Some experiments which indicates the role of the tensor force:

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   Proton splitting $1h_{11/2} - 1g_{7/2}$ in $Z = 50$ increases with neutron excess
2. Gaudefroy *et al.*, Phys. Rev. Lett **97**, 092501 (2006):
   Reduction of the neutron splitting $1f_{7/2} - 2p_{3/2}$ in $N = 28$ going from ^{49}Ca to ^{47}Ar
3. Burgunder *et al.*, Phys. Rev. Lett **112**, 042502 (2014):
   Neutron splitting $2p_{3/2} - 2p_{1/2}$ for $N = 20$

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The tensor interaction

- We have proposed different types of finite range tensor interactions onto D1S and D1M Gogny parametrizations.
- Different fits have been done in order to fix the free parameters in each case:
  1. Adding a the tensor-isospin term, and modifying the strength of the spin-orbit term: D1ST
  2. Adding a pure tensor and tensor-isospin terms: D1ST2a, D1ST2b
  3. Adding a pure tensor, tensor-isospin and modifying the spin-orbit term: D1ST2c
- With these interactions, we have studied:

1. Binding and single particle energies in HF approximation.
2. Excitation states with DRPA and CRPA approximations:
   - 2.1 0^- excitation in spherical nuclei
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Our Hartree-Fock (HF) approximation

- We considere as effective nucleon-nucleon interaction a finite-range two-body force of the type:

$$V(\vec{r_1},\vec{r_2}) = \sum_{p=1}^{6} V_p(\vec{r_1},\vec{r_2})O_p(1,2) + V_{\rm SO}(\vec{r_1},\vec{r_2}) + V_{\rm DD}(\vec{r_1},\vec{r_2}) + V_{\rm Coul}(\vec{r_1},\vec{r_2})$$

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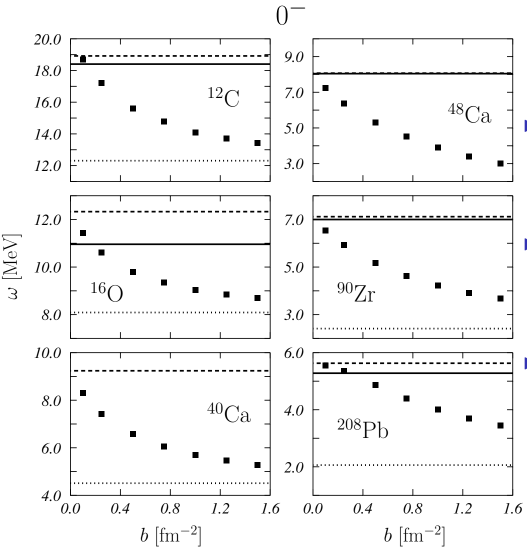
Fit of the tensor terms: D1ST interaction

$$v_{6,b}(r) = v_{6,AV18}(r)\left(1 - e^{-br^2}\right)$$

$$V_6(q)S_{12}(\mathbf{q}) = \int d^3r e^{i\mathbf{q}\cdot\mathbf{r}} v_6(r)S_{12}(\mathbf{r}) = -4\pi \int dr r^2 j_2(qr) v_6(r) S_{12}(\mathbf{r})$$

Fit of the tensor force: D1ST

Energies of the first 0^- states

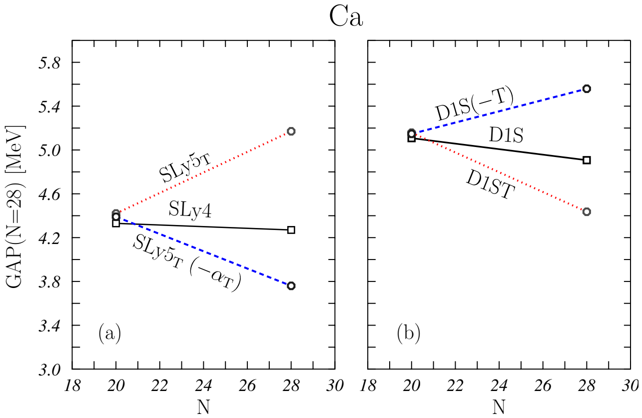


- Fit for ^{16}O: $E(0^-)$=10.96 MeV
- **D1ST** b=0.6 fm^{-2}, W_0=134 MeV
- **D1MT** b=0.25 fm^{-2}, W_0=122.5 MeV

Phenomenological RPA with LM + $v_{6,b}(r)$

Fit of the tensor force: D1ST2a and D1ST2b

- Experimentally, the difference between the energies of the single-particle neutron $2p_{3/2}$, $1f_{7/2}$ states increases from ^{40}Ca to ^{48}Ca: O. Sorlin and M.-G. Pourquet, Prog. Part. Nucl. Phys. **61**, 602 (2008)



M. A *et al.*, Phys. Rev. **C86**, 054302 (2012)

Fit of the tensor force: D1ST2a and D1ST2b

N. Onishi and J.W. Negele, NPA301 (1978), 336

$$
\begin{aligned}
V_{\text{tensor}}(\vec{r}_1, \vec{r}_2) &= (V_{T1} + V_{T2}\, P^{\tau}_{12})\, S_{12}\, e^{-(r_1 - r_2)^2/\mu_T^2} \\
&= \left[\left(V_{T1} + \frac{1}{2} V_{T2} \right) + \frac{1}{2} V_{T2}\, \boldsymbol{\tau}(1) \cdot \boldsymbol{\tau}(2) \right] S_{12}\; e^{-(r_1 - r_2)^2/\mu_T^2}
\end{aligned}
$$

D1ST2a $\rightarrow$ neutron $1f$ splitting in ^{48}Ca and 0^- state of ^{16}O:

$V_{T1} = -135$ MeV, $V_{T2} = 115$ MeV

D1ST2b $\rightarrow N = 28$ neutron gap increase from ^{40}Ca to ^{48}Ca as obtained in HF calculations with the SLy5T force and 0^- state of ^{16}O:

$V_{T1} = -182$ MeV, $V_{T2} = 102$ MeV

Fits of the tensor force: D1ST2c

Following the strategy of Zalewski *et al.*, Phys. Rev. **C77**, 024316 (2008):

D1ST2c $\rightarrow$ neutron $1f$ splitting in ^{40}Ca, ^{48}Ca and ^{56}Ni

1. First, we fit the splitting $1f$ in ^{40}Ca by modifying the spin-orbit parameter $W_{\rm LS}$,
2. second, we fit the splitting $1f$ in ^{48}Ca adjusting the like-particle part of the Gogny tensor term and, $V_{T1} + V_{T2}$,
3. finally, we use the ^{56}Ni to fit the neutron-proton contribution of the tensor term, V_{T2} .[1]

$$W_{\rm LS} = 103 \text{ MeV fm}^5, \quad V_{T1} = -135 \text{ MeV}, \quad V_{T2} = 60 \text{ MeV}$$

D1MT2c $\rightarrow$ following the same procedure, and using D1M as starting point we have fit another interaction

$$W_{\rm LS} = 95 \text{ MeV fm}^5, \quad V_{T1} = -175 \text{ MeV}, \quad V_{T2} = 40 \text{ MeV}$$

[1] M. Grasso and M. A, Phys. Rev. **C88**, 054328 (2014)

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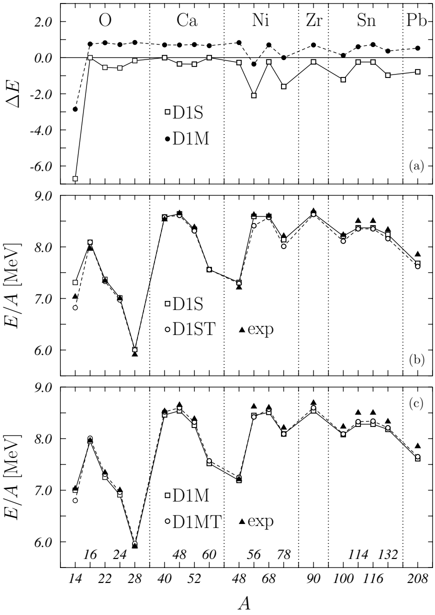
Bulk properties of spherical nuclei

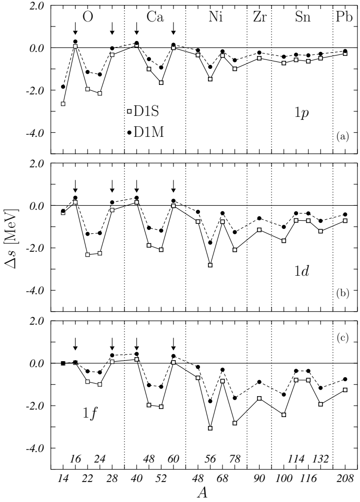


$$\Delta E = 100 \frac{E_{\mathrm{D1}\alpha\mathrm{T}} - E_{\mathrm{D1}\alpha}}{E_{\mathrm{D1}\alpha}}$$

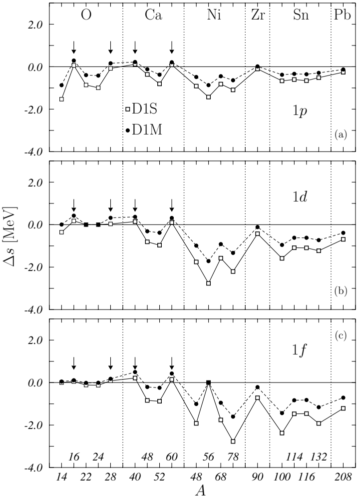
$$\alpha \equiv \mathrm{S}, \mathrm{M}$$

s.p. energies of spin–orbit partners

Protons



Neutrons



$$s = \epsilon_{l-1/2} - \epsilon_{l+1/2}$$

$$\Delta s = s_{\mathrm{D1}\alpha\mathrm{T}} - s_{\mathrm{D1}\alpha}$$

Discrete RPA: 0^- states

	exp	D1S	D1ST	D1M	D1MT
^{12}C	18.40	19.63	14.42	18.83	15.27
^{16}O	10.96	13.95	10.94	13.08	10.96
^{40}Ca	10.78	12.22	9.57	11.56	9.60
^{48}Ca	8.05	14.10	11.63	12.85	11.26
^{208}Pb	5.28	8.27	7.93	8.24	7.92

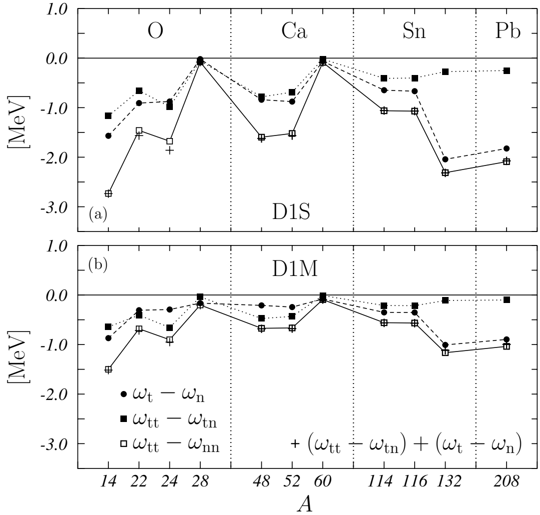
M. A *et al.* Phys. Rev. **C83** (2011) 064306

Exp. values:

A. Heusler *et al.* Phys. Rev. **C75** (2007) 024312

http://www.nndc.bnl.gov/

Discrete RPA: 1^+ excitations in $N \neq Z$ nuclei

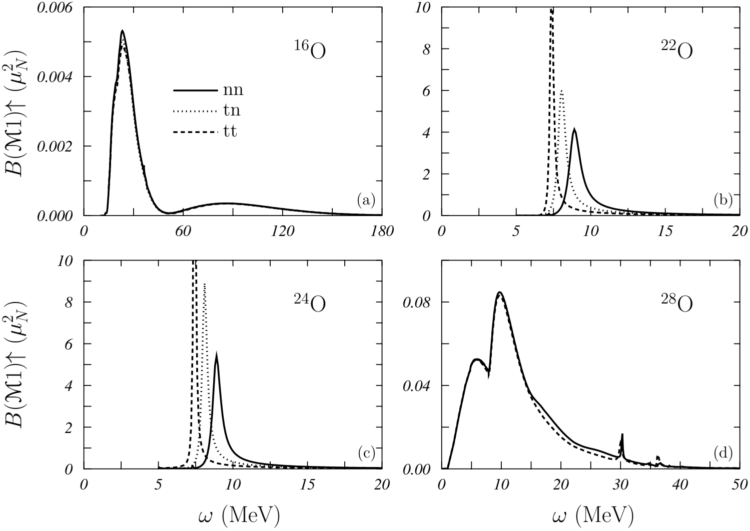


M. A *et al.* Phys. Rev. **C83** (2011) 064306

First 1^+ state in ^{208}Pb

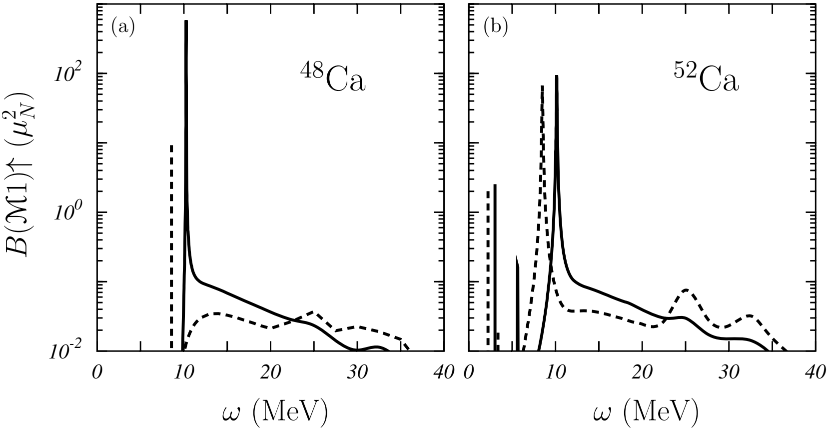
	$E(1^+_1)$ [MeV]	$B(M1)_1$ $[\mu^2_n]$
exp	5.85	2.0
D1S	7.80	5.08
D1ST	4.76	2.41
D1M	6.50	2.33
D1MT	4.82	1.80

Continuum RPA: Magnetic dipole response in O isotopes



main p-h excitation $\Rightarrow$ $[(\nu 1d_{3/2})(\nu 1d_{5/2})^{-1}]$

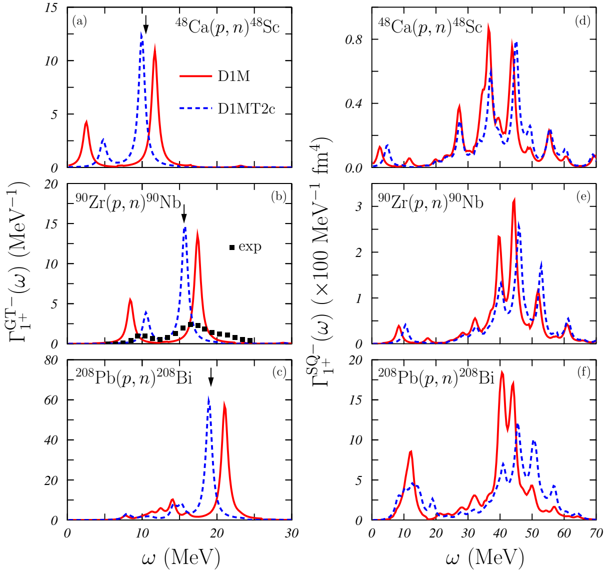
Continuum RPA: Magnetic dipole response in Ca isotopes



main p-h excitation $\Rightarrow$ $[(\nu 1f_{5/2})(\nu 1f_{7/2})^{-1}]$

E(1^+): 10.23 MeV (EXP) 10.15 MeV (D1S) 8.56 MeV (D1ST)

Charge exchange excitations: 1^+ GT and SQ



V. De Donno *et al.*, Phys. Rev. **C90**, 024326 (2014)

Splitting in ^{40}Ca, ^{36}S and ^{34}Si: $N = 20$ isotones

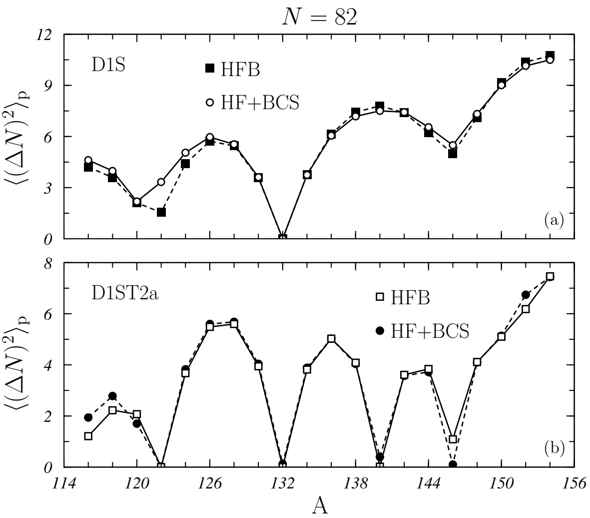
Tensor induced and pure spin-orbit effects

	From ^{40}Ca to ^{36}S (tensor)	From ^{36}S to ^{34}Si (spin orbit)
Splitting	**D1S**	**D1S**
$2p$	13%	43%
	D1ST2a	**D1ST2a**
$2p$	40%	39%
	D1ST2c	**D1ST2c**
$2p$	27%	42%

Reductions of the neutron $2p$ splitting.

M. Grasso and M. Anguiano, Phys. Rev. **C92**, 054216 (2015)

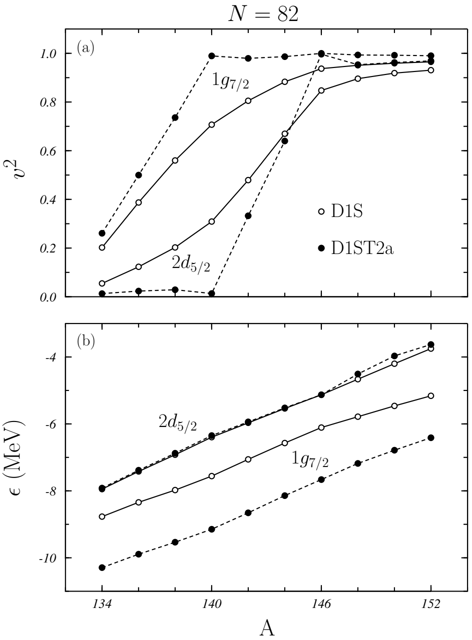
Interplay between tensor force and pairing correlations



Pairing field in HFB: $V_{\mathrm{Central}} + V_{\mathrm{SO}} + V_{\mathrm{Coul}}$.

Pairing field in BCS: V_{Central}

Interplay between tensor force and pairing correlations



Proton Levels

Tensor force?

neutron $1h_{11/2}$

A new fit for the tensor interaction

$$V_{\text{tensor}}(\vec{r}_1, \vec{r}_2) = V_T\, S_{12}\, e^{-(r_1-r_2)^2/\mu_T^2} + V_{T\tau}\, \boldsymbol{\tau}(1) \cdot \boldsymbol{\tau}(2)\, S_{12}\; e^{-(r_1-r_2)^2/\mu_{T\tau}^2}$$

1. A more general fit, with five parameters

$$W_{\text{LS}} \quad V_T \quad V_{T\tau} \quad \mu_T \quad \mu_{T\tau}$$

2. How? Using the procedure following to obtain D1ST2c, and adding two observables more.

Energy of the first 0^- state of ^{16}O and 1^+ GT of ^{48}Ca