# Nuclear Chiral Dynamics: Spin-Isospin Excitations ◇

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In Ref. [1] we have introduced a relativistic nuclear energy density functional based on the following conjectures:

1. The nuclear ground state is characterized by strong scalar and time-like vector mean fields which have their origin in the in-medium changes of the scalar quark condensate (the chiral condensate) and of the quark density. The inclusion of these large fields is crucial for a correct description of nuclear ground state properties and, in particular, of the single particle spectrum (i.e. spin-orbit splittings).

2. Nuclear binding and saturation arise primarily from chiral (pionic) fluctuations in combination with Pauli blocking effects and three-nucleon interactions, superimposed on the condensate background fields and calculated according to the rules of in-medium chiral perturbation theory [2].

This energy functional has been tested successfully by systematic studies throughout the nuclear periodic table.

We have recently developed a relativistic random phase approximation in the $pn$ basis to test the validity of the previous assumptions in detailed studies of charge-exchange excitations (Fermi and Gamow-Teller type) for closed and open shell nuclei [4].

The residual two-body interaction reads:

$$
\begin{aligned}
V^{ph}(\boldsymbol{r}_1, \boldsymbol{r}_2) &= G_{TS}^{(\pi)}(\rho)\,\vec{\tau}_1 \cdot \vec{\tau}_2\,(\mathbb{1})_1(\mathbb{1})_2\,\delta^3(\boldsymbol{r}_1 - \boldsymbol{r}_2) \\
&+ G_{TV}^{(\pi)}(\rho)\,\vec{\tau}_1 \cdot \vec{\tau}_2\,(\beta\gamma^\mu)_1(\beta\gamma_\mu)_2\,\delta^3(\boldsymbol{r}_1 - \boldsymbol{r}_2) \\
&+ \frac{g_A^2}{16\pi f_\pi^2}\,\vec{\tau}_1 \cdot \vec{\tau}_2\,(\boldsymbol{\Sigma}_1 \cdot \boldsymbol{\nabla})(\boldsymbol{\Sigma}_2 \cdot \boldsymbol{\nabla})\frac{e^{-m_\pi|\boldsymbol{r}_1 - \boldsymbol{r}_2|}}{|\boldsymbol{r}_1 - \boldsymbol{r}_2|} \\
&+ g_0'(\rho)\,\vec{\tau}_1 \cdot \vec{\tau}_2\,(\beta\boldsymbol{\Sigma})_1 \cdot (\beta\boldsymbol{\Sigma})_2\,\delta^3(\boldsymbol{r}_1 - \boldsymbol{r}_2)\,.
\end{aligned}
$$

Short-distance spin-isospin dynamics is encoded in the zero range Landau-Migdal term $g_0'(k_F)$ that has been calculated using in-medium chiral perturbation theory in a recent detailed study of the role of $2\pi$-exchange in the interaction of quasi-nucleons at the Fermi surface $|\vec{p}_1| = |\vec{p}_2| = k_F$ [3]. This calculation includes contributions from $1\pi$-exchange, iterated $1\pi$-exchange and $2\pi$-exchange with virtual $\Delta(1232)$-isobar excitations. In Fig. 1 we plot $g_0'$ as a function of the Fermi momentum in comparison with some theoretical estimates around nuclear matter saturation density.

Fig. 2 shows $J^\pi = 0^+$ and $J^\pi = 1^+$ strength distributions for doubly closed-shell nuclei. The experimental positions (denoted by arrows) are evaluated with respect to the parent nucleus. The agreement between theoretical estimates and experimental data is indeed very good.

In conclusion we have shown that the relativistic nuclear energy functional introduced in Ref. [1] can be properly generalized to include spin and isospin excitations. IAS and GTR resonances are successfully reproduced for magic and open shell nuclei [4].
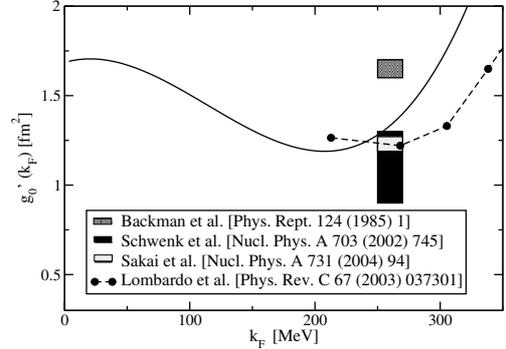


Fig. 1: The isotropic (dimensionfull) Landau parameter $g_0'(k_F)$ as a function of the Fermi momentum $k_F$ (black line) in comparison with some theoretical estimates around nuclear matter saturation density $k_F = 260$ MeV. See Ref. [3] for more details.
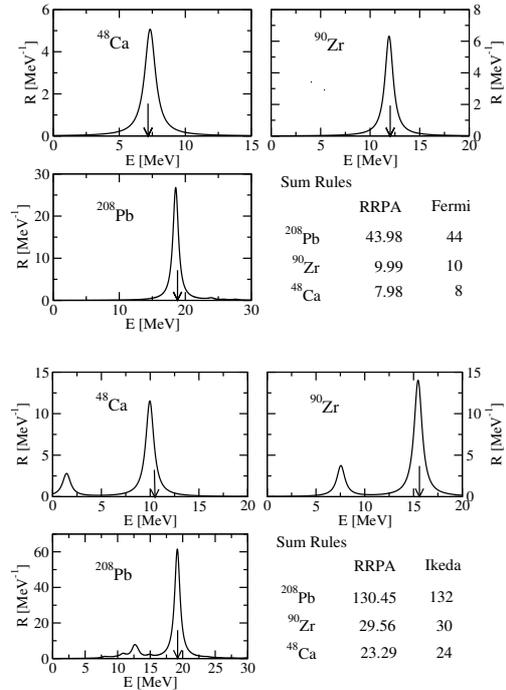


Fig. 2: Isovector $J^\pi = 0^+$ (IAR, upper figure) and $J^\pi = 1^+$ (GTR, lower figure) strength distributions for $^{48}$Ca, $^{90}$Zr and $^{208}$Pb. The experimental positions of the GTR are denoted by arrows. In the lower right panels the total sums of the IAS and GTR are compared to the model independent sum rule predictions.

## References

[1] P. Finelli, N. Kaiser, D. Vretenar and W. Weise, Nucl. Phys. **A770** (2006) 1; and references therein.
[2] N. Kaiser, S. Fritsch and W. Weise, Nucl. Phys. **A750** (2005) 259; and references therein
[3] N. Kaiser, Nucl. Phys. **A768** (2006) 99
[4] P. Finelli, N. Kaiser, D. Vretenar and W. Weise, [nucl-th/0612026]

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