# Pairing and symmetry energy effects in low density nuclear matter: nuclear structure and neutron stars

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# Collective patterns and effective interaction terms

- **Collective phenomena** and **correlations** in nuclear many-body systems
  - **Superfluidity** in neutron stars: **pairing** effect on heat capacity (**cooling**)
    **Collaboration with theoretical group of LPC of Caen, France**
  - **Dipole excitations** in nuclei: **Giant/Pygmy Dipole Resonances (GDR/PDR)**
    **Collaboration with theoretical group of IPN of Orsay, France**
- **Isovector** term of **effective interaction**: **symmetry energy** in EoS

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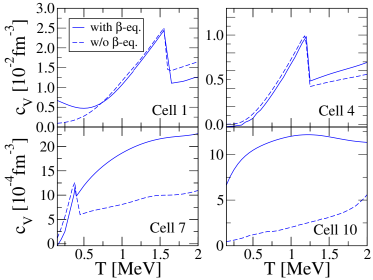


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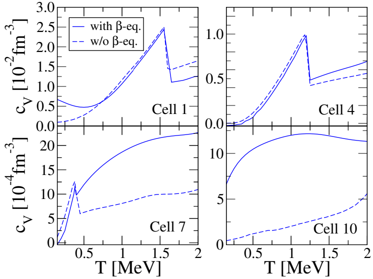


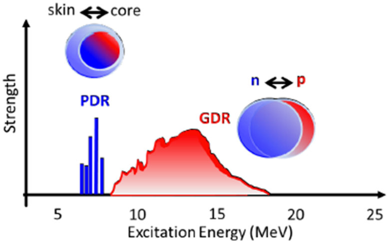


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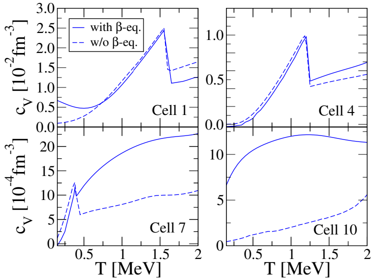


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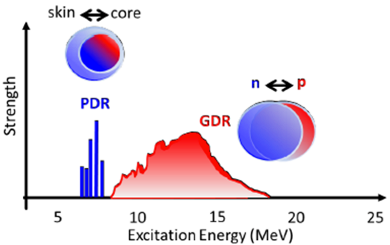

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  $\Rightarrow$ no **explicitly** surface terms ($C_\nabla = D_\nabla = 0$) to reproduce **experimental** values ($\sqrt{\langle r_p^2 \rangle}$, B/A)
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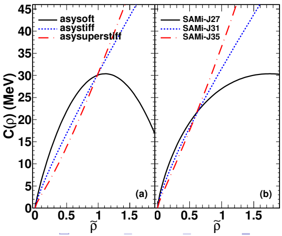

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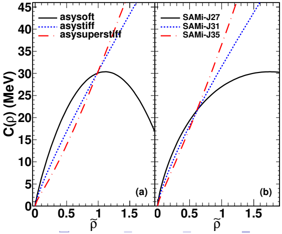


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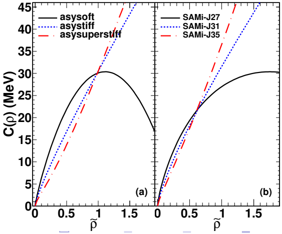

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- Instantaneous **ground-state perturbation**:

$$\hat{V}_K^{ext}(\mathbf{r},t) = \eta_K \delta(t-t_0)\hat{D}_K(\mathbf{r}) \qquad K = S, V$$

$$\Rightarrow |\Phi_0\rangle \rightarrow |\Phi_K(t_0)\rangle = e^{i\eta_K \hat{D}_K}|\Phi_0\rangle$$

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$$\hat{D}_S = \sum_i \left( r_i^2 - \frac{5}{3} < r^2 > \right) z_i, \qquad \hat{D}_V = \sum_i \tau_i \frac{N}{A} z_i - (1-\tau_i)\frac{Z}{A} z_i, \quad \tau_i = 0\,(1) \quad \text{for n (p)}$$

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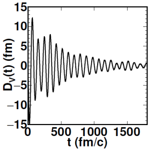

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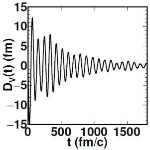


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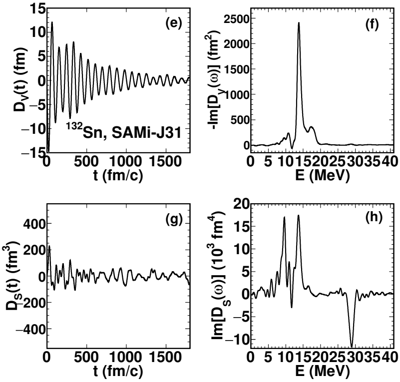


**IV perturbation** → **IV + IS response**

- **IV response**:
  - main **IV GDR** peak
  - smaller IV peak at higher E
  - some strength at lower E (**PDR**)
- **IS response**:
  - larger PDR strength ⇒ **isoscalar-like**
  - peak at higher E (**IS GDR**)

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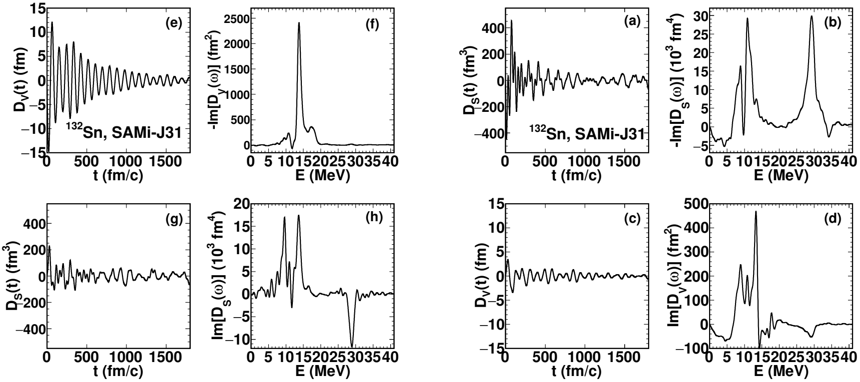


**IV perturbation $\rightarrow$ IV + IS response**     **IS perturbation $\rightarrow$ IS + IV response**

# Results (2): influence of IV term of the interaction

- **Three regions of A**: $^{68}$**Ni** $(N/Z = 1.43)$, $^{132}$**Sn** $(N/Z = 1.64)$, $^{208}$**Pb** $(N/Z = 1.54)$

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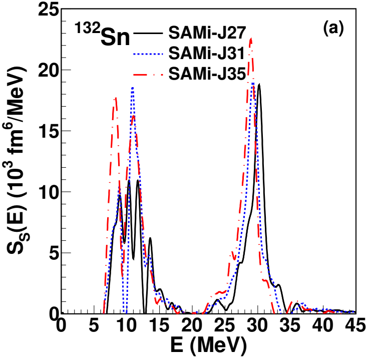


- **Two peaks** in PDR region

  [see M. Urban, PRC85, (2012)]

- Semi-classical treatment for **surface**

  ⇒ **discrepancy** with **RPA**

- Larger **L** ⇒ higher IV PDR peak (**mixing**)

- Larger **L** ⇒ larger **neutron-skin**

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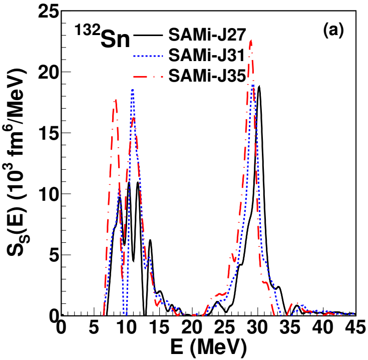
  [H. Zheng et al., arXiV:1603.03594, (2016)]

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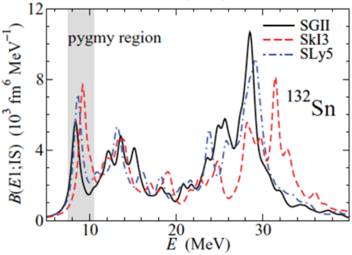


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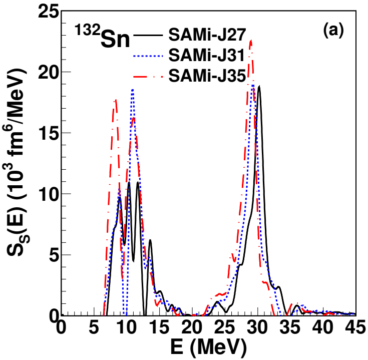


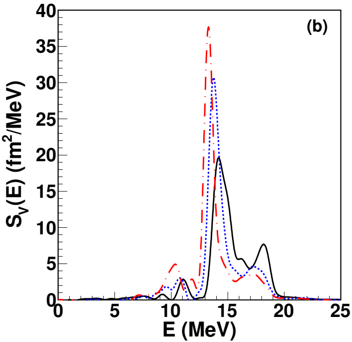


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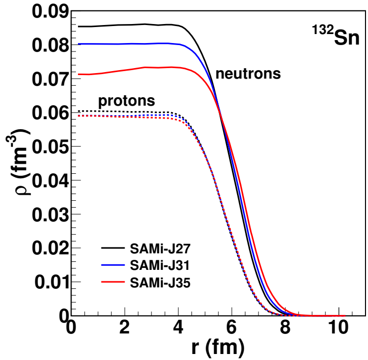


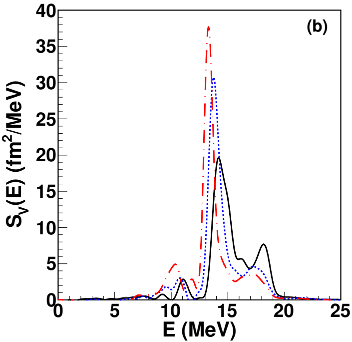


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- **Transition densities**: information on spatial structure of excitation dynamics

$$\delta\rho_q(r,E) \propto \int_{t_0}^{\infty} dt\, \delta\rho_q(r,t)\, \sin\frac{Et}{\hbar} \qquad E \equiv \text{energy with a peak in the strength}$$

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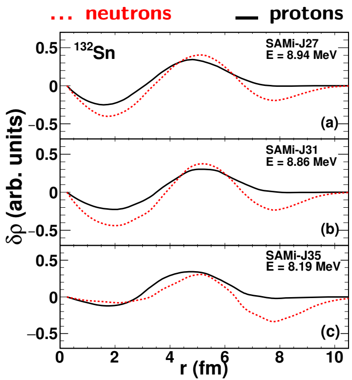


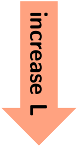


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- Amplitude in the surface increases while increasing **L**
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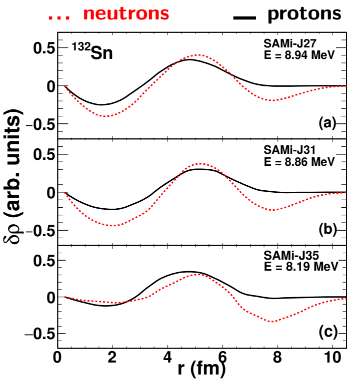


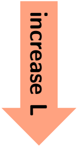


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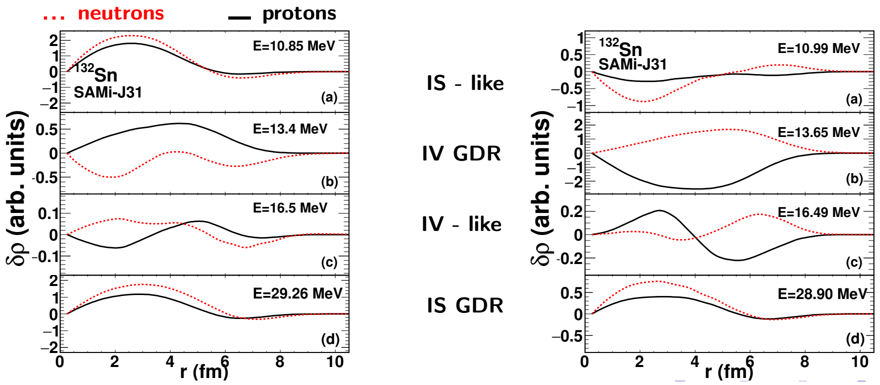

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- **TDHF** [D. Lacroix, G. Scamps] calculations: **PRELIMINARY RESULTS**
- Difference in the **initial density profile**: **sharper** in TDHF case
- **Overestimation** of PDR energy and **merging** of IS-L peak with GDR
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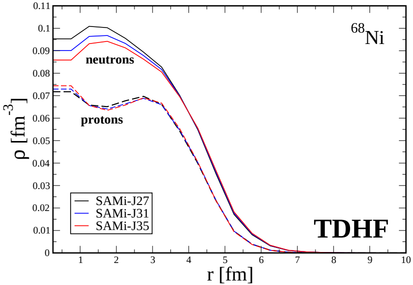


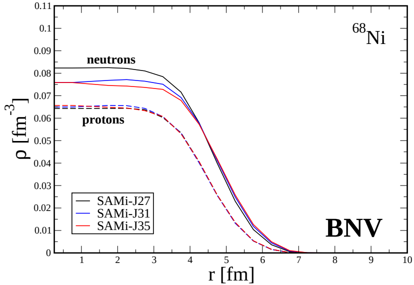

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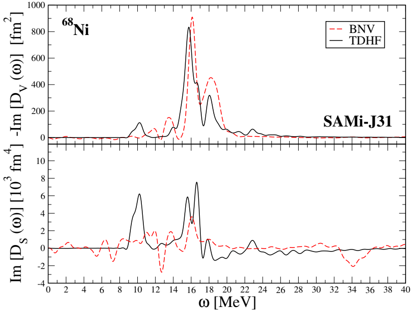

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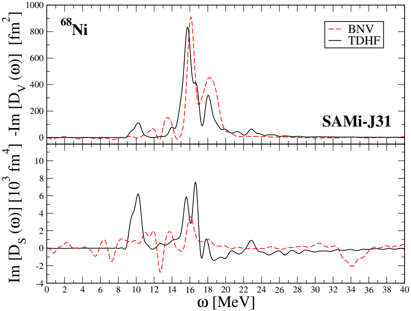


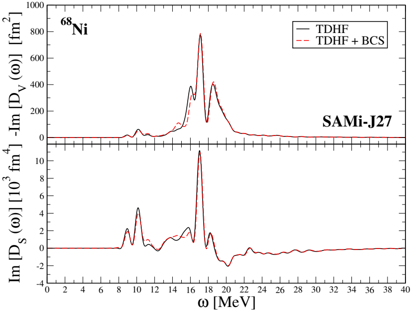

# Final remarks and conclusions

## Summary

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## Further developments and outlooks

- Tuning of finite size terms to improve the **treatment of surface** effects
- Comparison with **TDHF calculations** (coll. with D. Lacroix group, Orsay)
- Study some **isotopes chains** to understand **isovector** and **pairing** terms role

# French collaborations of our group

## Nuclear structure (TDHF)

**D. Lacroix** (IPN, IN2P3-CNRS, Orsay, France),

**G. Scamps** (Department of Physics, Tohoku University, Japan)

## Neutron stars modelization

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**A. Raduta** (NIPNE, Bucharest-Magurele, Romania)

## Multifragmentation reactions

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THANK YOU FOR YOUR KIND ATTENTION!

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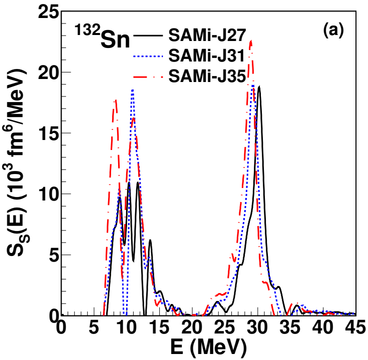


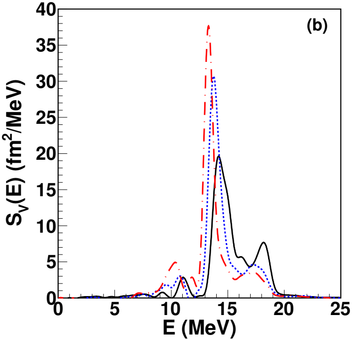


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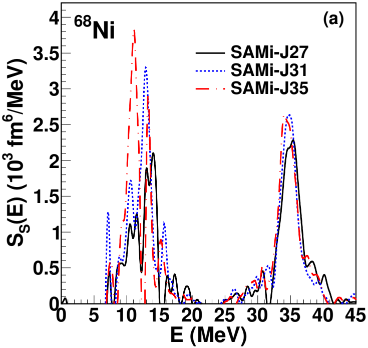


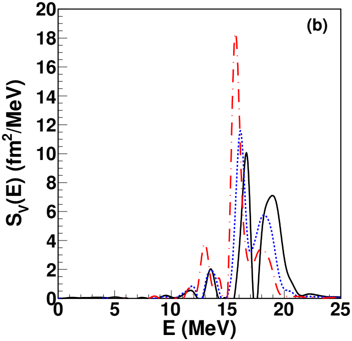


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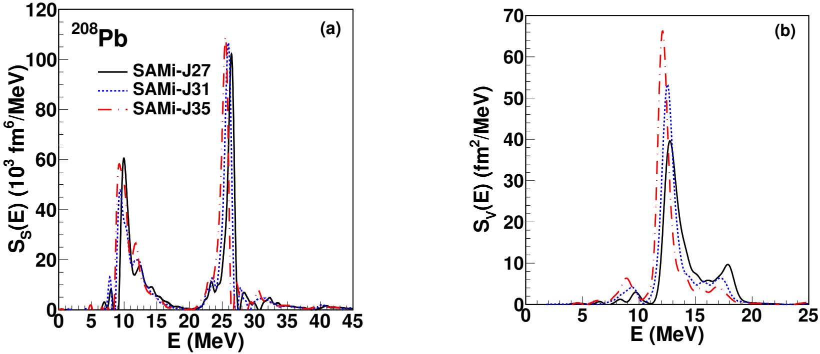


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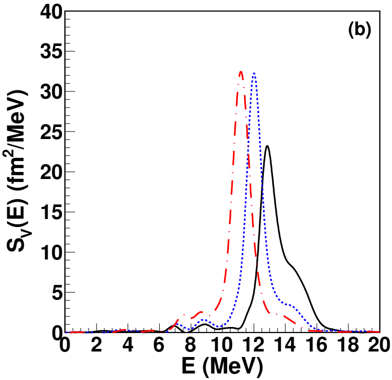


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