SELF-CONSISTENT CONTINUUM RANDOM PHASE APPROXIMATION CALCULATIONS

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Facilities:

EUROPE

SPES, LNL - 2015

SPIRAL2, Caen -2015

FAIR,GSI $<$2020

ISOLDE, CERN - operating

HIE-ISOLDE,CERN $<$2020

EURISOL - 2020

JAPAN

RIBF, RIKEN - operating

AMERICA

HRIBF, Oak Ridge National Laboratory- operating

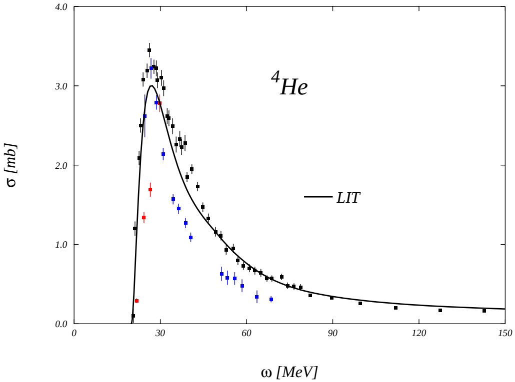
FRIB, Michigan State University $<$2020

RIBRAS, São Paulo Pelletron Laboratory- operating

Aim:

How can we give predictions about ground and excited states of unstable nuclei?

Microscopic calculation: Helium



Data:
T. Shima et al., Phys. Rev. C 72 (2005) 044004
B. Nilsson et al., Phys. Lett. B 626 (2005) 65;Yu. M. Arkatov et al. Yad. Konst. 4 (1979) 55.

LIT: D. Gazit at al., Phys. Rev. Lett. 96 (2006) 112301; G. Orlandini, priv. comm.

Effective theory

$$H|\Psi >= E|\Psi > \qquad H^{\rm eff}|\Psi^{\rm eff} >= E|\Psi^{\rm eff} >$$

Random Phase Approximation

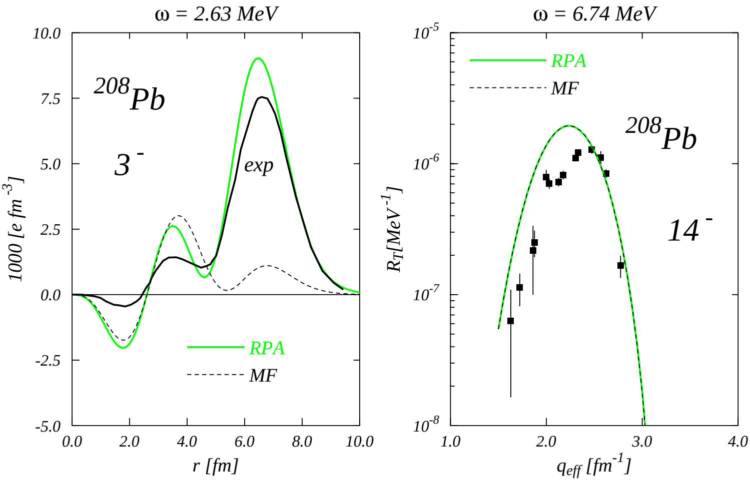
$$|\nu >= Q_\nu^\dagger |0> \qquad Q_\nu |0 >= 0$$

$$Q_\nu^\dagger = \sum_{ph} X_{ph} a_p^\dagger a_h - \sum_{ph} Y_{ph} a_h^\dagger a_p$$

$$\begin{aligned}
(\epsilon_p - \epsilon_h - \omega) X_{ph} + \sum_{p'h'} [v_{ph,p'h'} X_{p'h'} + u_{ph,p'h'} Y_{p'h'}] &= 0 \\
(\epsilon_p - \epsilon_h + \omega) Y_{ph} + \sum_{p'h'} [u^*_{ph,p'h'} X_{p'h'} + v^*_{ph,p'h'} Y_{p'h'}] &= 0
\end{aligned}$$

$$\begin{aligned}
v_{ph,p'h'} &= < ph' | V | hp' > - < ph' | V | p'h > \\
u_{ph,p'h'} &= < pp' | V | hh' > - < pp' | V | h'h >
\end{aligned}$$

MF and RPA


ω = 2.63 MeV
^{208}Pb
3 -
exp
RPA
MF
1000 [e fm -3]
r [fm]
ω = 6.74 MeV
RPA
MF
^{208}Pb
14 -
R_T[MeV -1]
q_{eff} [fm -1]

RPA calculations

Input

Single particle wavefunctions
Single particle energies
Effective nucleon-nucleon interaction

Phenomenological RPA calculations

Input

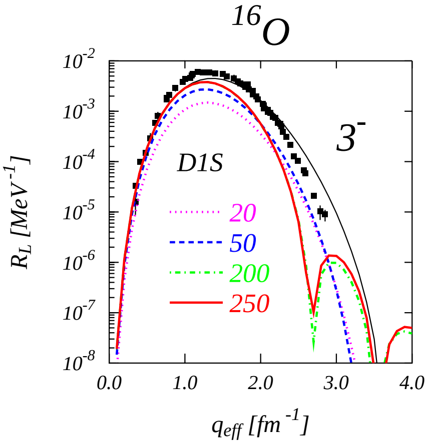
Single particle wavefunctions from Woods-Saxon potentials
Experimental single particle energies (when available)
Effective nucleon-nucleon interaction chosen to reproduce some empirical quantity.

The input changes for each nucleus.

Input

Single particle basis taken from Hartree Fock (HF) calculations
The same interaction is used in HF and RPA

A unique interaction for all the nuclei



$\epsilon_{ph}^{\max}$ [MeV]	ω [MeV]
20.0	9.11
50.0	8.55
200.0	7.87
250.0	7.85
exp	6.13

Data: R. Buti et al., Phys. Rev. C 33 (1986) 755

Continuum Random Phase Approximation

$$Q_\nu^\dagger = \sum_{ph,\epsilon_p<0} X_{ph}(\epsilon_p) a_p^\dagger a_h - \sum_{ph,\epsilon_p<0} Y_{ph}(\epsilon_p) a_h^\dagger a_p$$

$$+ \sum_{[p]h} \int d\epsilon_p X_{ph}(\epsilon_p) a_p^\dagger a_h - \sum_{[p]h} \int d\epsilon_p Y_{ph}(\epsilon_p) a_h^\dagger a_p$$

problem: integration to infinity

Continuum Random Phase Approximation

new unknowns

$$f_{[p],h}(r) = \sum_{\epsilon_p=\epsilon_F}^{0} X_{ph}(\epsilon_p) R_p(r,\epsilon_p) + \int d\epsilon_p X_{ph}(\epsilon_p) R_p(r,\epsilon_p)$$

$$g_{[p],h}(r) = \sum_{\epsilon_p=\epsilon_F}^{0} Y_{ph}(\epsilon_p) R_p(r,\epsilon_p) + \int d\epsilon_p Y_{ph}(\epsilon_p) R_p(r,\epsilon_p)$$

system of integro differential equations

Sturmian functions

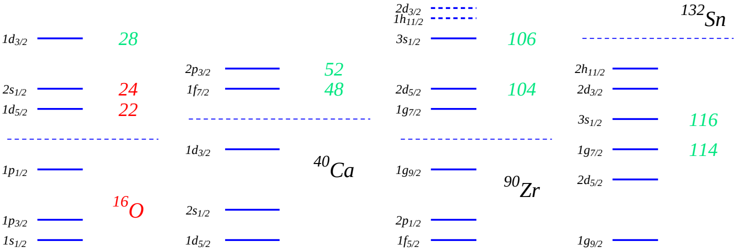
$$\Phi_p^\mu(r \to \infty) \to \lambda H_p^-(\epsilon_p, r) \qquad se\ \epsilon_p > 0$$

$$\Phi_p^\mu(r \to \infty) \to \chi \frac{1}{r} exp\left(-r\left(\frac{2m|\epsilon_p|}{\hbar^2}\right)^{\frac{1}{2}}\right) \qquad se\ \epsilon_p < 0$$

expansion of f and g on **STURM-BESSEL** function basis
⇒algebraic system with expansion coefficient unknowns

M.Buballa, S. Drożdż, S. Krewald, J.Speth, Ann. of Phys. 208 (1991) 346.

Isotope Chains



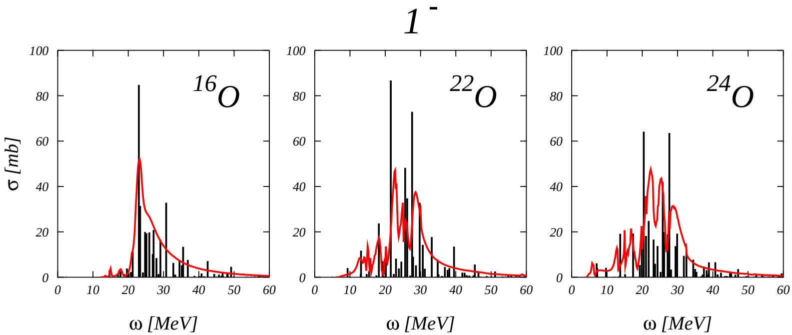
Nucleon-Nucleon Interaction

- Gogny-like interaction
- finite range
- zero-range Spin-Orbit term
- zero-range Density dependent term
- 14 parameters chosen with a fit of about 2000 nuclear binding energies and 700 charge radii.

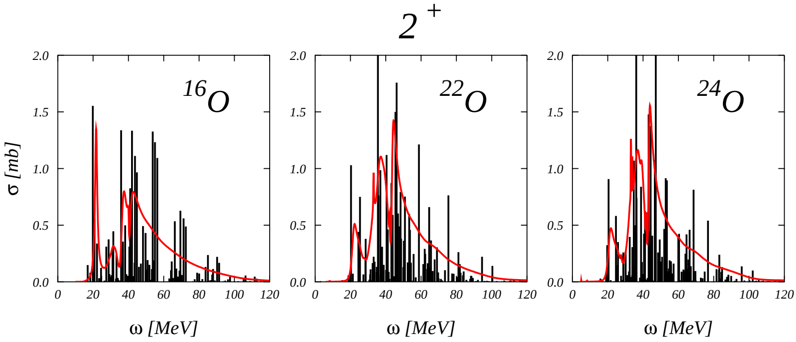
Two parametrizations

-D1S: J. F. Berger et al., Comp. Phys. Comm. 63 (1991) 365
-D1M: S. Goriely et al,: Phys. Rev. Lett. 102 (2009) 252501

Continuum versus Discrete RPA: 1^- Oxygen chain



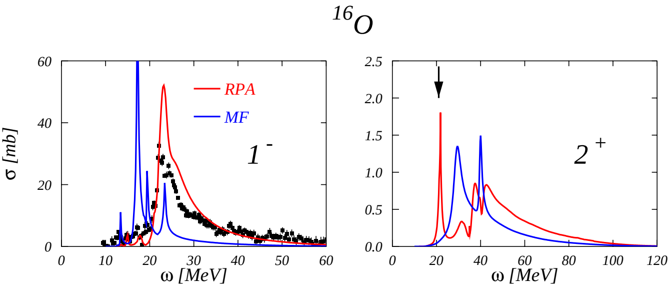
Continuum versus Discrete RPA: 2^+ Oxygen chain



Centroid energies in MeV

	discrete	continuum
1^-		
^{16}O	28.27	28.58
^{22}O	27.34	27.43
^{24}O	26.08	26.18
2^+		
^{16}O	67.99	45.45
^{22}O	68.77	44.87
^{24}O	67.54	44.21

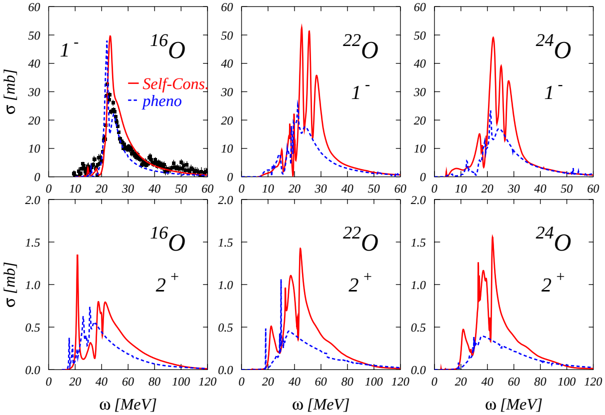
RPA versus MF



1^- data: J. Ahrens et al., Nucl. Phys. A 251 (1975) 479.

2^+ data: K. T. Knöpfke et al., Phys. Rev. Lett. 35 (1975) 779

Self consistent versus Phenomenological approach: Oxygen chain



1^- data: J. Ahrens et al., Nucl. Phys. A 251 (1975) 479.

2^+ data: K. T. Knöpfke et al., Phys. Rev. Lett. 35 (1975) 779

Conclusions

1. Our continuum RPA technique allows us to do calculations with interactions with finite range and tensor channel.
2. The D1S and D1M forces produce very similar results.
3. Comparison with MF calculations: MF does not predict the presence of giant resonances.
4. Comparison with discrete RPA: need of a correct treatment of the continuum in self-consistent calculations.
5. Comparison with phenomenological CRPA: inadequacy of the phenomenological approach in the study of nuclei lying in experimentally unexplored parts of the nuclear isotope chart.

Conclusions

1. Self-consistent CRPA calculations describe rather well the experimental positions of the giant resonances peaks, both for the 1^- and 2^+ excitations.
2. On the other hand, the strengths distibutions are incorrect, and the problem could be solved by considering the excitation of two particles-two holes pairs.