Pygmy resonances in the mirror

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Pygmy Dipole Resonance
- Electric dipole transition strength on the lower-energy tail of the giant dipole resonance

Origin and implications
- Isospin asymmetry? Neutron/proton skin? Shell structure? Deformation? Clustering?
- Symmetry energy and capture reactions

This work
- Compare a chain of loosely bound isotones (N=20) to their stable mirrors (Ca isotopes)
- The absolute asymmetry is the same; the pygmy resonance is not.

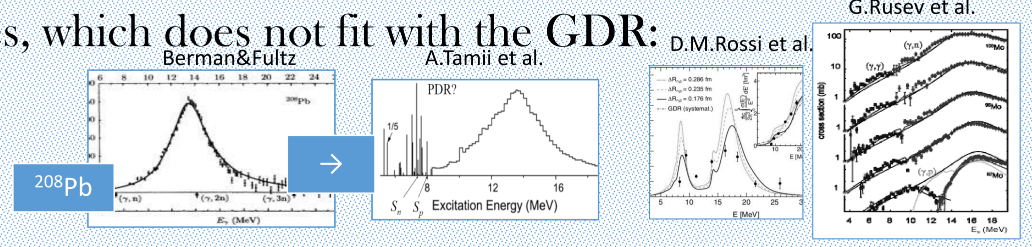
Conclusion
- Coulomb field → loose binding: hugely important
- Prediction for a coherent proton-pygmy resonance in ^{46}Fe - and ^{44}Cr?

*... and further explorations of symmetry energy and effective mass under way – with KIDS**

**See talk*

What is called a pygmy dipole resonance?

- When the photonic field acts on the atomic nucleus, the giant dipole resonance (GDR) is strongly exited. In many heavy nuclei it has a smooth shape, which can be described by one or two Lorenzian curves.
- Depending on the nucleus, there is often excess transition strength at lower energies, which does not fit with the GDR:



- That excess strength may or may not appear as a clean resonance peak. But it is customarily called a pygmy dipole resonance (PDR) until further notice.

What is it then?

- The PDR is observed in asymmetric nuclei (N>Z). Asymmetry must play a role - but how?
- An exotic mechanism proposed early on is the neutron-skin mode: An asymmetric nucleus develops a neutron skin; that skin can oscillate against the isospin-symmetric core.
- It can be an unglamorous shell effect: Single-particle transitions across one ħω shell that "failed" to join the GDR.
- Or both in some degree or other – or something else yet.

Why do we care?

- If there is a vibrational mechanism involved (neutron-skin oscillation?), there must be a restoring force, plausibly related to the symmetry energy. We want to know that - for nuclear structure and astrophysical modeling.
- The PDR is typically observed in the vicinity of the particle emission threshold. Resonances near a threshold can influence capture reaction rates drastically. We must factor them in when simulating nucleosynthesis paths.
- As a shell effect it can unlock information on nuclear structure.

What are the issues?

- Where to begin. Is it in fact vibrational? Enhanced in r-process nuclei? What is the role of asymmetry? What is the role of deformation? ...
- ... Model validation: What is the role of the continuum? What is the role of phonon coupling? Of clustering?
- The PDR is likely of mixed isospin: it responds (partly?) to isoscalar probes. Then what is the role of the collective isoscalar mode ("IS-LED"), in the same energy region, which has nothing to do with asymmetry and skins?
- There is more than the PDR at the bottom of the GDR curve... [PP, EXON2016]

- If asymmetry plays a role, what about *absolute* asymmetry? Is N>Z the same as Z<N? Why not?

Present work: mirror (a)symmetry

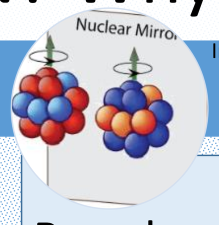


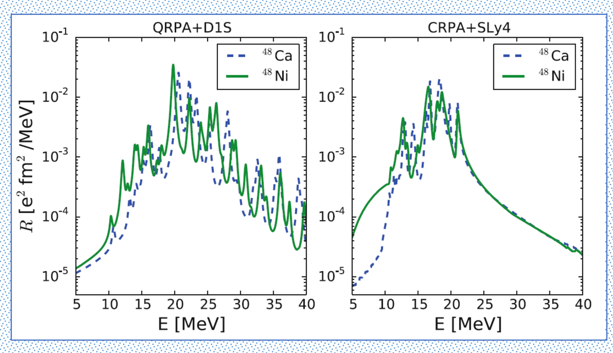
Image:Univ.York

Let us look in the mirror then: N=20 *vs* Z=20

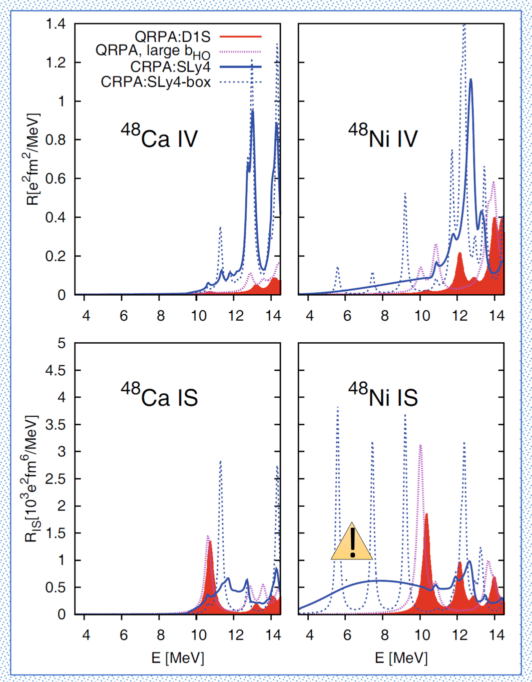
Ni-48 *vs* Ca-48

- Below, "CRPA" means a complete treatment of particle states, i.e., continuum; while in "QRPA" a harmonic-oscillator basis is used.

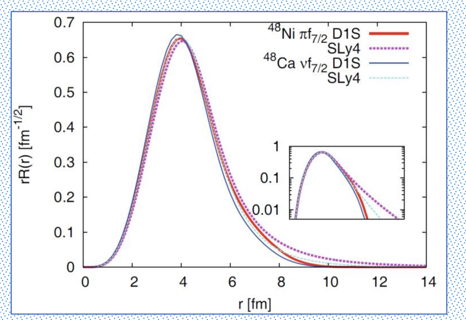
Huge effect of continuum!



And huge difference between mirrors! But why?



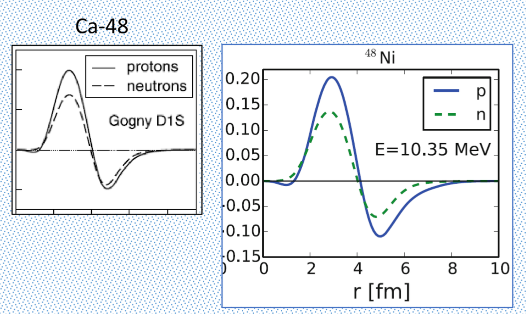
- Clues: the least bound occupied state, $f_{7/2}$



and proton skin thickness in Ni-48 vs neutron skin thickness in Ca-48: 0.25 vs 0.15 fm

Whatever happened to isospin symmetry?

- The strong violation of symmetry shows the importance of the Coulomb field. Owing to the Coulomb repulsion there are very loosely bound protons in Ni-48. A small binding energy means a very extended wave function, hence the above results. The Coulomb barrier is no remedy.



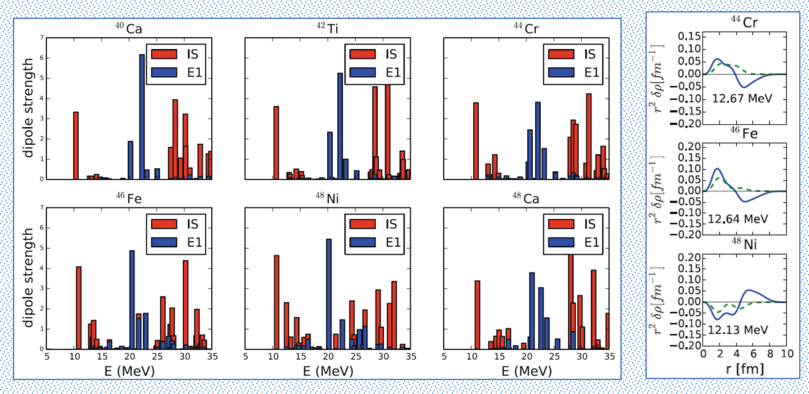
What seems to be rather symmetric is the collective isoscalar state, IS-LED – see transition densities on the left. But it would be difficult to make out experimentally, being embedded in a continuum of mixed-isospin states.

All N=20, A=40-48 isotones (QRPA)

- Similar conlusions

  Fe-46, Ni-48: > 1% TRK

Any sign of coherence? Proton-skin mode?



- A microscopic analysis points to Fe-46 as a strong candidate for a coherent isovector state, i.e., a possible proton-skin oscillation; in Cr-44 also likely.

And what about the equation of state, the nucleon effective mass m*, etc?

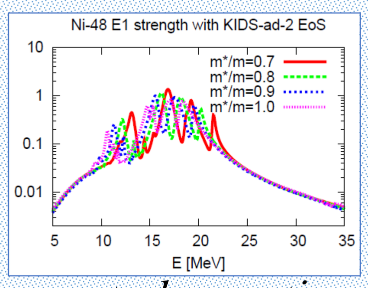
- Here are some more model results (left). The symmetry-energy slope parameter L may play a role; m* may have an effect insofar as it affects the Fermi energy and shell spacing; all else equal, the m* effect is like this: ↓

	$\int_{E<10} dB(E)$	$\int_{E<13} dB(E)$	$\frac{100 m_1^{low}}{m_1^{tot}}$	e_F
SLy4:^{48}Ni	0.242	1.241	1.01	−0.06
^{48}Ca	0.028	0.560	0.11	−9.05
BSk5:^{48}Ni	0.254	0.950	1.08	0.01
^{48}Ca	0.029	0.528	0.12	−9.03
SkI3:^{48}Ni	0.517	1.277	2.11	0.767
^{48}Ca	0.080	0.564	0.37	−7.96

L=46 MeV, m*/m=0.7

L=17 MeV, m*/m=0.8

L=101 MeV, m*/m=0.6



... to be continued

To conclude...

Based on:
Y. Kim and P.P., Eur. Phys. J A 52, 176 (2016).

Related reviews:
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- S.Krewald and J.Speth, Int. J. Mod. Phys. E 18, 1425 (2009)
- D. Savran et al., Prog. Part. Nucl. Phys. 70, 210 (2013)

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