Measurements of the isoscalar monopole response in the neutron-rich nucleus $^{68}\text{Ni}$

Introduction
Motivations
Setup : the active target MAYA
Results
Conclusion and outlook

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What are giant resonances?

<table>
<thead>
<tr>
<th>Electric GR</th>
<th>T = 0</th>
<th>T = 1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>isoscalar</td>
<td>isovectorial</td>
</tr>
<tr>
<td>$L = 0$</td>
<td><img src="image" alt="ISGMR" /></td>
<td><img src="image" alt="ISGMR" /></td>
</tr>
<tr>
<td>monopole (GMR)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$L = 1$</td>
<td><img src="image" alt="ISGMR" /></td>
<td><img src="image" alt="ISGMR" /></td>
</tr>
<tr>
<td>dipole (GDR)</td>
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<td></td>
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<tr>
<td>$L = 2$</td>
<td><img src="image" alt="ISGMR" /></td>
<td><img src="image" alt="ISGMR" /></td>
</tr>
<tr>
<td>quadrupole (GQR)</td>
<td></td>
<td></td>
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</table>
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Motivations Nuclear matter incompressibility and ISGMR

Asymmetry
\[ \delta = (N-Z)/A \]

Microscopic calculation

- Centroid of the ISGMR \( E_{\text{ISGMR}} \)
  \[ E_{\text{ISGMR}} = \sqrt{\frac{\hbar^2 K_A}{m \langle r^2 \rangle}} \]

- Determination of the compression modulus of the nucleus \( K_A \)
- Liquid drop development
- Determination of the nuclear matter incompressibility \( K_\infty \)

Status

\( K_\infty \) has been constrained for symmetric and asymmetric matter. To gain a better knowledge of \( K_\infty \), we need studies along isotopic chains, including exotic nuclei.

Motivations  Nuclear matter incompressibility and ISGMR

In supernovae bounce

Density profile at bounce

- $K_\infty = 180$ MeV
- $K_\infty = 220$ MeV
- $K_\infty = 375$ MeV

In neutron stars

Gravitational Mass $M_G [M_\odot]$ vs Radius $R [\text{km}]$

- J1614-2230
- TM1
- TMA
- FSUgold
- NL3
- DD2
- LS180
- LS220
- STOS
- Steiner et al.

A. Fantina PhD (2010) IPNO-IAA

M. Hempel ITP Franckfurt
Motivations Nuclear matter incompressibility and ISGMR

Does ISGMR really related to $K_\infty$?

- $K_\infty = 220 \text{ MeV} \pm 30 \text{ MeV}$
- No single functional to reproduce $K_\infty$ calculated from $E^{*}_{\text{GMR}}(\text{Pb})$ and $K_\infty$ calculated from $E^{*}_{\text{GMR}}(\text{Sn})$
- $K_\infty \leftrightarrow$ asymmetry $\delta = (N-Z)/A$

- Surface: 2/3 of nucleons in $^{208}\text{Pb}$
- Saturation density area may not be the most probed

$E^{*}_{\text{GMR}}$ provides $K(\rho)$ and not $K_\infty$

Need measurement of $E^{*}_{\text{GMR}}$ along isotopic

Motivations  Prediction of a soft monopole mode

Prediction of the monopole strength in Ni isotopic  

\[ \text{Prediction of a low energy mode} \]

\[ \text{RQRPA} \]

\[ \text{Soft GMR} \]

\[ \text{E. Khan, N. Paar and D. Vretenar, Phys. Rev. C 84, 051301 (2011)} \]
Motivations Prediction of a soft monopole mode

Prediction of the monopole strength in Ni isotopic

Prediction of a low energy mode

RPA with exact treatment of continuum

Motivations Status of the GR measurement in unstable nuclei

- Understand these excitation modes from stable to exotic nuclei: the IVGDR/PDR has been measured in $^{68}\text{Ni}$, neutron rich Oxygen and Tin isotopes at GSI, in $^{26}\text{Ne}$ at Riken...
- 1st measurement of the ISGMR and ISGQR in unstable nuclei $^{56}\text{Ni}:^{56}\text{Ni}(d,d')^{56}\text{Ni}^*$
  

Study of the ISGMR and ISGQR in a neutron rich Ni: $^{68}\text{Ni}$

Continue the study of the Ni isotopic chain

Study of the ISGMR and ISGQR using inelastic scattering $^{68}\text{Ni}(\alpha,\alpha')^{68}\text{Ni}^*$ and $^{68}\text{Ni}(d,d')^{68}\text{Ni}^*$

Experiment at GANIL
Measurements of the isoscalar monopole response in the neutron-rich nucleus $^{68}\text{Ni}$
We have to consider:
- Inverse kinematics with a low recoiling energy
- Low production rate

Use of an Active Target:
- low detection threshold
- thick target

Study of the ISGMR and in ISGQR using inelastic scattering $^{68}\text{Ni}(\alpha,\alpha')^{68}\text{Ni}^*$ and $^{68}\text{Ni}(d,d')^{68}\text{Ni}^*$

Challenge:
Measurement at small angles and low energies
Setup: the active target MAYA Principle

The active target MAYA

1. The scattered deuteron or \( \alpha \) ionizes the gas
2. The electrons drift towards the Frisch grid
3. Amplification on the wires
4. Signal on each pad proportionnally to the amount of electrons collected on the wire above

Which information are stored?
- Time on each wire
- Charge induced on each pad

The experiment was performed on LISE beam line
Production of $^{68}\text{Ni}$ beam from fragmentation of $^{70}\text{Zn}$

Production of $^{68}\text{Ni}$ at 50 A.MeV

Intensity: $10^4$ pps

Purity: 75%

Experimental setup

$^{68}\text{Ni}$ 50MeV/A
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Results Tracking reconstruction

T. Roger et al., Nucl. Instrum. Meth. 638, 134 (2011)
Results Efficiency

- Geometric efficiency using ACTARSim code (based on Geant4 and ROOT)
- Each simulated event is reconstructed with the code for physical events

Geometric and reconstruction efficiency

![Efficiency plots](image)

\[ ^{68}\text{Ni}(\alpha,\alpha')^{68}\text{Ni}^* \]

\[ ^{68}\text{Ni}(d,d')^{68}\text{Ni}^* \]
Results $^{68}\text{Ni}(\alpha,\alpha')^{68}\text{Ni}^*$ Excitation energy spectra

Results $^{68}$Ni(α,α$'$)$^{68}$Ni* Excitation energy spectra

<table>
<thead>
<tr>
<th></th>
<th>Centroid (MeV)</th>
<th>FWHM (MeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resonance 1</td>
<td>12.9±1.0</td>
<td>1.2±0.4</td>
</tr>
<tr>
<td>Resonance 2</td>
<td>15.9±1.3</td>
<td>2.3±1.0</td>
</tr>
<tr>
<td>Resonance 3</td>
<td>21.1±1.9</td>
<td>1.3±1.0</td>
</tr>
</tbody>
</table>
Results $^{68}\text{Ni}(\alpha,\alpha')^{68}\text{Ni}^*$ Angular distribution

Results $^{68}\text{Ni}(\alpha,\alpha')^{68}\text{Ni}^*$ Multipole Decomposition Analysis

\[
\frac{d\sigma}{d\Omega}_{\text{exp}}(\theta_{CM}, E^*) = \sum_{L=0}^{2} S_L(E^*) \left. \frac{d\sigma_L}{d\Omega} \right|_{\text{theo}}(\theta_{CM}) + \left. \frac{d\sigma_{\text{fond}}}{d\Omega} \right|_{\text{theo}}(\theta_{CM})
\]

Results $^{68}\text{Ni}(\alpha,\alpha')^{68}\text{Ni}^*$ Multipole Decomposition Analysis

\[
\frac{d\sigma}{d\Omega}_{\text{exp}}(\theta_{CM}, E^*) = \sum_{L=0}^{2} S_L(E^*) \frac{d\sigma_L}{d\Omega}_{\text{theo}}(\theta_{CM}) + \frac{d\sigma_{\text{fond}}}{d\Omega}(\theta_{CM})
\]

Résultats

- **L = 0**: fragmentation of the ISGMR with a shoulder at 21 MeV
  - increase of the strength at 13 MeV
- **L = 1**: increase of the strength at 21 MeV and below 15 MeV
- **L = 2**: concentration of the strength around 16 MeV
- From 23 MeV other multipolarities…

Results $^{68}\text{Ni}(d,d')^{68}\text{Ni}^*$

### Fitting method

### Multipole Decomposition Analysis (MDA)

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<th>Resonance</th>
<th>Centroid (MeV)</th>
<th>FWHM (MeV)</th>
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<tbody>
<tr>
<td>Resonance 1</td>
<td>12.7±0.3</td>
<td>2.2±0.5</td>
</tr>
<tr>
<td>Resonance 2</td>
<td>16.5±2.0</td>
<td>4.3±2.6</td>
</tr>
<tr>
<td>Resonance 3</td>
<td>20.9±1.0</td>
<td>4.4±0.5</td>
</tr>
</tbody>
</table>

Results Synthesis

**Soft ISGMR**

*Mixed with ISGDR*
- $12.9 \pm 1.0$ MeV in $(\alpha,\alpha')$
- $12.7 \pm 0.3$ MeV in $(d,d')$

**ISGQR**
- $15.7 \pm 1.0$ MeV in $(\alpha,\alpha')$
- $16.5 \pm 2.0$ MeV in $(d,d')$

**ISGMR**

*Fragmented strength with a shoulder at:*
- $21.1 \pm 1.9$ MeV in $(\alpha,\alpha')$
- $20.9 \pm 1.0$ MeV in $(d,d')$
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Conclusion and outlook

- First measurement of the isoscalar giant resonances in neutron-rich nucleus ($^{68}$Ni)
  $^{68}$Ni($\alpha$,$\alpha$)$^{68}$Ni* and $^{68}$Ni(d,d)$^{68}$Ni
  ➔ Indication new modes
  ➔ Active targets suited for ISGR studies

- Some difficulties…
  ➔ Limited Resolution
  ➔ Analysis considering fragmentation of the strength
Conclusion and outlook

- New detection systems
  - Next generation of active target like ACTAR (T. Roger talk)

- Storage ring + gas-jet target + detector telescopes (N. Kalantar talk)

- Isoscalar monopole strength in heavier exotic nuclei (S. Ota talk)
Collaboration


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