Fine Structure Of The Isoscalar Giant Quadrupole Resonance And Fragmentation Of E2 Strengths in $^{28}\text{Si}$ And $^{27}\text{Al}$*

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Outline

- Fine structure of Giant Resonances
- High energy-resolution experiments with K600 Magnetic Spectrometer of iThemba LABS
- Extracted Energy Scales and Comparison in $^{28}\text{Si}$ and $^{27}\text{Al}$ using Wavelet Analysis techniques
- Summary
Fine Structure of Giant Resonances

Have been established as a Global phenomenon in
- nuclei across the periodic table
- other resonances

Dominant processes of the decay?

Spin- and parity-resolved level densities at high excitation energies?
Contribution to the width of giant resonances

\[ \Delta \Gamma = \Gamma_{\uparrow} + \Gamma_{\downarrow} \]

Direct decay
Pre-equilibrium and statistical decay

\[ \Gamma = \Delta \Gamma + \Gamma_{\uparrow} + \Gamma_{\downarrow} \]

Resonance width
Landau damping
Escape width
Spreading width

1p-1h
2p-2h
np-nh compound nucleus

GR

A_X

1h
A^{-1}_X

1p-2h

\Gamma_{\uparrow}

\Gamma_{\downarrow}
K600 magnetic spectrometer at 0°

Focal plane detectors:
2 multiwire drift chambers (U and X wireplanes)
2 plastic scintillators

(p,p') setup: \( B(D1)/B(D2) = 1.5 \)
(p,t) setup: \( B(D1)/B(D2) = 1 \)

<table>
<thead>
<tr>
<th>Matrix element/characteristic</th>
<th>Medium dispersion ( R = 1.00 )</th>
<th>High dispersion ( R = 1.49 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>((x</td>
<td>x))</td>
<td>(-0.52)</td>
</tr>
<tr>
<td>((\theta</td>
<td>\theta))</td>
<td>(-1.89)</td>
</tr>
<tr>
<td>((y</td>
<td>y))</td>
<td>(-5.45)</td>
</tr>
<tr>
<td>((\phi</td>
<td>\phi))</td>
<td>(-0.20)</td>
</tr>
<tr>
<td>(\frac{\Delta p}{p})</td>
<td>(-8.4,\text{cm/%})</td>
<td>(-10.9,\text{cm/%})</td>
</tr>
<tr>
<td>(p_{\text{max}}/p_{\text{min}})</td>
<td>1.097</td>
<td>1.048</td>
</tr>
</tbody>
</table>

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Fine structure of the ISGQR

Excitation energy spectra at angles corresponding to the maximum of the ISGQR in $^{28}\text{Si}$ and $^{27}\text{Al}$.

$^{28}\text{Si}(p,p')$ $E_p = 200 \text{ MeV}$, ISGQR

$\theta_{\text{Lab}} = 12^\circ$

$\Delta E = 38 \text{ keV}$
Wavelet Analysis

Wavelets:
\[ \int_{-\infty}^{\infty} \Psi(x) dx = 0 \]
\[ \int_{-\infty}^{\infty} |\Psi(x)|^2 dx < \infty \]

Wavelet coefficients:
\[ C(E_x, \delta E) = \frac{1}{\sqrt{\delta E}} \int \sigma(E) \Psi \left( \frac{E_x - E}{\delta E} \right) dE \]

- Position Scale
- Spectrum
- Wavelet

Morlet:
\[ \Psi(x) = \frac{1}{\pi^{1/4}} \cos(ikx) \exp\left( -\frac{x^2}{2} \right) \]

Complex Morlet:
\[ \Psi(x) = \frac{1}{\sqrt{\pi f_b}} \exp(2\pi if_c) \exp\left( -\frac{x^2}{f_b} \right) \]

Complex Lorentzian:
\[ \Psi(x) = \sum_{n=-8}^{8} \frac{(\Gamma/2)^2}{(x - (x_o + nf_c))^2 + (\Gamma/2)^2} \exp\left( -\frac{x^2}{2f_b} \right) \]
Characteristic Energy Scales in $^{28}\text{Si}$

Power Spectra

Wavelet Coefficient
Comparison with theoretical calculations

- To understand the origin and physical nature of different scales, comparison of experimental results with model calculations is important.

- Such models include
  - Quasi-particle Phonon Model (QPM)
  - Random Phase Approximation (RPA)
  - Second-RPA (SRPA)
What is the origin of scales in $^{40}\text{Ca}$?

The RPA model accounts for Landau damping, which plays an important role in the case of $^{40}\text{Ca}$. 
Experimental and Theoretical Energy Scales
Semblance and Dot Product Analysis

- **Wavelet based semblance** $S$
  \[ S = \cos^n(\theta) \]
  \[ \theta = \tan^{-1}\left( \frac{I(CWT_{1,2})}{R(CWT_{1,2})} \right) \]

- **Cross-wavelet transform** $CWT_{1,2}$
  \[ CWT_{1,2} = CWT_1 \cdot CWT_2^* \]

- **Dot-product** $D$
  \[ D = \cos^n(\theta) |CWT_{1,2}| \]

Where $n$ is an odd integer greater than zero,

$\theta$ is the local phase which can be range from $-\pi$ and $+\pi$,

$CWT_{1,2}$ is a complex quantity with $CWT_1$ as the continuous wavelet transform of dataset 1 and $CWT_2$ as the continuous wavelet transform of dataset 2.

Semblance Analysis of $^{28}\text{Si}$ and $^{27}\text{Al}(p,p')$

$^{28}\text{Si}(p,p')$ ISGQR $E_p = 200$ MeV, $\theta_{\text{lab}} = 12^\circ$

$^{27}\text{Al}(p,p')$ ISGQR, $E_p = 200$ MeV, $\theta_{\text{lab}} = 12^\circ$

Wavelet Coefficients

Semblance

Dot Product
Summary

- The Fine structure conforms to the suggestion of the global character of this phenomenon in the ISGQR, present in many different nuclei.

- RPA and SRPA calculations do not reveal the energy scales below 300 KeV in $^{28}$Si.

- Blue area indicating anti-correlation between the ISGQR regions of $^{28}$Si and $^{27}$Al. This can be due to the restricted configuration available in the extreme single-particle shell model.
Thank You