# Anomaly in the giant dipole resonance spectrum of $^{28}$Si

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The Jacobi shape transition, an abrupt change of shape from non-collective oblate to collective triaxial or prolate shape above a critical spin ($J_C$), has been predicted to appear in atomic nucleus due to its liquid drop nature at high excitation energy [1]. The onset of Jacobi shape transition has been observed in a few light nuclei through the Giant Dipole Resonance (GDR) decay spectrum, characterized by a narrow low energy component $\sim$ 10 MeV arising due to the Coriolis splitting [2]. Recently, it has been reported that a self-conjugate $\alpha$-cluster $^{32}$S nucleus populated with the angular momentum $J > J_C$, does not undergo the Jacobi shape transition and was explained in terms of formation of $^{16}$O + $^{16}$O molecular structure in a superdeformed state of $^{32}$S [3]. In another case, the observation of a narrow resonance in the reaction $^{24}$Mg + $^{24}$Mg populating $^{48}$Cr at $J = 36\ \hbar$ ($> J_C$) was interpreted in terms of the highly deformed Jacobi like shape corresponding to a molecular state, but no clear signature of the Jacobi shape transition was observed [4]. It is therefore interesting to study high energy $\gamma$-ray spectra in self-conjugate $\alpha$-cluster nuclei at high $J$ to understand the interplay of nuclear orbiting, cluster structure and Jacobi shape transition etc. With this motivation, measurement of the GDR spectrum from a self-conjugate $\alpha$-cluster nucleus $^{28}$Si, populated in the reaction $^{16}$O + $^{12}$C at $\langle J\rangle \sim 21\ \hbar$, which is higher than $J_C = 17\ \hbar$, is carried out [5].

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The experiment was performed using pulsed beam of 125 MeV $^{16}$O from the Pelletron Linac Facility (PLF) at Mumbai bombarding a self-supporting $^{12}$C target (400 $\mu$g/cm$^2$). The high energy $\gamma$-rays in the region of 5–30 MeV were measured in an array of seven close-packed hexagonal $BaF_2$ detectors, surrounded by an annular plastic shield for cosmic muon veto. A 14-element BGO multiplicity filter was employed for measuring the multiplicity of low energy discrete $\gamma$-rays to extract angular momentum information. The details of the experimental set-up and data analysis are discussed in Ref. [5].

The high energy $\gamma$-ray spectra for different folds ($F$) are generated in offline analysis after taking care of corrections due to chance coincidence and Doppler effect. In order to extract the GDR parameters, fold gated high energy $\gamma$-ray spectra are compared with the SMCC calculation [6] after incorporating a bremsstrahlung component [7] folded with the detector response function. A calculated $\gamma$-ray spectrum with an arbitrary constant $E1$ strength of 0.2 W.u., folded with the detector response function, was used for generating the divided plots for better visualization. The high energy $\gamma$-ray spectrum for $F \geq 4$ and the corresponding divided plot along with the best fit statistical model calculations are shown in

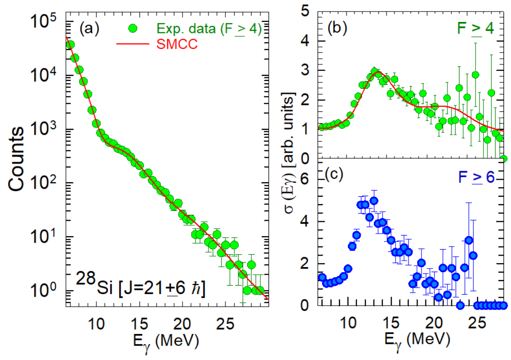


FIG. 1: Fold ($F$) gated high energy $\gamma$-ray spectrum (a) and the corresponding divided plot (b). The divided plot for $F \geq 6$ is shown in (c).

Fig. 1. It is observed that a two component strength function corresponding to a prolate shape describes the experimental data reasonably well. The best fit GDR parameters from the SMCC analysis are given in Table I. The mean centroid energy $E_{GDR}$ = 20.5 MeV, is consistent with the ground state systematics.

TABLE I: Best fit GDR parameters for $^{28}$Si from the SMCC analysis ($\langle J \rangle = 21(6)\ \hbar$, $\langle T \rangle$ = 2.1(3) MeV)

| $E_{GDR}$ (MeV) | $\Gamma_{GDR}$ (MeV) | $S_{GDR}$ |
|---|---|---|
| 14.6(3) | 6.0(3) | 0.44(4) |
| 24.6(8) | 10.0(7) | 0.62(3) |

As mentioned earlier, since $\langle J \rangle = 21\ \hbar$ is higher than $J_C = 17\ \hbar$ [1], the $^{28}$Si nucleus is expected to undergo a Jacobi shape transition. The TSFM calculations also predict an equilibrium shape to be highly deformed tri-axial ($\beta_2 \sim 0.4$, $\gamma \sim 140°$) shape for the measured temperature ($T$) and $J$ [5]. In such a scenario, the high energy $\gamma$-ray spectrum should have shown a distinct peak around $\sim$ 10 MeV. The experimental spectrum does not display a signature of the Jacobi shape transition and hence, appears to be anomalous. It should be noted that the data for $F \geq 6$, corresponding to $\langle J \rangle = 24(6)\ \hbar$, has lower statistics but has similar shape - namely, no low energy component is visible [Fig. 1(c)]. However, the deformation deduced from the conventional statistical model analysis is large ($\beta_2 > 0.6$) and points towards the elongated structure.

It should be pointed out that reactions involving $\alpha$-cluster nuclei are known to exhibit nuclear orbiting phenomenon [8]. Such a molecular configuration akin to a two body rotor with mass concentrated on the periphery, will have a large moment of inertia and consequently the angular frequency would be smaller. It should be pointed out that the net excitation energy as well as effective $T$ and $J$ for such a state can not be estimated in a simple manner. Further, in case of quasi-molecular resonances there would be an interplay of rotational motion of the dinuclear complex and vibrational motion of constituent nuclei, which would result in the fragmented strength [9] and detailed theoretical calculations are required to extract the strength function. Based on the present result for $^{28}$Si and similar observation in $^{32}$S [3], it is proposed that the nuclear orbiting phenomenon exhibited by $\alpha$-cluster nuclei, hinders the Jacobi shape transition.

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