Soft negative-parity excitations of rotating super- and hyperdeformed states around ^{40}Ca studied by Skyrme-RPA calculations

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Soft mode connected to the violation of symmetries is one of the central issues in nuclear physics. It emerges when the correlations increase by the addition of nucleons for a closed major shell or a change in the shell structure caused by weakly bound orbits, isovector properties of the nuclear force, and so on. Here, we discuss soft modes emerging from the superdeformed (SD) state toward a non-axial reflection-asymmetric shape due to the change in the shell structure by collective rotation.

We have already investigated the rotational bands of the SDf^4 and SDf^8 states in ^{36}Ar and the SDf^8 and hyperdeformed (HD) states in ^{40}Ca and ^{44}Ti by performing mean-field calculations with the Skyrme energy density functional (Skyrme-EDF)[1]. Here, the SDf^4 (SDf^8) state has four (eight) nucleons in single-particle (sp) levels originating from the $f_{7/2}$ shell, and the sp levels from $f_{7/2}$ and $g_{9/2}$ shells are occupied in the HD state.

In the present study, we predict the emergence of soft modes in these rotating SD and HD states by means of random phase approximation (RPA) calculation with the Skyrme-EDF.[2]

As an illustrative example, the vibrational energy E_{vib} of the SDf^8 state in ^{40}Ca is shown as a function of ω_{rot} in Fig. 1. Here, the size of the symbol is proportional to the isoscalar octupole transition strength $B(IS3)$.

At $\omega_{rot} = 0$, excitation with large transition strength $B(IS3) = 195.2$ W.u. appears at $E_{vib} = 5.46$ MeV. In this state, $S_{K=0}$ is dominant (98.2 %). Here, S_K is the K-component of $B(IS3)$. The main configuration is a particle-hole (ph) excitation [330]1/2 → [440]1/2. Other ph excitations from hole states originating from the $f_{7/2}$ shell to particle states from the $g_{9/2}$ shell also contribute largely.

The vibrational energy of the $K = 0$ state is strongly lowered by the rotational alignment of the [440]1/2 levels that have rapid down-sloping as a function of ω_{rot}. We obtain the vibrational state up to the critical rotational frequency $\hbar\omega^{(c)}_{rot} = 1.60$ MeV, where a sudden change of the internal structure occurs when the [440]1/2 levels are occupied in our framework. The properties at $\omega^{(c)}_{rot}$ are listed in Table 1. Due to the Coriolis K-mixing effect, $S_{K=1}$ becomes dominant.

We can expect the continuity of this trend such that the vibrational energy will decrease further and cross the yrast line. Specifically, we predict the emergence of the soft mode of the SD state that leads to the transition to a non-axial reflection-asymmetric shape (banana shape).

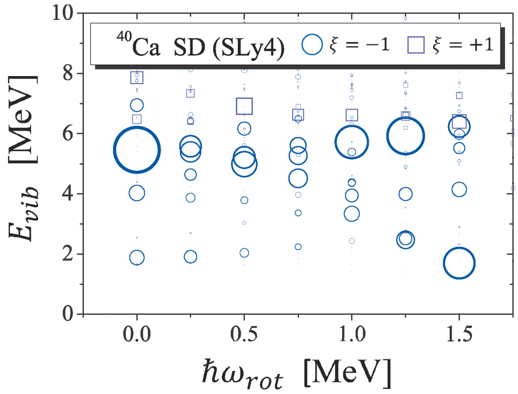

Fig. 1. E_{vib} of the SDf^8 state in ^{40}Ca as a function of $\hbar\omega_{rot}$. The size of the symbol is proportional to the $B(IS3)$ value. Circles and boxes represent the negative-parity excitations with x-signature $\xi = -1$ and $+1$, respectively. Here, Skyrme SLy4 is used.

	$\hbar\omega^{(c)}_{rot}$ [MeV]	E_{vib} [MeV]	$B(IS3)$ [W.u.]	$S_{K=0}$ [W.u.]	$S_{K=1}$ [W.u.]
^{36}Ar (SDf^4)	2.25	1.21	47.7	8.5	39.2
^{36}Ar (SDf^8)	1.25	1.81	289.4	162.8	125.1
^{40}Ca (SDf^8)	1.60	1.37	170.3	26.7	132.6
^{44}Ti (SDf^8)	1.50	1.47	154.1	44.5	101.4
^{40}Ca (HD)	1.75	2.33	544.9	371.6	171.9
^{44}Ti (HD)	1.75	1.82	315.3	33.7	258.9

Table 1. Properties of negative-parity excitations at $\omega^{(c)}_{rot}$ in the SDf^4, SDf^8, and HD states around ^{40}Ca. Here, Skyrme SLy4 is used.

We also predict the emergence of soft modes in the SD and HD states around ^{40}Ca systematically. The properties at $\omega^{(c)}_{rot}$ are summarized in Table 1. In the HD states, the rotational alignment of the [550]1/2 orbits originating from the $h_{11/2}$ shell plays a key role, and the ph configurations between the $h_{11/2}$ shell and the $g_{9/2}$ shell produce extremely large transition strength.

In conclusion, we emphasize the role of rotational alignment of special high-j orbits, the [440]1/2 orbits in the SDf^4 and SDf^8 states and the [550]1/2 orbits in the HD states, for the emergence of the soft modes toward banana shape around ^{40}Ca.

References
1) T. Inakura et al., Nucl. Phys. **A710**, 261 (2002).
2) M. Yamagami et al., JPS Conf. Proc. **6**, 030051 (2015).

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