Report of the RCNP Collaboration Research Network (COREnet003)

1. **Title of research**

   Microscopic understanding of nuclear collectivity through collaboration of experiment and theory

2. **List of participants** (Name; Position; Affiliation; E-mail)

   - Yutaka Utsuno (Contact person); Principal Researcher; Advanced Science Research Center, Japan Atomic Energy Agency; utsuno.yutaka@jaea.go.jp
   - Eiji Ideguchi; Associate Professor; RCNP, Osaka University; ideguchi@rcnp.osaka-u.ac.jp
   - Rudrajyoti Palit; Professor; Tata Institute of Fundamental Research; r.palit1@gmail.com
   - Noritaka Shimizu; Project Associate Professor; Center for Nuclear Study, The University of Tokyo; shimizu@cns.s.u-tokyo.ac.jp
   - Nori Aoi; Professor; RCNP, Osaka University; aoi@rcnp.osaka-u.ac.jp

3. **Period of research**

   From September/2019 to March/2021

4. **Main location of collaboration implementation**

   RCNP, Osaka University

5. **Publication list**

   - Papers in refereed journals

     [1] Md. S. R. Laskar, R. Palit, S. N. Mishra, N. Shimizu, Y. Utsuno, E. Ideguchi, U. Garg, S. Biswas, F. S. Babra, R. Gala, C. S. Palshetkar, and Z. Naik
     "Structure of the $11/2^-$ isomeric state in ^{133}La"
     Phys. Rev. C **101**, 034315 (2020).

     [2] Y. Utsuno, T. Ichikawa, N. Shimizu, and T. Otsuka
     "Consistent description of N=Z=20 shell gap and deformed intruder states around ^{40}Ca"
     submitted to Phys. Rev. C.

   - Talks

     [3] E. Ideguchi et al.
     "Shape coexistence in mass 40 region studied via E0 and gamma transitions"
     HIAS2019 conference, Sep. 7-15, 2019, Canberra, Australia.

[4] R. Palit et al.
"Structure and isomers odd-A isotopes in A~130 region"
XXIII International School on Nuclear Physics, Neutron Physics and Applications, Varna, Bulgaria, Sep. 22-28 2019.

[5] Md. S. R. Laskar, R. Palit et al.
"Nuclear moment measurements in Lanthanum (La) isotopes"
3−day theme meeting on Nuclear reactions involving weakly bound stable and radioactive ion beams, DAE Convention Centre, Anushaktinagar, BARC, India, Dec. 1-3, 2019.

[6] E. Ideguchi et al.
Electric monopole transition from the superdeformed band in ^{40}Ca"
5th Topical Workshop on Modern Aspects in Nuclear Structure, Bormio, Italy, Feb. 3-9, 2020.

[7] Md. S. R. Laskar, R. Palit et al.
"Nuclear moment measurements in Lanthanum (La) isotopes"
Vth Topical Workshop on Modern Aspects in Nuclear Structure: The Many Facets of Nuclear Structure, Bormio, Italy, Feb. 3-9, 2020.

[8] E. Ideguchi, T. Kibédi, J.T.H. Dowie, T.H. Hoang, M. Kumar Raju, A.A. Akber, L. Bignell, B. Coombes, T.K. Eriksen, M.S.M Gerathy, T.J. Gray, G.J. Lane, B.P. McCormick, A.J. Mitchell, A.E. Stuchbery, N. Shimizu, and Y. Utsuno
"E0 transitions from the superdeformed state in ^{40}Ca"
The 75th Annual Meeting of the Physical Society of Japan, Nagoya, Japan, Mar. 16-19, 2020.

[9] Y. Utsuno, N. Shimizu, E. Iduguchi, and N. Aoi
"Large-scale shell-model calculations of the E0 transitions in ^{40}Ca and their interpretation"
The 75th Annual Meeting of the Physical Society of Japan, Nagoya, Japan, Mar. 16-19, 2020.

6. Description of the outputs

- **Mass 40 region**

The superdeformed band in ^{40}Ca, which was observed about 20 years ago, still attracts much interest in the nuclear-structure community. The goal of this project is to fully understand the nature of various super- or largely-deformed states observed in the $A \approx 40$ region. In this FY, we are devoted to discussing the origin

of the extraordinary small E0 transition from the superdeformed 0^+ state to the ground state in ^{40}Ca that has recently been measured by our experimental group. Carrying out large-scale shell-model calculations developed by our theoretical group recently [2], we are successful in reproducing this very small E0 transition from a fully microscopic point of view. Very interestingly, the observed and calculated E0 probabilities in ^{40}Ca are by two orders of magnitude smaller than that of ^{42}Ca.

Thanks to the meetings supported by this project, we have reached the conclusion that what makes the E0 probabilities hindered in ^{40}Ca is both a small mixing amplitude between the spherical and the superdeformed states and a destructive phase contribution in the E0 matrix element. In the usual case, only two states, the spherical and the deformed states, are relevant to the E0 transition. In this situation, the phase contribution does not appear. On the other hand, what is unique in ^{40}Ca is the appearance of three kinds of deformed states, spherical, normal-deformed, and superdeformed states. In such a particular case, the phase degrees of freedom make sense, thus causing the observed small E0 probability. This finding is a novel feature of the E0 transition, which is known as a good probe of deformation from a classical point of view. We are now writing a paper for publication.

- **Mass 130 region**

  In this FY, we concentrated on discussing what is the implication of the magnetic and quadrupole moments of the $11/2^-$ isomeric state in ^{133}La that has recently been measured by our experimental group. It is well known that the $h_{11/2}$ orbital plays a crucial role in some unique collective properties appearing in this region, such as the chiral bands. Since this isomeric state has $J^\pi=11/2^-$, its nuclear moments are good probes for identifying the $h_{11/2}$ single-particle nature and the coupling to quadrupole collectivity. The measured g factor, 1.16(7), and the absolute value of the Q moment, 1.71(34), are well reproduced by our large-scale shell-model calculations. The comparison between experiment and theory indicates that this $11/2^-$ isomeric state is dominated by a proton coupled to a modest prolate deformation with $\beta \approx 0.2$. Its low excitation energy, 535 keV, is caused by both proton shell evolution and quadrupole collectivity. This result has been published as a collaborative paper in Physical Review C [1].