Shape coexistence and superdeformation in ^{28}Si

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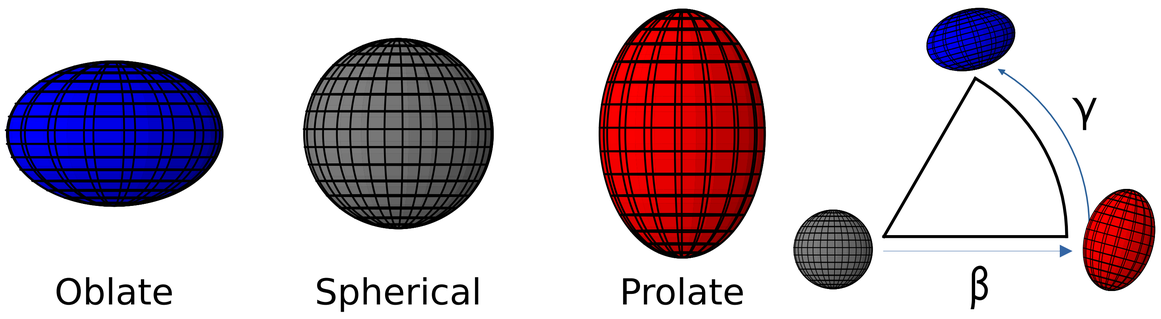
Shape coexistence

- **Different shapes** among states of the same nucleus
- Narrow energy range: a few MeV of excitation energy

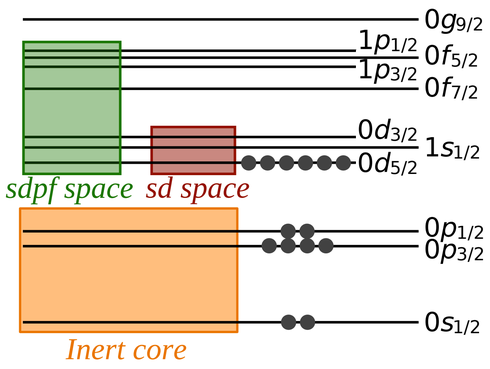
Motivation for ^{28}Si

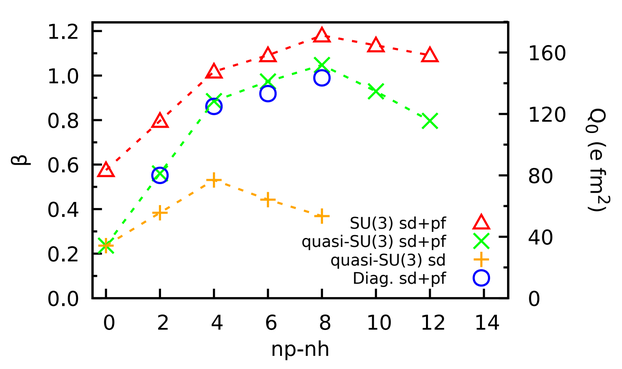
- Coexistence of different collective structures[1]:
  1. 0^+_1 (0.0 MeV): Oblate bandhead of a rotational band
  2. 0^+_2 (5.0 MeV): Vibration of the ground state
  3. 0^+_3 (6.7 MeV): Prolate bandhead of a rotational band
  4. Superdeformed rotational band? ($E \gtrsim 10$ MeV) [2]



Methodology

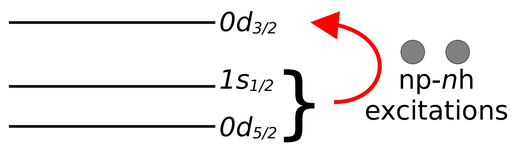
Nuclear shell model[3]: Exact diagonalization
Projected-GCM[4]: Visualization of deformation
Elliott's SU(3)[5]: Analytical insight





Elliott's SU(3)

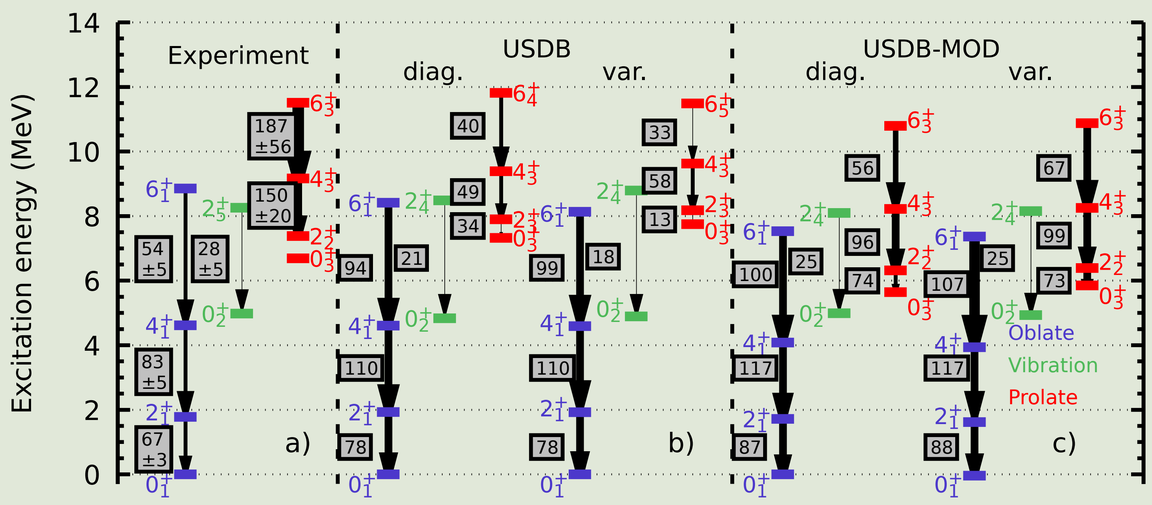
- **Pure SU(3)**: Degenerated oblate and prolate structures
- **Quasi-SU(3)+$d_{3/2}$**: excitations from $d_{5/2}$-$s_{1/2}$ to $d_{3/2}$
  - 0p-0h oblate ground state and 4p-4h prolate excited bandhead
- Collective vs single-particle **competition**: $\mathcal{H} = \mathcal{H}_0 - \kappa\beta^2$



β	0p-0h	2p-2h	4p-4h
Oblate	-0.37	-0.45	-0.53
Prolate	0.24	0.38	0.53

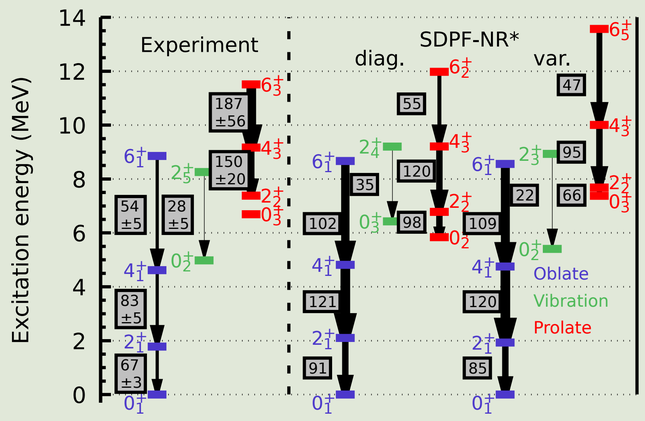
sd-shell calculations (USDB/USDB-MOD)

- Oblate+vibration structures are well reproduced
- Prolate structure **is not** reproduced: weak $B(E2, 4^+_3 \rightarrow 2^+_3)$
- **Reduction** of $d_{3/2}$ single-particle energy (USDB-MOD)
  - Oblate and vibration remain mostly unperturbed (0p-0h component)
  - Prolate structure gains deformation (more 4p-4h component)



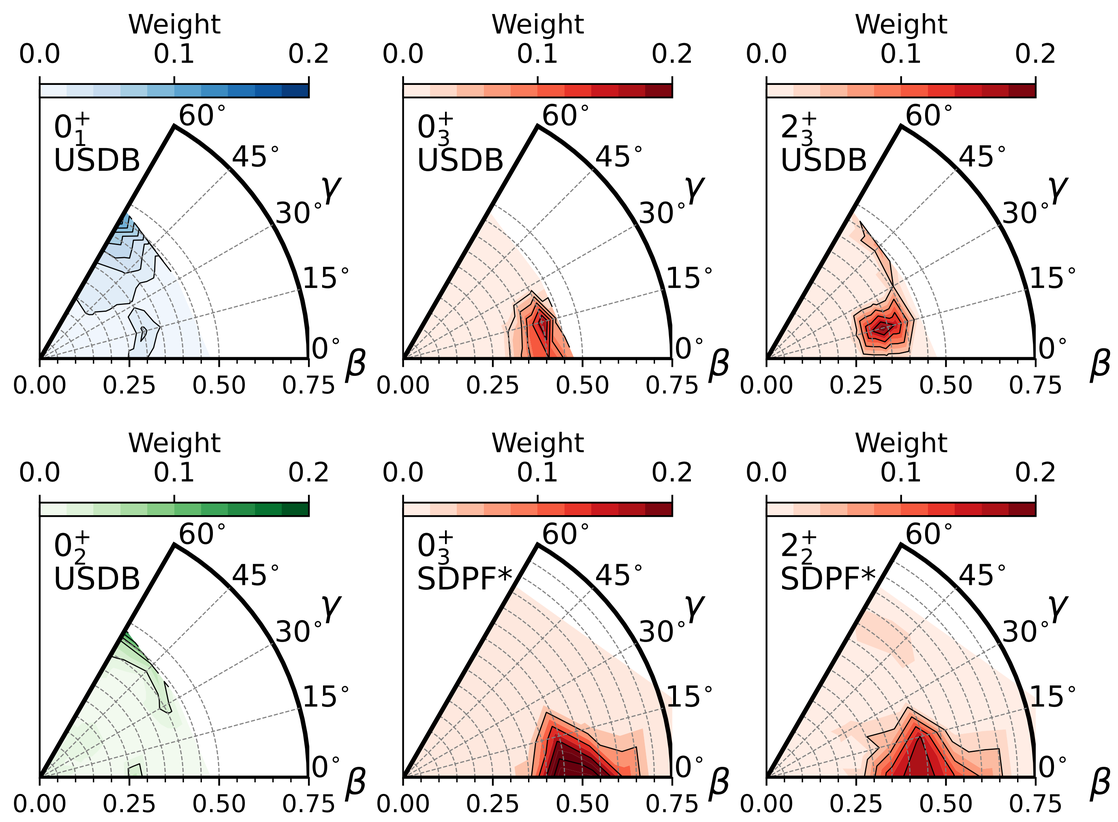
sdpf-space calculations (SDPF-NR*)

- Adjusted SDPF-NR interaction to reproduce ^{28}Si shell gap
- Additional deformation from *pf*-shell particles:
  - Slight gain for oblate and vibration
  - Significant gain in prolate deformation:
    $B(E2)_{\text{USDB}} = 49\ e^2\text{fm}^4$
    $B(E2)_{\text{SDPF}} = 120\ e^2\text{fm}^4$
  - 1 particle in *pf*-shell (38% of *sdpf* 2p-2h).



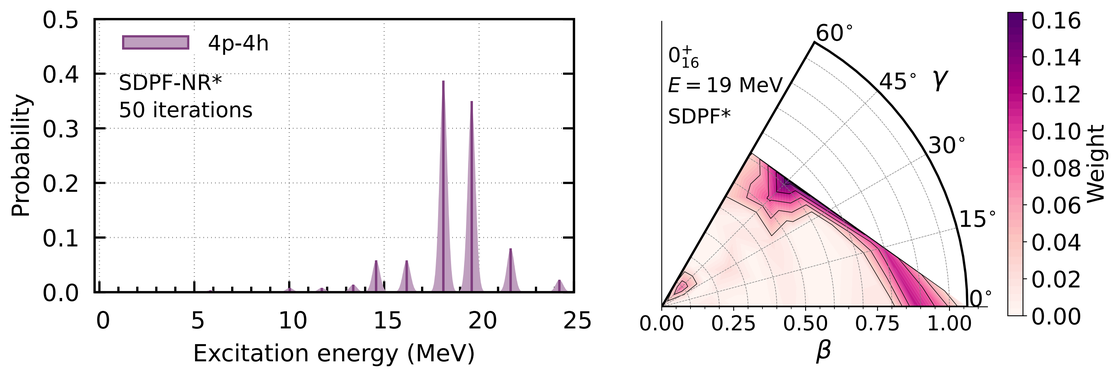
Projected generator-coordinate method

- **Beyond-mean field** approach (constrained HFB basis + symmetry restoration + configuration mixing)
- Successful description of shape coexistence:



Superdeformation

- Superdeformed structures (*sdpf* 4p-4h) appear at 18-20 MeV:



Shape invariants

- Are the shapes of the bandheads physically meaningful?
  - Oblate ground state: $\beta = 0.47 \pm 0.08$, $37° \leq \gamma \leq 60°$
  - Vibrational state: $\beta = 0.42 \pm 0.12$, $34° \leq \gamma \leq 60°$
  - Prolate excited state: $\beta = 0.50 \pm 0.08$, $0° \leq \gamma \leq 32°$
- The bandheads are **β-soft** and present a **broad γ range**

References

1. L. Morris et al., PRC 104, 054323 (2021)
2. Y. Taniguchi, Y. Kanada-En'yo, and M. Kimura, PRC 80, 044316 (2009)
3. E. Caurier and F. Nowacki, Acta Phys. Pol. B 30, 705 (1999)
4. B. Bally, A. Sánchez-Fernández, and T. R. Rodríguez, EPJ A 57, 69 (2021)
5. J. P. Elliott, Proc. R. Soc. Lon. Ser-A 245, 128 (1958)

Dorian Frycz (UB/ICCUB)
Mail: dorianfrycz@fqa.ub.edu
Coauthors: J. Menéndez, A. Rios, B. Bally, T. R. Rodríguez & A. M. Romero

UNIVERSITAT DE BARCELONA