^{28}Si の α クラスター相関と超変形状態

谷口億宇 (大阪大学)

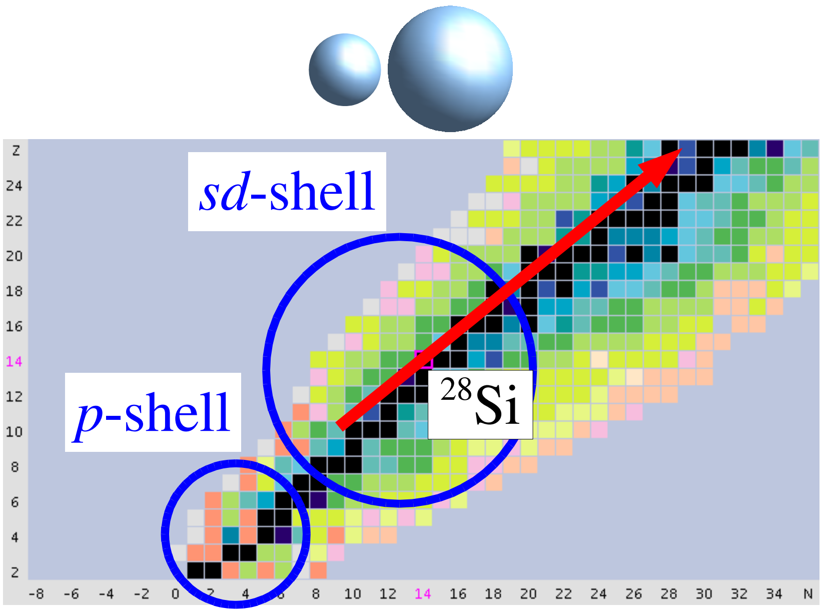
延与佳子 (京都大学)

木村真明 (北海道大学)

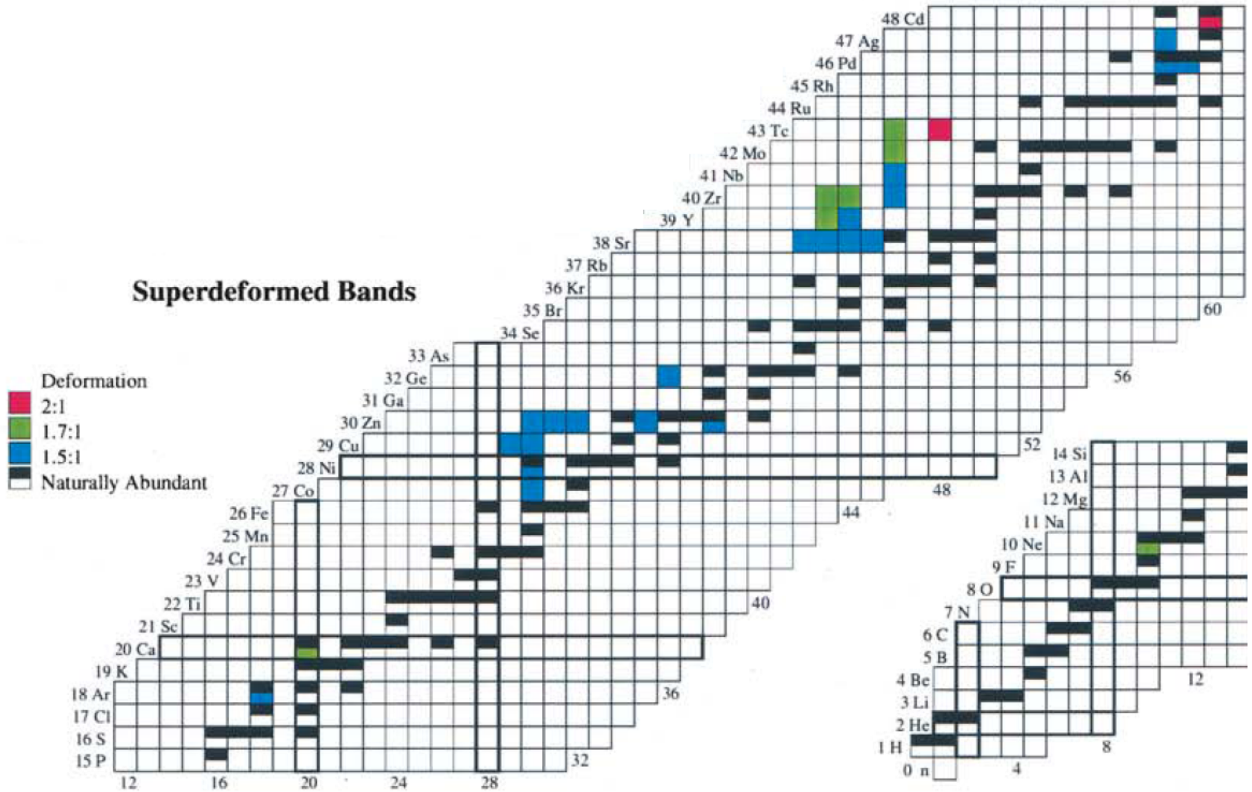
平成 20 年 12 月 23–25 日
大阪大学核物理研究センター

Introduction: Cluster structure

- Structures or correlations, which have subsystems (clusters).
- Important in light nuclei such as *p*-shell and light *sd*-shell region. Be isotopes, ^{12}C, ^{16}O, ^{20}Ne, ...
- In heavy *sd*- and *f*-shell region and heavier region? $\longrightarrow$ $\boxed{^{28}\text{Si}}$



Introduction: Superdeformation



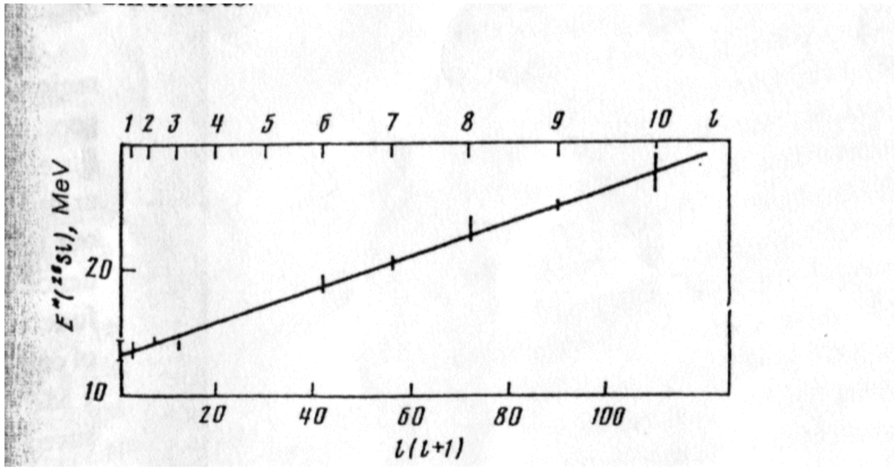
[B. Singh *et al*, Nuclear Data Sheets, **97**, 241 (2002).]

What is the lightest nucleus which have an SD state?

^{36}Ar??

Introduction: α and ^{12}C clustering

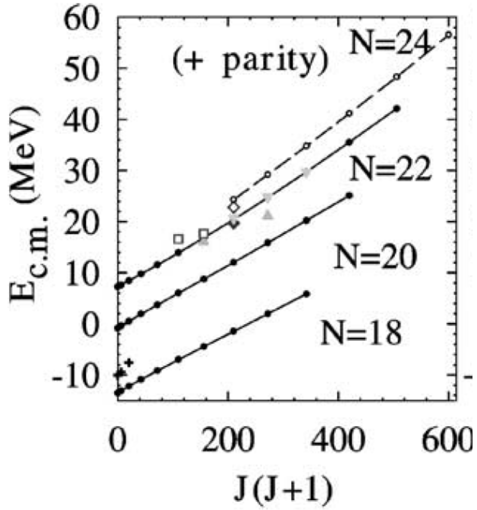
^{24}Mg(^{6}Li, d), ^{24}Mg(α,α) and ^{24}Mg(α,γ) reactions



[K. P. Artemov *et al.*, Sov. J. Phys. 51, 777 (1990).]

Candidates of α-^{24}Mg states have been observed, but theoretical studies have not been progressed yet.

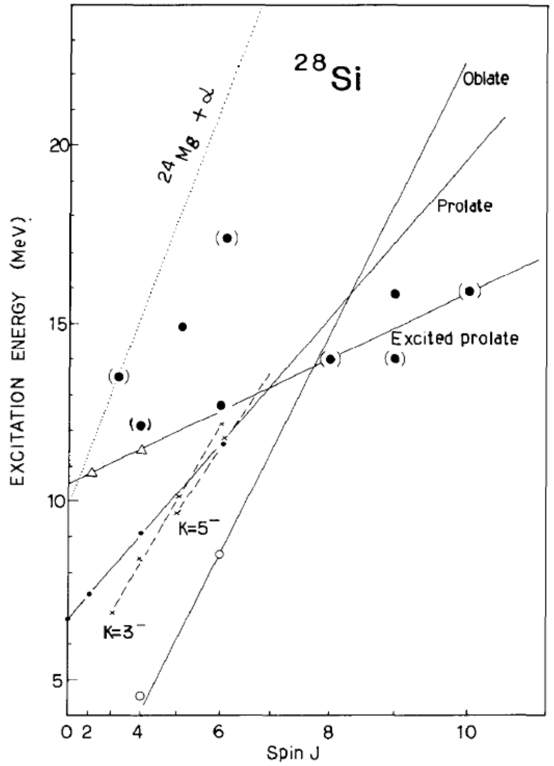
^{12}C+^{16}O potential model



[S. Ohkubo *et al.*, Phys Lett. B578, 304 (2004).]

It is suggested that the prolate band built on $J^{\pi} = 0^{+}$ (6.69 MeV) state contains ^{12}C-^{16}O cluster structure.

Introduction: Various deformed structures



[S. Kubono *et al.*, Nucl. Phys. A457, 461 (1986).]

Shape coexistence

Oblate shape

- the ground band (g)
- the β vibration band (vib)

Prolate shape

- the prolate band [normal-deformed (ND)]
- the excited prolate band [superdeformed (SD)]

Electric transitions in the SD band have not been observed.

Introduction

Topics

1. α-^{24}Mg and ^{12}C-^{16}O clustering
2. Prolate and oblate shape coexistence, β vibration and a largely deformed band.

Method

- Deformed-basis antisymmetrized molecular dynamics (AMD)
  - Both clustering and deformations are described simply.
- Multi-configuration mixing
  1. quadrupole deformation parameter β.
  2. distances d between centers of masses for α-^{24}Mg and ^{12}C-^{16}O clusters.

Antisymmetrized molecular dynamics (AMD)

Wave function

$$|\Phi\rangle = \hat{\mathcal{A}}|\varphi_1,\ \varphi_2, \cdots, \varphi_A\rangle.$$

φ = single-particle wave function: triaxially deformed Gauss' wave packet

Energy variation imposing constraints (VAP: parity, VBP: angular momentum)

$$\delta\langle\Phi^+|(\hat{H} + V_{\mathrm{cnst}})|\Phi^+\rangle = 0$$

effective interaction $\hat{H}$: Gogny D1S

constraint potential V_{cnst}: quadrupole deformation parameter β

distances d between centers of masses of clusters

Multi-configuration mixing

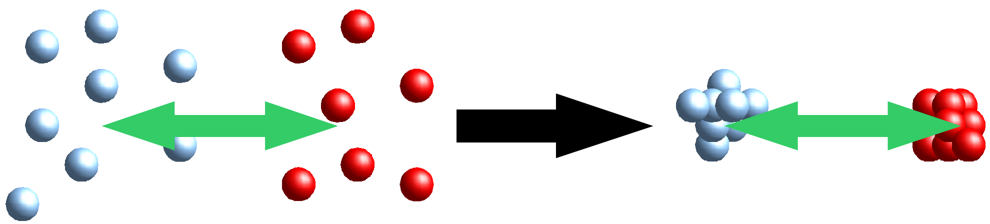
Diagonalize Hamiltonian and Norm matrices.

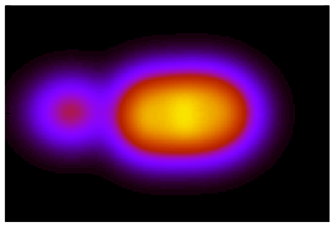
$$|\Phi^{\mathrm{GCM}}\rangle = \sum_i f_i|\Phi_i\rangle$$

Constraint of a distance between centers of masses of clusters

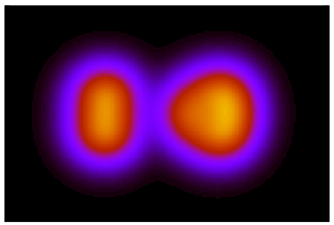
[Y. Taniguchi, M. Kimura and H. Horiuchi, PTP 112, 475 (2004).]

1. It is easy to calculate various kinds of cluster structures.
2. Structure of each cluster, such as shape, orientation and core excitation, is optimized to minimize a total energy.

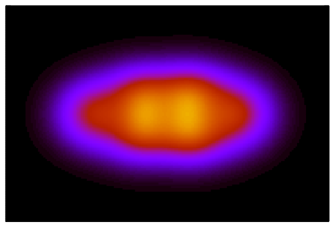




α-^{24}Mg



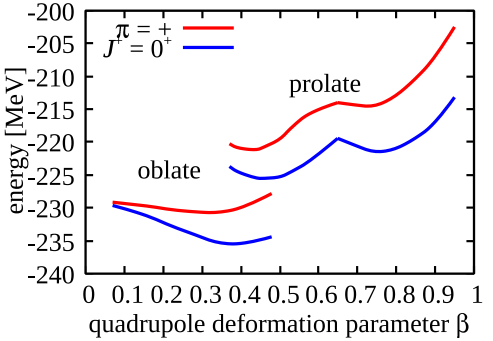
^{12}C-^{16}O



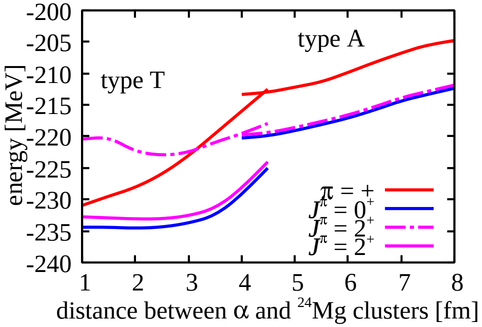
quadrupole deformation

Energy curves

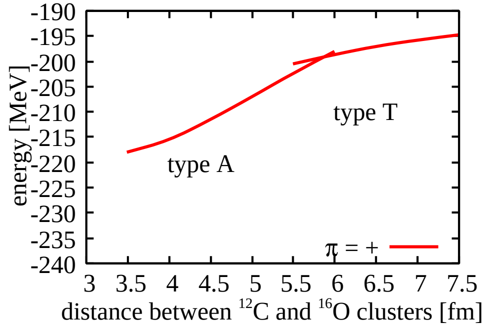
β



α-^{24}Mg



^{12}C-^{16}O

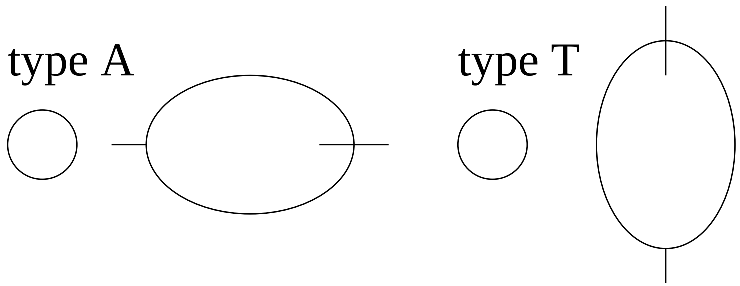


type A (Axial symmetric shape)

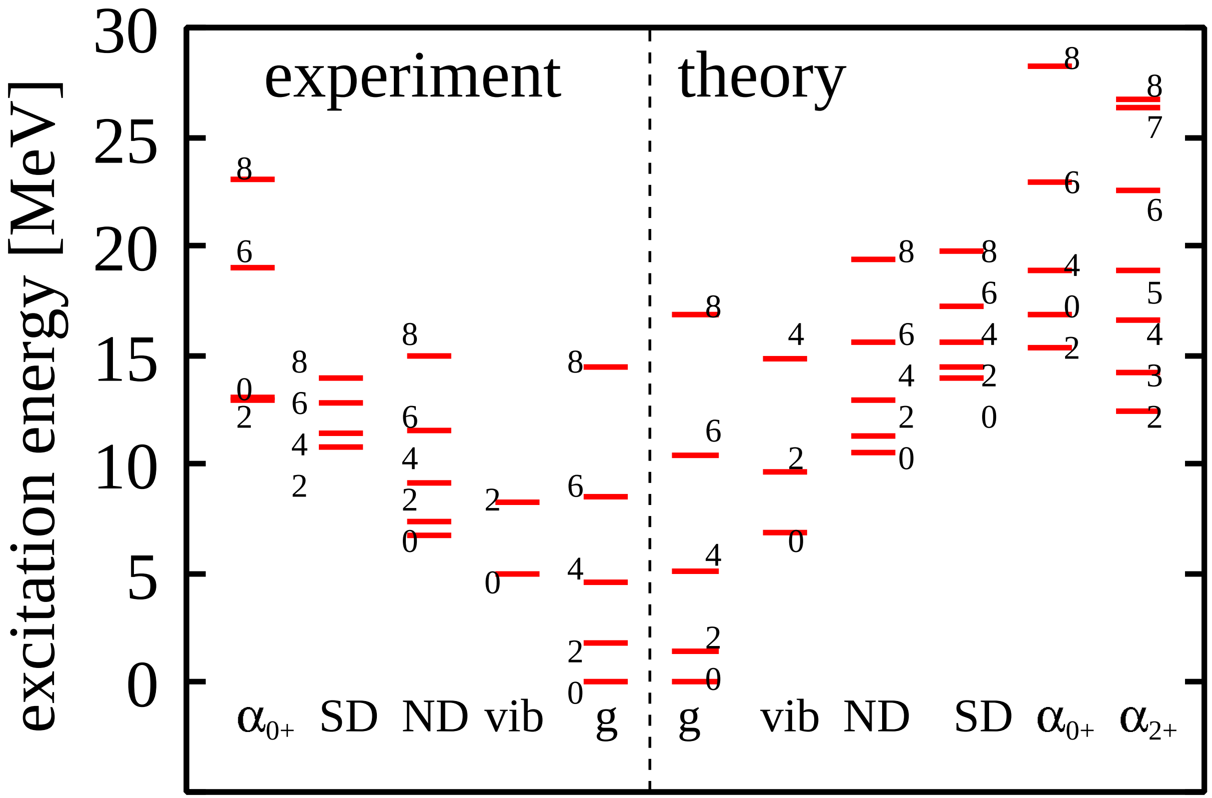
An α (^{16}O) is located on symmetric axis of prolate ^{24}Mg (oblate ^{12}C).

type T (Triaxial shape)

A vector that connects α (^{16}O) and ^{24}Mg (^{12}C) clusters is perpendicular to symmetric axis of prolate ^{24}Mg (oblate ^{12}C).



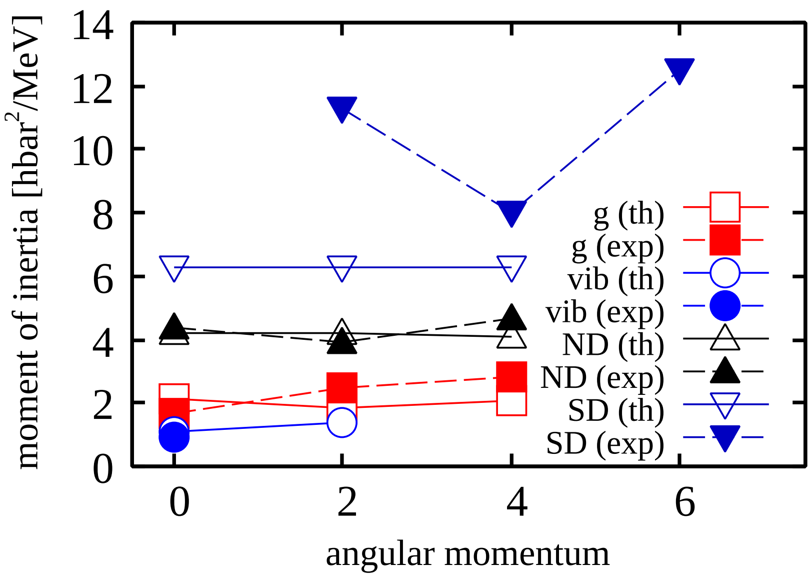
Energy spectrum



Five $K^\pi = 0^+$ bands and one $K^\pi = 2^+$ band.

Two developed α-^{24}Mg bands α_{0+} and α_{2+}.

Moments of inertia (MOI)

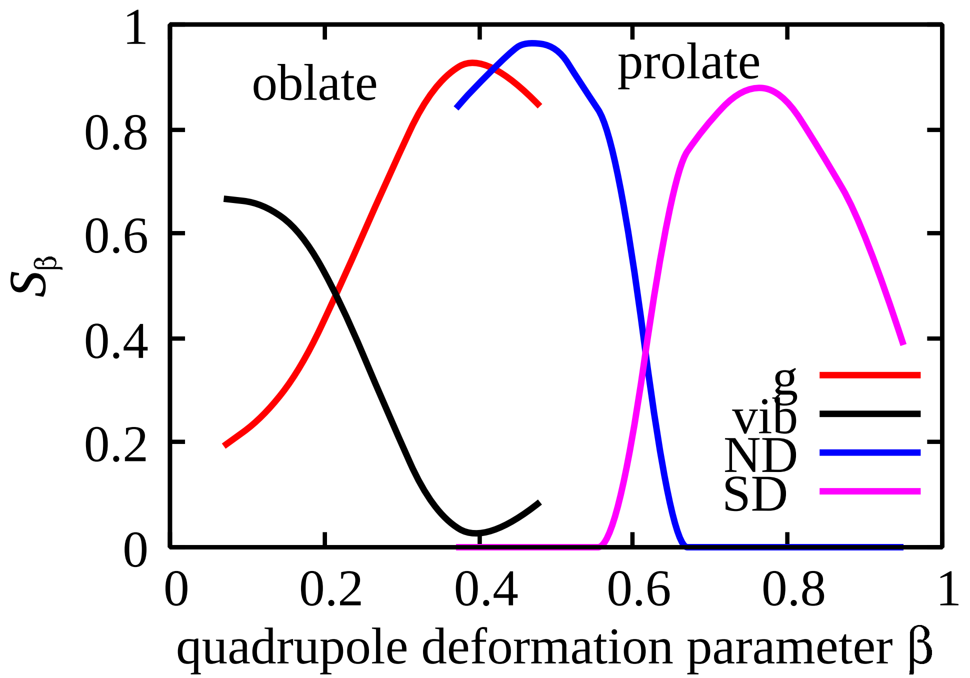


$$\mathcal{J}(J) = \frac{2J+3}{E(J+2)-E(J)}\hbar^2.$$

1. The theoretical and experimental MOI values for g, vib and ND states are consistent.

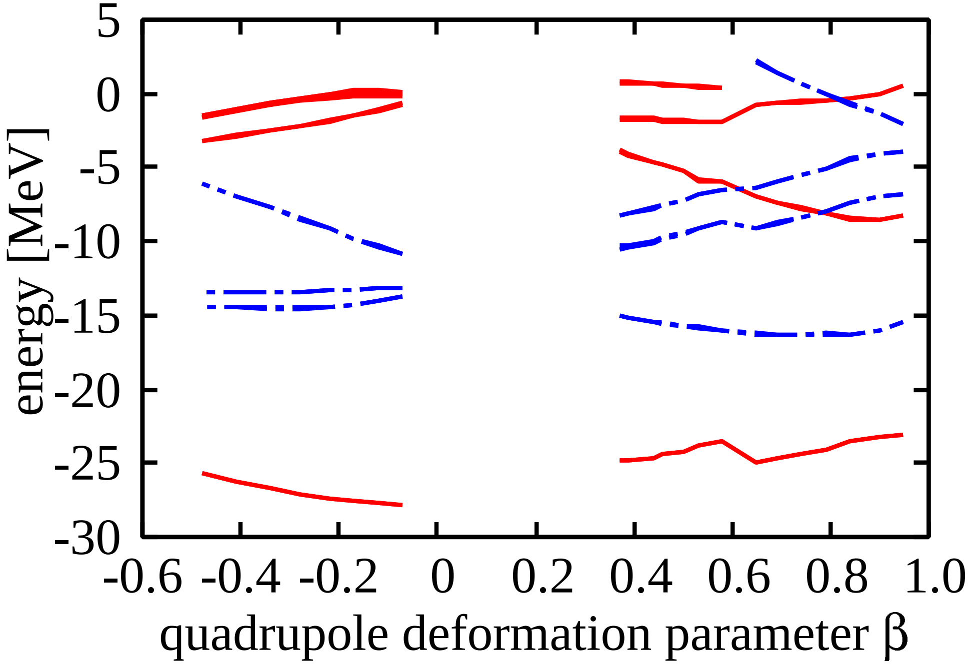
2. Those for SD states are inconsistent.
   More experimental data such as $E2$ transitions are required for band assignment.

Shape coexistence and β vibration



1. Shape coexistence: g, vib and ND
2. β vibration: g and vib
3. Superdeformation?: SD

Single-particle wave function (neutron)



red: positive parity, blue: negative parity

The ground and ND bands: $0p0h$ $[(sd)^{12}]$

The SD band: $4p4h$ $[(sd)^8(pf)^4]$

Quadrupole electric transition strengths $[B(E2)]$

	J_i	J_f	$B(E2)_{\mathrm{exp}}$	Theory
intra	2^+_{g}	0^+_{g}	13.2 ± 0.3	15.0
	4^+_{g}	2^+_{g}	13.8 ± 1.3	22.9
	6^+_{g}	4^+_{g}	9.9 ± 2.5	28.3
	2^+_{vib}	0^+_{vib}	5.5 ± 1.3	8.31
	2^+_{ND}	0^+_{ND}	—	41.3
	4^+_{ND}	2^+_{ND}	29 ± 5	56.9
	6^+_{ND}	4^+_{ND}	> 16	58.4
	2^+_{SD}	0^+_{SD}	—	130.7
	4^+_{SD}	2^+_{SD}	—	186.3
	6^+_{SD}	4^+_{SD}	—	204.0
inter	0^+_{vib}	2^+_{g}	8.6 ± 1.6	5.96
	2^+_{vib}	0^+_{g}	0.029 ± 0.009	0.27
	2^+_{vib}	4^+_{g}	0.8 ± 0.3	3.11

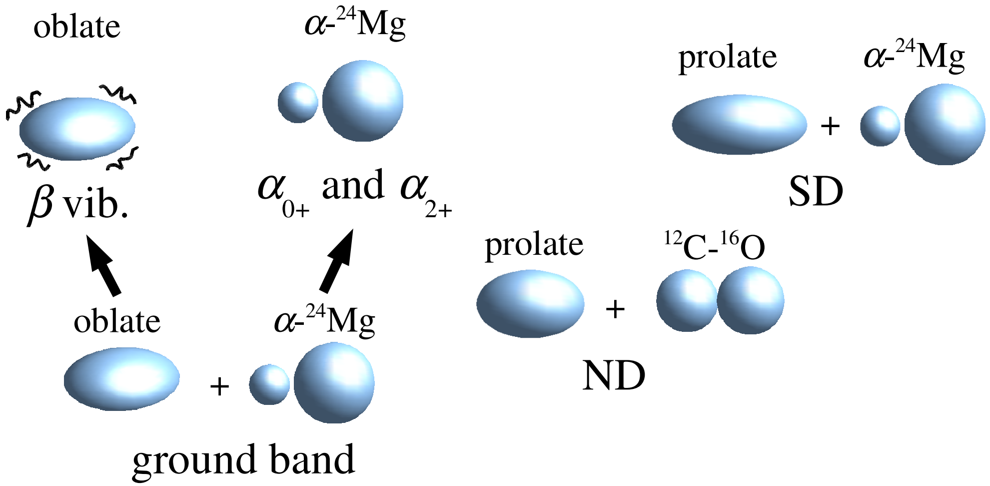
Component of cluster structures

band	J^π	β		α-^{24}Mg		^{12}C-^{16}O	
		oblate	prolate	T	A	T	A
g	0_1^+	.97		.95			
	2_1^+	.96		.95			
vib	0_2^+	.96		.88			
	2_2^+	.94		.85			
ND	0_3^+		.98				.86
	2_3^+		.98				.86
SD	0_5^+		.93		.87	.14	
	2_5^+		.93		.87	.15	
α_{0^+}	0_6^+	.21		.69			
	2_6^+	.23		.85			
α_{2^+}	2_4^+	.21		.96			
	3_1^+			1.00			

$$|\Phi\rangle = c\,|\Phi_X\rangle + \sqrt{1-|c|^2}\,|\Phi_{R_X}\rangle,\ \langle\Phi_X|\Phi_{R_X}\rangle = 0,$$

$$\text{component} = |c|^2$$

Summary



1. Structures of ^{28}Si has been studied using AMD + Multi-configuration mixing.
2. The ground, β vibration and SD bands contain the α-^{24}Mg cluster component, and the SD band contains the ^{12}C-^{16}O cluster component.
3. The α_{0+} and α_{2+} bands have developed α-^{24}Mg cluster structure.
4. Prolate and oblate shape coexistence (g, vib and ND) and β vibration (g and vib) are described.
5. $B(E2)$ and MOI values have good agreement with experimental data in low-spin states.