Phases of clusterized nuclei

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I. Clusters and phases

II. Symmetries

III. Dictionary

IV. Connection: MUSY

V. Isomers

VI. Conclusions

I. Clusters and phases

Phases of quadrupole collectivity

Detailed studies

1. Within algebraic model (IBM).
2. Within geometrical model.
3. On the relation of the two approaches.

Clusterization is another important collectivity.

Phases of cluster states

(Summary in 1 slide)

1. Much interest

2. Few studies
   In particular very few quantitative studies

3. Within diversed approaches, whose relations are hardly or not at all known.

Phases of cluster states

(Last 3 cluster conference)

Stratford 2007, Itagaki:
Solid, liquid and gas phases

Debrecen 2012, Horiuchi:
Localized, delocalized and alpha-condensate

Napoli 2016
Iachello-Bijker: rot-vibr (e.g. D_{3h}) molecules
Sambataro, Cseh: quartets
Schuck+J: BEC, kinematical and dynamical localiz.
Not much inter-school discussion!

Models

Traditional

- Phenomenological: potential
- Microscopic: BB-alpha-cl, GCM, RGM, GCM

Phases:

- Quasicluster
- BEC
- Algebraic: ACM, SACM

No-(a priori) clusters:

- FMD, AMD, shell, no-core sh, quartet, meanfield

II. Symmetries

For a long time: wavefunctions

Fully algebraic description of the relative motion

1981 F. Iachello, Vibron Model

Clusters	Model	
2	U(4)	
3	U(7)	(Bijker, Leviatan)
4	U(10)	

Different versions;

- internal cluster structure
- model space
- interactions

Quantitative studies on phases

Algebraic approach

Vibron Model et al: relative motion

Van Roosmalen, Dieperink, Zhang et al, Bijker

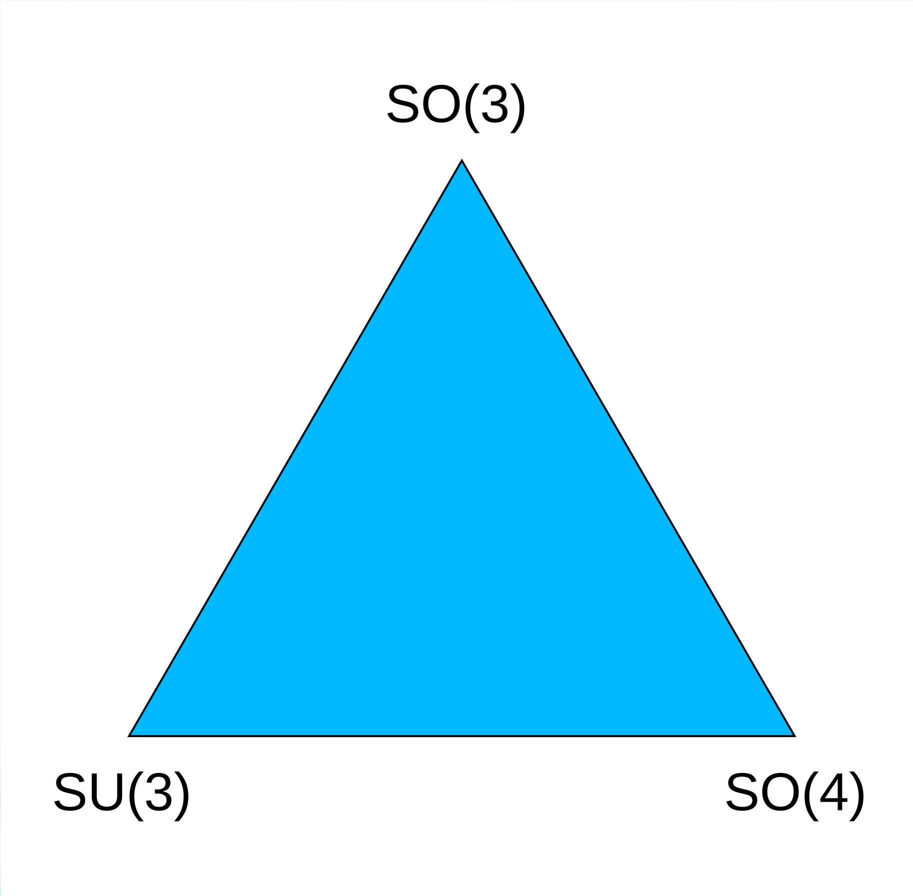
Semimicros. Algebraic Cluster Model

Internal cluster structure: Wigner-Elliott $U^{ST}(4)xU(3)$

Microscopic model space

2-cluster-configurations:

3 dynamical symmetries: U(3), O(4), O(3).


SO(3)
SU(3)
SO(4)

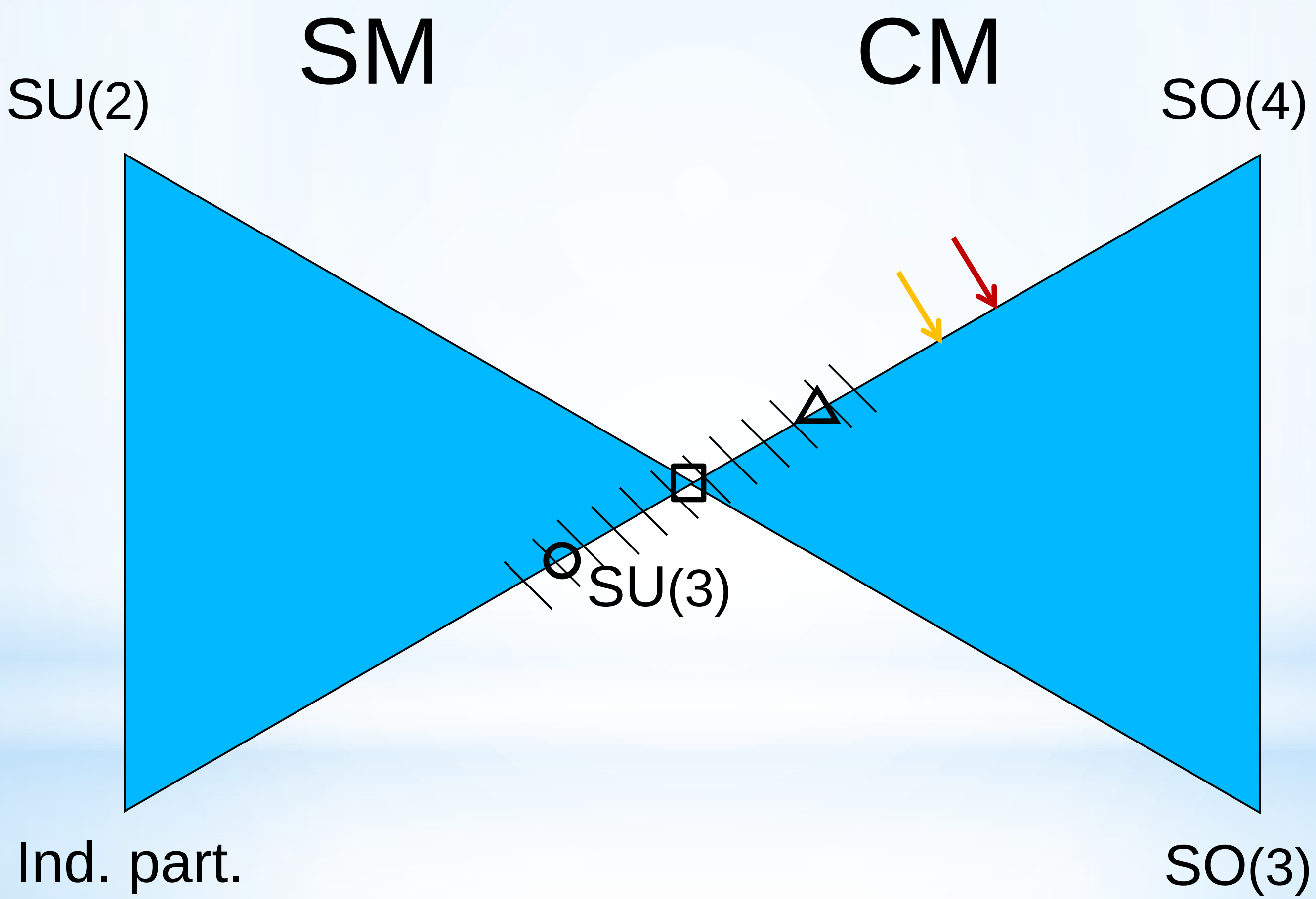
SACM phase diagram

Phase transitions: Hess et al

Persistence of quasidynamical SU(3) symmetry

Localization of real nuclei

Connection to other models


SM
CM
SU(2)
SO(4)
SU(3)
Ind. part.
SO(3)

○ 4 nucleons full sd shell model

C. Vargas et al., *PRC 58 (1998) 1488*.

□ Symplectic no-core shell model

G.K. Tobin et al., *PRC 89 (2014) 034312.*

(G.s) overlap (cluster space) > 65%

△ SACM

H.Yepez et al., *PRC 86 (2012) 034309.*

//// Quasi-cluster: fr rigid mol. to strong LS

N. Itagaki et al., *PRC 83 (2011) 014302.*

III. Dictionary
(Qualitative correspondance)

Model	Shell-like	Molecule	Weak
SACM	U(3)	O(4)	O(3)
Itagaki	liquid	solid	gas
Horiuchi	delocal	local	AC
Schuck	kinem.l.	dynam.l.	BEC
ACM		D_{3h}	
D_{3h}	BB-alpha	ACM	

IV. Multichannel dynamical symmetry

Quantitative connection between the shell, collective and cluster models for multi major-shell problems

(No-core) Symplectic shell model
(G. Rosensteel, D. Rowe, PRL 38 (1977) 10;
T. Dytrych et al. J. Phys. G 35 (2008) 123101.)

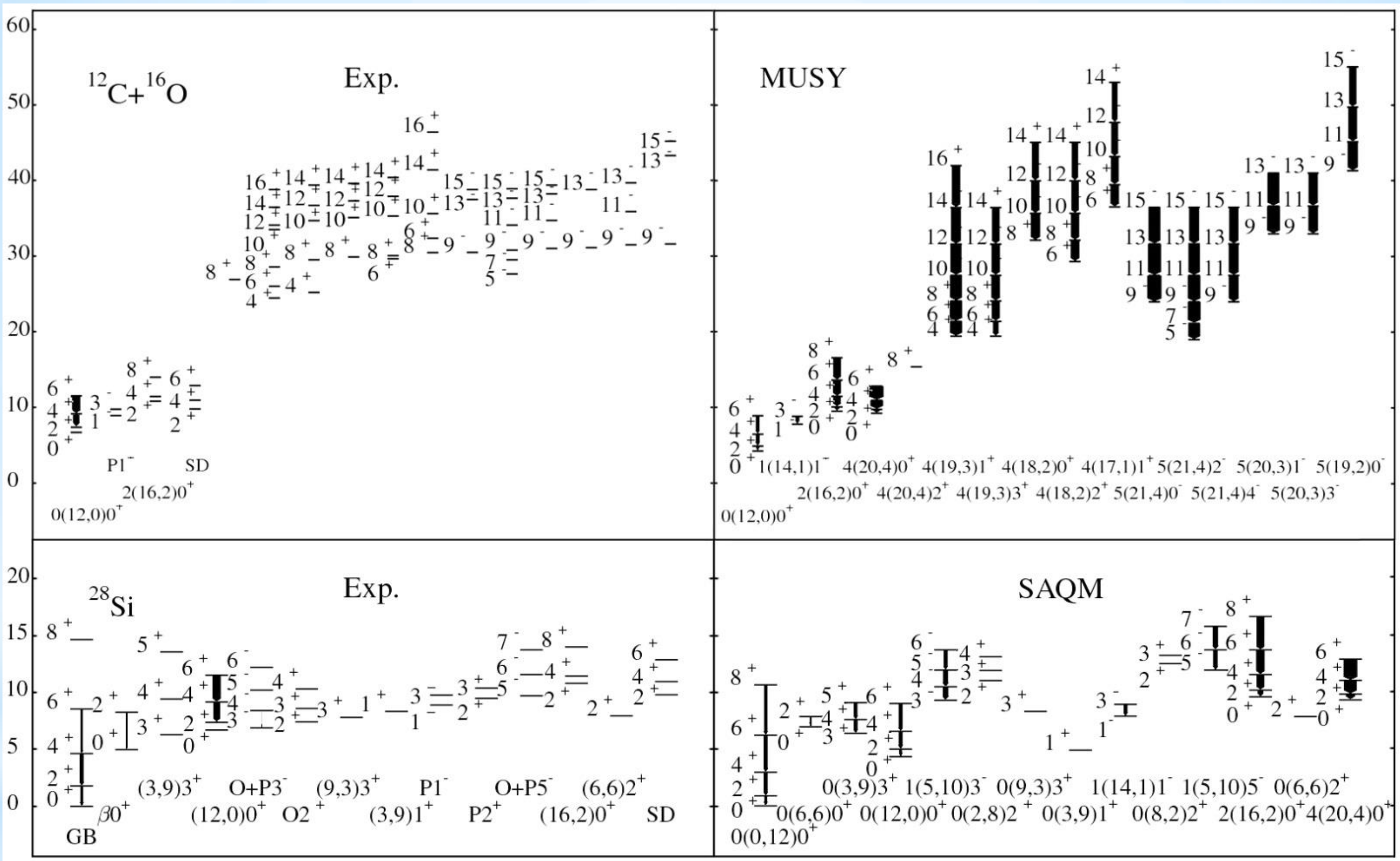
Contracted symplectic model
(D.J. Rowe, G. Rosensteel, Phys. Rev. C 25 (1982) 3236(R);
O. Castanos, J. P. Draayer, Nucl. Phys. A 491 (1989) 349.)

Semimicroscopic algebraic cluster model
(J. Cseh, G. Lévai, Ann. Phys. 230 (1994) 165.)

Quantitative connection

Unified description of different configurations in different energy ranges.
J. Cseh, G. Riczu, Phys. Lett. B 757 (2016) 312.

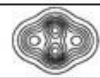
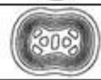
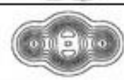
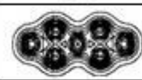
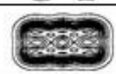
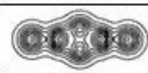
Experimental spectra, predictions.

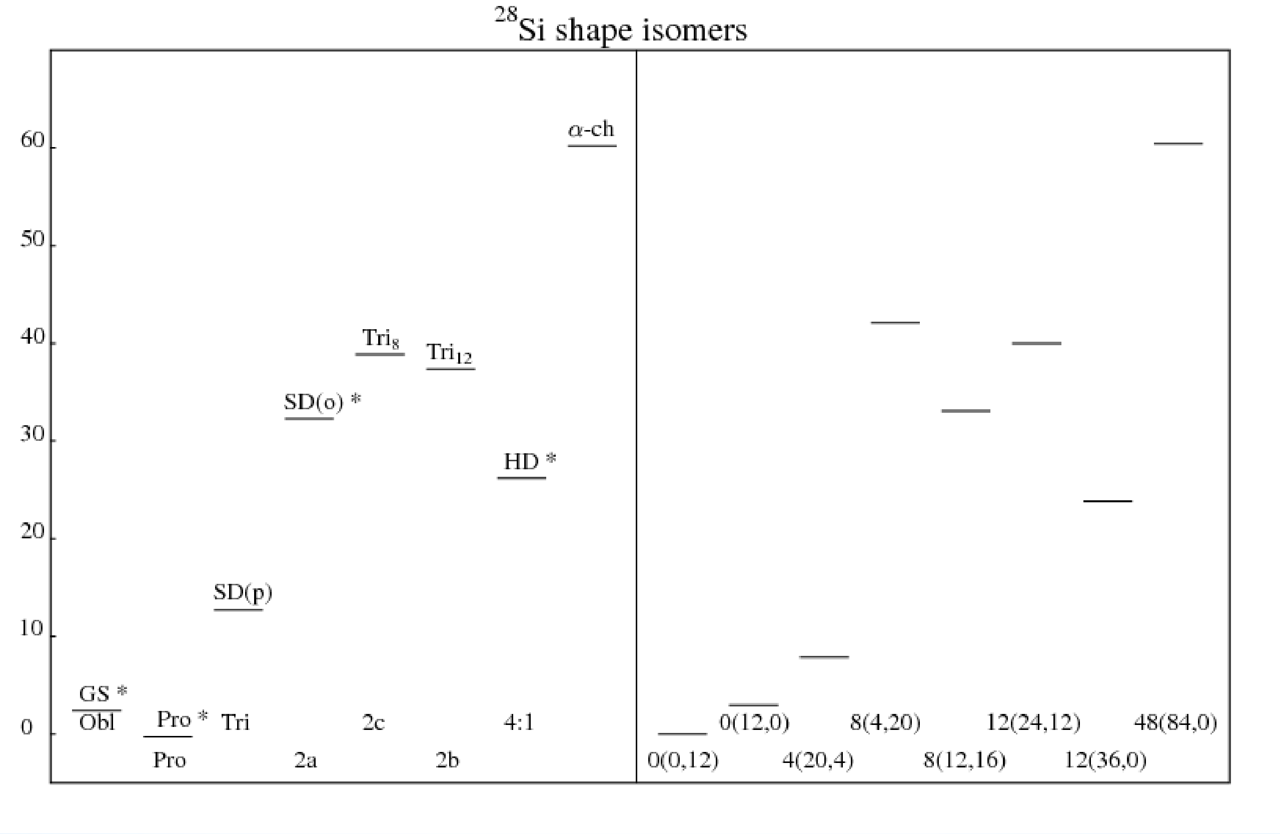


(J. Cseh, G. Riczu, Phys. Lett. B 757 (2016) 312.)

$$\hat{H} = (h\omega)\hat{n} + a\hat{C}^{(2)}_{SU3} + b\hat{C}^{(3)}_{SU3} + d\,\frac{1}{2\theta}\hat{L}^2$$

V. Shape isomers in ^{28}Si

Nilsson $\omega_x:\omega_y:\omega_z$ (β,γ)	Alpha-cluster Shape	Name	E	Shape-selfconsist.	Present work E	$\hbar\omega$	U(3)	SU(3)	(β,γ)	a:b:c
2:1:1 (0.52,60)		Obl	2.4	GS	***0.0***	0	$[16,16,4]_1$	(0,12)	(0.50,60)	1.7:1.7:1
3:3:2 (0.48,0)		Pro	-0.3	Pro	3.0	0	$[20,8,8]_1$	(12,0)	(0.50,0)	1.5:1:1
		Tri	12.7	SD(p)	***7.9***	4	$[28,8,4]_1$	(20,4)	(0.88,9)	2.3:1.2:1
(1.43,60) ?		2a	32.3	SD(o)	42.1	8	$[24,20,0]_1$	(4,20)	(0.84,51)	2.7:2.4:1
		2c	38.9	(Tri_8) ([26,11,7])	33.1	8	$[28,16,0]_1$	(12,16)	(0.91,35)	3:2.1:1
		2b	37.4	(Tri_{12}) ([35,8,5])	40.0	12	$[36,12,0]_3$	(24,12)	(1.14,19)	3.6:1.9:1
(1.06,0)		4:1	26.2	HD	***23.8***	12	$[40,4,4]_1$	(36,0)	(1.29,0)	3:1:1
6:3:1 (1.40,35)				(Tri_{16}) ([43,6,3])	31.52	16	$[44,8,0]_1$	(36,8)	(1.40,10)	4.1:1.6:1
				ED_{28}	***39.2***	28	$[60,4,0]_1$	(56,4)	(1.76,3)	5.3:1.3:1
				(ED_{38}) ([72,2,0])	***49.4***	38	$[72,2,0]_1$	(70,2)	(1.97,1)	6.1:1.1:1
			60.2	α-ch	***60.4***	48	$[84,0,0]_1$	(84,0)	(2.14,0)	7:1:1



28Si shape isomers
60
50
40
30
20
10
0
α-ch
Tri8
Tri12
SD(o) *
HD *
SD(p)
GS *
Obl
Pro *
Tri
2c
4:1
Pro
2a
2b
0(12,0)
8(4,20)
12(24,12)
48(84,0)
0(0,12)
4(20,4)
8(12,16)
12(36,0)

Similar (or the same) shape isomers from different models with different interactions.

Major role of the shell structure.

VI. Conclusions

Clusters and phases: many open questions.
A rich hunting field.

1. Phase structure of the models.
2. Position of the nuclei in the phase diagram.
3. Dictionary between different approaches
   Qualitative correspondence: (educated) guess.
   Qunatitaive: e.g. MUSY (shell and cluster).

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1784 Körös, Hungary – 1842 Darjeeling, India

Author of the first Tibetan-English dictionary and grammer book.

Boddhisatva, Japan 1933.