Cluster12

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Debrecen, Hungary

http://cluster12.atomki.hu

Shell and cluster structure of atomic nuclei

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Kyoto, 20th September – (21st October) – 28th October, 2011.

1. Introduction

Shell model: the nucleus is like a small atom.

Cluster model: the nucleus is like small molecule.

Shell or cluster structure?

2. Summary

Shell AND cluster structure.

Not new.

i) Tend to forget.
ii) New evidences.
iii) New application of this connection.

Content

3. Logical arguments

Two sets of (over)complete basis
Real nuclear state: expand.

1. Good SM state (bad CM)
2. Good CM state (bad SM)
3. Good SM and CM
   shell-like cluster state
4. Not simple

Definition of clustering

Clustering: experimental observation
   large overlap with a reaction channel
   2 and 3 are cluster states

4. History

Oh, those fifties!

Important events in the history of popular culture

Wembley stadium: Hungary-England: 6-3

England was unbeaten at home for more than 90 years until November 25,1953.

… as well as in the history of the nuclear structure theories

From shell model to cluster model:

Wildermuth-Kanellopoulos:
Harm. osc. appr. $H_{SM} = H_{CM}$

Bayman-Bohr: SU(3)

From shell model to cluster model:

Elliott: SU(3) deformation + rotation

Later on : Many others:

Kramer
Moshinsky
Hecht
Draayer
Suzuki
Neudatchin
Smirnov
Arima
Horiuchi
Kato

5. Experimental arguments

5.1. New analysis of old data

CM→SM
(N.Itagaki, J. Cs, M.Ploszajczak, PRC83, 14302, 2011.)
Microscopic model for describing shell and cluster

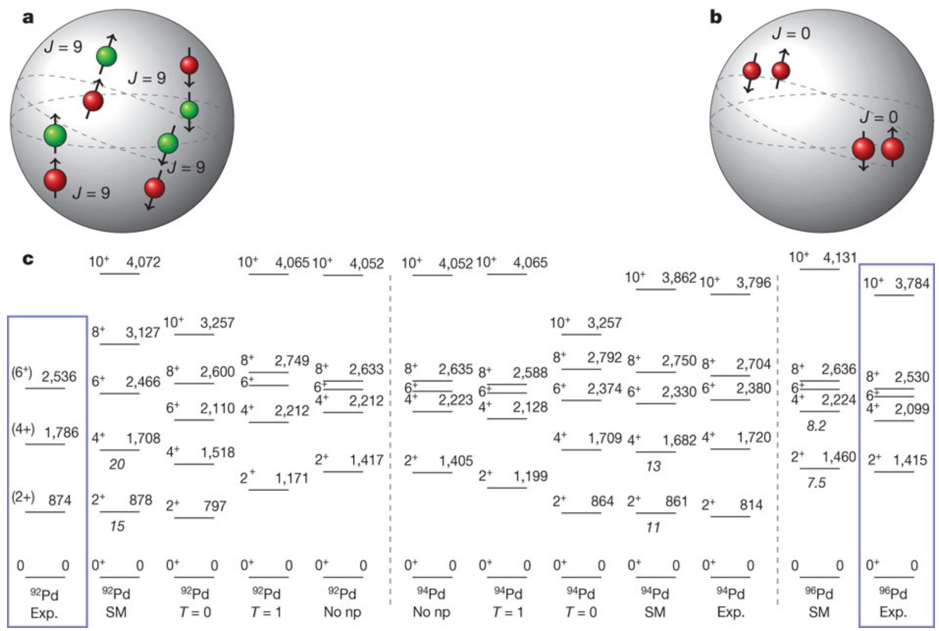
- 2 parameters in the wf. → SM
- ^{20}Ne, ^{24}Mg ground state band
- close to shell structure

SM→CM
SU(3) Draayer, Hecht, Suzuki

Shell-like clusterization is important!

5.2. Far from the stability

Illustration of the predicted ground-state wavefunctions of ^{92}Pd and ^{96}Pd, and comparison of calculated and experimental level energies in ^{92}Pd, ^{94}Pd and ^{96}Pd.



B Cederwall *et al. Nature* **469**, 68-71 (2011)

nature

6. Symmetries

6.1. From the cluster side

Semimicroscopic Algebraic Cluster Model (SACM)

Rigid-molecule-like and shell-like clusterizations

O(4) and U(3) dyn. sym.

Internal cluster structure

$U_C^{ST}(4) \times U_C(3)$

Relative motion: vibron $U_R(4)$

+ Pauli exclusion

(J. Cseh, Phys. Lett. 281B, 173, 1992;
J. Cseh, G. Lévai, Ann.Phys.(NY)230,165,1994.)

Applications: U(3) dyn. symm., shell-like clusters.

Multichannel U(3) dynamical symmetry

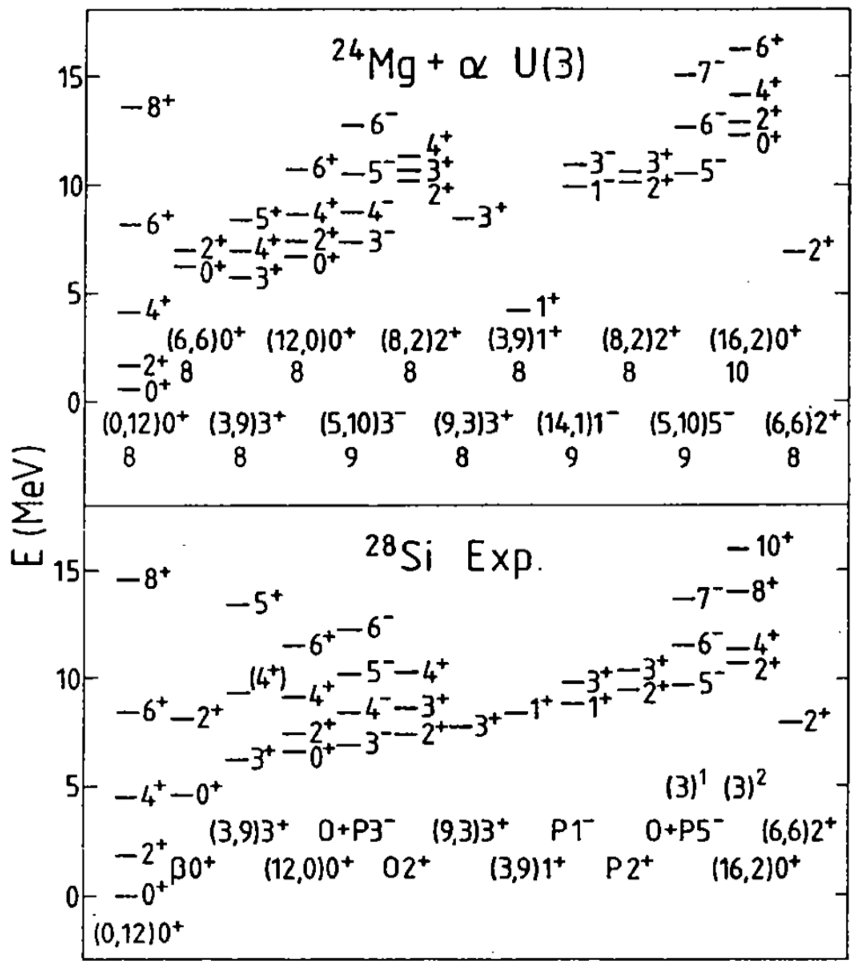
(J. Cseh, PRC 50, 2240, 2004; K. Kato, J. Cseh, in progress.)

Coexisting cluster-configurations in a nucleus, e.g.

$$^{24}Mg+^{4}He,\ ^{12}C+^{16}O$$

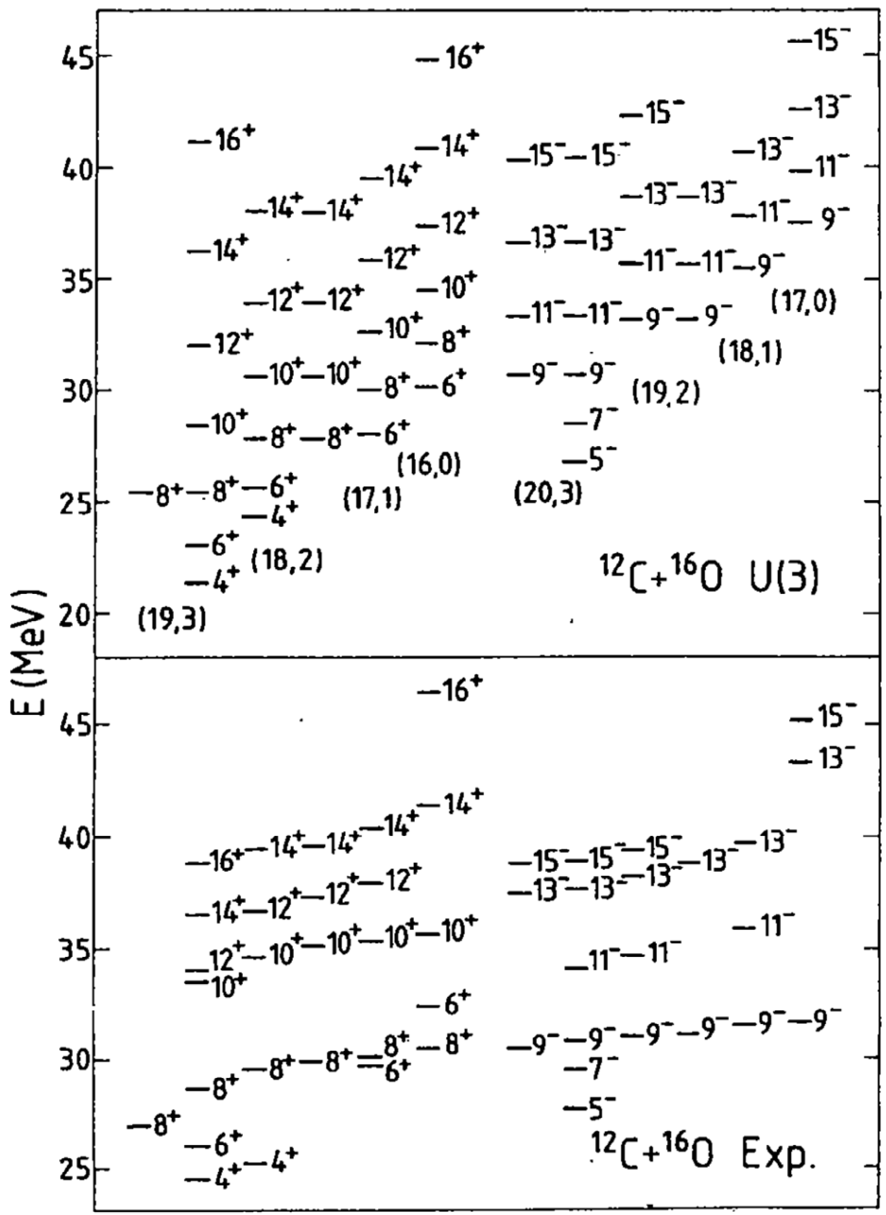
$U_{C_i}(3)\otimes U_{R_i}(4)$ dynamical symmetry
+ Talmi-Moshinsky symmetry.

Unified classification scheme + operators.
Strong constraints, less ambiguity, strong predictive power.



$^{24}Mg + \alpha$ U(3)
^{28}Si Exp.
E (MeV)
(0,12)0+ 8
(6,6)0+ 8
(3,9)3+ 8
(12,0)0+ 8
(5,10)3− 9
(8,2)2+ 8
(9,3)3+ 8
(3,9)1+ 8
(14,1)1− 9
(8,2)2+ 8
(5,10)5− 9
(16,2)0+ 10
(6,6)2+ 8
β0+
(3,9)3+
(12,0)0+
0+P3−
O2+
(9,3)3+
(3,9)1+
P1−
P2+
0+P5−
(3)1 (3)2
(16,2)0+
(6,6)2+
(0,12)0+

$$H = \varepsilon + \gamma n_{\pi} + \beta L^2 + \theta n_{\pi} L^2 + \phi_1 C_2 + \phi_2 C_3 + \left(\phi_3 C_2 + \phi_4 C_3\right) L^2$$



E (MeV)
45
40
35
30
25
20
(19,3)
(18,2)
(17,1)
(16,0)
(20,3)
(19,2)
(18,1)
(17,0)
$^{12}C+^{16}O$ U(3)
$^{12}C+^{16}O$ Exp.

Reaction	L	N_{expt}	$N_{Mg\alpha}$	N_{CO}
$^{24}Mg+\alpha$	0	4	1	0
$^{24}Mg+\alpha$	1	7	10	1
$^{24}Mg+\alpha$	2	17	15	2
$^{12}C+^{16}O$	8	6	42	6
$^{12}C+^{16}O$	9	6	32	2
$^{12}C+^{16}O$	10	5	27	3
$^{12}C+^{16}O$	11	3	30	5
$^{12}C+^{16}O$	12	4	48	9
$^{12}C+^{16}O$	13	6	33	8

Supersymmetry of cluster systems

(G. Lévai, J. Cseh, P. Van Isacker, Eur. Phys. J. A12, 305, 2001.)

Bosons: dipole phonons, fermions: nucleons.

Unified description of even and odd nuclei.

Similar cluster configurations, e.g. core plus alpha-particle.

6.2. From the shell m. side: Quarteting

Gillet, Danos, Arima, Harvey

SM→CM
Quartet: (alpha-like SM state)

Algebraic qurtet model: in preparation.

6.3. More recently

Quasy-dynamical SU(3)

Shape-isomers and clusterization

Quasi-dynamical SU(3) symmetry

D. Rowe at al. (PL 210B,5; NPA 528, 409.)

Sym.	H	$|\Psi>$	E.g.
Exact s.	+	+	HO
Dyn. (br.) s.	-	+	Elliott, IBM, SACM
QDS	-	-	shell+cluster

7. Phases

Nonthermal phase transitions

Shape-phase tr.
Quantum phase tr.
Zero-temperature phase tr.

Extensive studies in the collective models
Iachello, Jolie, Cejnar, Rowe, Casten, Bonatsos,…

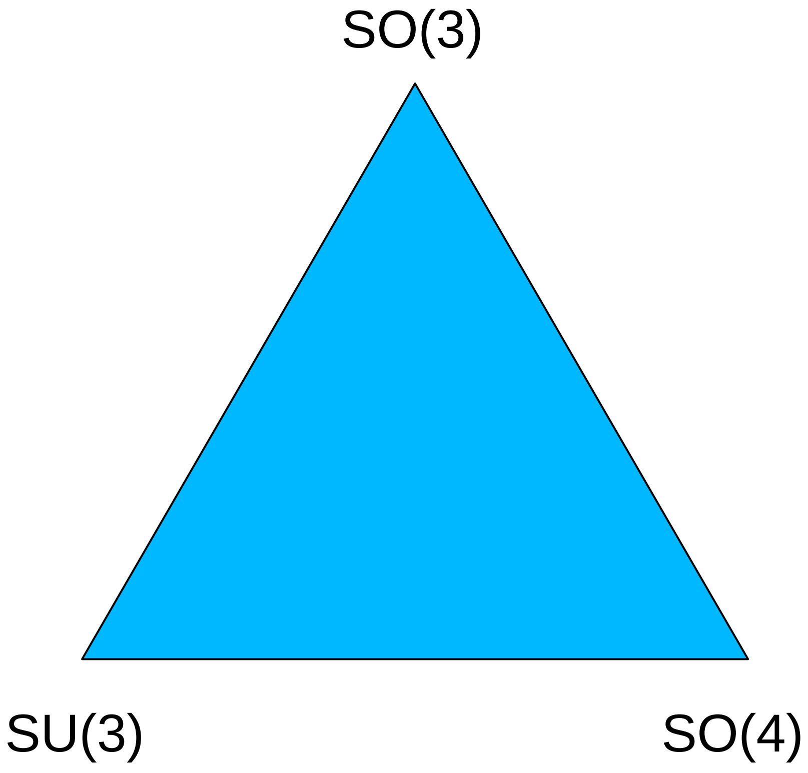
7.1. Phases and clusters

Rel. motion: vibron model

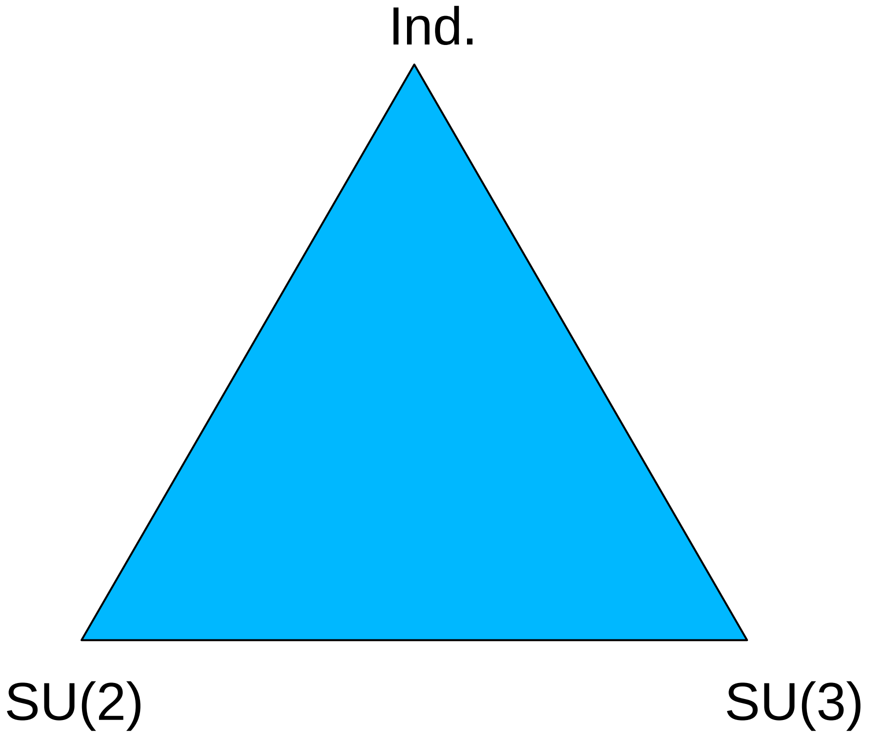
vibron model: U(3) – O(4)

Cluster model

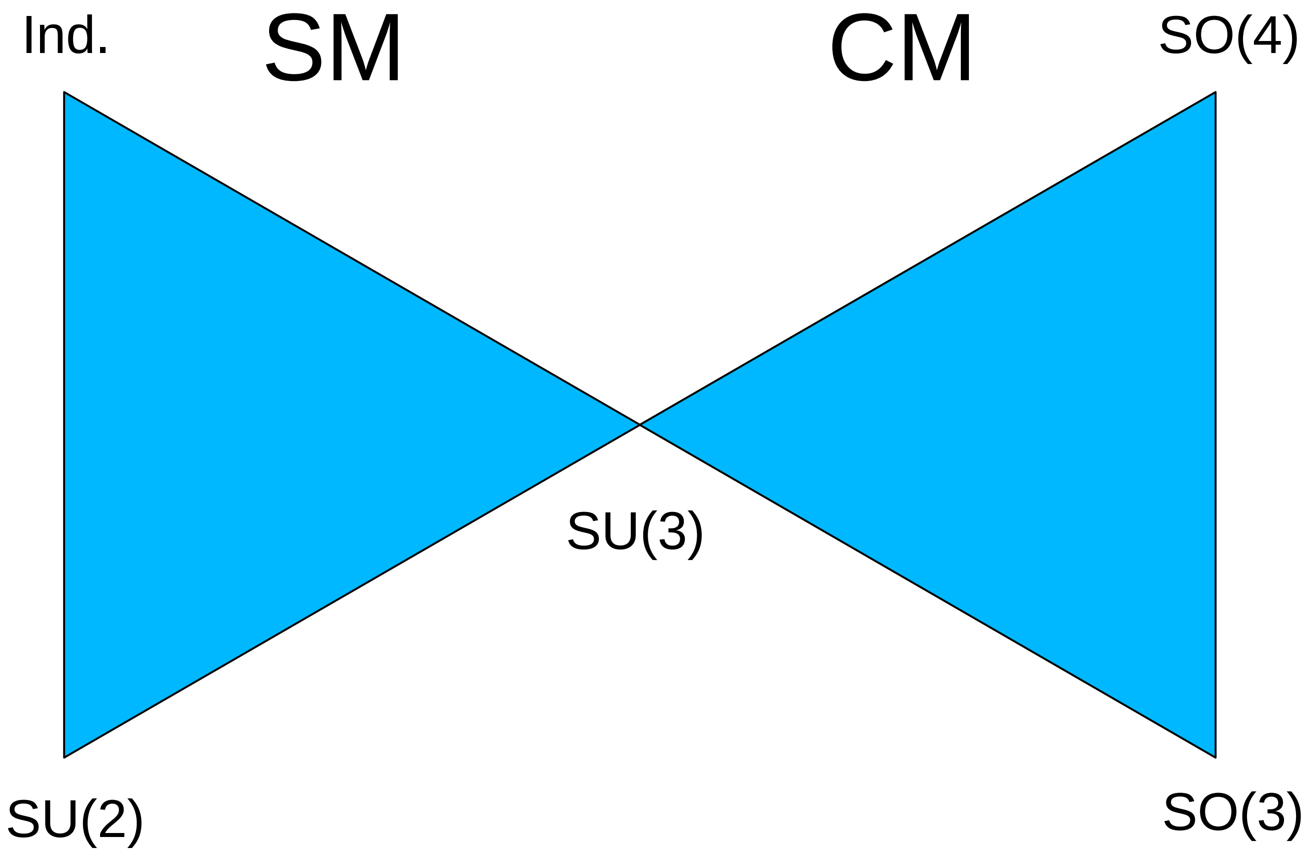
- Coupling to int. d. f.
- Pauli-principle



7.2. Shell model (P. Van Isacker)



7.3. Shell and cluster



8. New microscopic approach:

Symmetry-adopted no-core shell model

(J.P. Draayer et al, J.Phys. Conf.Ser. 321, 012040, 2011.)

NCSM: ab initio, i.e.

i) realistic (bare, QCD-inspired…) interactions, and

ii) first principle equqtions.

^{6}Li, ^{7}Li, … N_{max} = 6.

SA-NCSM: proton-neutron L-S coupling,

Low-spin, high deformation dominance,

Wf: 99.6%, bind.en.: 98.7%.

Only a small fraction of the complete model space is needed to model the low-energy dynamics.

Build up the model space as suggested by the symmetry considerations. Gain in the dimension: several orders of magnitude.

Computational group theory
(including third leg W.N).
Extension of NCSA in particle no, and major shell.

E.g. ten 0^+ in ^{12}C, only 1st and 6th has cluster str.
Experiment 2nd is Hoyle-state.
Where are the others?
Is te realistic n-n interaction really realistic?
Questions from many-body theory to n-n force!

Twofold role of SU(3)!

9. Conclusion

Shell or cluster structure?

Clusterization in the ground-state?

i) No-way.

ii) Yes, of course.

Different kind of clusterizations, at least two.

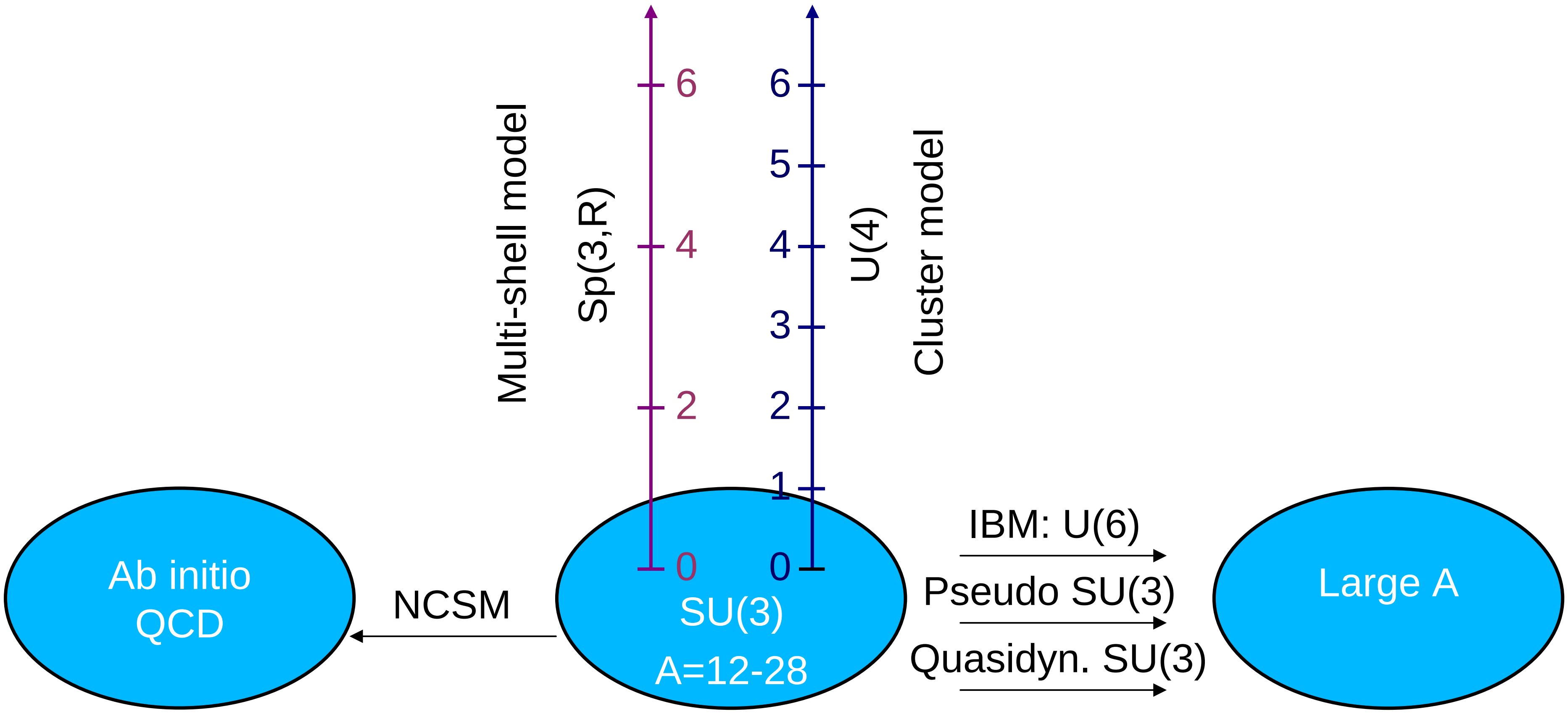
(Just like in shell or q. collective model.)

Better language for discussion.

Quantitatively: phases and transitions of the clusterized finite nuclear matter.

SU(3) connection from low to high energy,
from light to heavy nuclei.
from light nuclei to n-n interaction.

Extension of Elliott´s SU(3)



Arigato gozaimasu!

Thank you for your attention!

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