

Symmetry-Guided Ab Initio Approach to Light and Medium-Mass Nuclei

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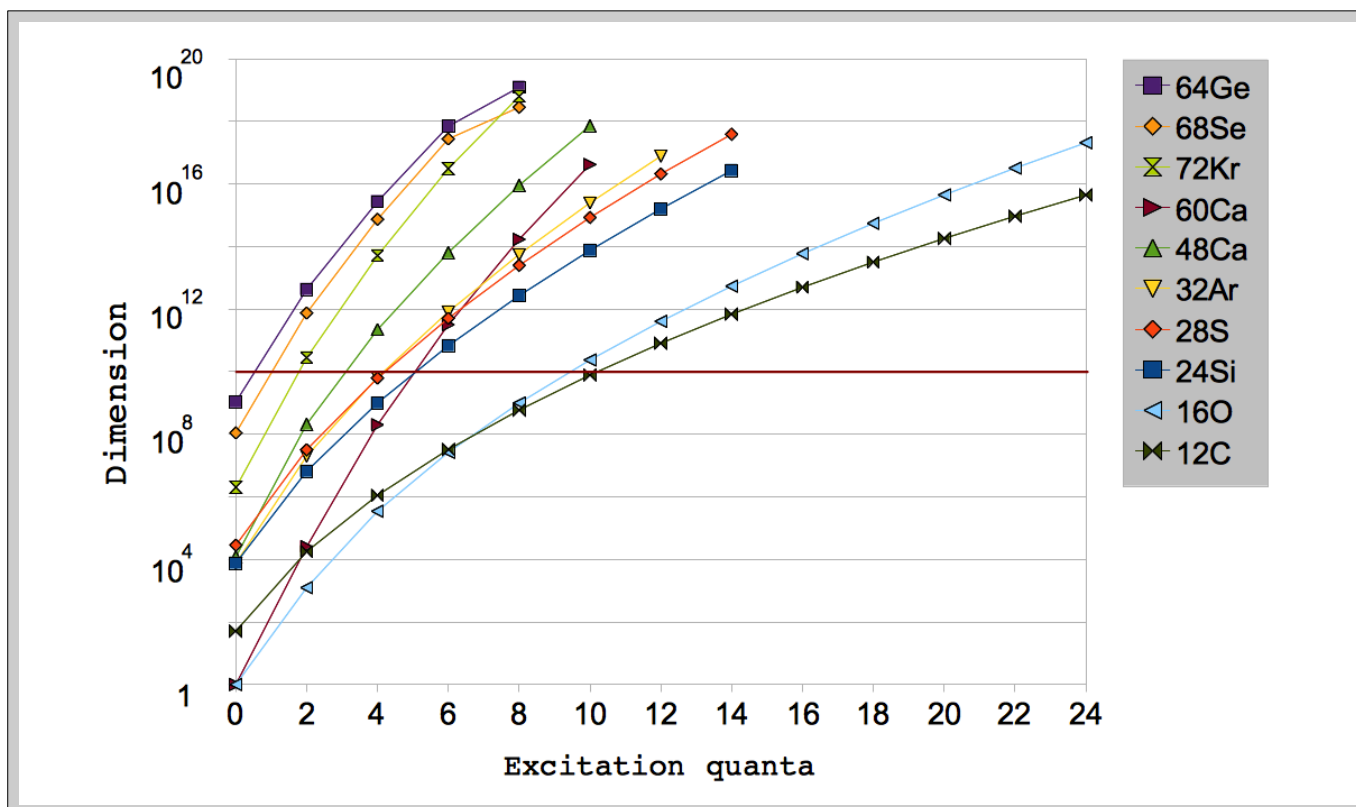
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Symmetry-Guided Ab Initio Approach

Motivation: exponentially increasing size of model space \Rightarrow computational scale explosion

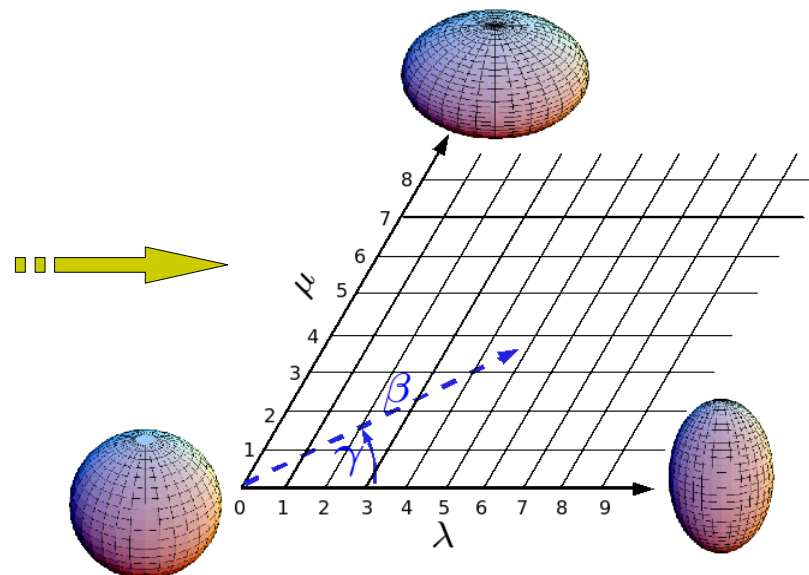


Symmetry-Guided Approach

- realistic interactions + symmetries of nuclear collective motion: $Sp(3,R)$ & $SU(3)$
- extend reach of ab initio approaches towards medium mass nuclei
- include physically relevant many-particle correlations beyond current computational limits

SU(3)-Scheme Basis

- Complete basis
- Relevant for description of spatially deformed nuclei & nuclear collective motion
- SU(3) is a subgroup of the symplectic model of the nuclear collective motion
- $(\lambda \mu)$ related to shape variables β and γ of the collective model
- Allows to include correlations important for α - cluster structures



J-coupled proton-neutron basis labeled by intrinsic spins $S_p S_n S$ and deformations

$$|\gamma \overbrace{S_p S_n S}^{\text{intrinsic spin part}} \overbrace{(\lambda \mu) \kappa L}^{\text{spatial part}} J M \rangle$$

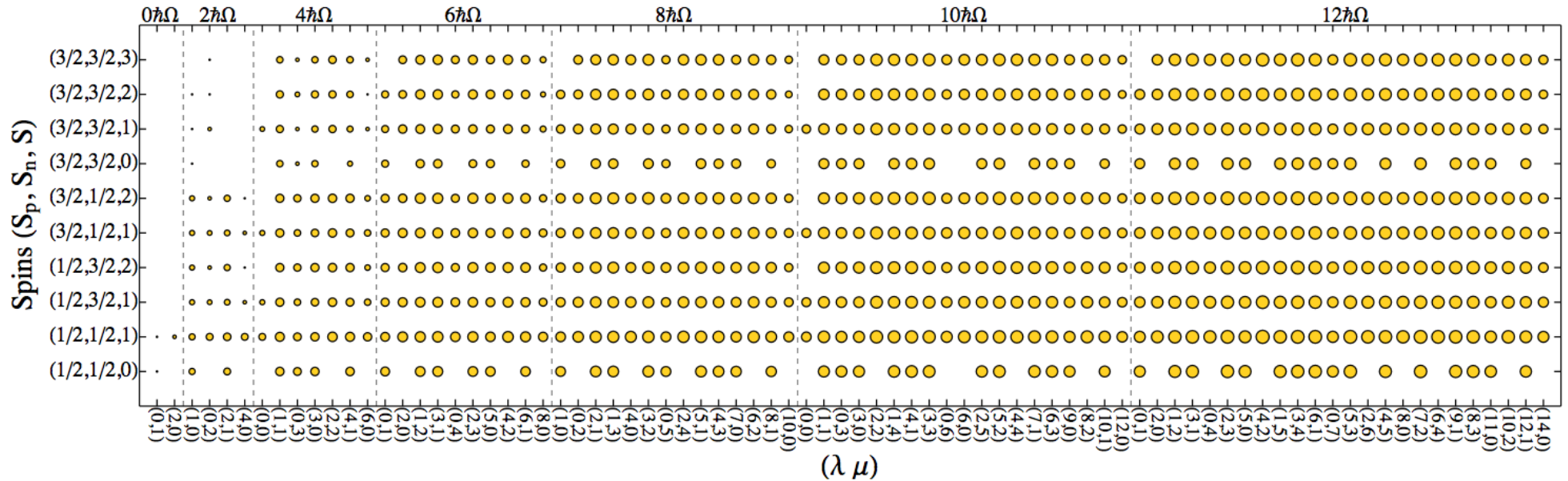
orbital angular momentum

multiplicity label – needed to distinguish multiple occurrence of L

SU(3) quantum numbers

Shape & Spin Decomposition of Model Space

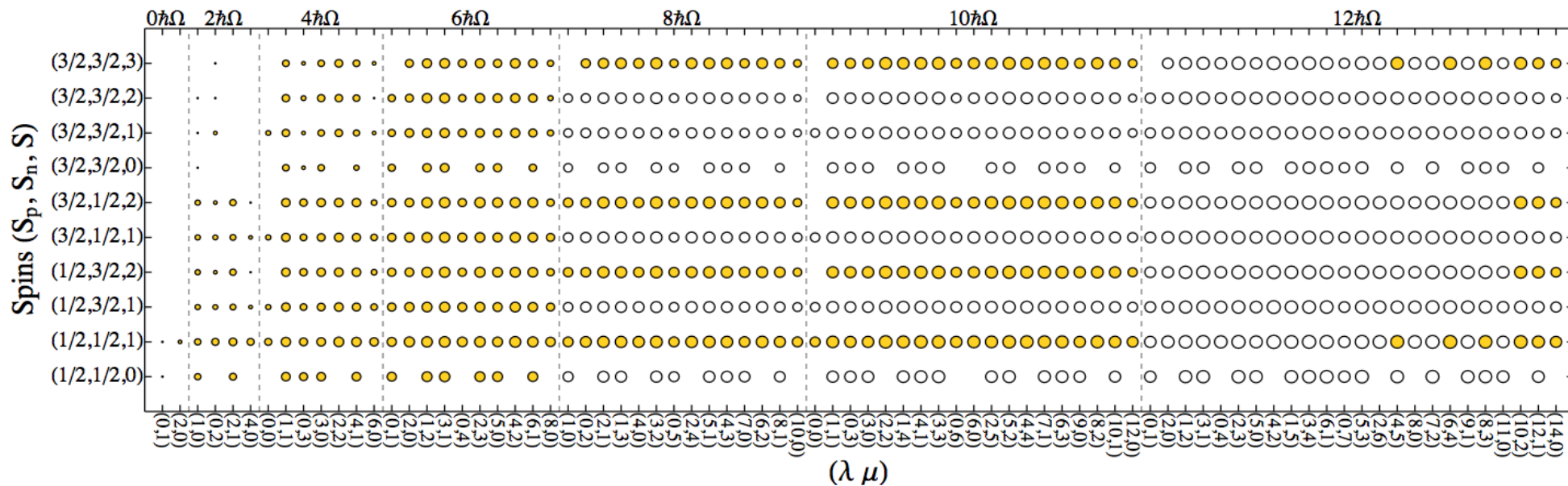
Example: decomposition of Nmax=12 model space of ${}^6\text{Li}$ in terms of shapes $(\lambda \mu)$ and spins $S_p S_n S$



- Each circle represents states carrying $(\lambda \mu) S_p S_n S$ quantum numbers
- Area is proportional to the number of such states [log]
- Center-of-mass degrees of freedom can be factorized within each $(\lambda \mu) S_p S_n S$ subspace

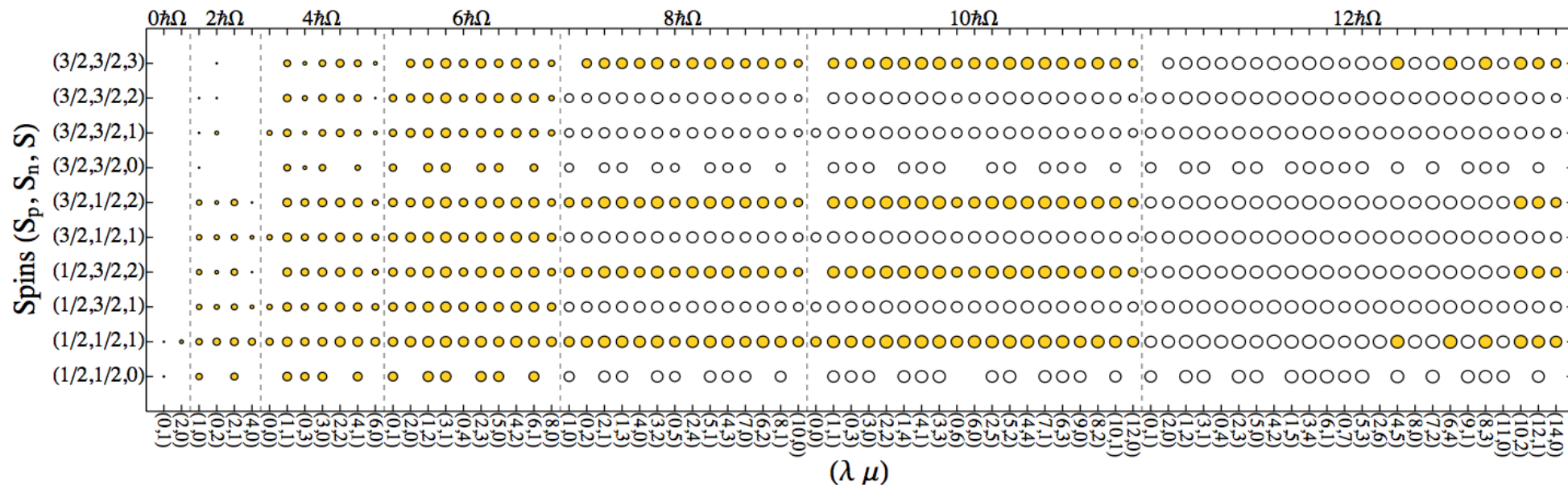
Winnowing of Model Space

- Winnowing of model space by (1) intrinsic spins
- (2) deformations



Winnowing of Model Space

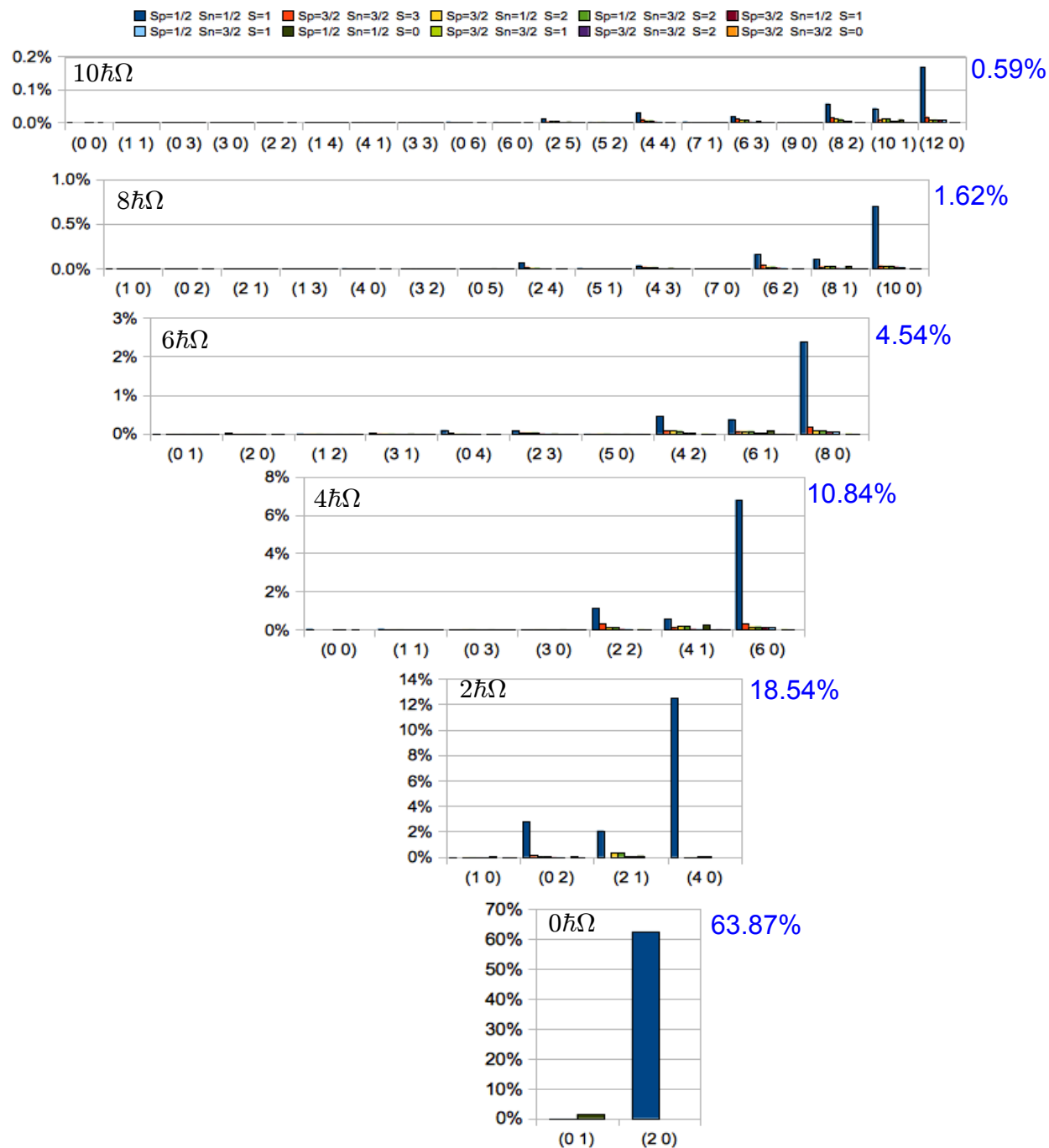
- Winnowing of model space by (1) intrinsic spins
(2) deformations



- Realistic interactions: enormous mixing of different $S_p S_n S (\lambda \mu)$ subspaces

- Coherent mixing ?

⁶Li : decomposition of the ground state



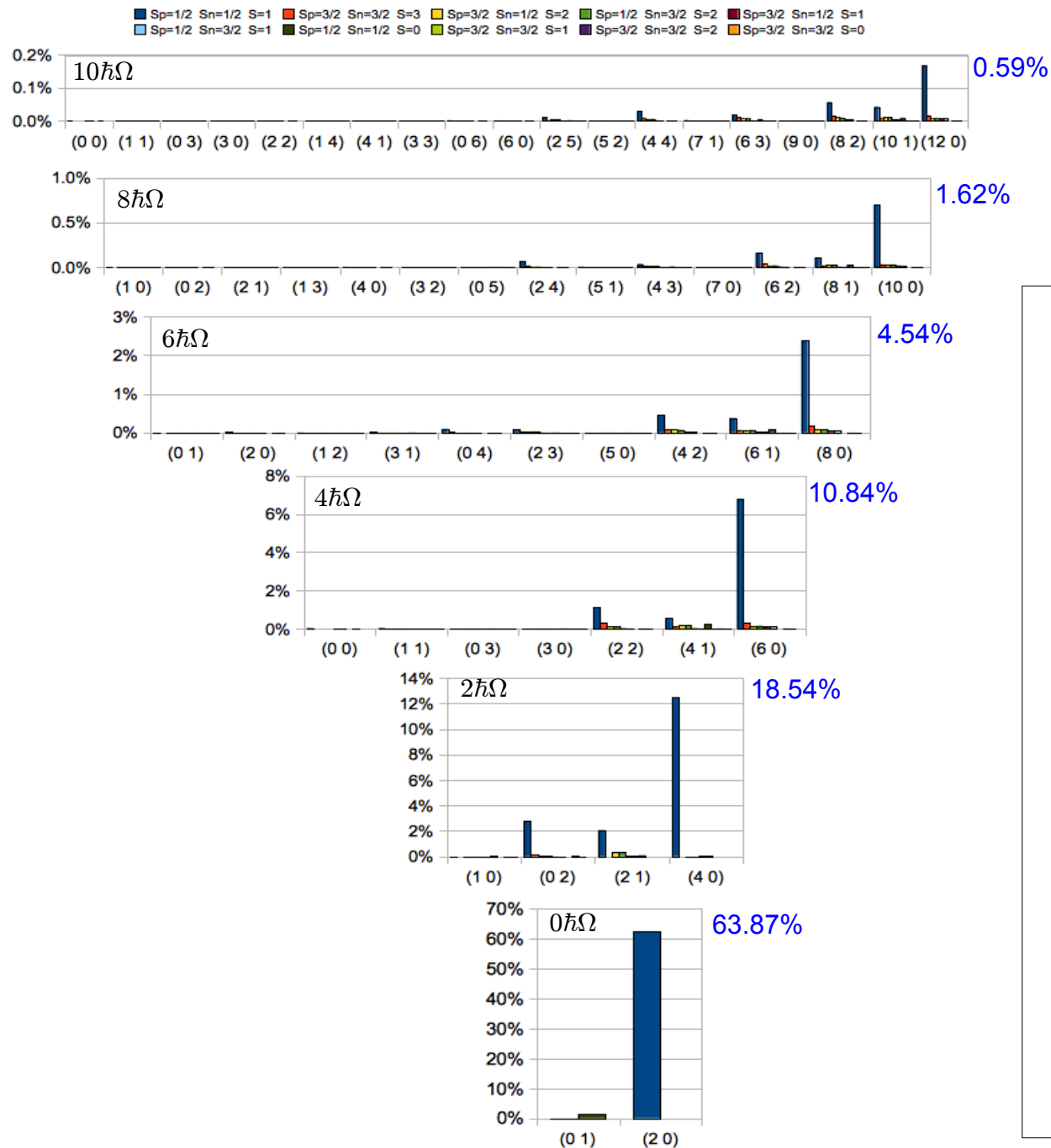
JISP16 bare + Vcoul interactions

$\hbar\Omega = 20$ MeV $N_{\max} = 10$

Four spin components dominate (over 99%)

S_p	S_n	S
1/2	1/2	1
3/2	3/2	3
1/2	3/2	2
3/2	1/2	2

⁶Li : decomposition of the ground state



Coherent mixing of shapes

■ valence space ($0\hbar\Omega$)

- Dominated by the most deformed configuration $(\lambda_0 \mu_0) = (2 0)$
- Consistent with Elliot's $SU(3)$ model

■ $k\hbar\Omega$ space

- Dominated by $(\lambda \mu)$ satisfying

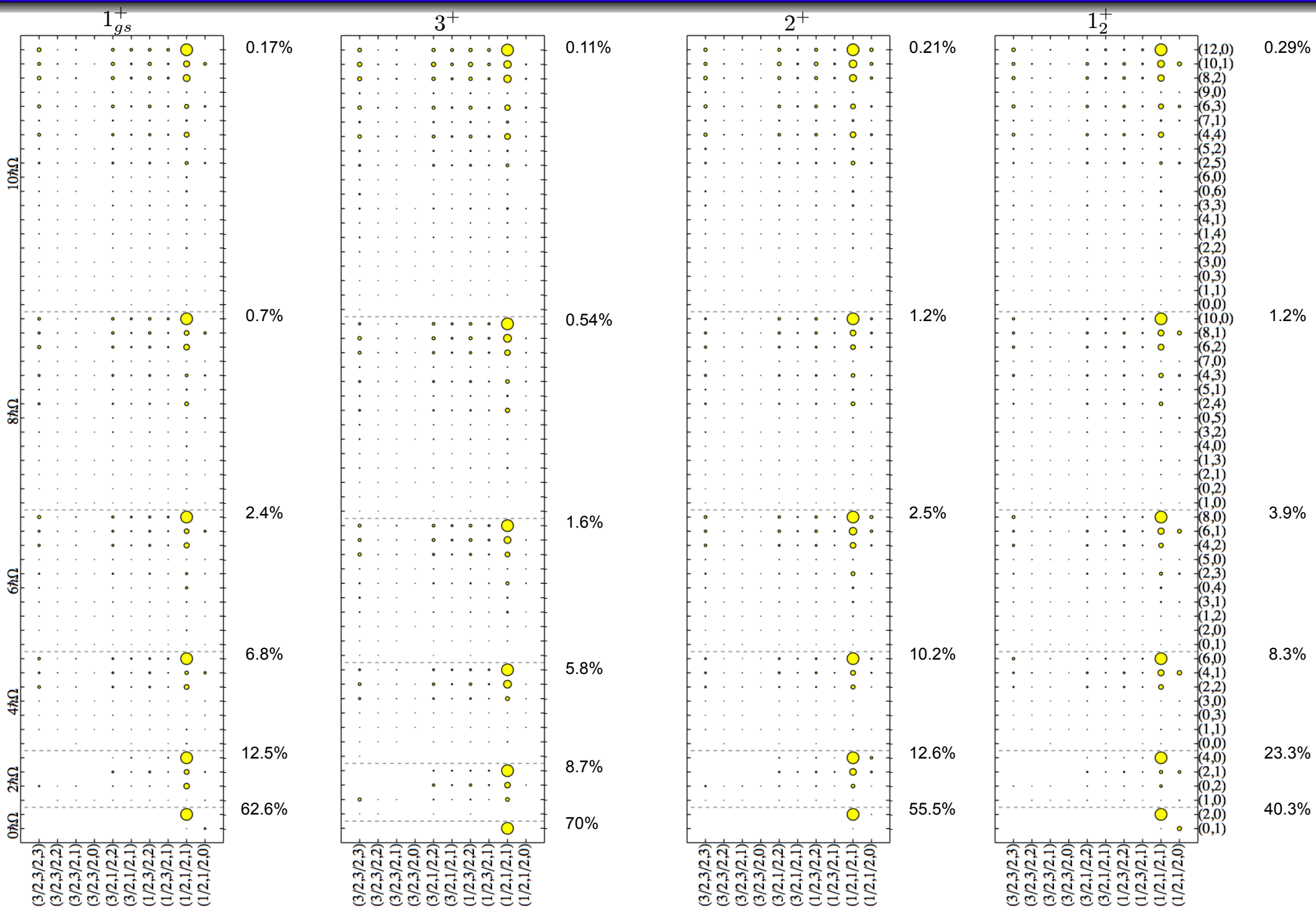
$$\lambda + 2\mu = \lambda_0 + 2\mu_0 + k$$

highest contribution: $(\lambda_0 + k \mu_0)$

- Consistent with symplectic model

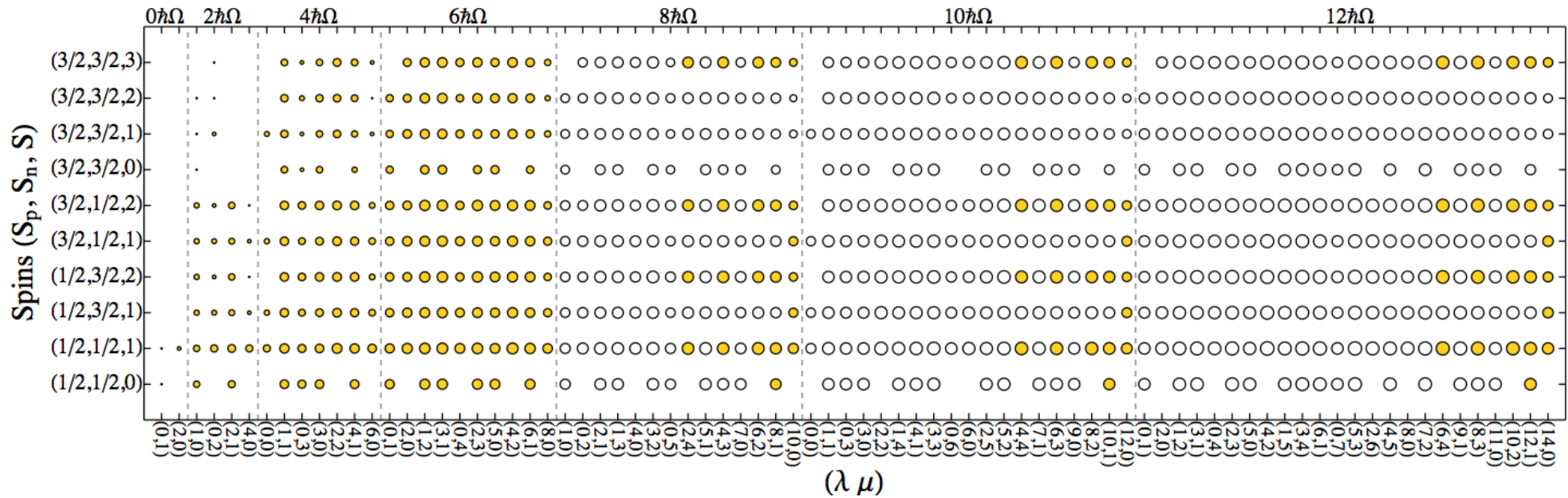
$$Sp(3, R) \supset Sp(2, R) \supset Sp(1, R)$$

${}^6\text{Li}$ - intrinsic structure of $T=0$ states



12[6] Model Space

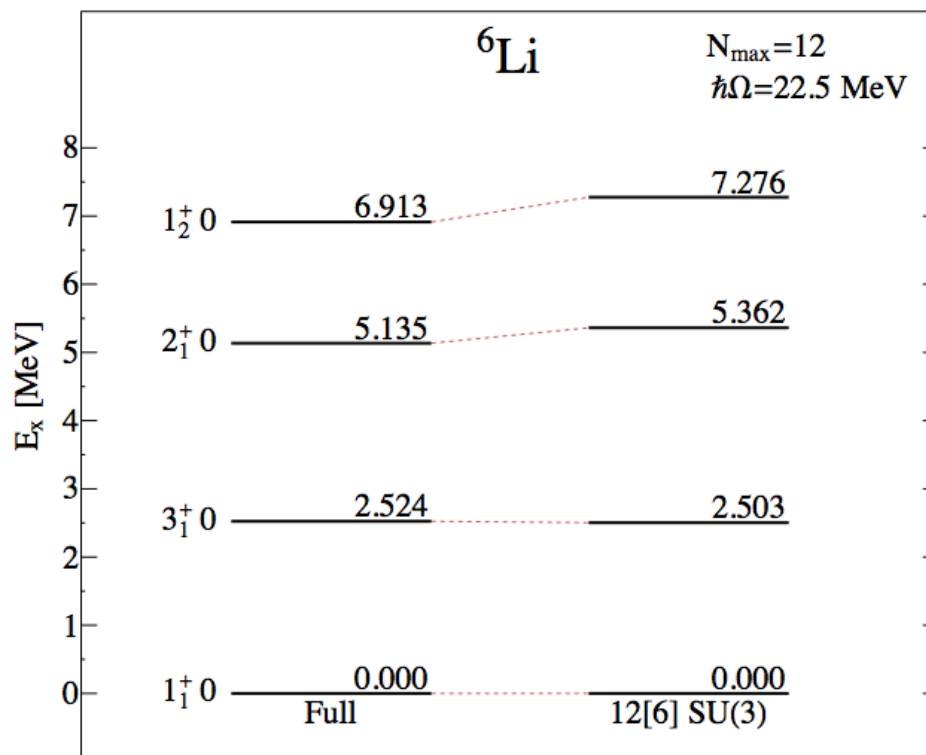
Structure of 12[6] winnowed model space



Properties of the ground state in 12[6] and full Nmax=12 model space

	12[6]	Full
Binding energy [MeV]	-30.433	-30.875
rms [fm]	2.075	2.09
E2 moment [e fm ²]	-0.074	-0.066
M1 moment [μ_N]	0.837	0.836
dimension	~1%	100%

Spectroscopic Properties in 12[6] Model Space



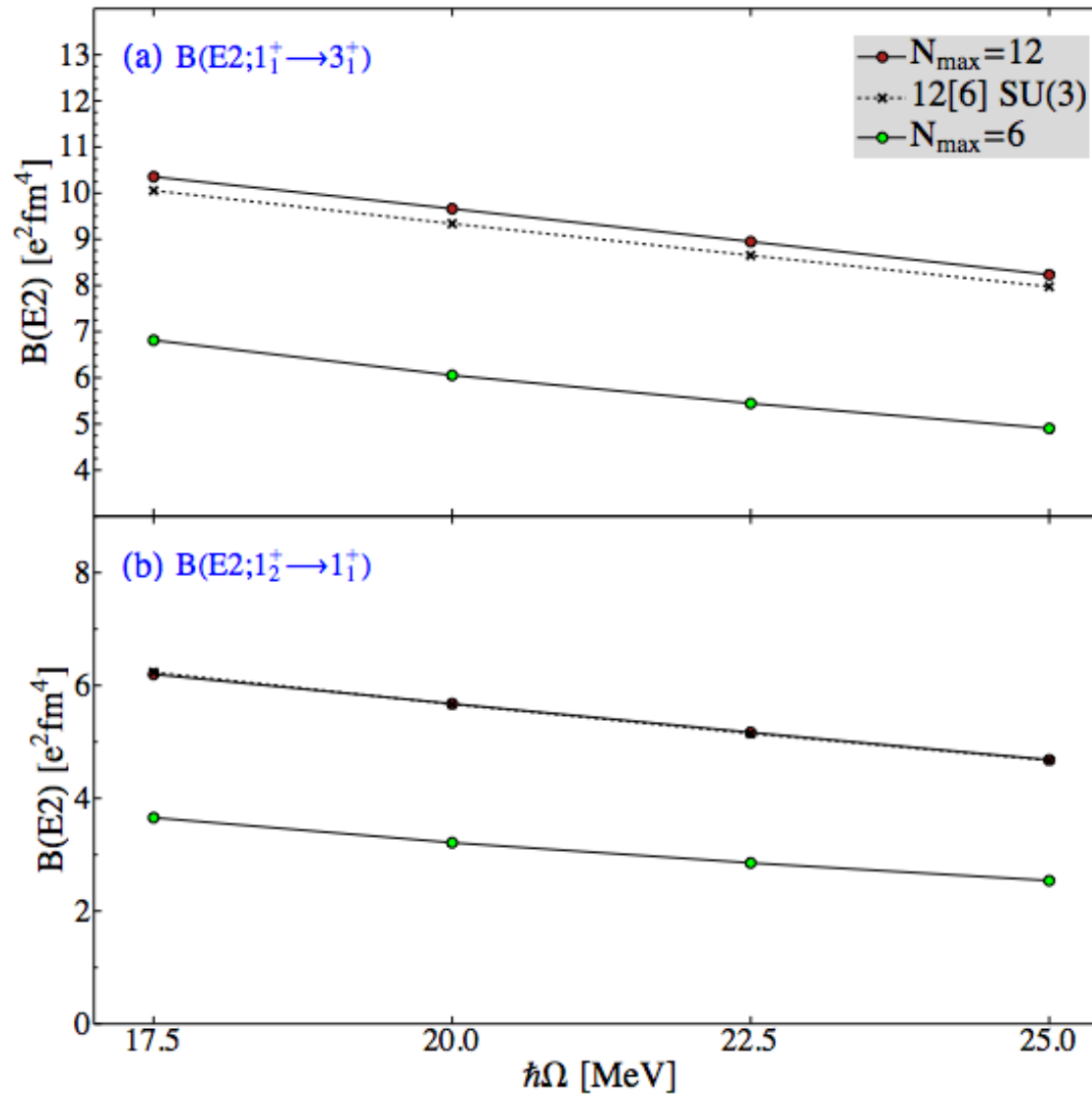
$\hbar\Omega = 17.5$ MeV

Magnetic dipole moments [μ_N]

$N_{\text{max}} = 12$	1_{gs}^+	3^+	2^+	1_2^+
full	0.838	1.866	0.960	0.336
12[6]	0.840	1.866	1.015	0.337

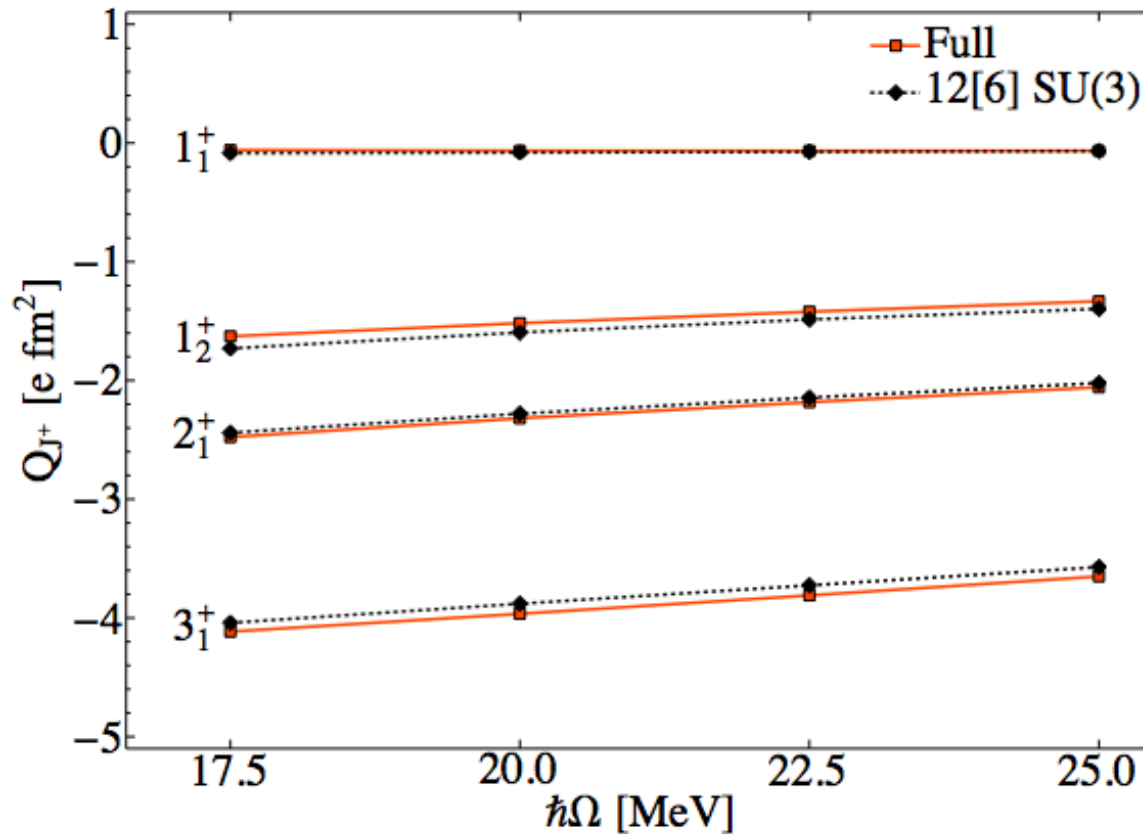
Physical Observables in 12[6] Model Space

■ BE2 transitions in 12[6] and full Nmax=12 model space

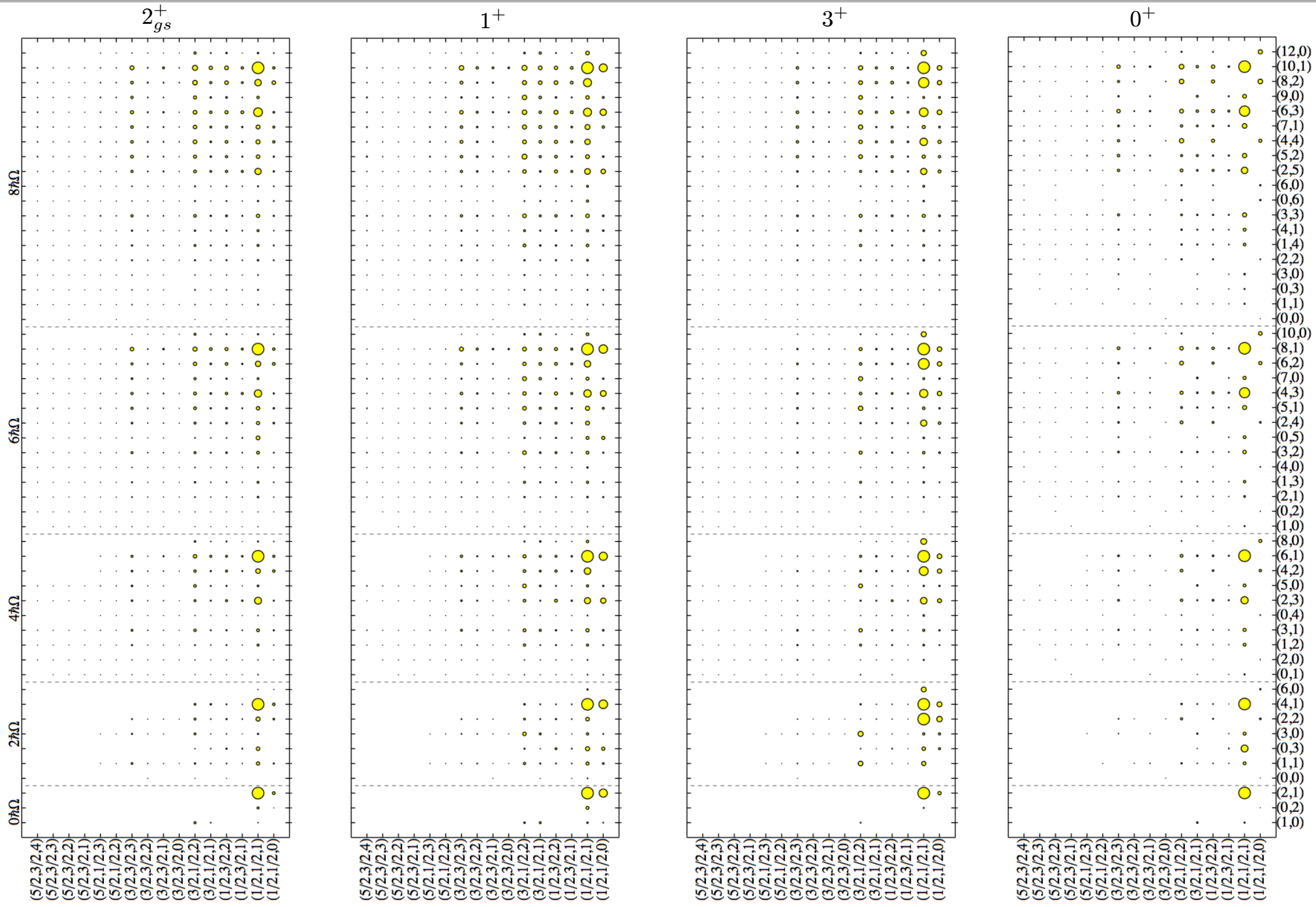


Physical Observables in 12[6] Model Space

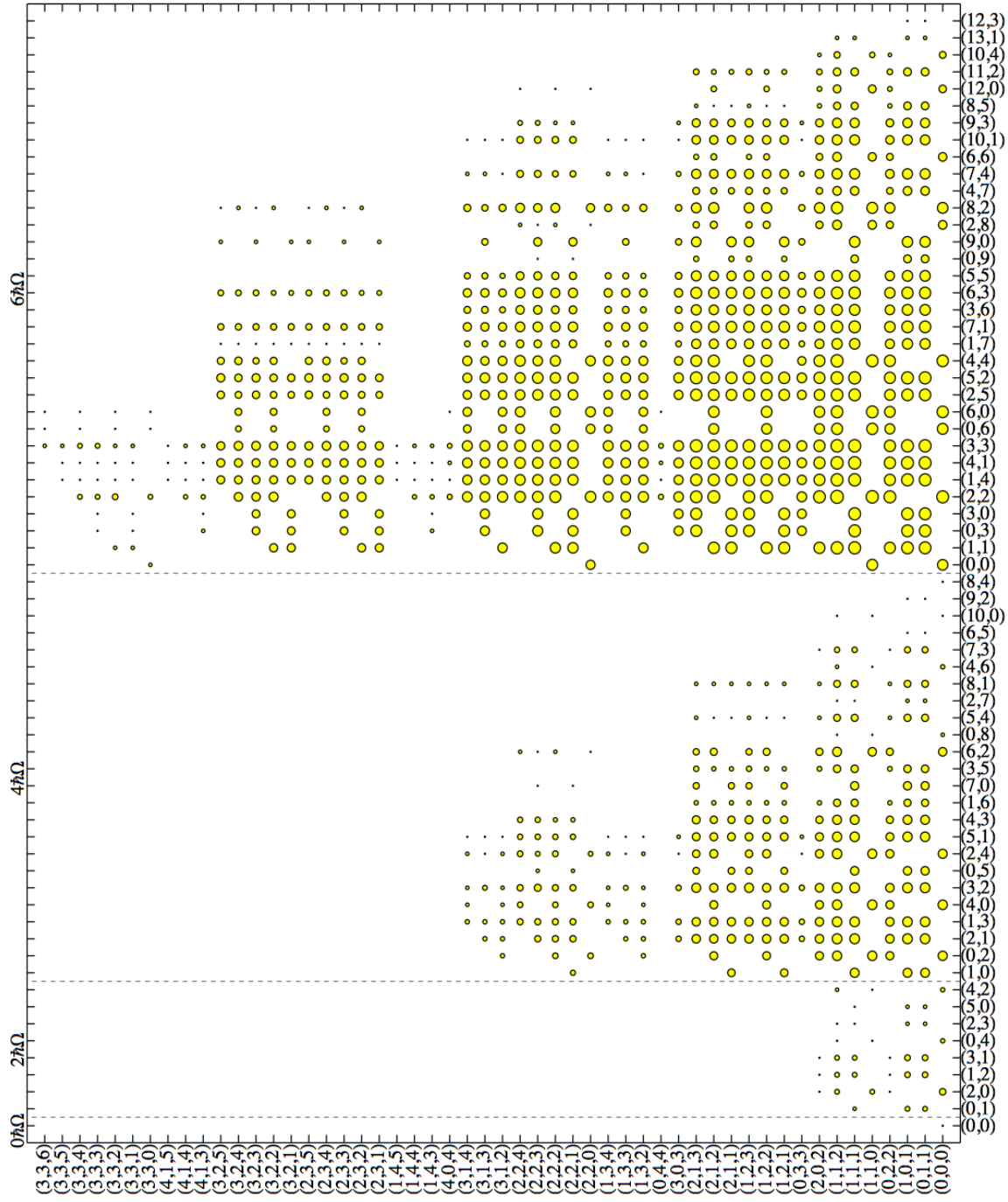
■ E2 moments in 12[6] and full $N_{\max}=12$ model space



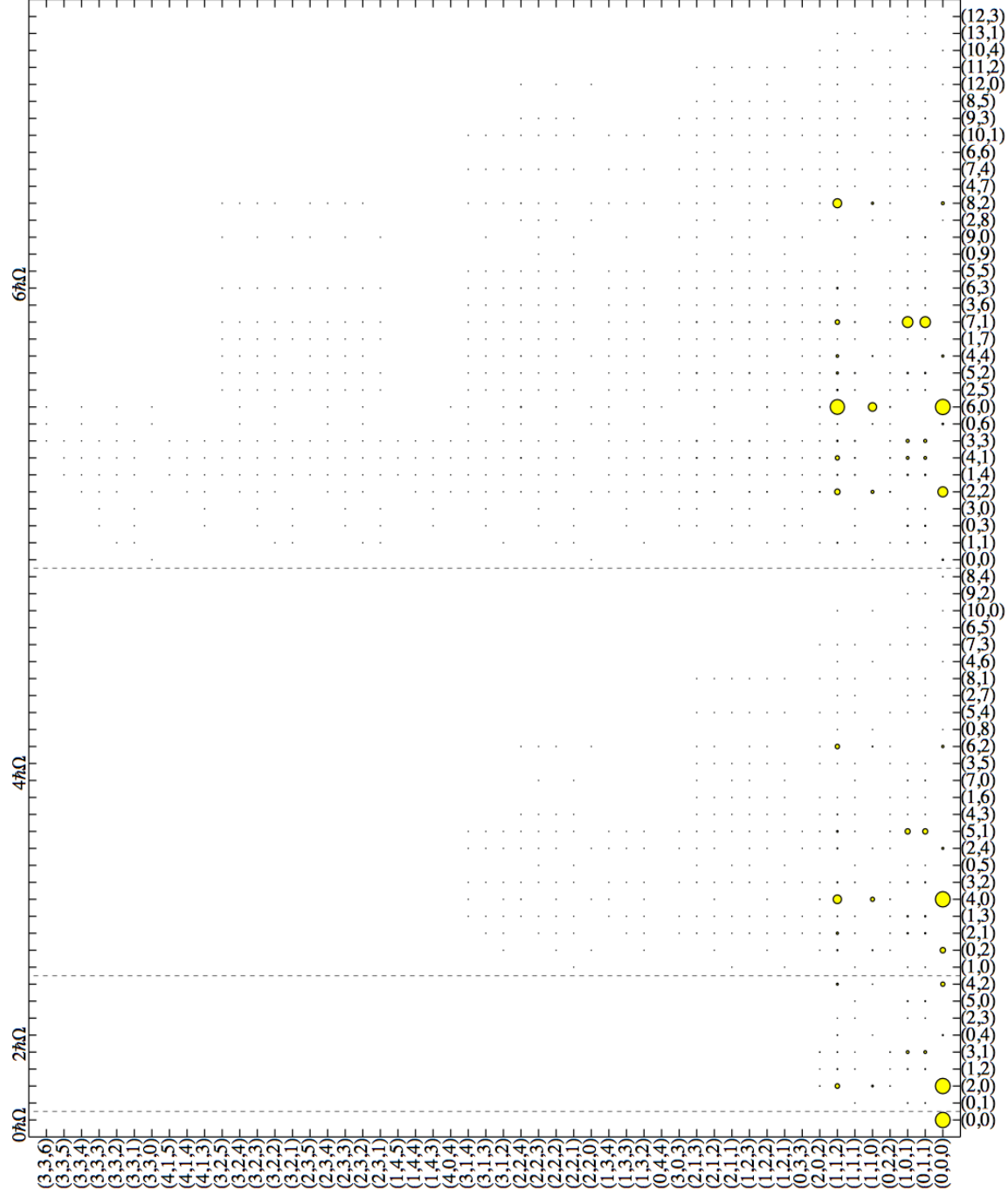
$N_{\max} = 12$	Matter rms radii [fm]				$\hbar\Omega = 17.5$ MeV
	1_{gs}^+	3^+	2^+	1_2^+	
full	2.146	2.092	2.257	2.373	
12[6]	2.139	2.079	2.236	2.355	



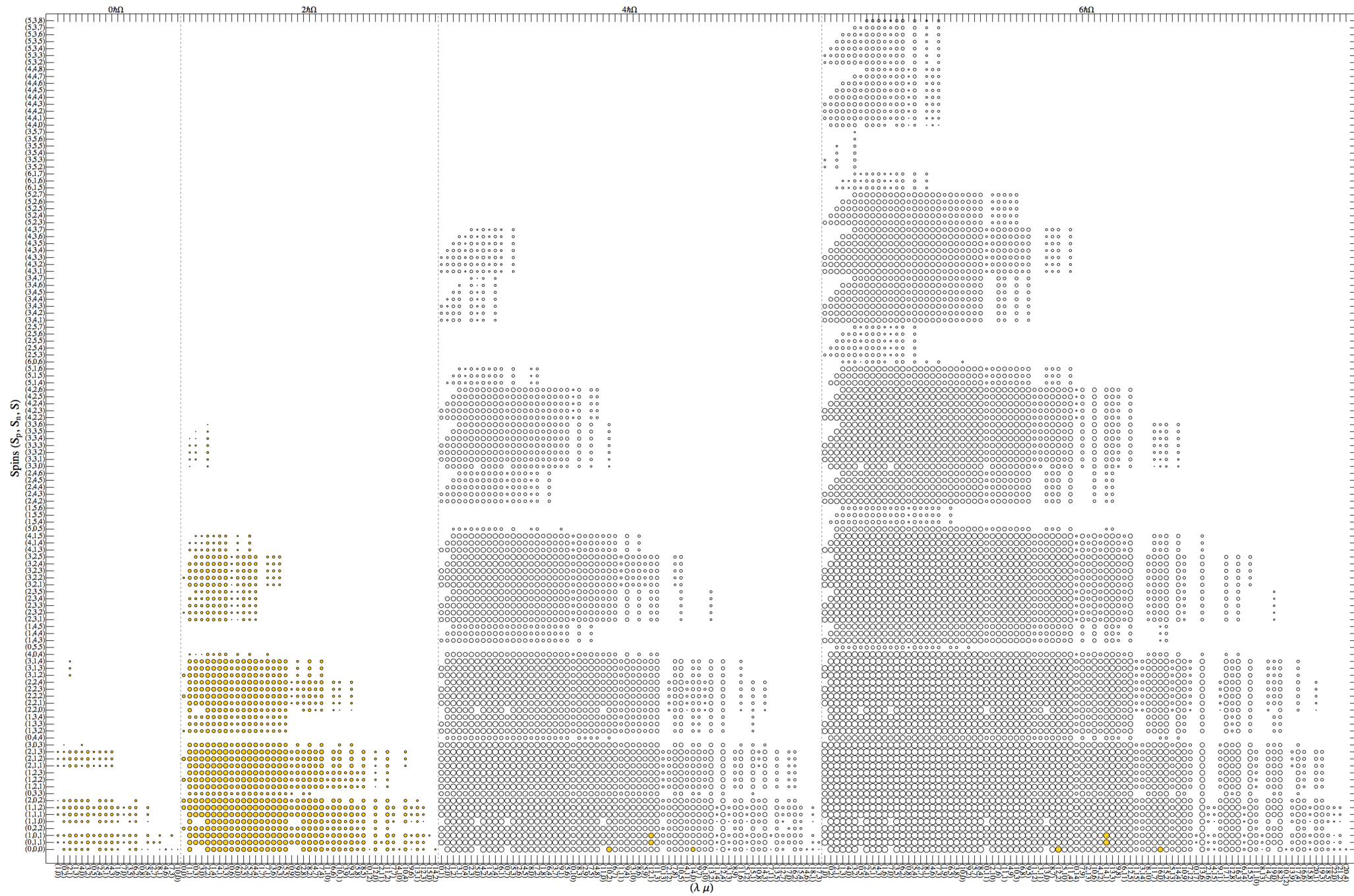
16 O : model space decomposition



^{16}O : ground state

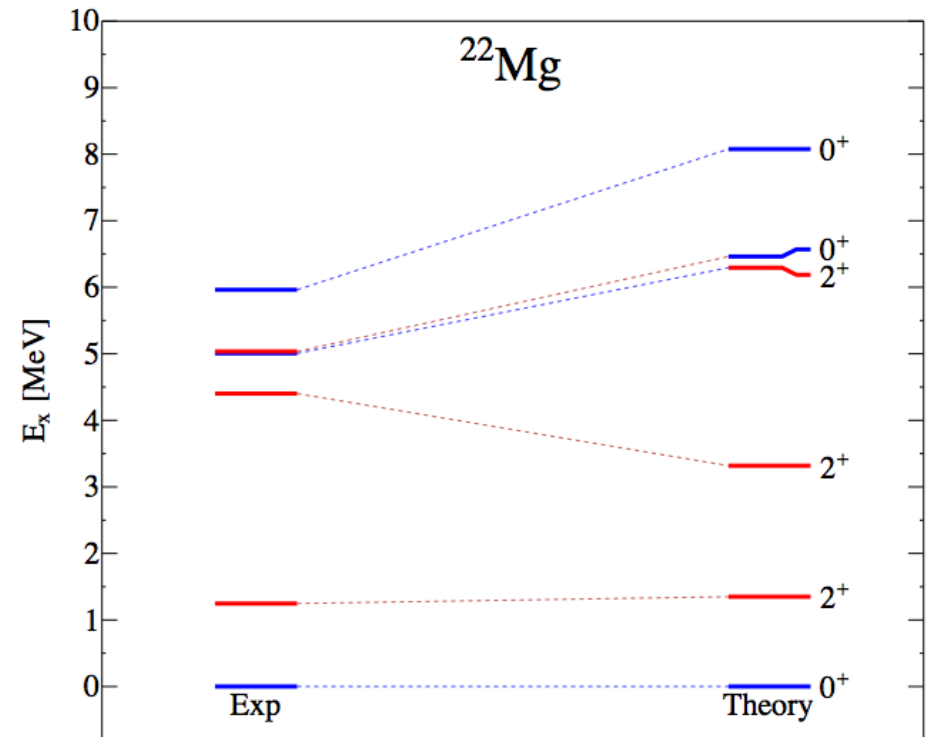
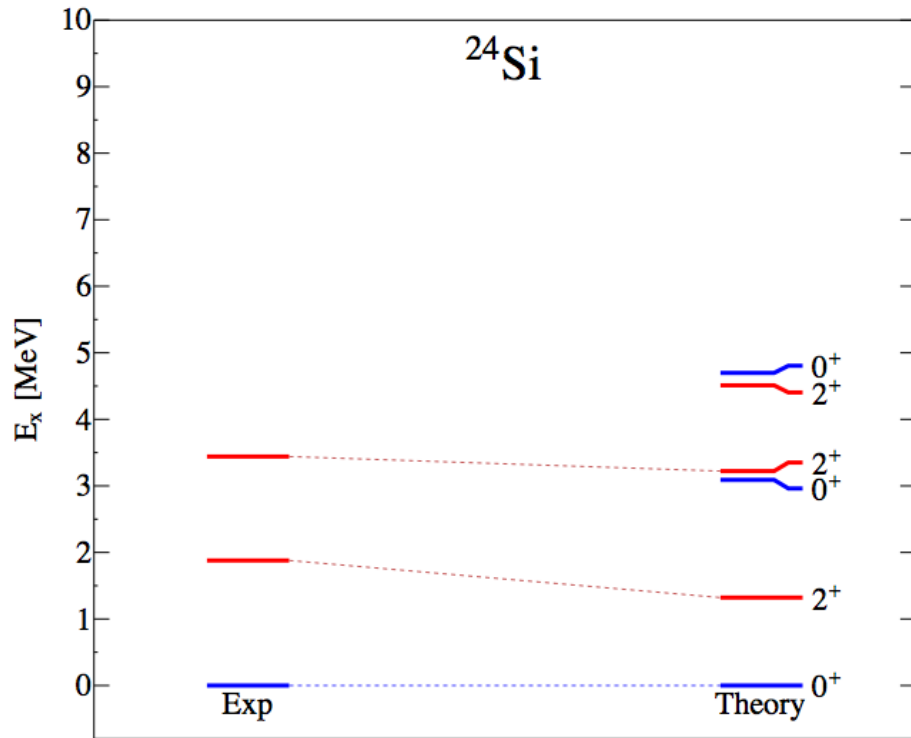


Sd-shell Nuclei: ²⁴Si



Sd-shell Nuclei

■ SRG-N3LO $\lambda = 2.0 \text{ fm}^{-1}$ $\hbar\Omega = 15 \text{ MeV}$



Summary

- We have tested $SU(3)$ and spin based truncation scheme
- Our results suggest the existence of coherent $SU(3)$ structures and reaffirm the importance of the symplectic symmetry
- Move toward sd -shell nuclei
- Collaboration with computer scientists is crucial