

Greater than the sum of its parts: Collectivity in the symmetry-adapted no-core shell model

Kristina Launey

... LSU Team ...

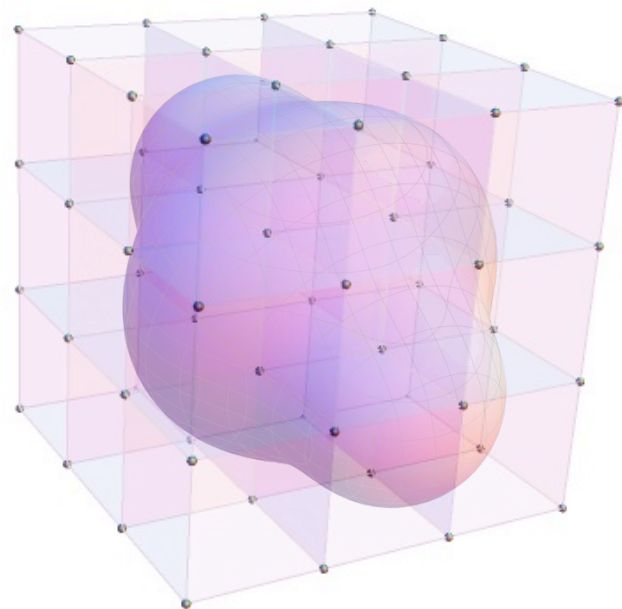
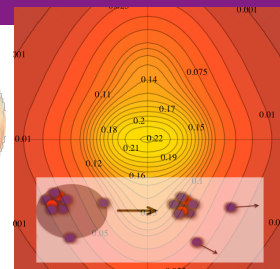
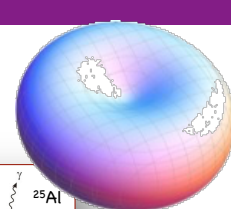
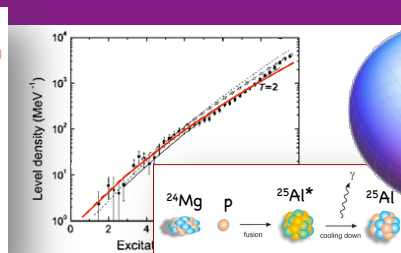
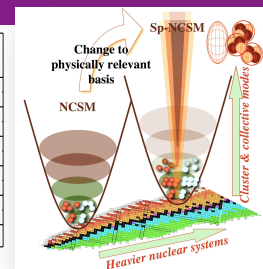
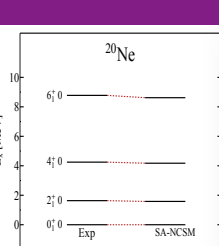
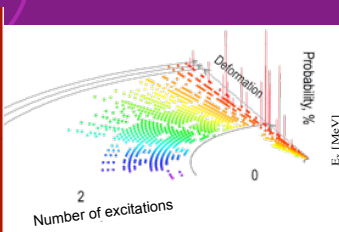
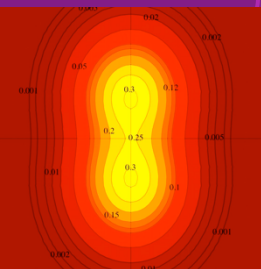
Jerry Draayer, Tomas Dytrych,
Robert Baker, Ali Dreyfuss,
David Kekejian, Grigor Sargsyan,
Harvey Shows, Logan Woolsey,
Sean Laughlin

In collaboration with

Iowa State U. – J. Vary & P. Maris
Czech Republic – D. Langr & T. Oberhuber
Princeton U. – W. Tang

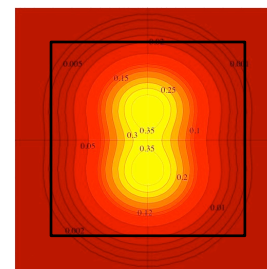
HPC Resources
NSF/U. of Illinois ...BlueWaters
LSU...SuperMike-II

Supported by NSF & DOE-EPSCoR



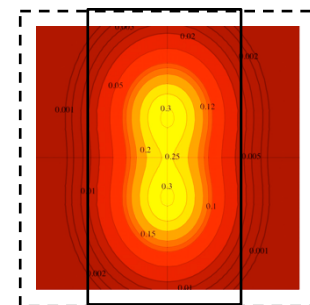
NCSM

Total HO quanta
 N_{\max}



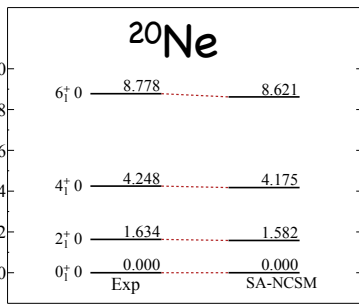
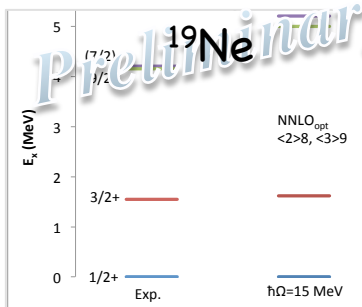
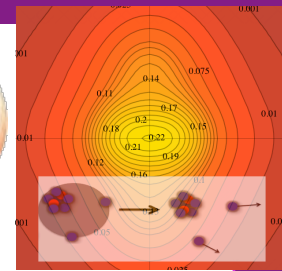
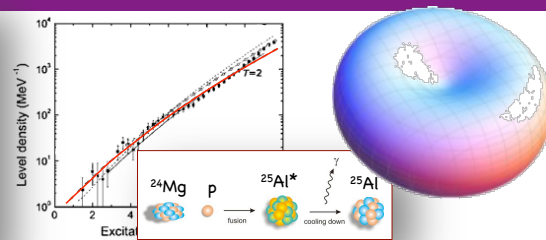
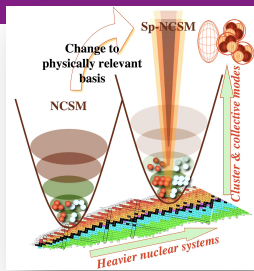
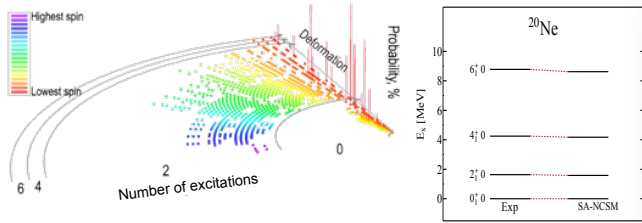
SA-NCSM

Total HO quanta
 $N_{\max} +$
Distribution:
z, x, y



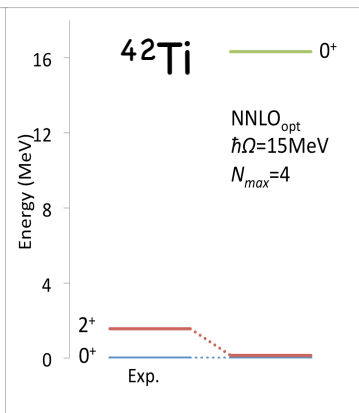
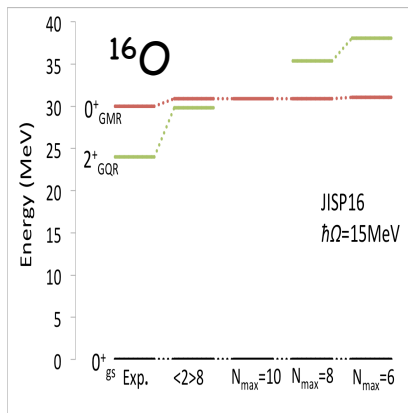
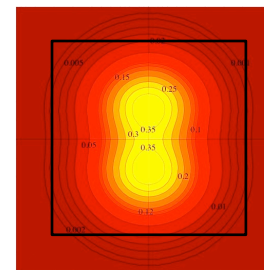
Dytrych et al., Phys. Rev. Lett. 111 (2013) 252501
 Launey et al., Prog. Part. Nucl. Phys. 89 (2016) 101





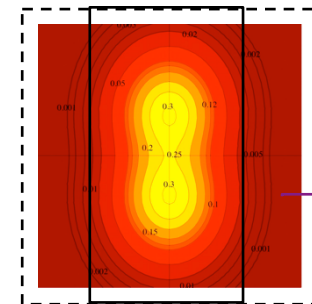
SU(3) basis

NCSM
Total HO quanta
 N_{max}



Symplectic
Sp(3,R) basis

SA-NCSM
Total HO quanta
 $N_{max} +$
Distribution:
z, x, y



Describes deformation

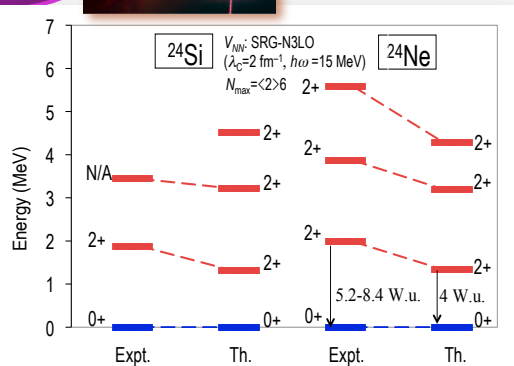
Symmetry-adapted:
SU(3), Sp(3,R)

Guided by
Symplectic
symmetry

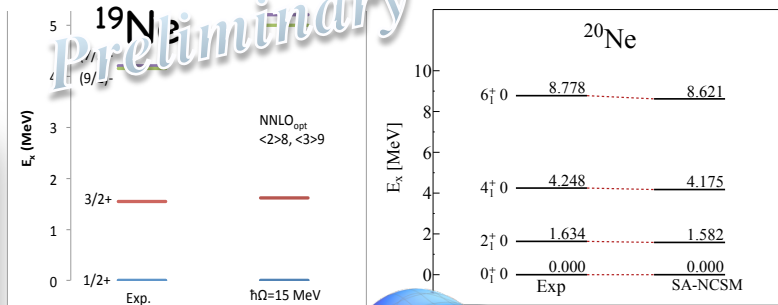
LSU code (LSU3shell): sourceforge.net/projects/lsu3shell
Dytrych et al., Phys. Rev. Lett. 111 (2013) 252501
Launey et al., Prog. Part. Nucl. Phys. 89 (2016) 101



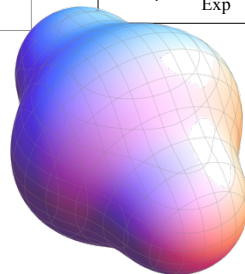
Deformed (in intrinsic frame)...



¹⁹N Preliminary

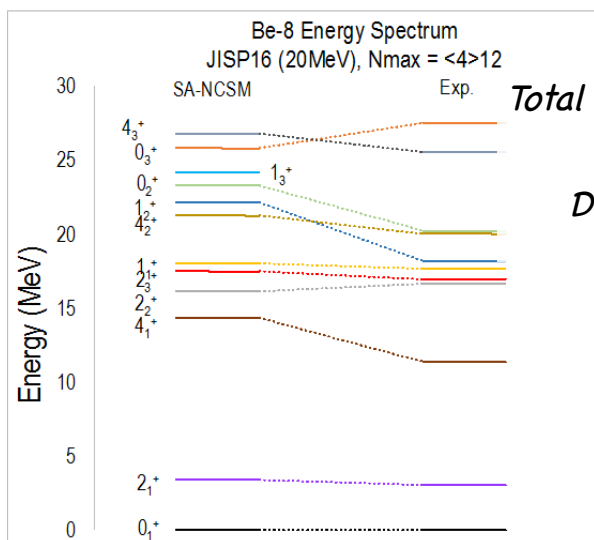
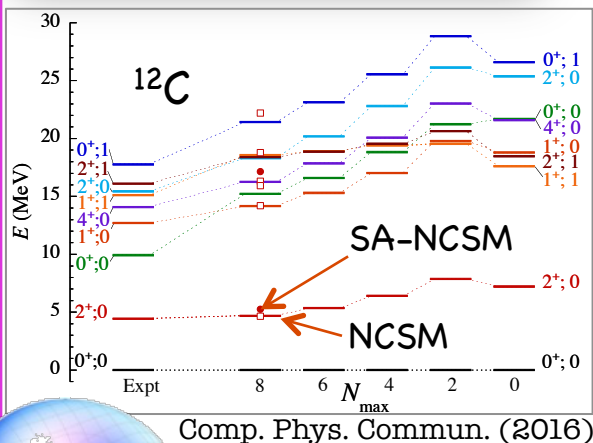
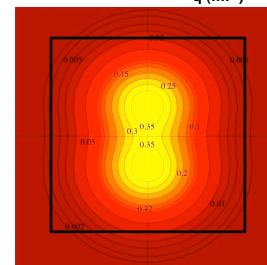
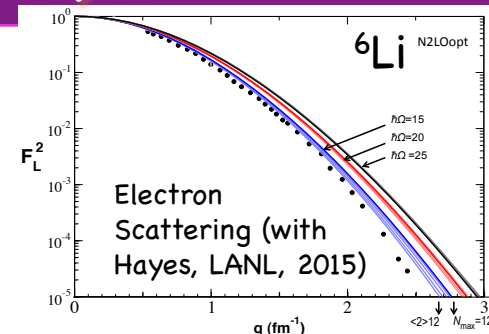


Robert Baker, LSU



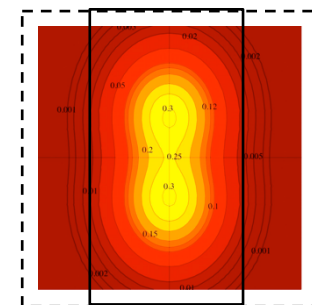
NCSM

Total HO quanta N_{max}



SA-NCSM

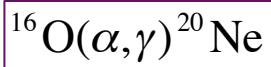
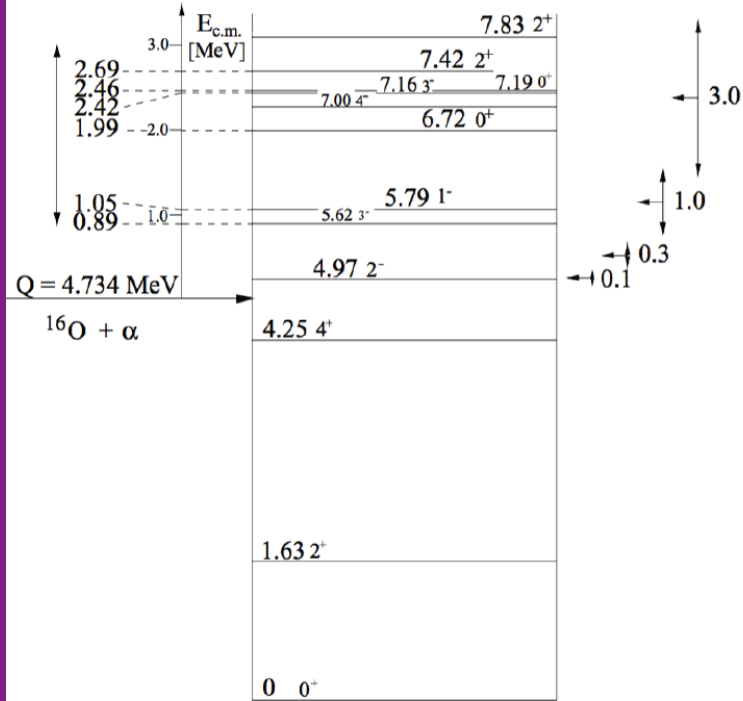
Total HO quanta N_{max}
Distribution: z, x, y



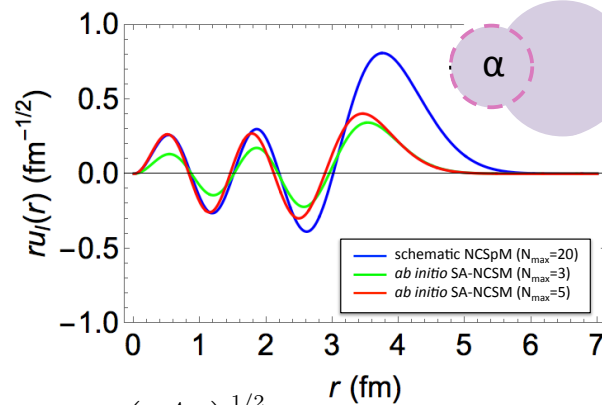
Deformation/collectivity:
important in nuclear
wave functions

Harvey Shows, LSU

Effect on X-ray Burst Nucleosynthesis

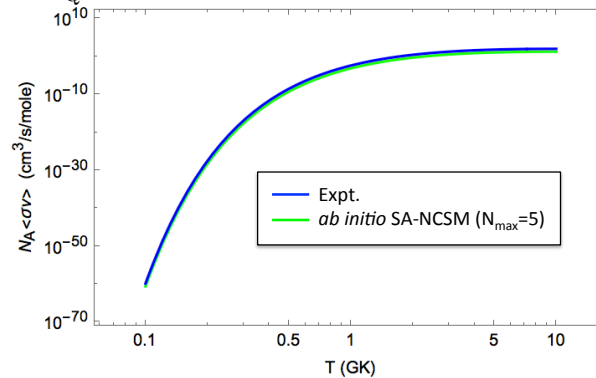


Ali Dreyfuss, LSU

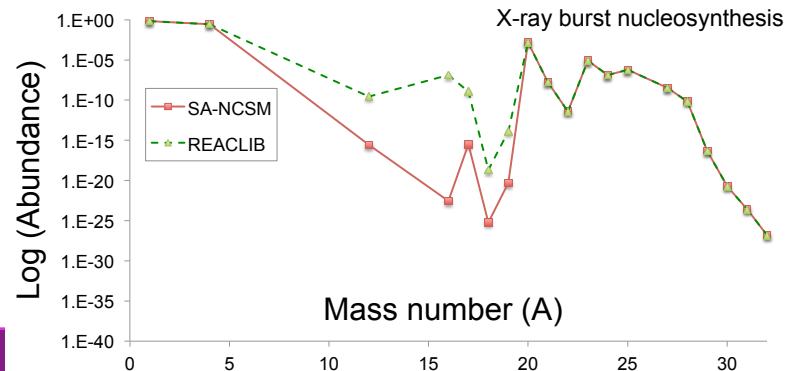


Wave functions from *ab initio* SA-NCSM

$$u_l(r) = \sum_Q \left(\frac{A}{A-a} \right)^{1/2} R_{Q,l}(r) c_Q \langle Q[\gamma(\lambda\mu)] | \{ \{ (\lambda_c \mu_c) \times (0\ 0) \}^{(\lambda_c \mu_c)} \times (Q\ 0) \}_l^{(\lambda\mu)} \rangle$$



Reaction rates

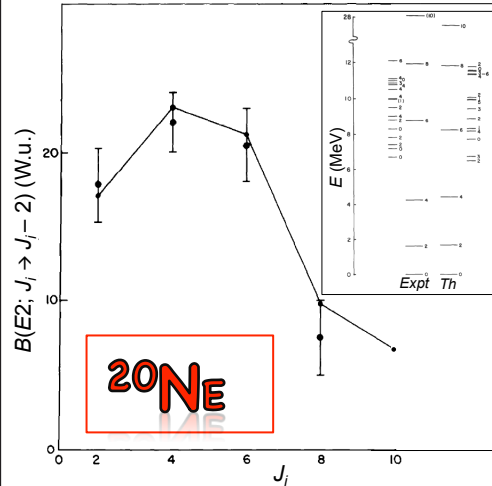
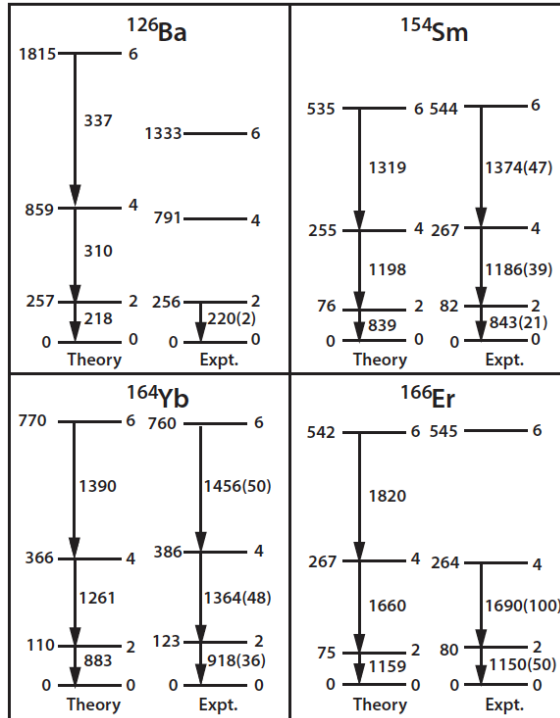


Nucleosynthesis simulations: XRB abundance pattern



Earlier studies ...

Algebraic models – Quite successful, but symmetries are assumed *a priori*:
Typically 1 (a few) irrep(s) + symmetry-preserving interaction



J. Draayer, et al.,
Nucl. Phys. A419, 1
(1984)

No effective charges!

P. Park et al., Nucl. Phys. A. 414, 93 (1984)

D. J. Rowe, Rep. Prog. Phys. 48, 1419 (1985)

SYMPLECTIC SYMMETRY, $Sp(3,R)$

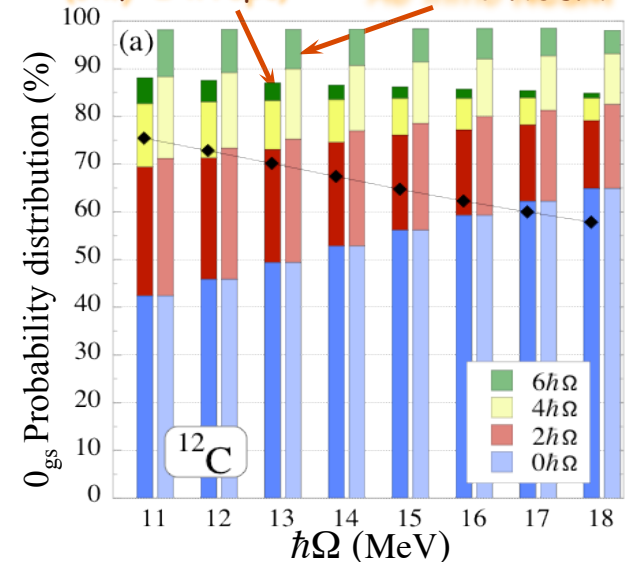
Ab initio results:

No *a priori* symmetry assumptions
(JISP16 NN)

Symplectic basis

(only 2 irreps)

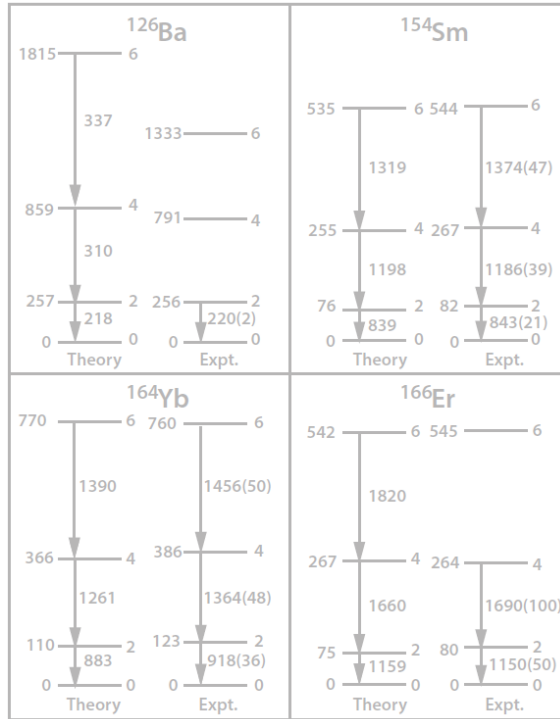
Ab initio NCSM



Dytrych, Launey, Bahri, Draayer, Vary,
Phys. Rev. Lett. 98 (2007) 162503

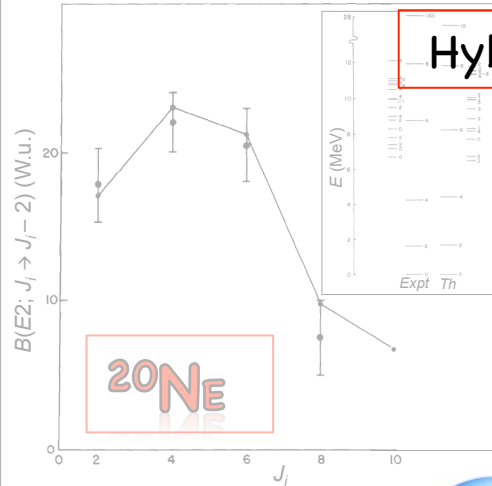
Earlier studies ...

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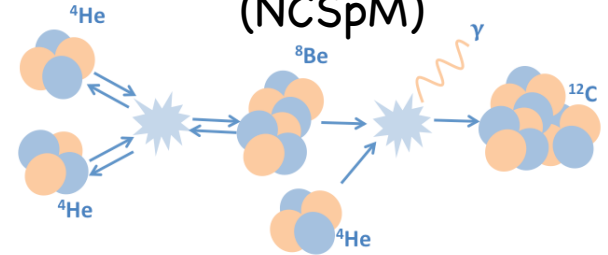


J. Draayer, et al.,
Nucl. Phys. A4.
(1984)

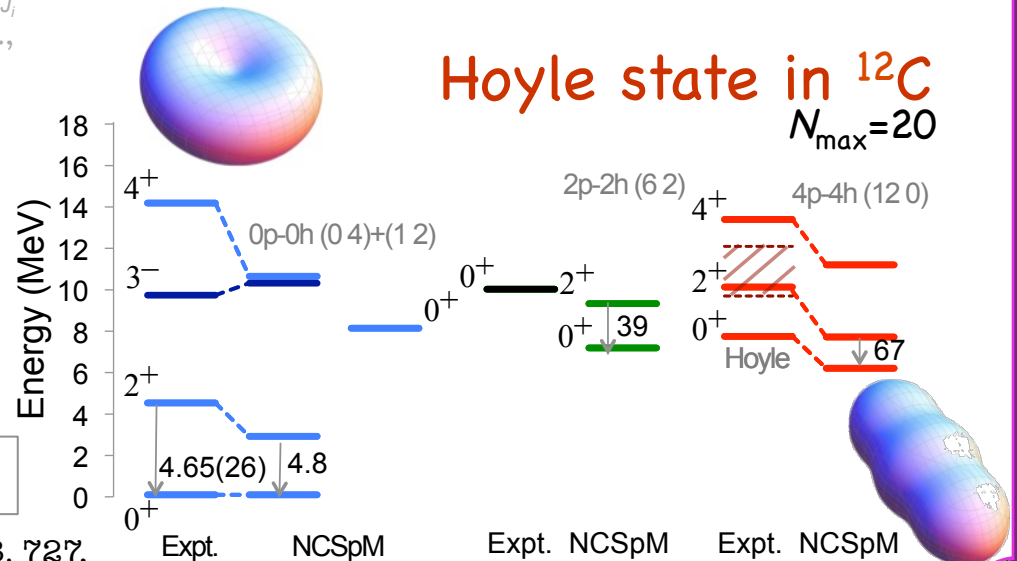
No effect

Hybrid: JISP16 (NM) + schematic (mM)

Only 4 symplectic slices
(NCSpM)



Hoyle state in ^{12}C
 $N_{\text{max}}=20$



SYMPLECTIC SYMMETRY, $Sp(3,R)$

Dreyfuss et al., Phys. Lett. B. 727,
511 (2013)

Greater than the sum of its parts:
Collectivity in the SA-NCSM



What can we learn from *ab initio* modeling?

SA-NCSM

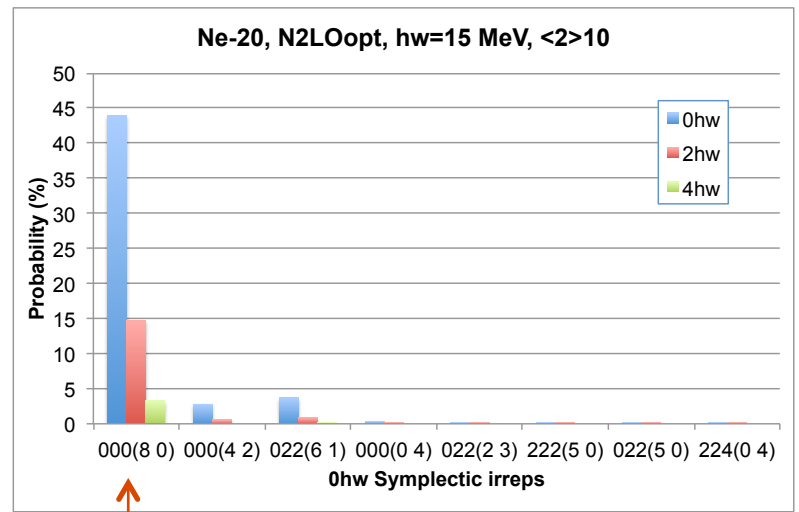
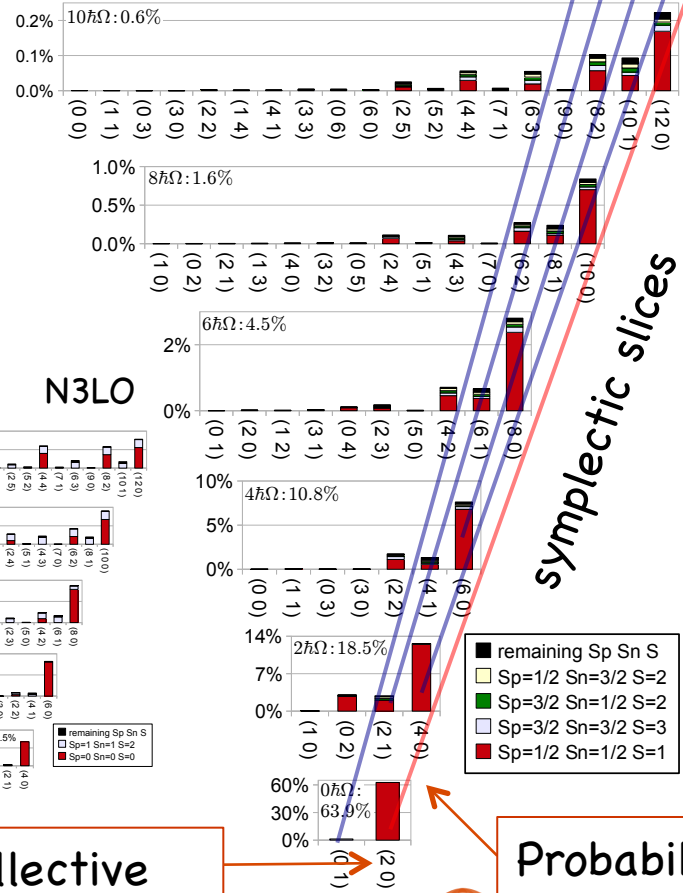
⁶Li

N3LO
1.4%
1.2%
2.0%
2.9%
79.4%

JISP16

From first principles:
light/intermediate-mass nuclei,
low-lying states

Approximate
symplectic symmetry
in nuclei



single dominant symplectic slice

Collective modes

Probability (%)



What is Symplectic Symmetry?

Formal definition

All linear canonical transformations of the single-particle phase-space observables

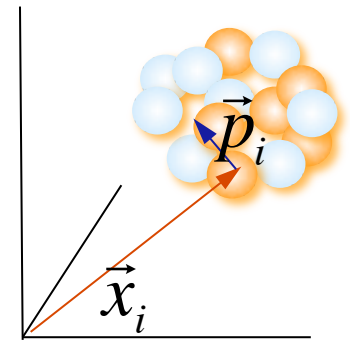
$$x_{i\alpha} \rightarrow \sum_{\beta=x,y,z} a_{\alpha\beta} x_{i\beta} + b_{\alpha\beta} p_{i\beta}$$

$$p_{i\alpha} \rightarrow \sum_{\beta=x,y,z} c_{\alpha\beta} x_{i\beta} + d_{\alpha\beta} p_{i\beta}$$

that **preserve the canonical commutation relation**

$$[x_{i\alpha}, p_{j\beta}] = i\hbar \delta_{ij} \delta_{\alpha\beta}$$

Nucleus with A nucleons



Generators: $Q_{ij} = \sum_n x_{ni} x_{nj}$

$$S_{ij} = \sum_n (x_{ni} p_{nj} + p_{ni} x_{nj}),$$

$$L_{ij} = \sum_n (x_{ni} p_{nj} - x_{nj} p_{ni}),$$

$$K_{ij} = \sum_n p_{ni} p_{nj},$$

SU(3)
in a HO shell
(Elliott, 1958)

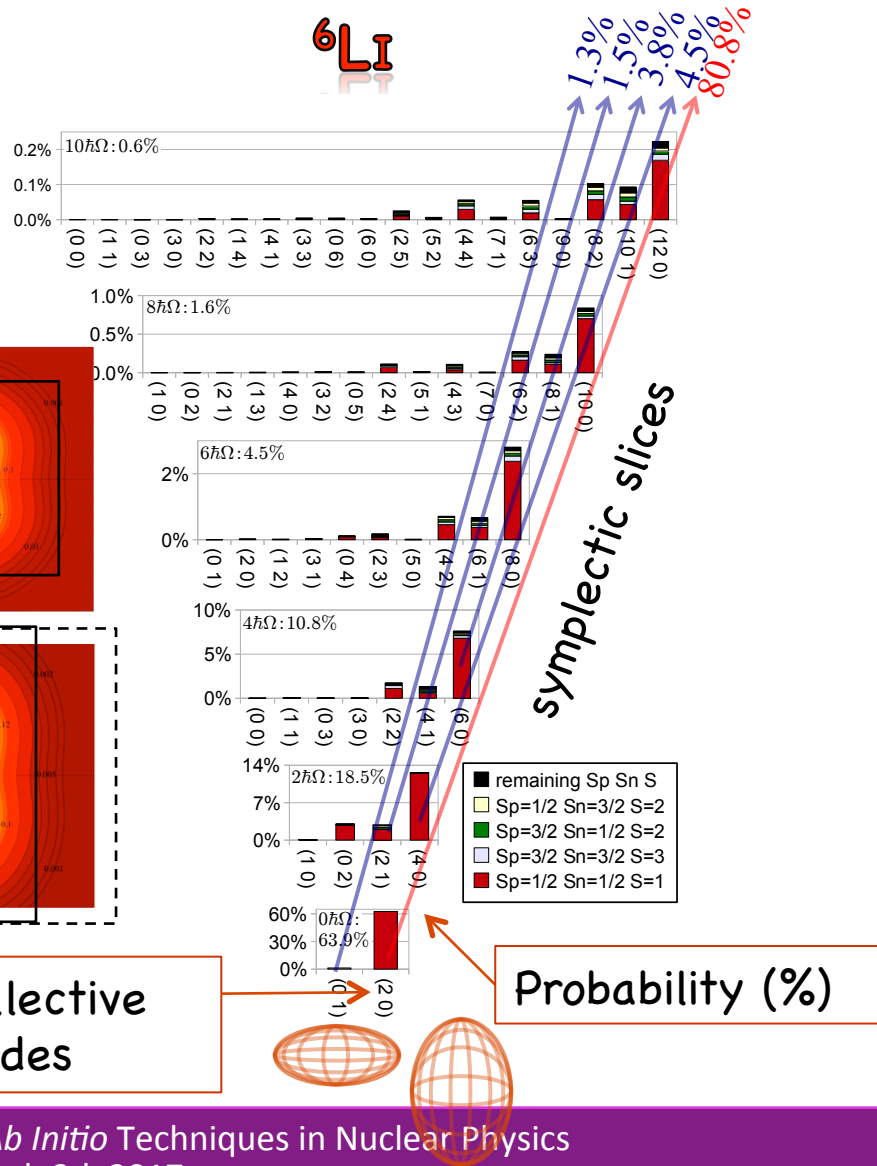
geometry

Symplectic Model

Rosensteel & Rowe,
PRL 38 (1977) 10

kinematics

What can we learn from symplectic symmetry?



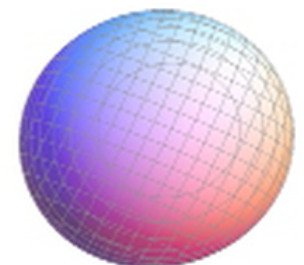
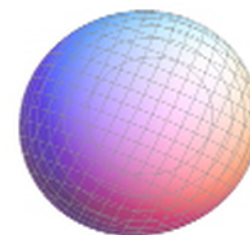
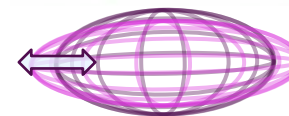
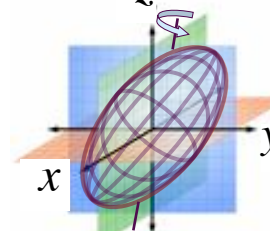
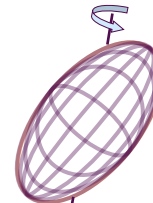
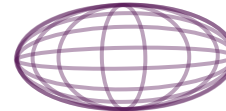
Symplectic slice:

one equilibrium deformation ("shape")

rotations

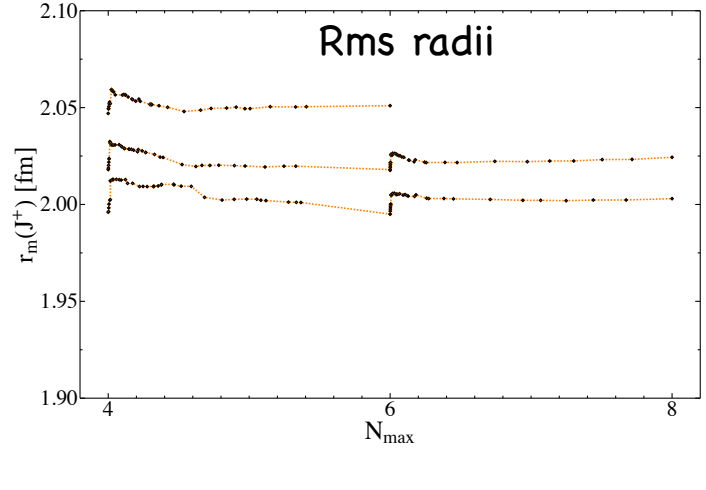
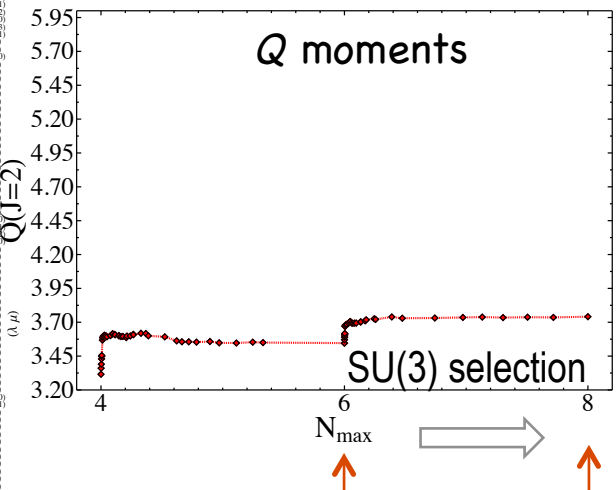
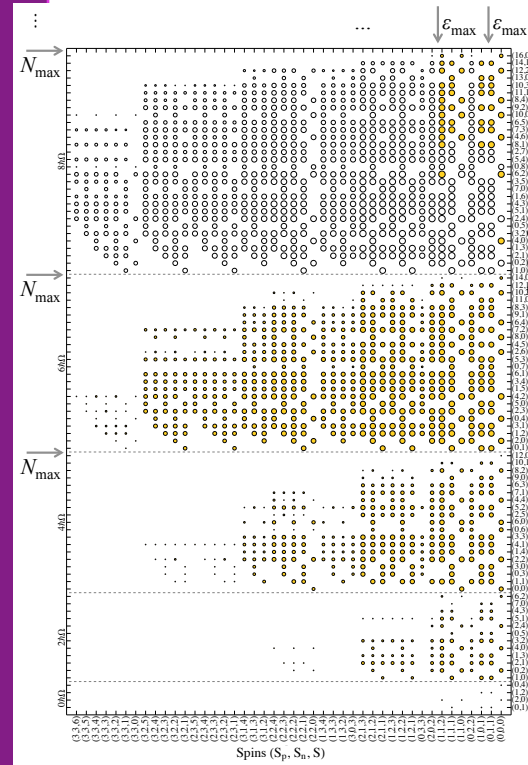
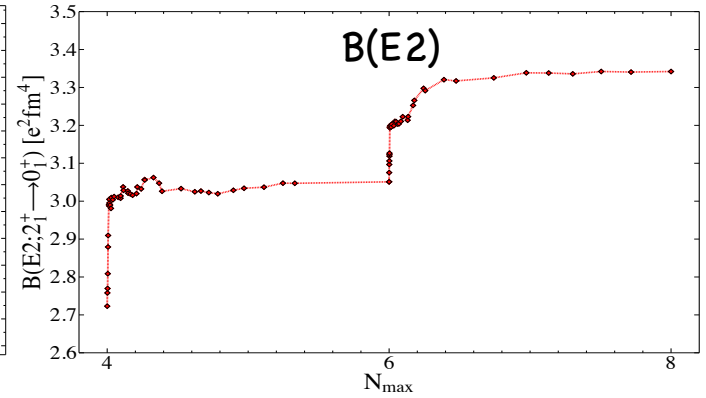
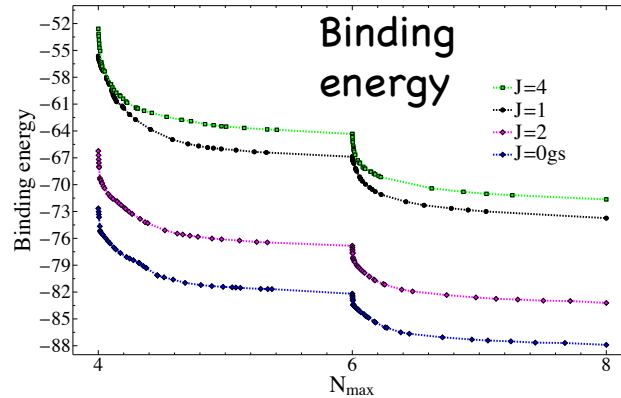
space orientation

Vibrations
(of the giant resonance monopole (r^2)/ quadrupole (Q) type)

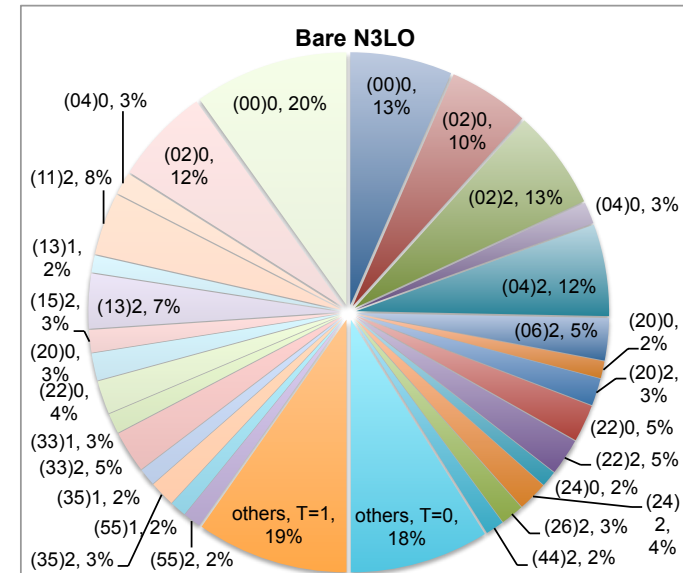
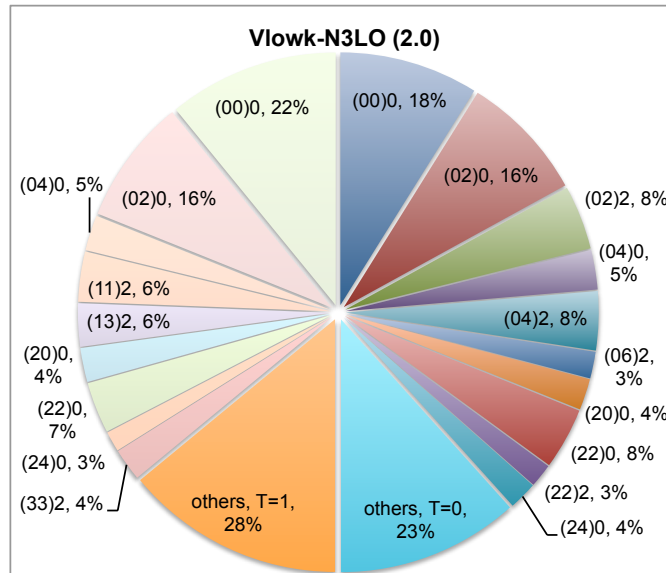
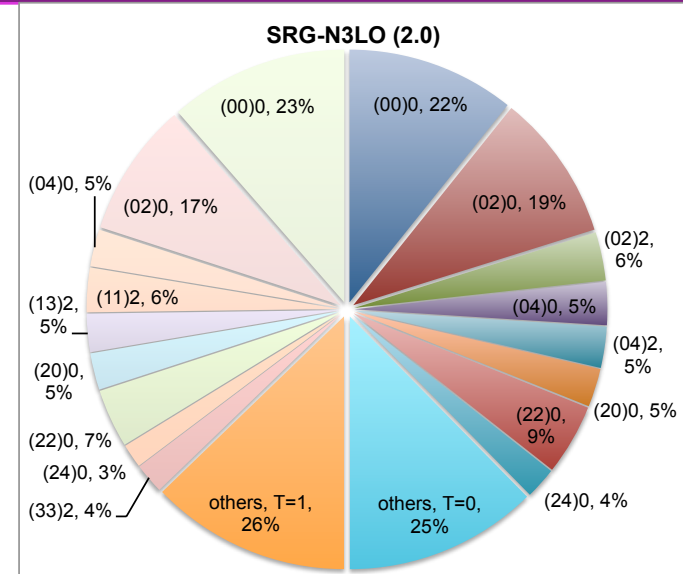
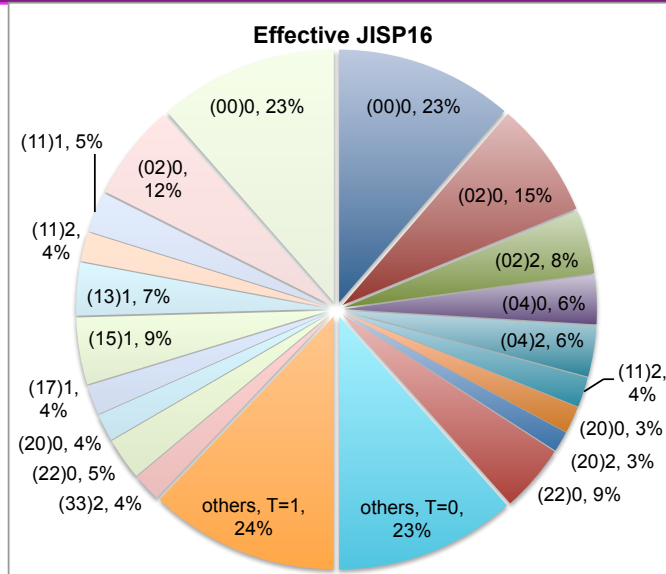


Collectivity features

¹²C



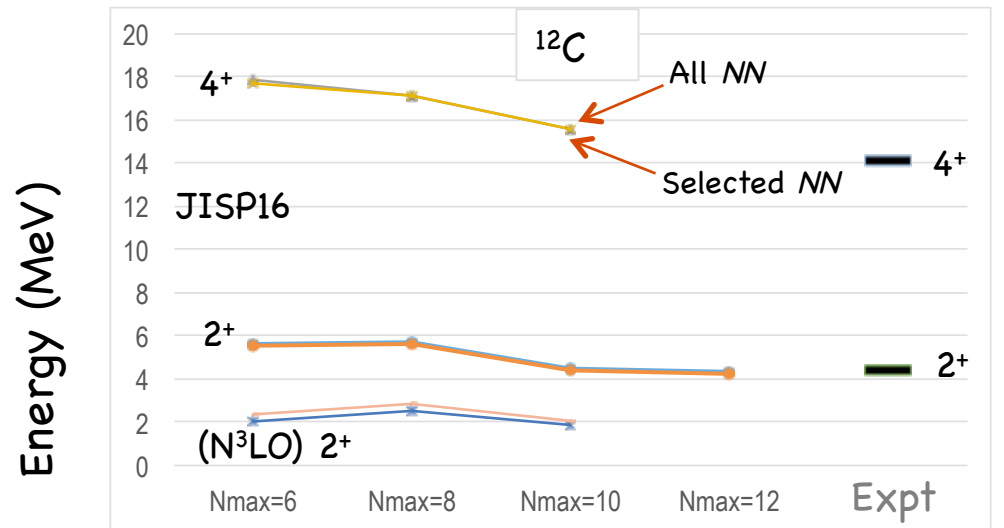
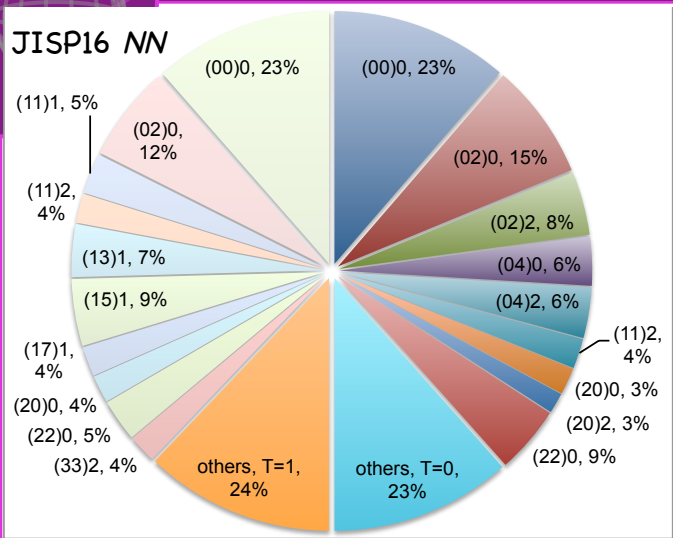
SU(3) NN interaction: keep track of x, y, & z



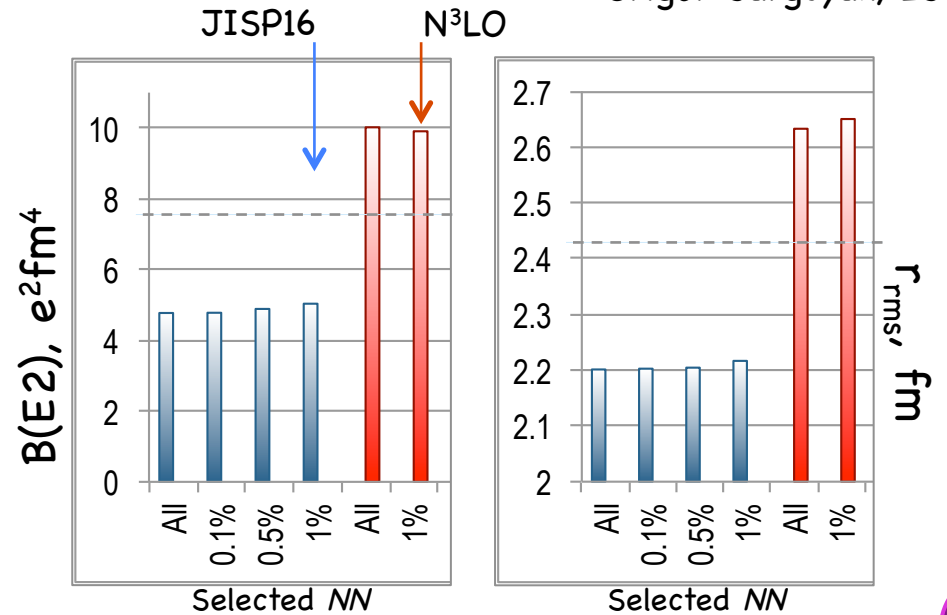
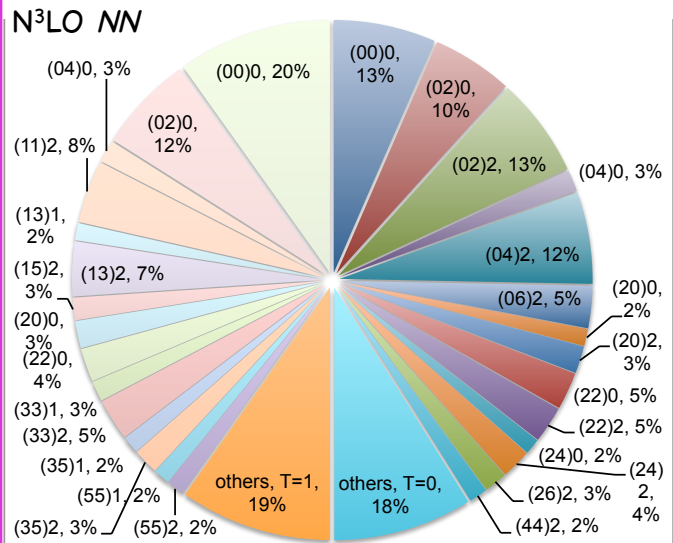
Launey et al., Int. J. Mod. Phys. E 24 (2015) 1530005



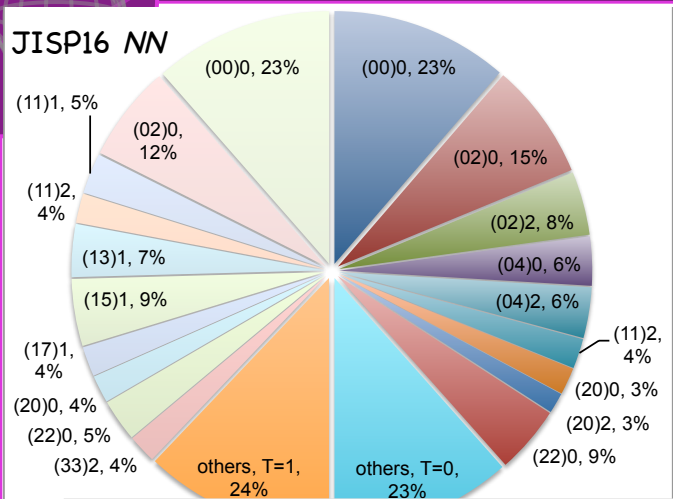
Important pieces of the NN interaction



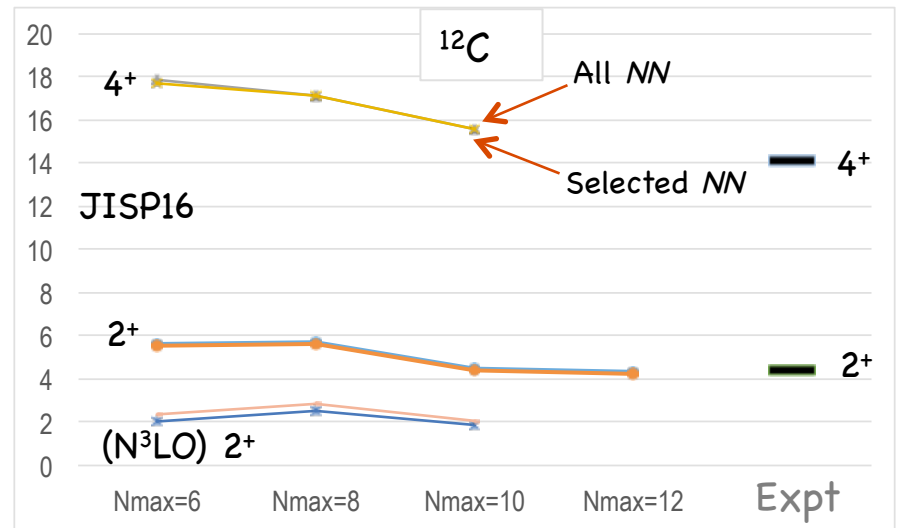
Grigor Sargsyan, LSU



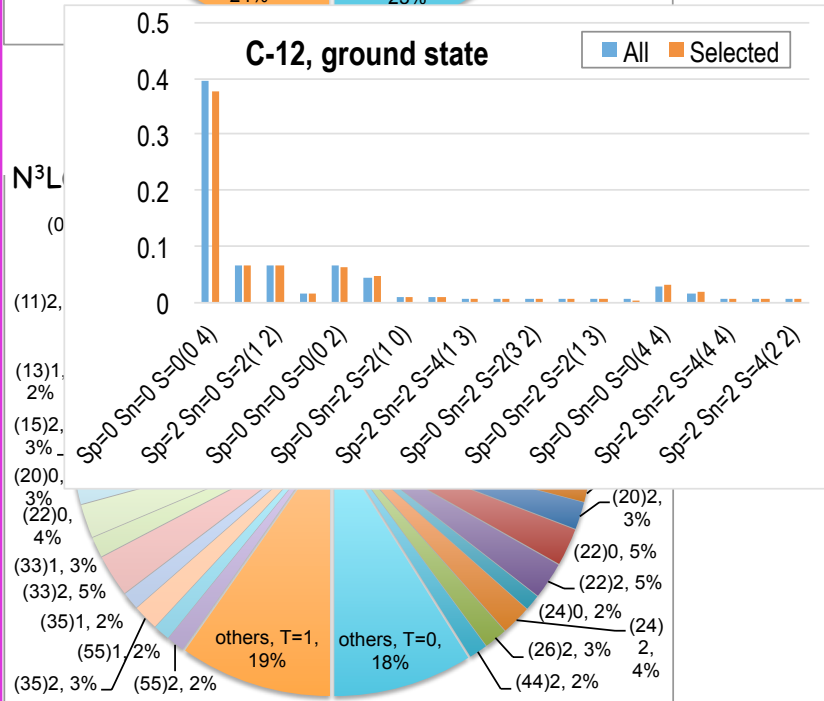
Important pieces of the NN interaction



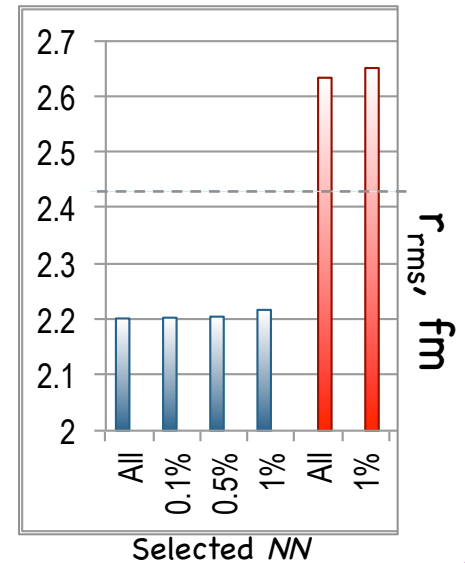
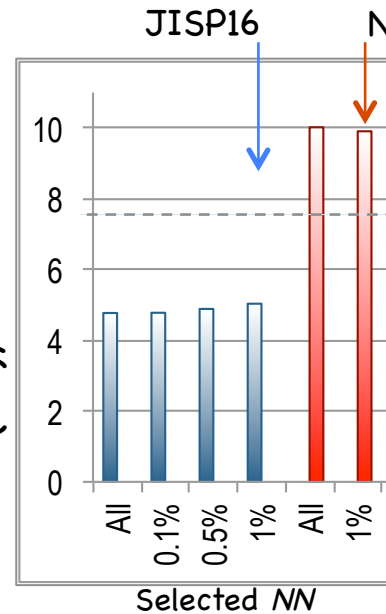
Energy (MeV)



Grigor Sargsyan, LSU

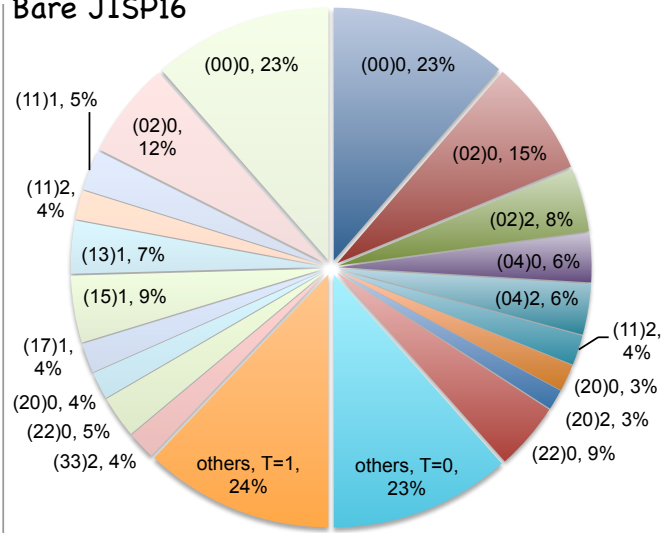


B(E2), e²fm⁴



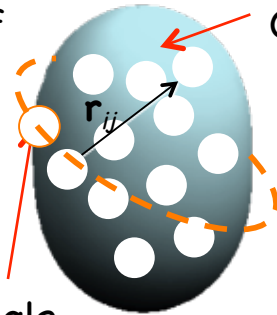
Important pieces of the NN interaction

Bare JISP16



Collectivity: emergent phenomenon

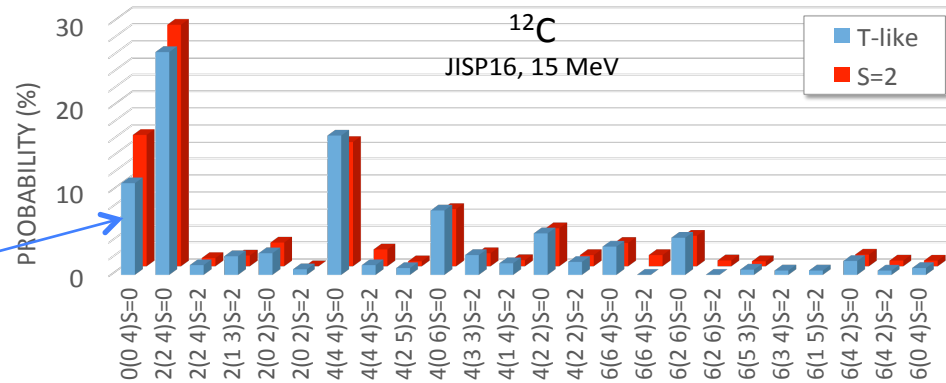
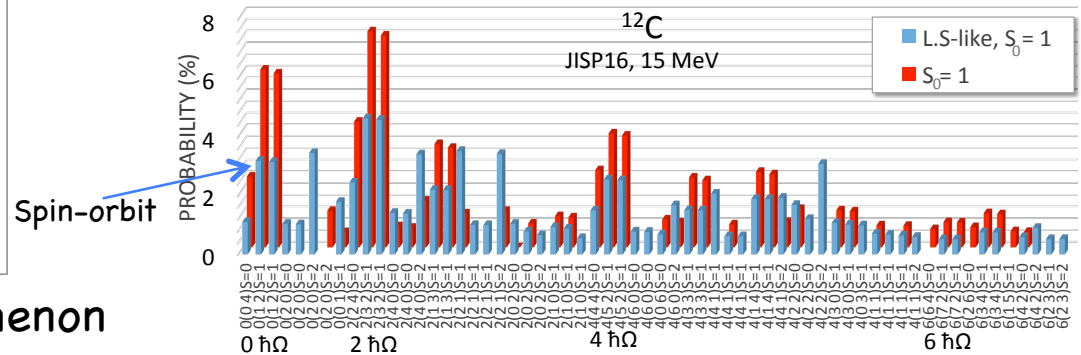
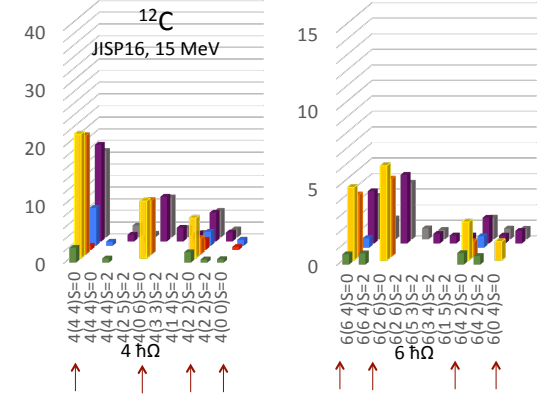
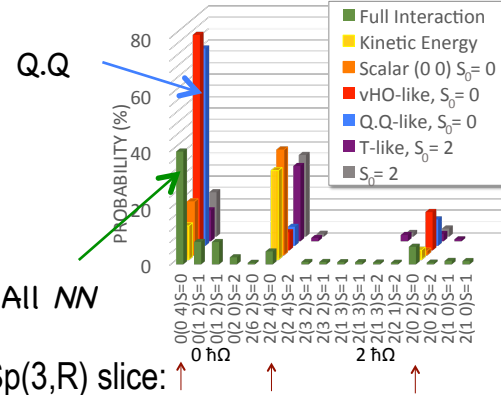
Interaction of each particle with nucleus quadrupole moment



Single particle

Collective structure

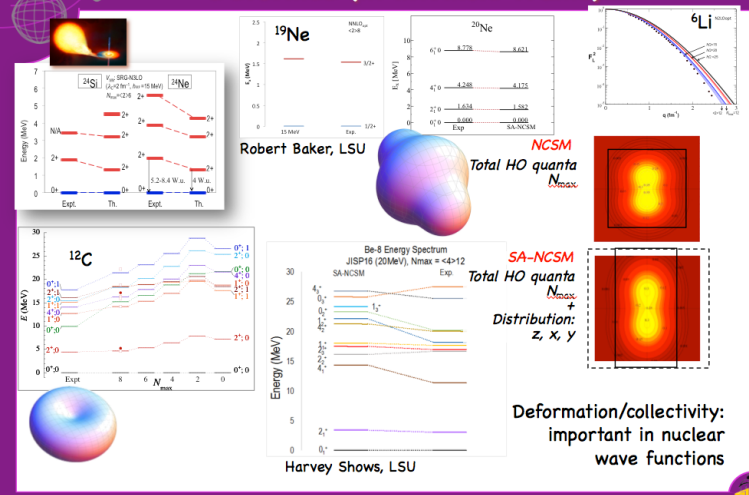
Tensor force



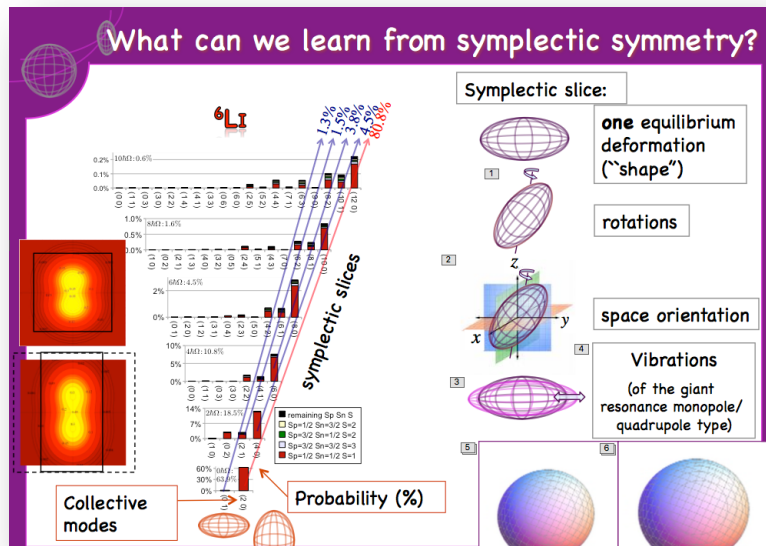
Greater than the sum of its parts:
Collectivity in the SA-NCSM

Deformed (in intrinsic frame)...

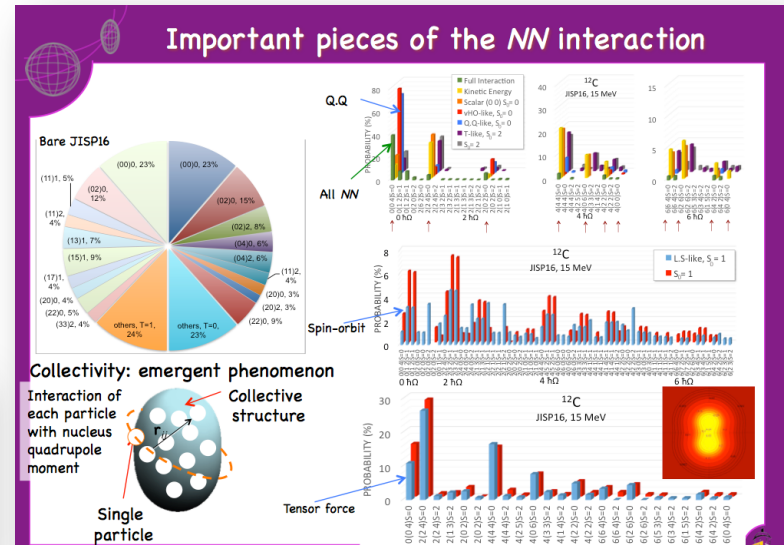
Conclusions



Deformation/collectivity: important in nuclear wave functions



Simple physics: "shape" + vibrations + rotations

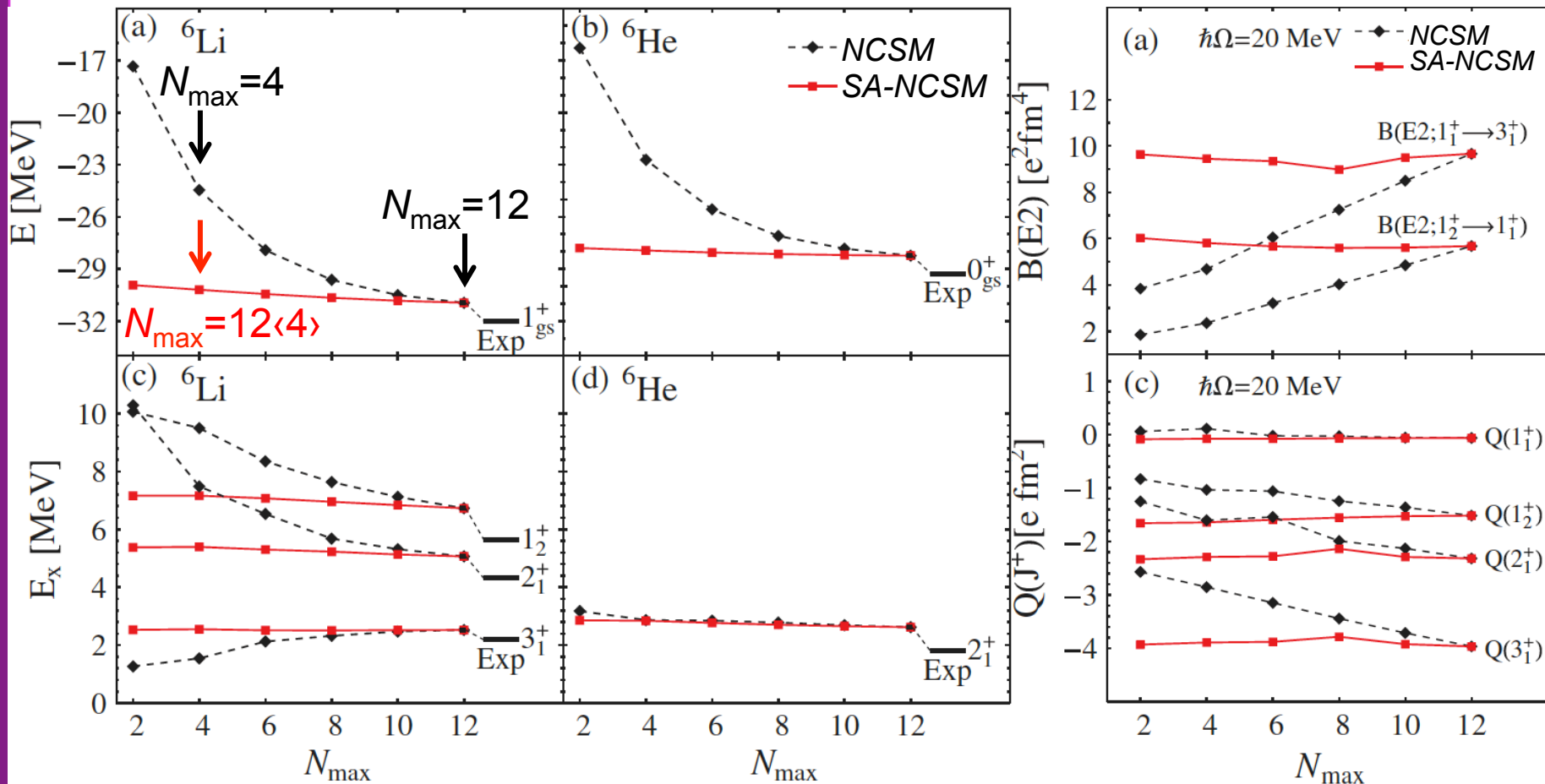


Informing the inter-nucleon interaction...



Efficacy of SA-NCSM: Li-6

JISP16, $\hbar\omega = 20$ MeV



Dytrych, Launey, Draayer, et al., Phys. Rev. Lett. 111 (2013) 252501