From Few Nucleons to X-ray Burst Abundances:
Reaction Rates from Overlaps of SA-NCSM and Cluster Bases

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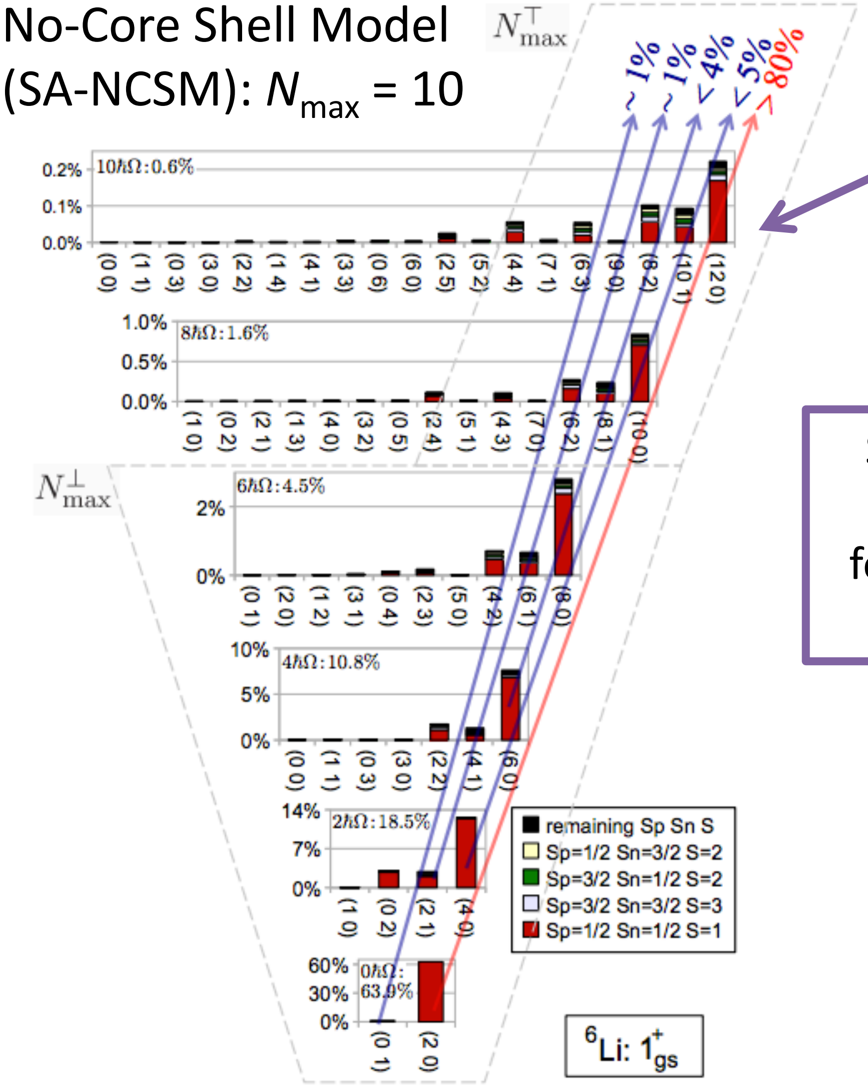
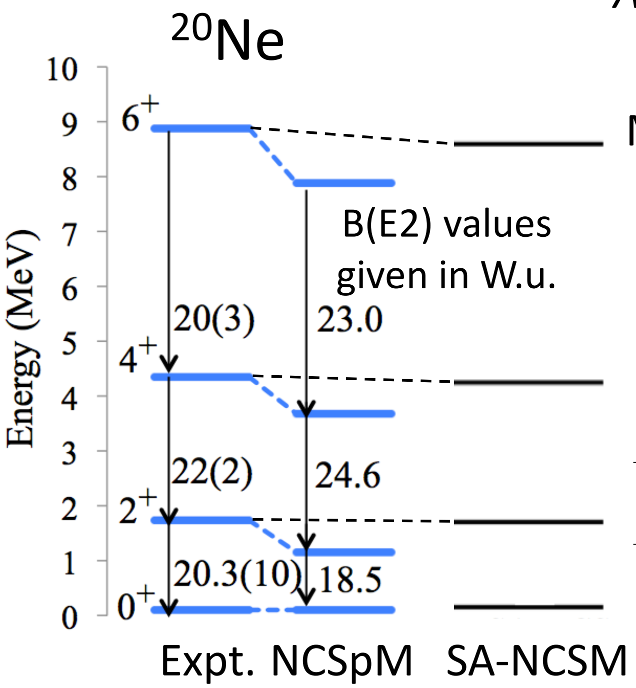
ROLE OF SYMMETRY-ADAPTED (SA) BASIS AND SYMPLECTIC SYMMETRY

Ab initio Symmetry-Adapted No-Core Shell Model (SA-NCSM): N_{max} = 10

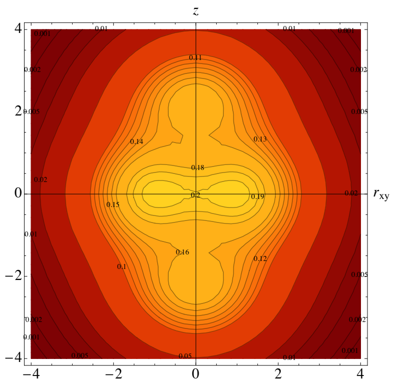


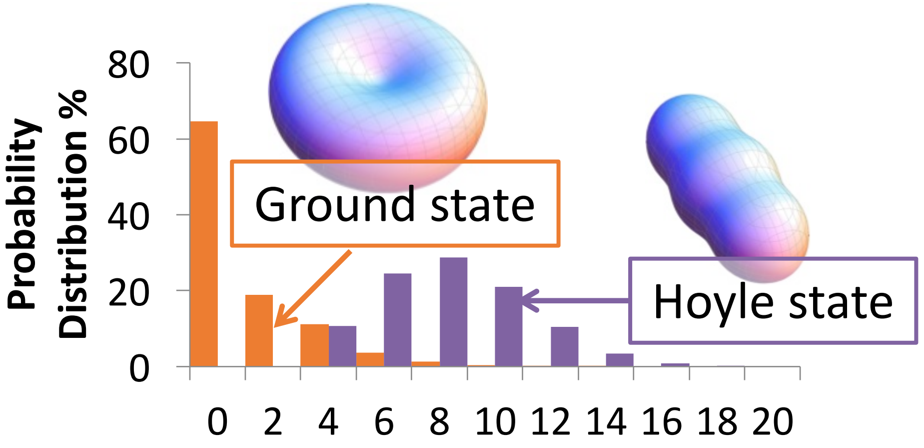
Symplectic symmetry emerges from *ab initio* studies

Symplectic symmetry exposes cluster formation – e.g., in the Hoyle state of ^{12}C



Ab initio description of ^{20}Ne (N2LOopt, ħΩ=15 MeV, 13 HO shells)



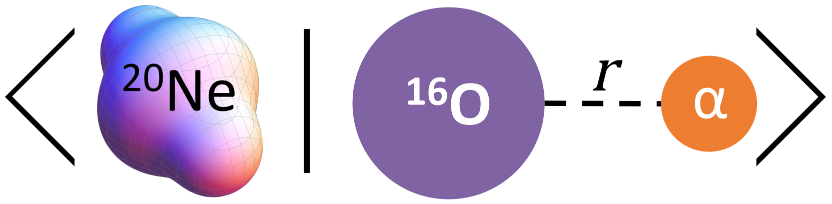


Schematic NCSpM reproduces observables: spectrum, rms radii, quadrupole moments

K. D. Launey *et al.*, Prog Part Nuc Phys **89** (2016)

PROBING CLUSTER STRUCTURE

$$u_l(r) = \langle \psi_A | \mathcal{A}\{\phi_{A-f} \times \phi_f\} Y_{l0} \frac{\delta(r-a)}{ra} \rangle$$



A-particle wave function eigenstates in symplectic basis:

$$|\psi_A\rangle = \sum_Q c_Q |Q[\gamma(\lambda\mu)]\rangle$$

Expand δ-function in orthonormal harmonic oscillator basis

$$u_l(r) = \sum_Q R_{Q,l}(r) c_Q \langle Q[\gamma(\lambda\mu)] | \{\{(\lambda_{A-f}\mu_{A-f}) \times (\lambda_f \mu_f)\}^{(\lambda_c\mu_c)} \times (Q0)\}_l^{(\lambda\mu)} \rangle$$

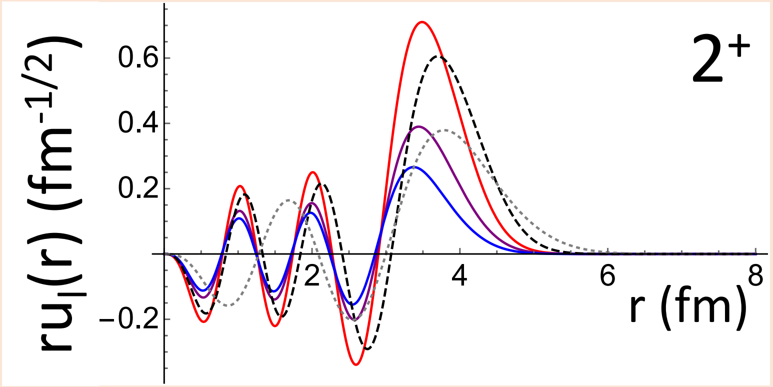
Overlaps computed recursively:

$$\langle [N\gamma'(\lambda'\mu') \times (2\,0)](\lambda\mu)\xi \,|\, [(\lambda_c\mu_c) \times (Q+2,0)](\lambda\mu)\xi \rangle$$
$$= \sqrt{\dim(Q\,0)}\; U[(\lambda_c\mu_c)(Q\;0)(\lambda\mu)(2\,0);(\lambda'\mu');(Q+2\,0)]\;\langle N\gamma'(\lambda'\mu')\xi' \,|\, [(\lambda_c\mu_c) \times (Q\,0)](\lambda'\mu')\xi' \rangle$$

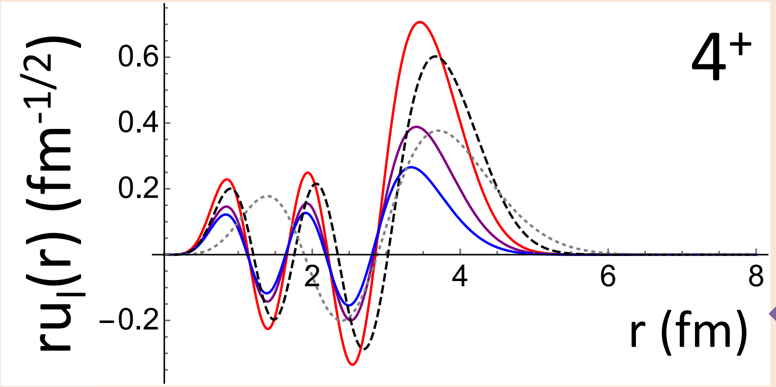
Y. Suzuki, Nuc Phys A **448**, 395 (1986)

EVIDENCE FOR CLUSTERING

^{24}Mg

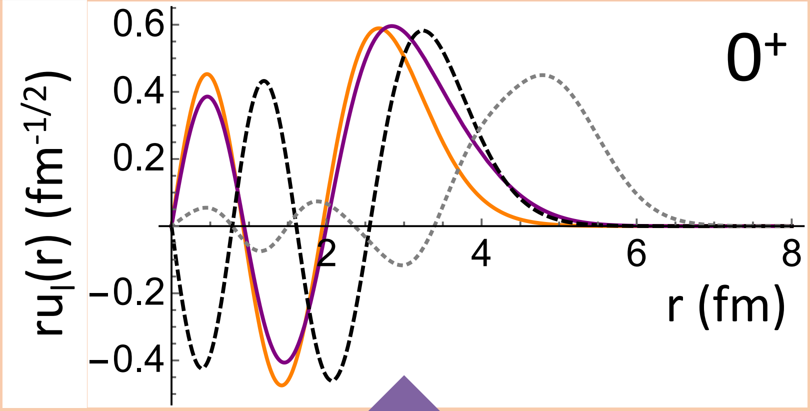


$\{^{20}Ne + \alpha\}_{NCSpM}$: (8 0)
$\{^{16}O + ^{8}Be\}_{NCSpM}$: (4 0)
$\{^{12}C + ^{12}C\}_{NCSpM}$: (0 8), (2 4), (4 0)



^{16}O: $\{^{12}C + \alpha\}$

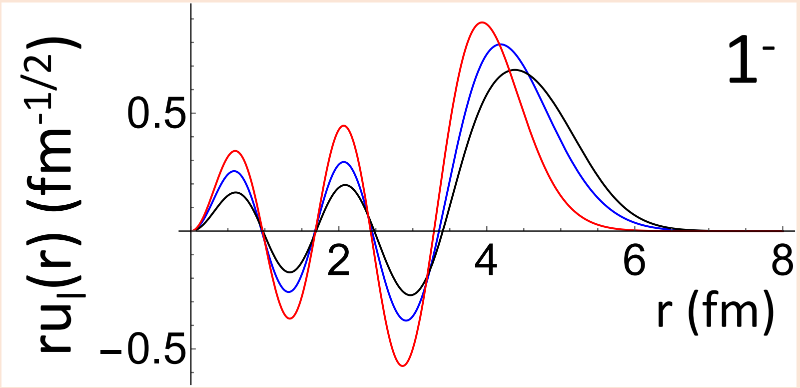
NCSpM (N_{max}=16): (0 0), (4 2), (8 4)
SA-NCSM (N_{max}=10): (0 0)



Evidence of cluster formation developing for the Hoyle-like second 0+ state in ^{16}O described by the (8 4) irrep in the NCSpM

We can consider multiple different partitions of clusters

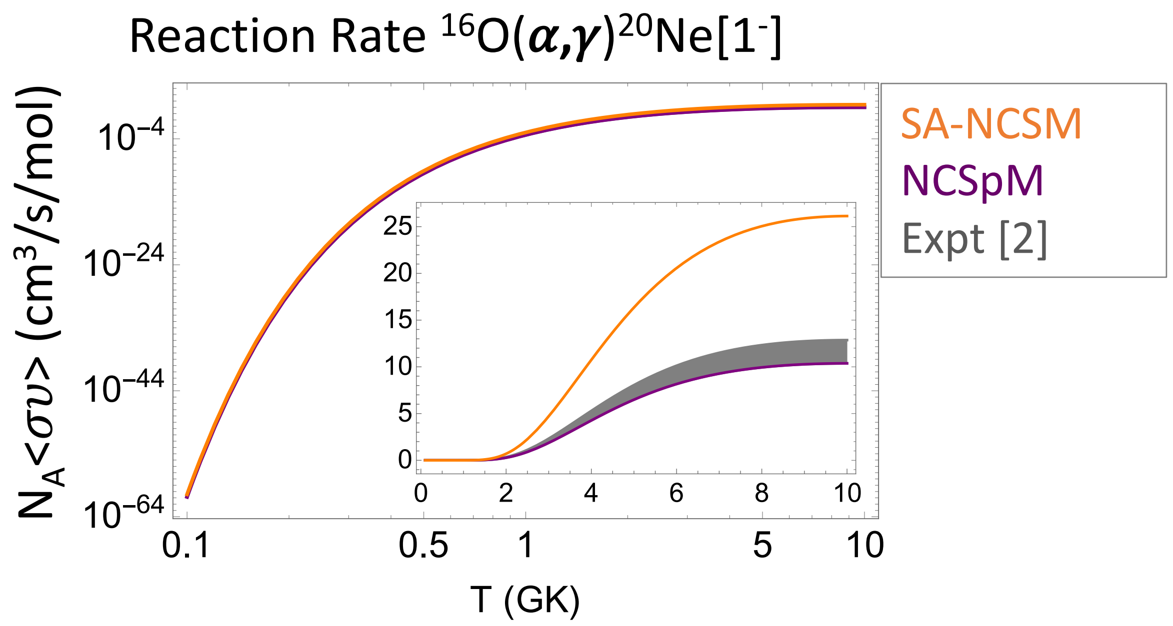
^{20}Ne: $\{^{16}O + \alpha\}$

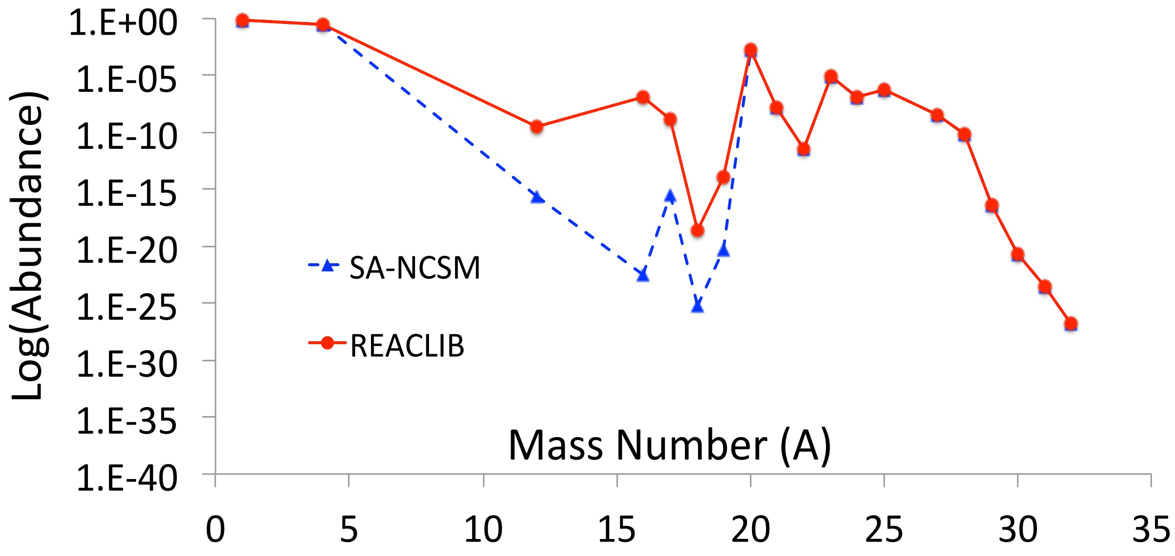


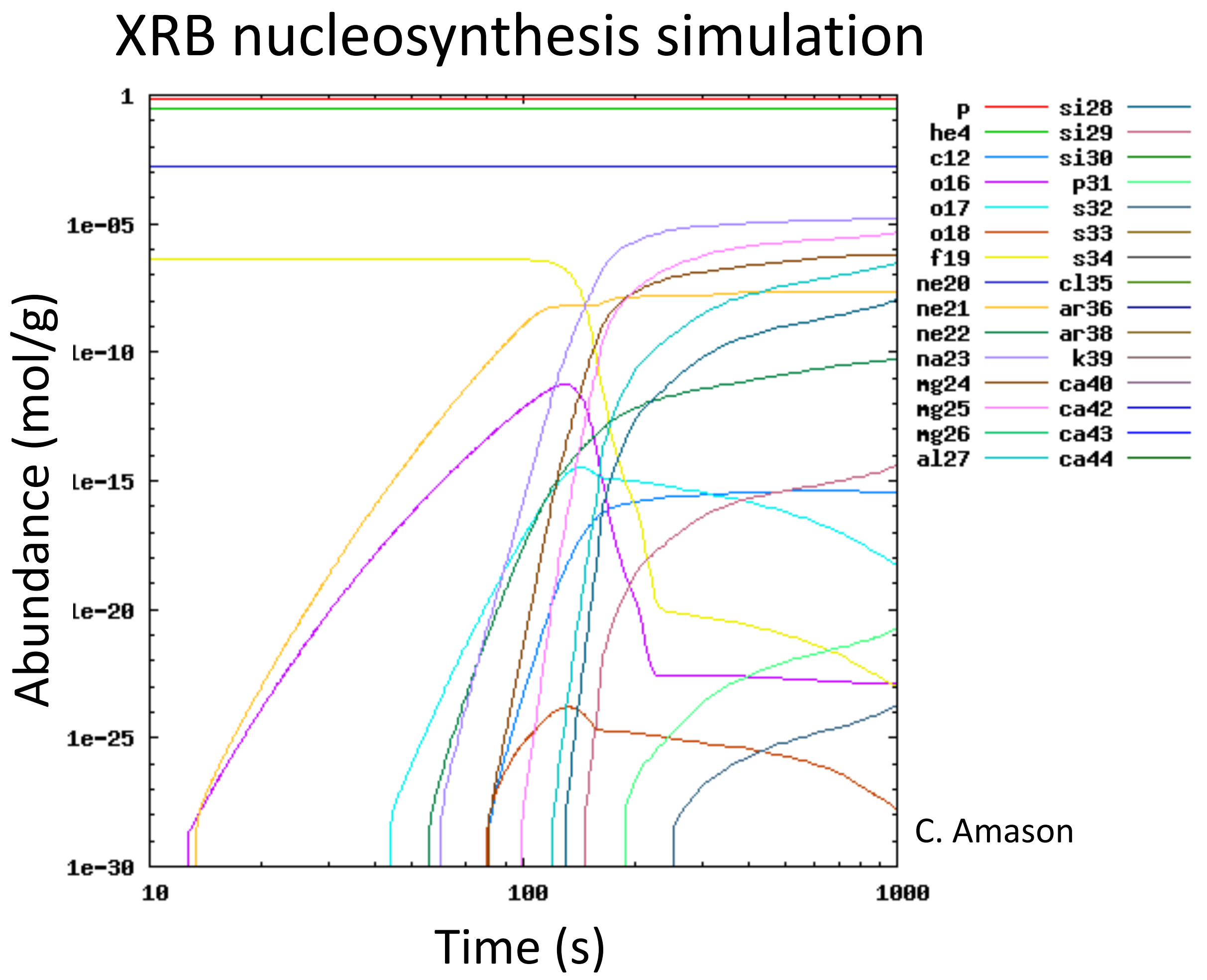
SA-NCSM N_{max}=3
SA-NCSM N_{max}=11
NCSpM N_{max}=13

Decay Widths (Γ_α)	
NCSpM (N_{max}=13)	25
SA-NCSM (N_{max}=3)	5.7
SA-NCSM (N_{max}=11)	63
Experimental [2]	28(3)

X-RAY BURST NUCLEOSYNTHESIS





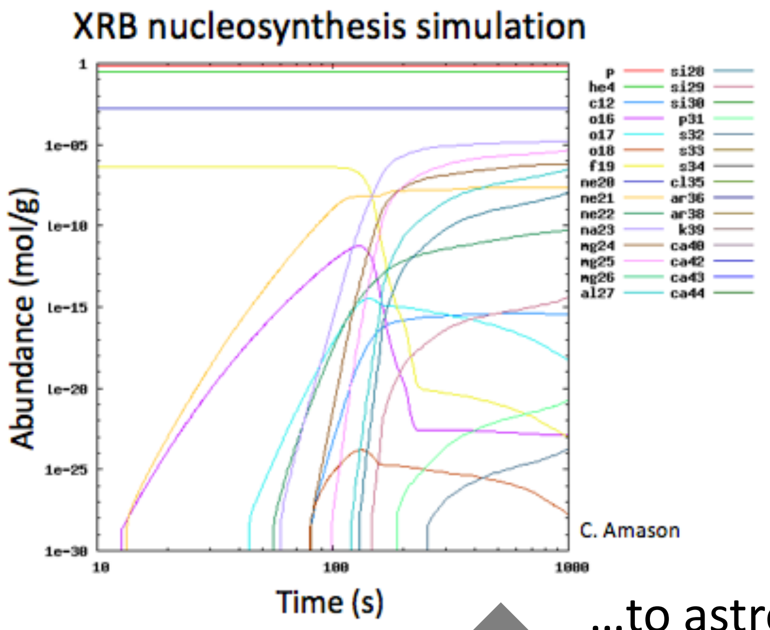


Using reaction rates computed with *ab initio* structure input, we can consider the development of nuclear abundances in astrophysical simulations and final abundance patterns.

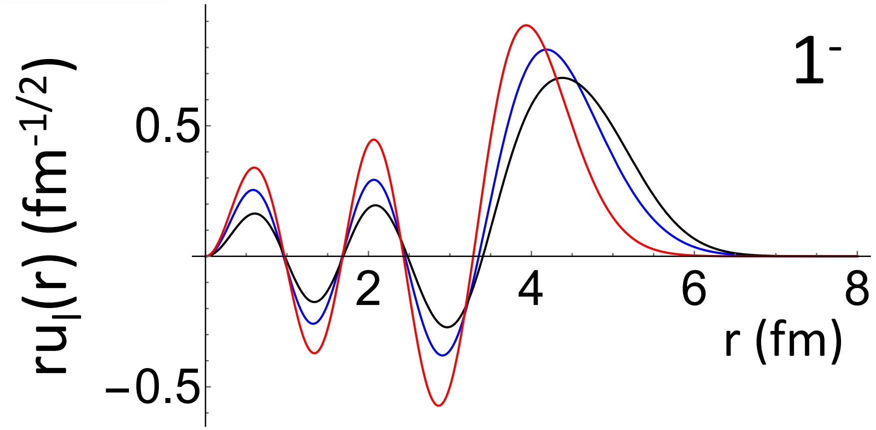
THANK YOU

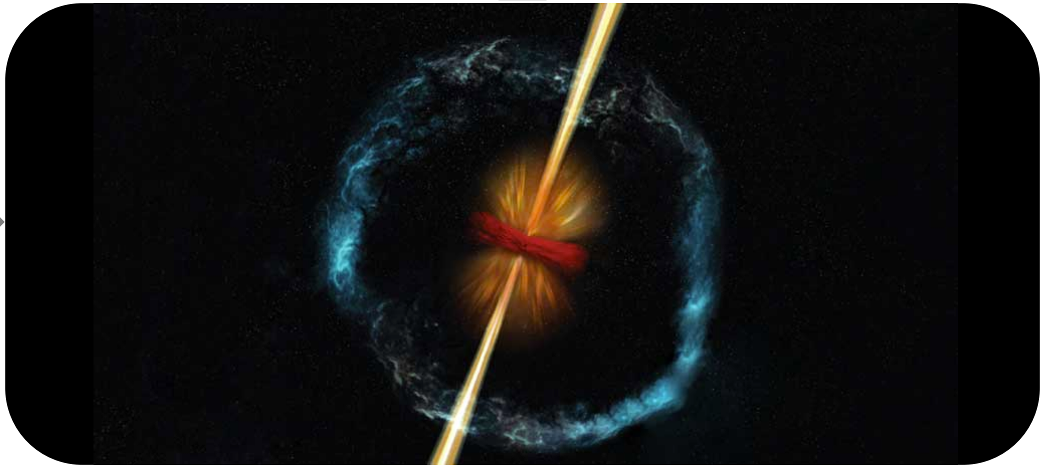
REFERENCES

[1] Y. Suzuki, Nuc Phys A **448**, 395 (1986)
[2] H. Constantini *et al.*, Phys Rev C **82**, 035802 (2010)
[3] A. C. Dreyfuss *et al.*, Phys Lett B **727** (2013)
[4] K. D. Launey *et al.*, Prog Part Nuc Phys **89** (2016)
[5] G. K. Tobin *et al.*, Phys Rev C **89** (2014)



From first principles descriptions of clustering…





…to astrophysical simulations!