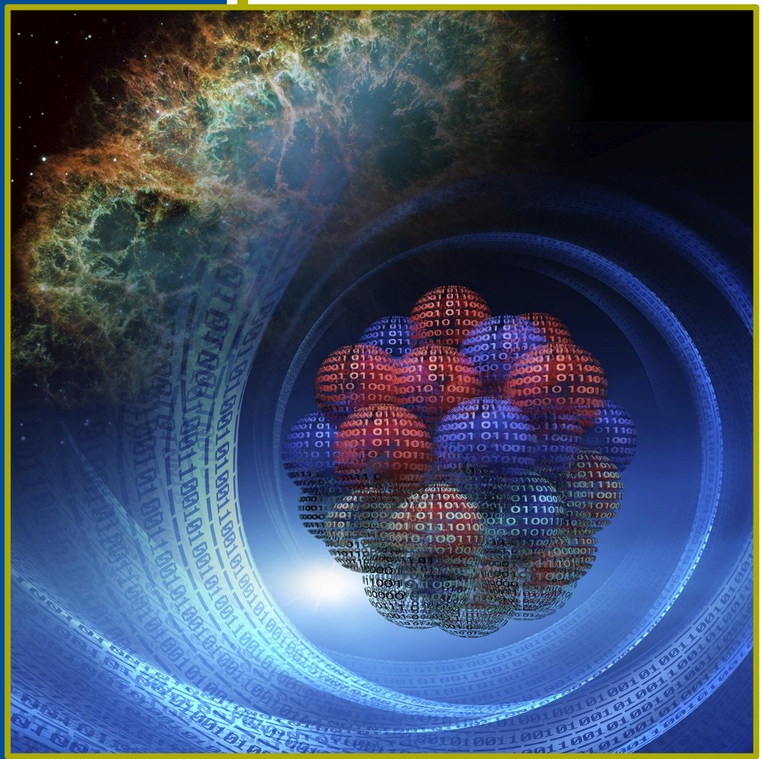
WOUTER RYSSENS



Andy Sproles, ORNL

Towards a truly global description of nuclei

W. Ryssens
N. Chamel, S. Bara, G. Grams, N. Shchechilin,
M. Bender and S. Goriely

7th of June 2024

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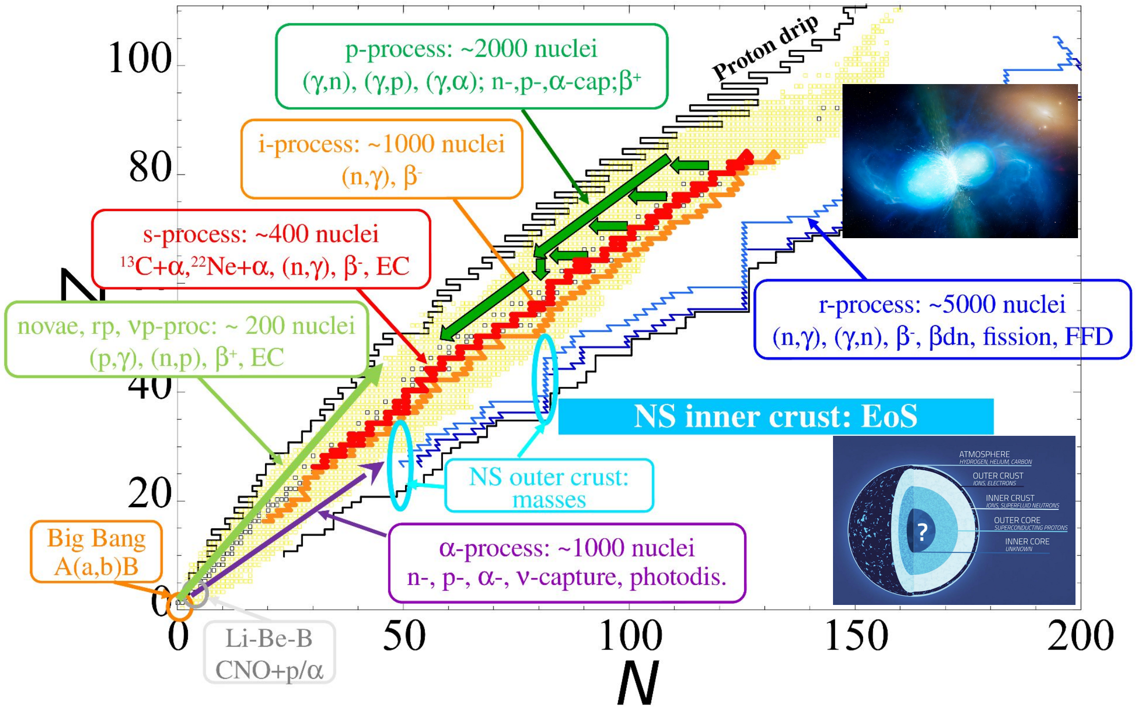
The nuclear chart and the processes traversing it

Extratpolations in

- nucleon number
- energy
- temperature
- density
- ……



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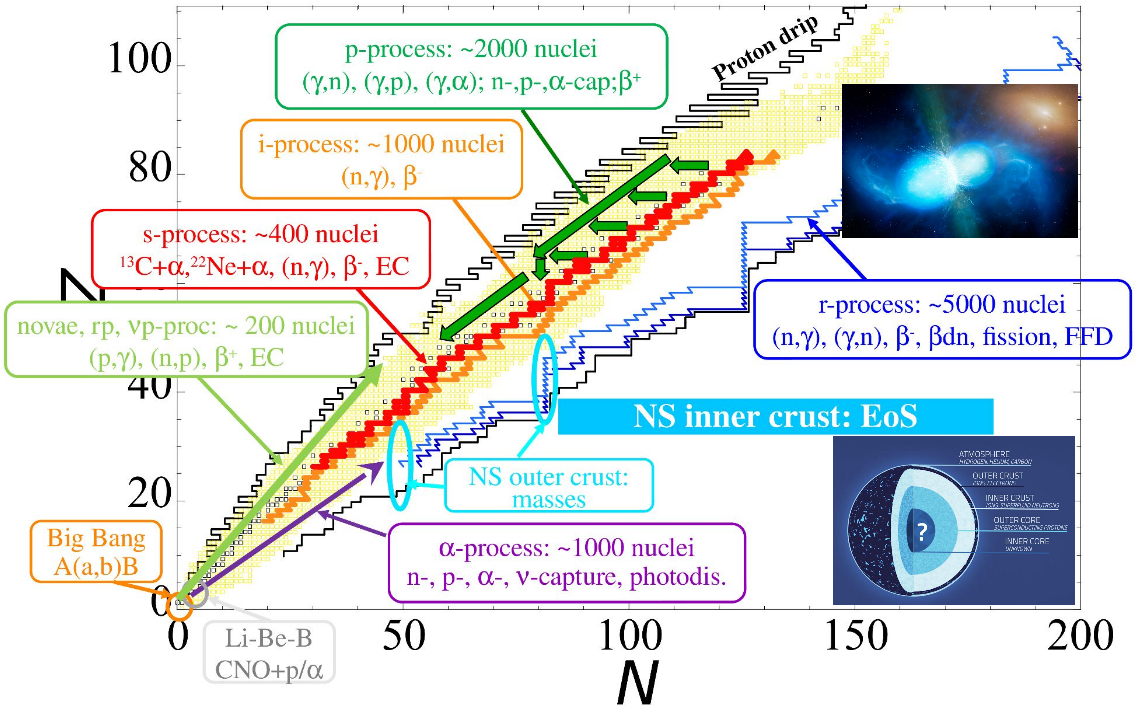
and all of that for
- **~7000** nuclei
- **many** reactions



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Extrapolations in
- nucleon number
- energy
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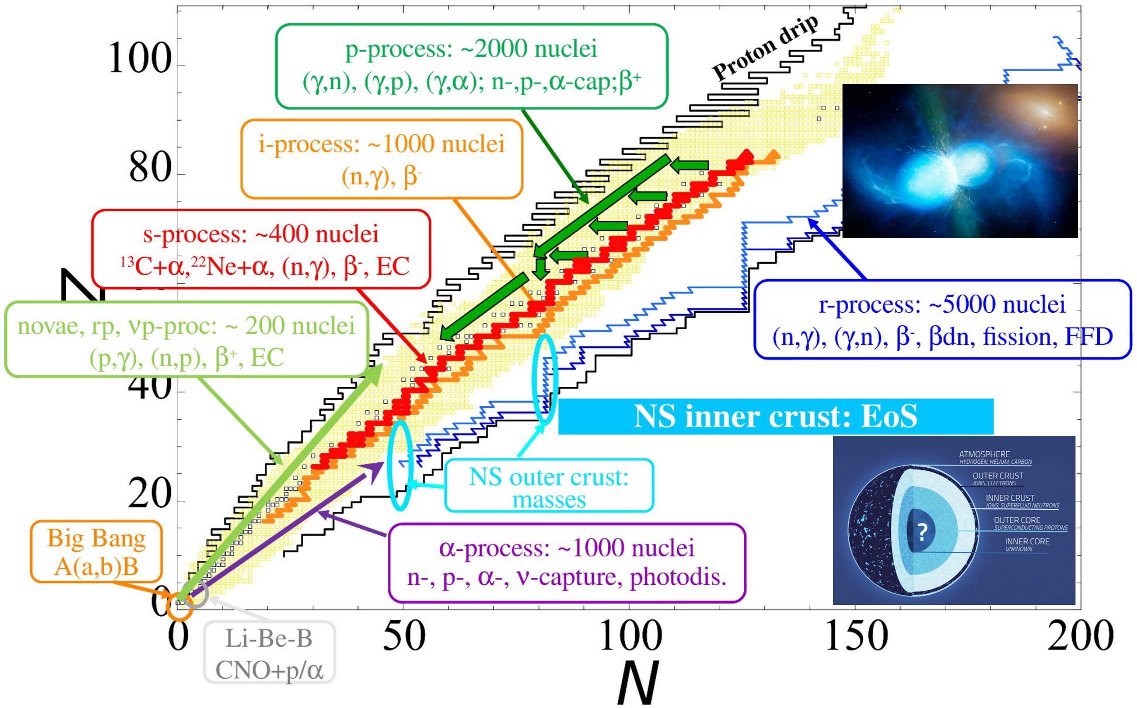
what we need is models that should be

1. **predictive….**
2. but also **complete**



Skyrme **E**nergy **D**ensity **F**unctionals (**EDF**s)

$$E \sim \int d^3r \left[C^\rho \rho(\mathbf{r})\rho(\mathbf{r}) + C^\tau \tau(\mathbf{r})\rho(\mathbf{r}) + \ldots \right]$$

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- **simple** wavefunctions but **individual** nucleons
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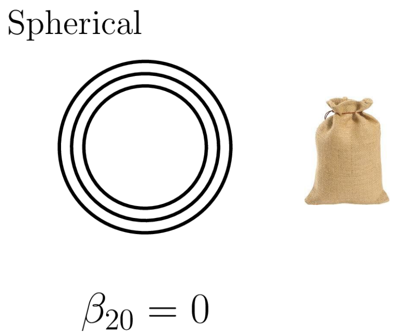
How to move forward?

1. search for a “better” EDF form
2. describe more observables simultaneously
3. include more physics in the wavefunction

Large-scale models in 1 dimensions



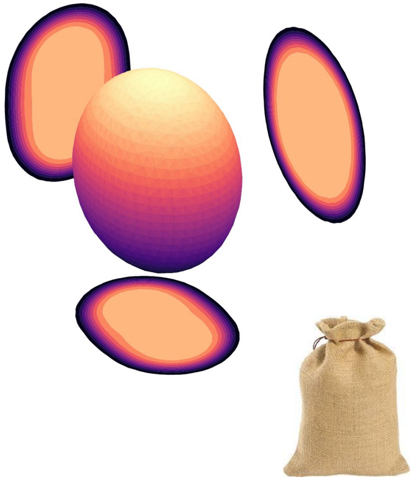
Large-scale models in 1-2 dimensions

Nuclear deformation

- larger variational space
- shape DOF characterized by multipole moments
- capture correlations at modest CPU cost
- intuitive interpretation

Large-scale models in 1-2-**3** dimensions

β_{20}, β_{22} or β_2, γ



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More general configurations

- triaxial shapes
- reflection asymmetry
- elongated shapes

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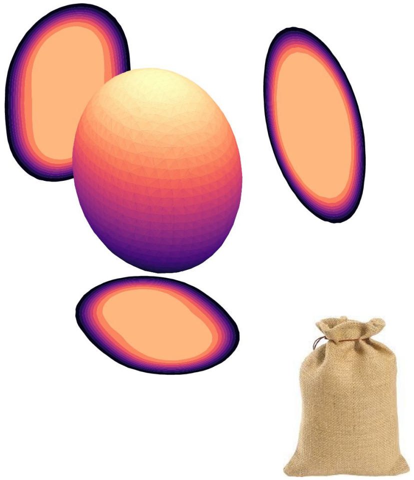
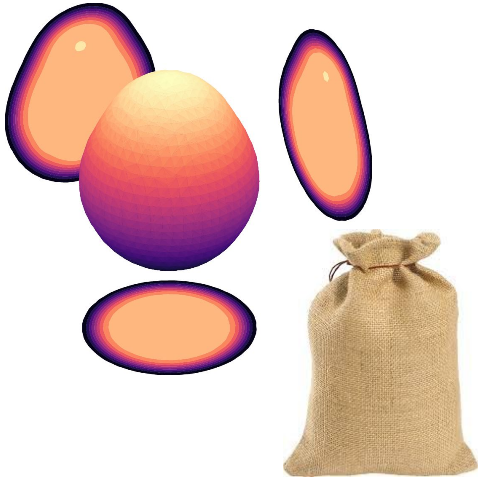


β_{20}, β_{30}



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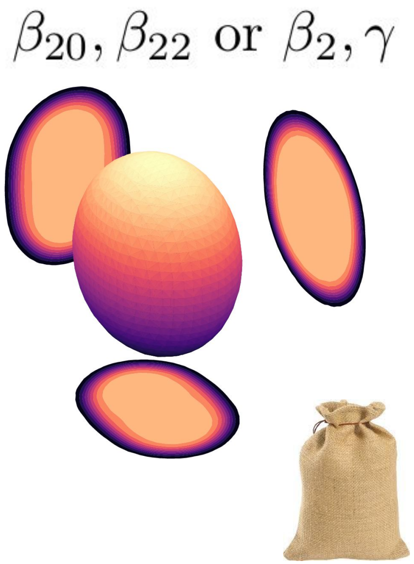

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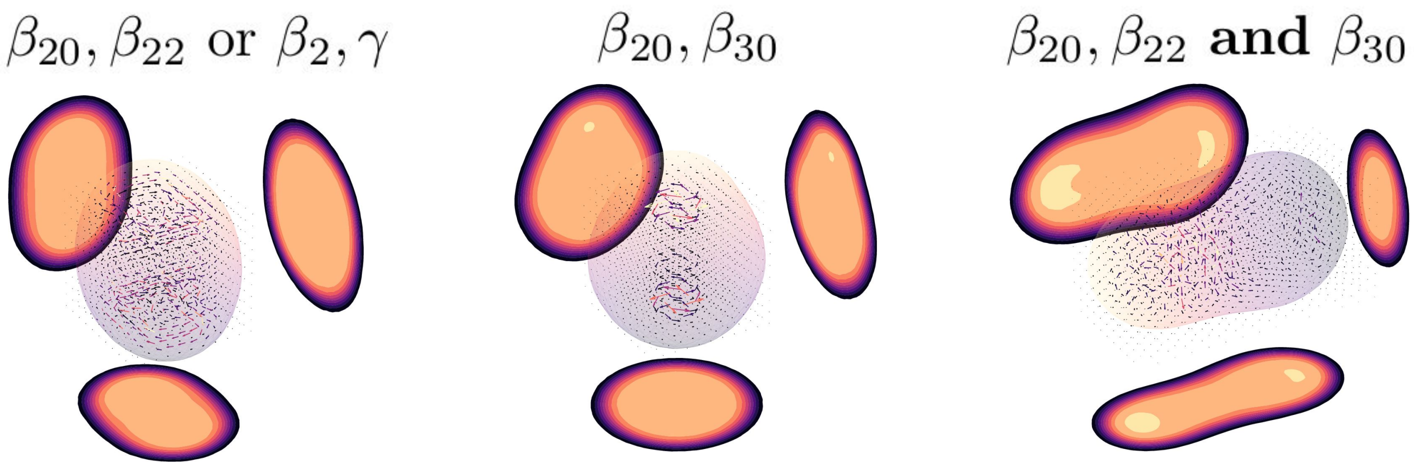

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- triaxial shapes
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- spin densities and currents

Brussels-**Sk**yrme-on-a-**G**rid: BSkG

BSkG1: G. Scamps et al., EPJA **57**, 333 (2021).
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BSkG1 (2021)

- fitted to 2457 masses
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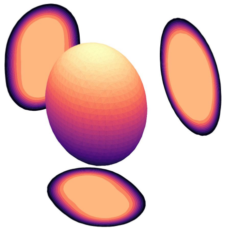

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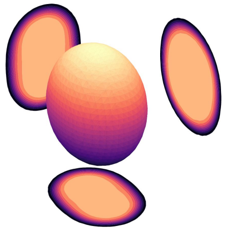

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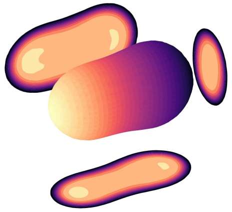

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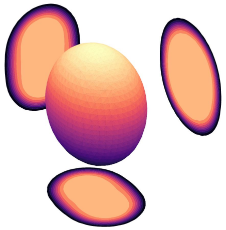

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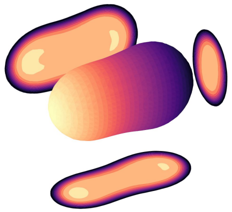

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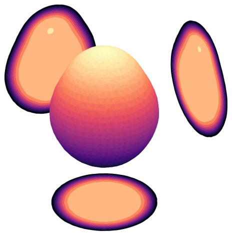

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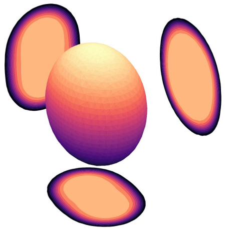

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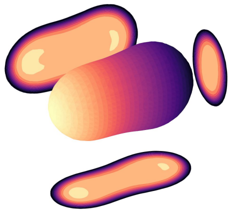

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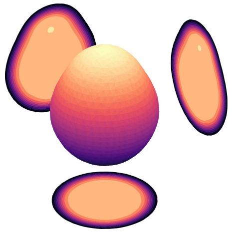

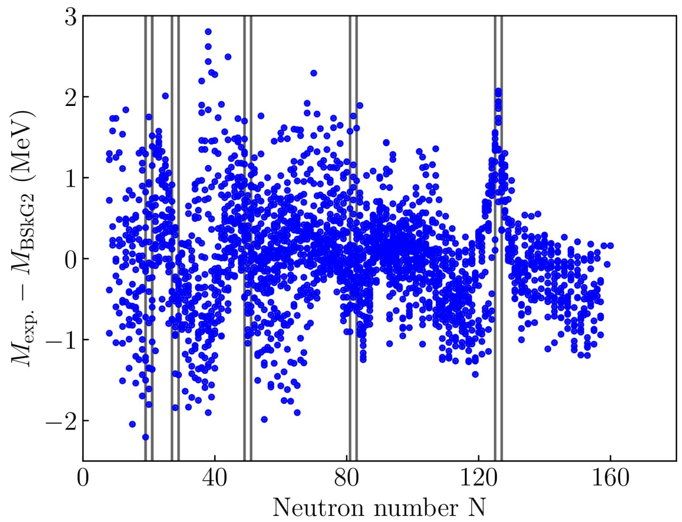

Rms σ	BSkG1	BSkG2	BSkG3
Masses [MeV]			
Radii [fm]			
Prim. barriers [MeV]			
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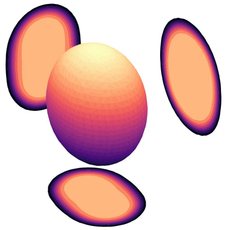

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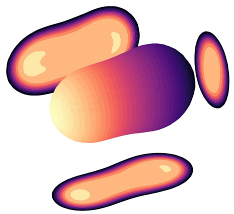

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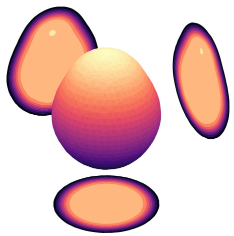

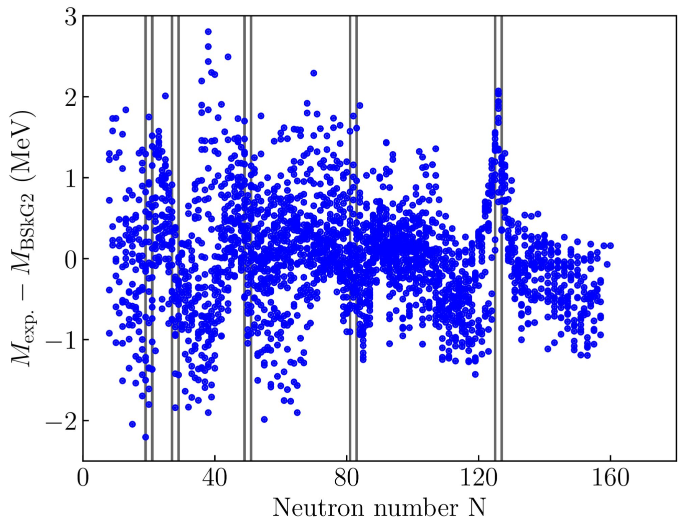

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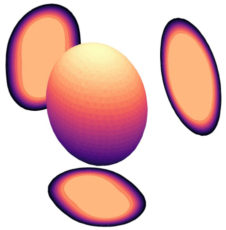

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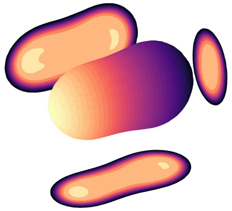

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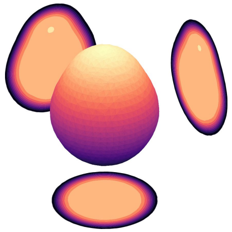

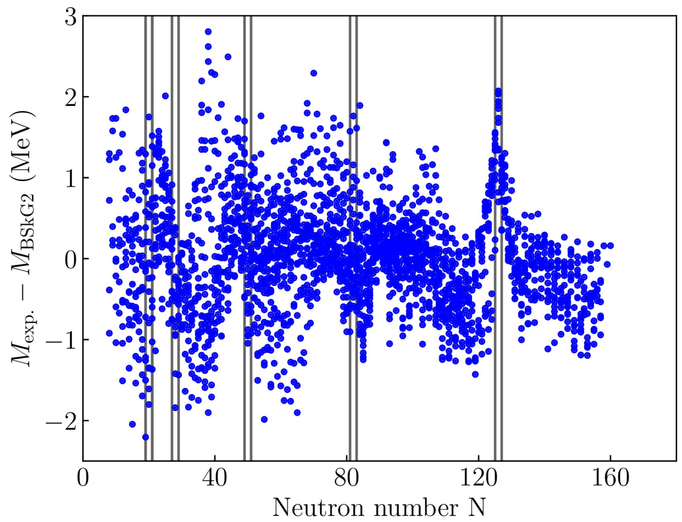

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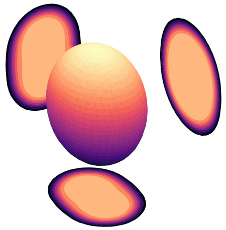

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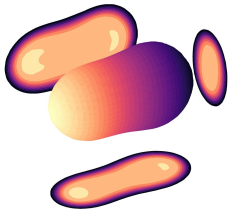

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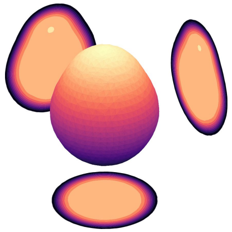

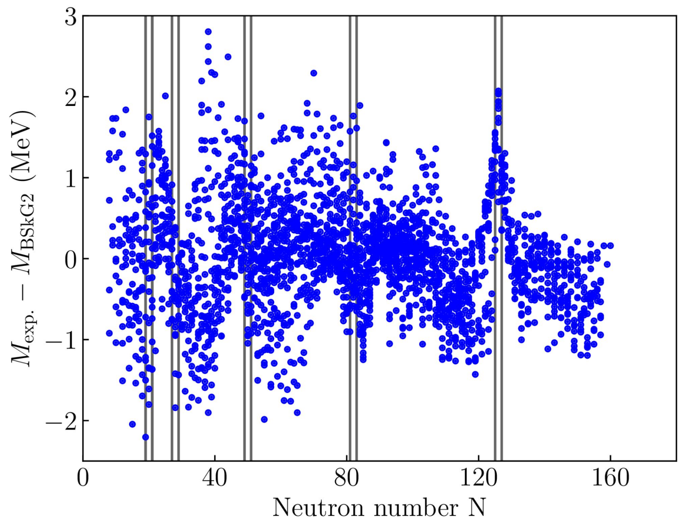

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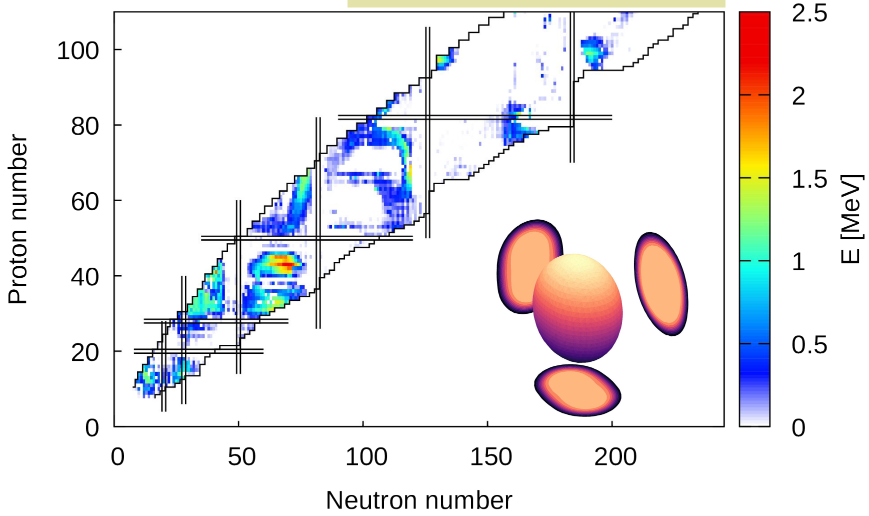

Triaxial deformation

- many nuclei are affected
- effects up to 2.5 MeV near Z~44

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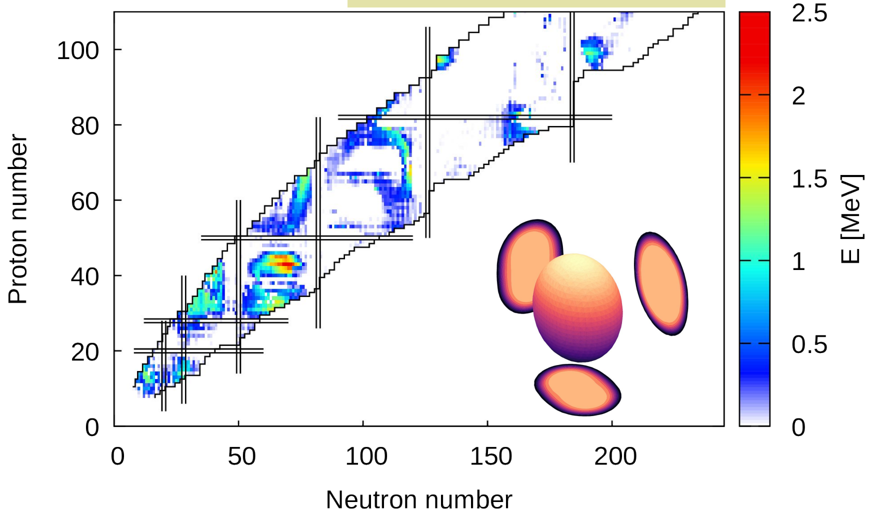
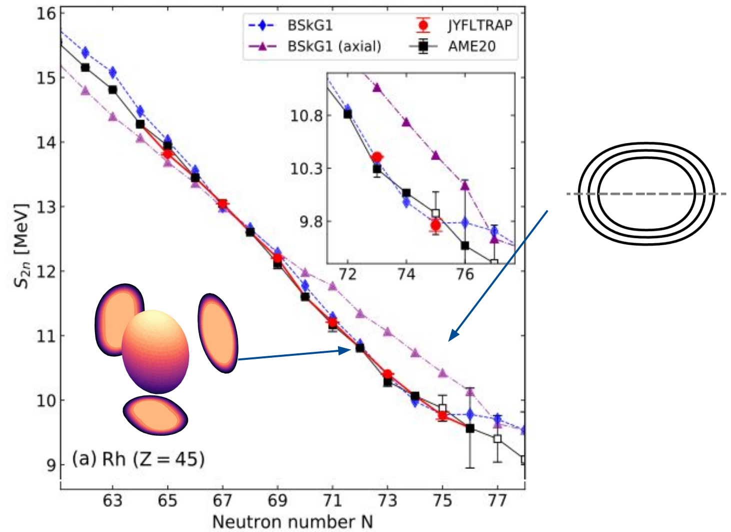


M. Hukkanen, W.R. et al., PRC **107**, 014306 (2023).



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Masses

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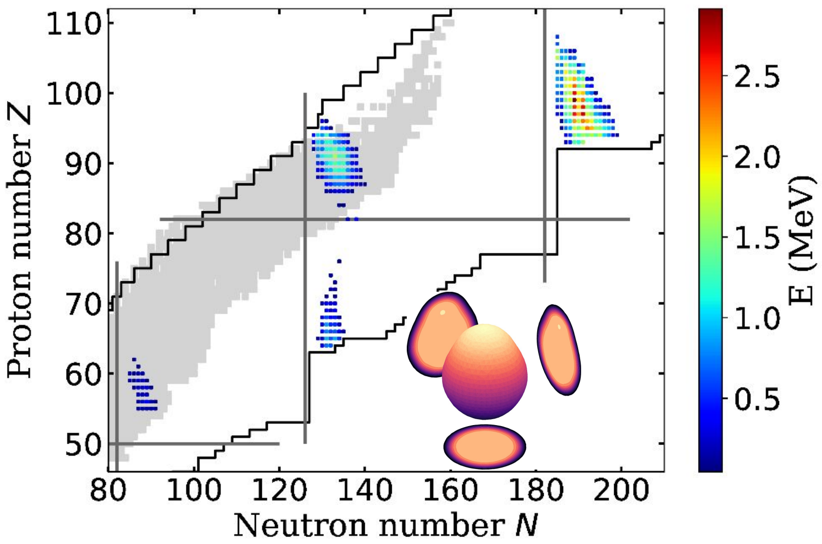
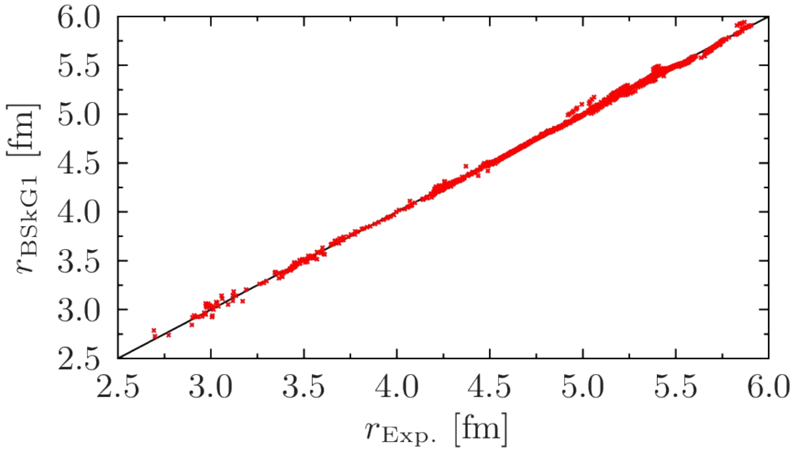


Reflection asymmetry

- small number of known nuclei affected
- Near N=184:
  - large effect up to 2.5 MeV
  - dripline modified
  - fission properties modified

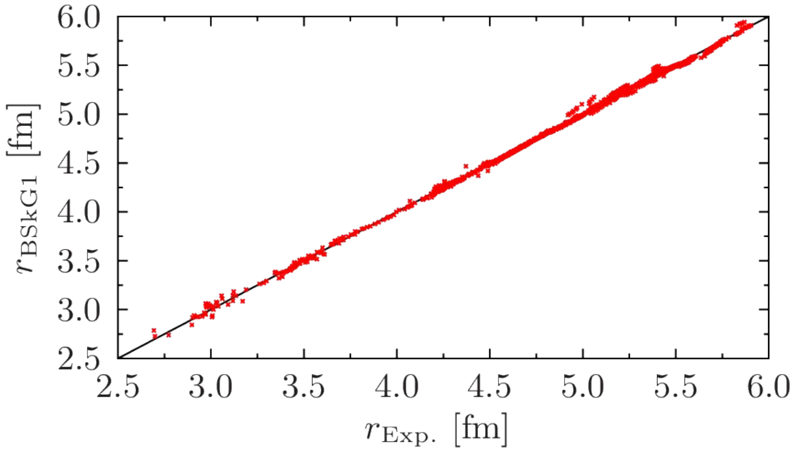
Radii



Systematics and details of charge radii

- rms (charge radii) ~ 0.027 fm
- complete charge densities
- ALL deformation affects radii!

Radii



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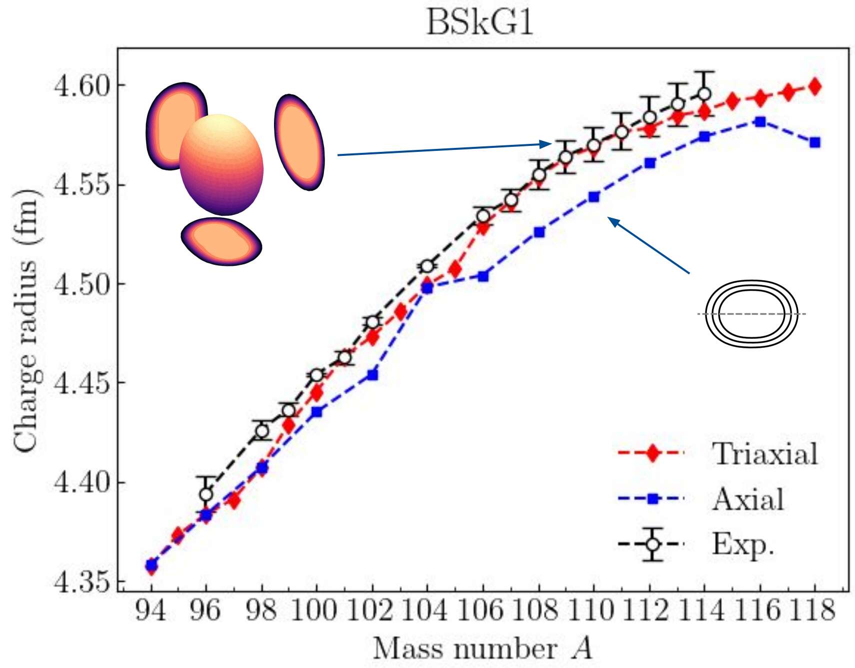
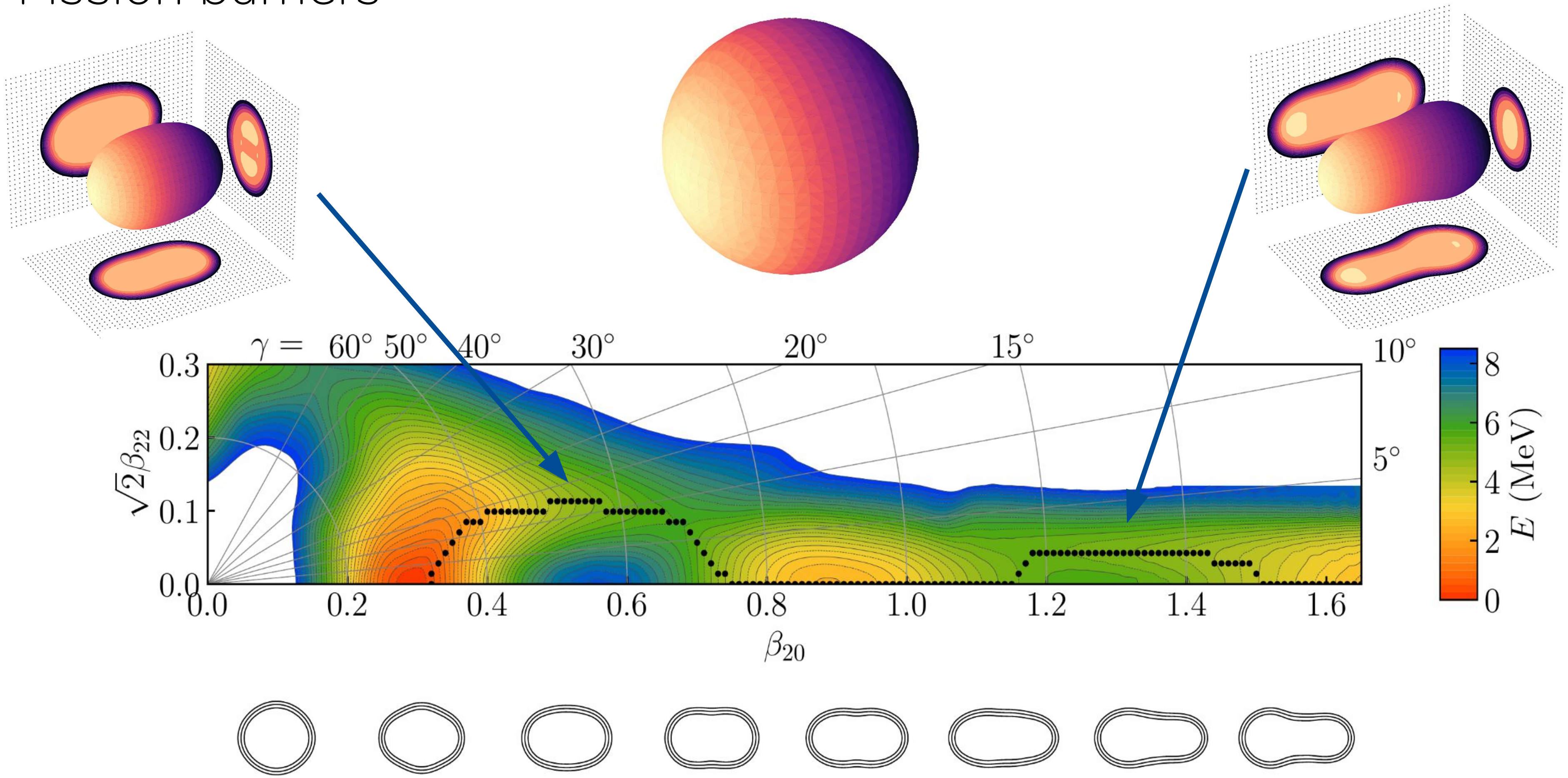


See talk by B. Maaß on Tuesday.

Fission barriers

W. R. et al., EPJA **59**, 96 (2023).



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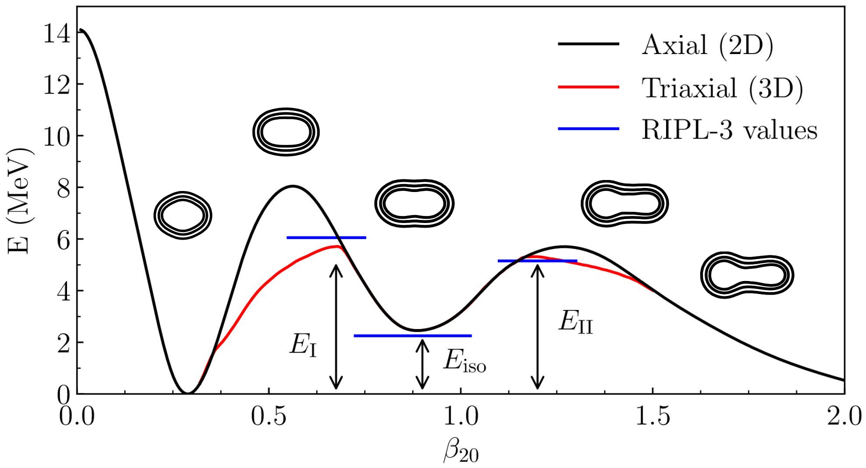

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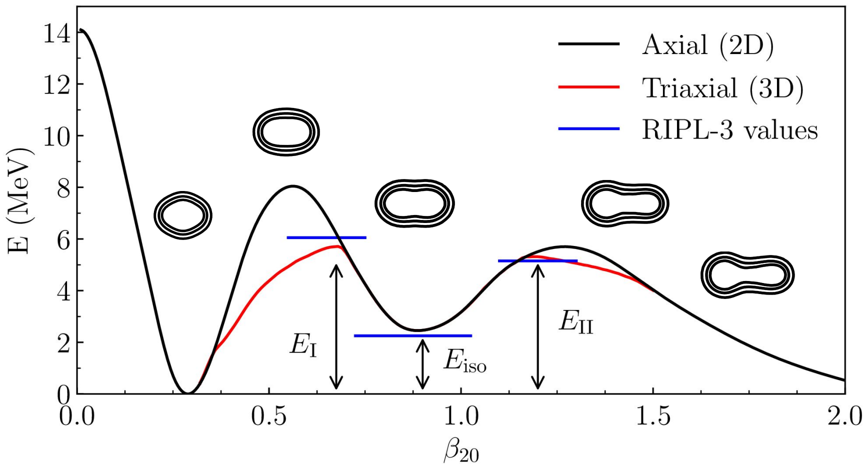
Fission properties of 45 actinide nuclei

- includes odd-A and odd-odds
- **all** inner barriers exploit triaxiality
- **all** outer barriers exploit
  - octupole deformation
  - triaxial deformation

Fission

W. R. et al., EPJA **59**, 96 (2023).



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Secon. barriers [MeV]	0.87	0.47	0.51
Fission isomers [MeV]	1.0	0.49	0.34
Max. NS mass [$M_\odot$]	1.8	1.8	2.3

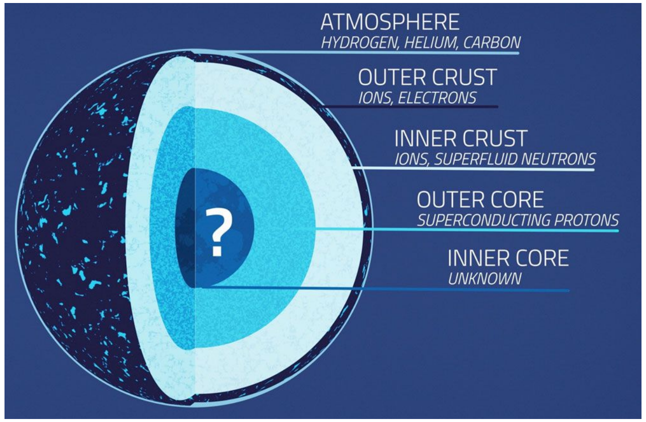
Fission properties of 45 actinide nuclei

- includes odd-A and odd-odds
- **all** inner barriers exploit triaxiality
- **all** outer barriers exploit
  - octupole deformation
  - triaxial deformation

.... to those of thousands of nuclei!

- calculations started: G. Grams
- pathfinding: S. Bara
- big effort in code optimisation

Neutron stars

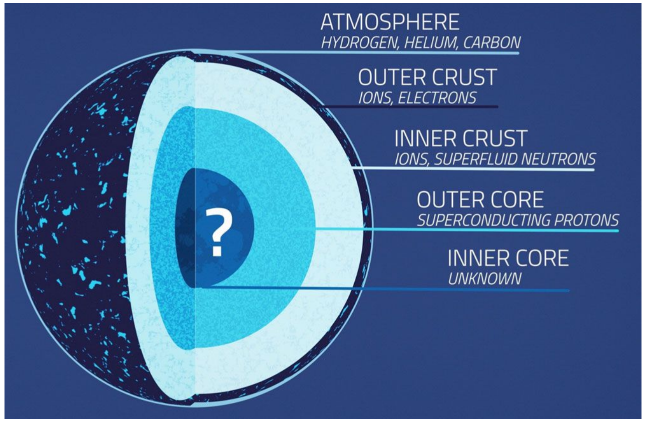


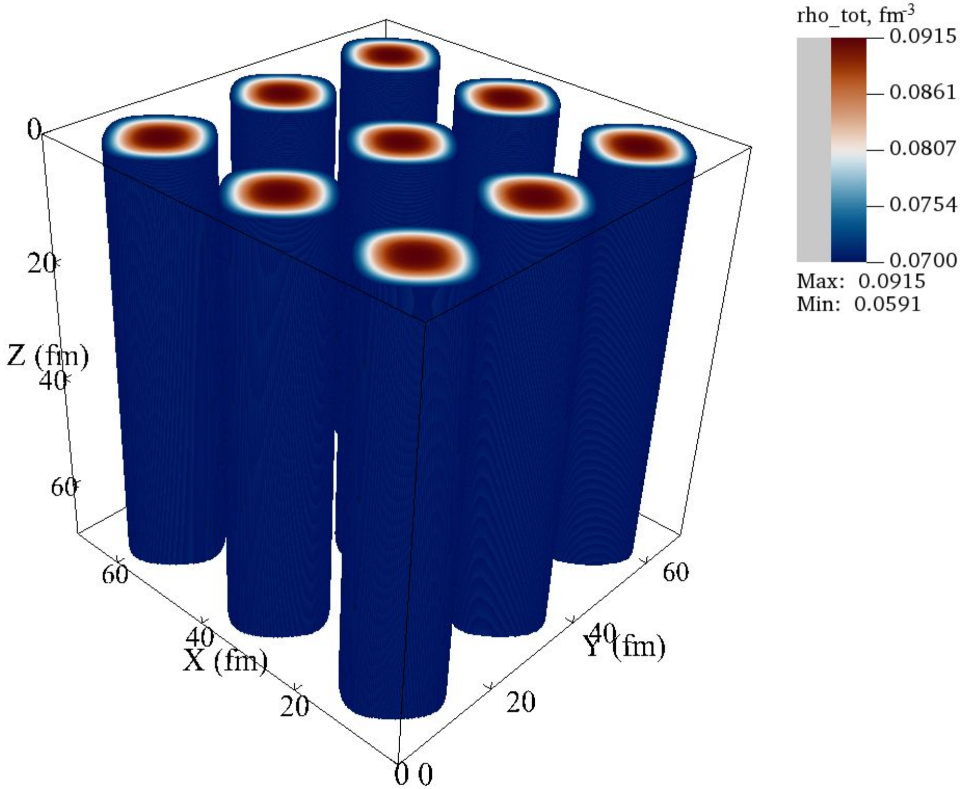
Simulations of crust composition

- does nuclear pasta exist?

Work by N. Shchechilin

Neutron stars





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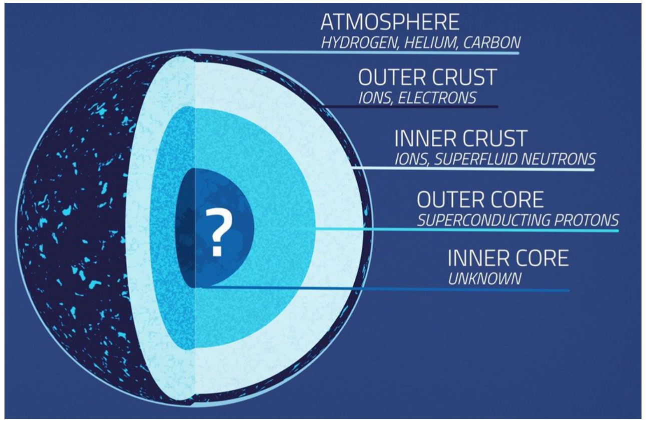
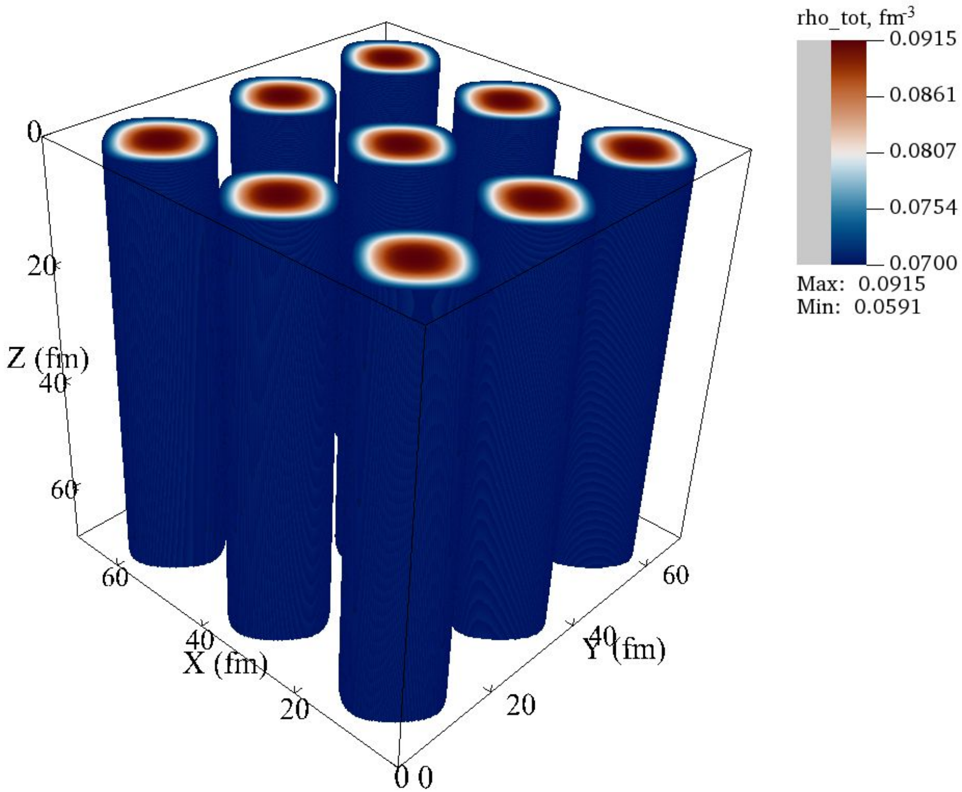




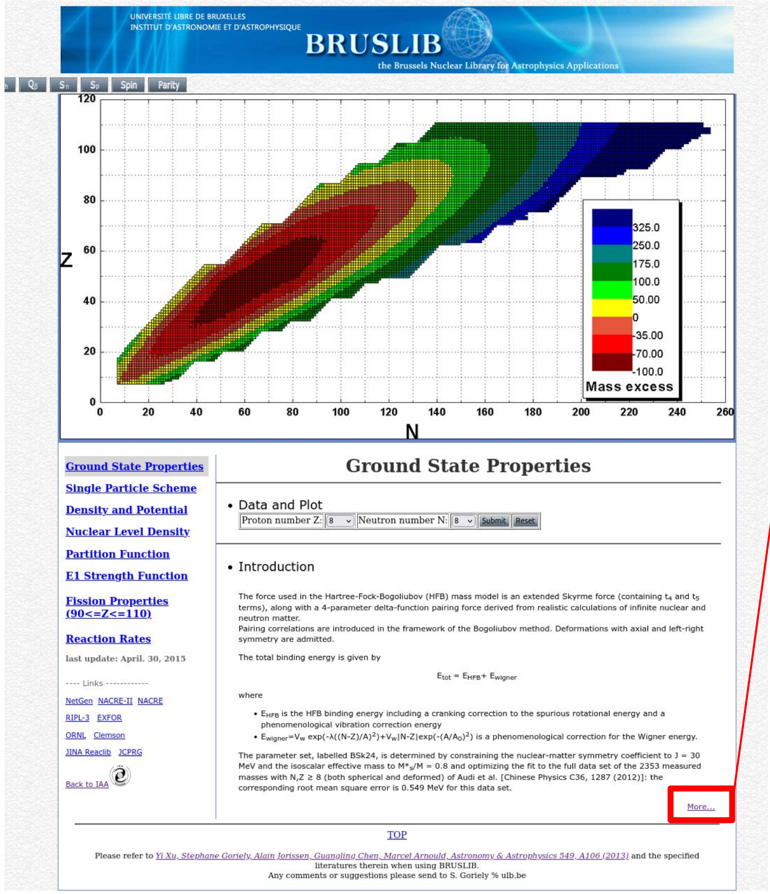
Simulations of crust composition

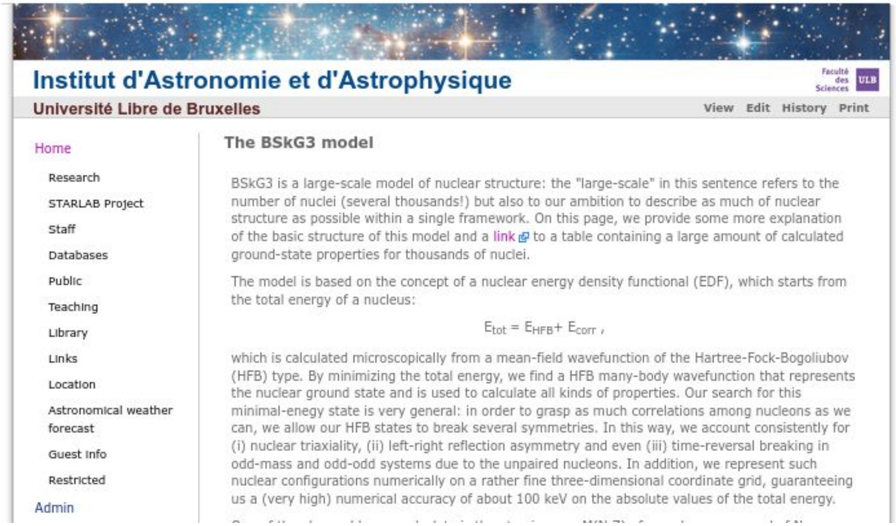
- does nuclear pasta exist?
- from ~200 to 25000 particles
- ... up to 100.000 will be possible!

Work by N. Shchechilin

BRUSLIB: **http://www.astro.ulb.ac.be/bruslib/**

G. Grams et al., EPJA 59, 270 (2023).





Available right now for BSkG3:

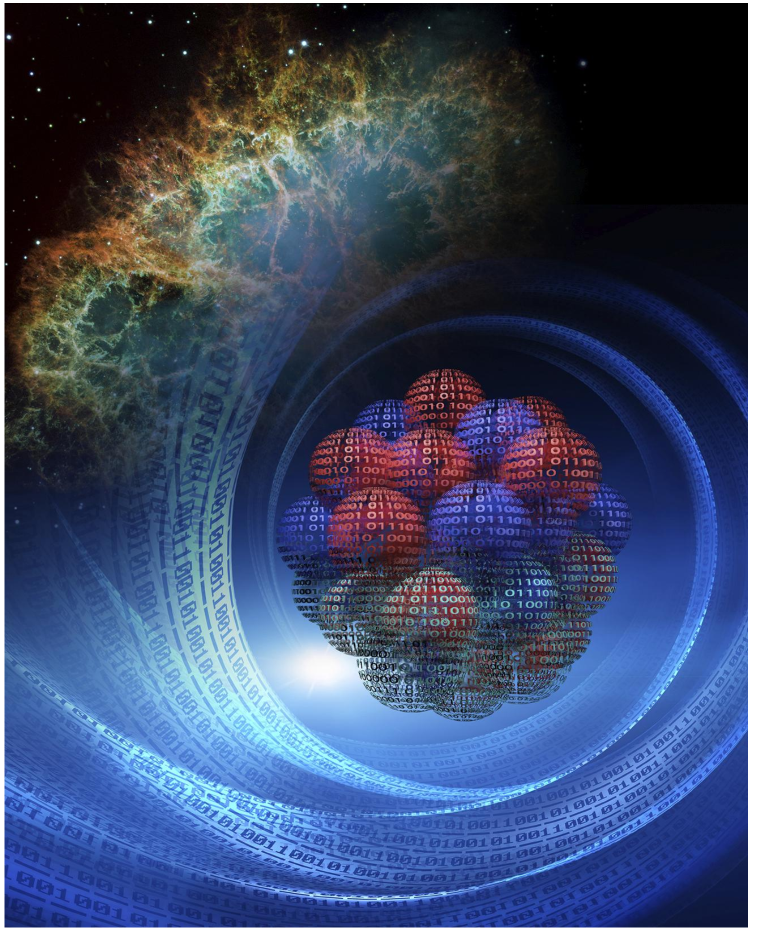
1. ground state properties for 7k nuclei
   a. masses
   b. deformations
   c. charge radii
   d. pairing properties
   e. rotational properties
2. Fission barriers for actinides

... or check the supplementary material!

Conclusion

We build **large-scale, microscopic** models for (astro) applications.

Large-scale = **thousands** of nuclei and **many observables.**
Microscopic = simple wave functions yet complex **symmetry breaking.**



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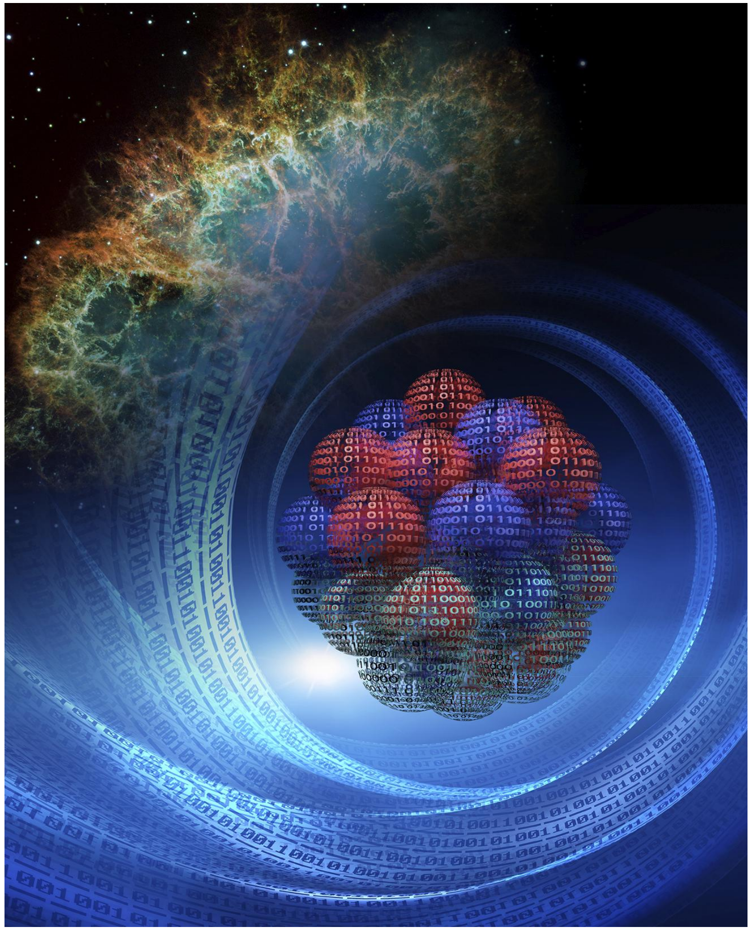
- triaxial, octupole and time-reversal deformation
- competitive for masses and charge radii
- unmatched for fission properties
- consistent with NS observations
- masses and densities in TALYS!



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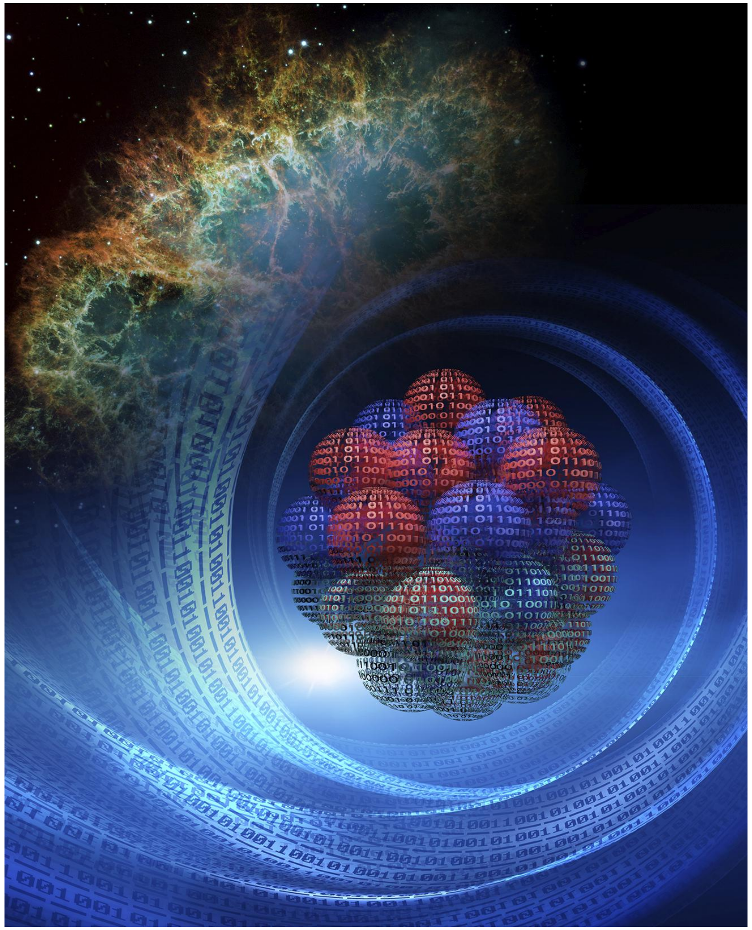
- nuclear level densities for BSkG1/2/3
- fission calculations at an extreme scale
- unified EoS for neutron star applications
- more with less: BSkG4



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Thank you for...

...... all the wonderful work!

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N. Chamel
N. Shchechilin

S. Hilaire

M. Bender

E. Tijskens

S. Bara

+ several experimental teams!

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