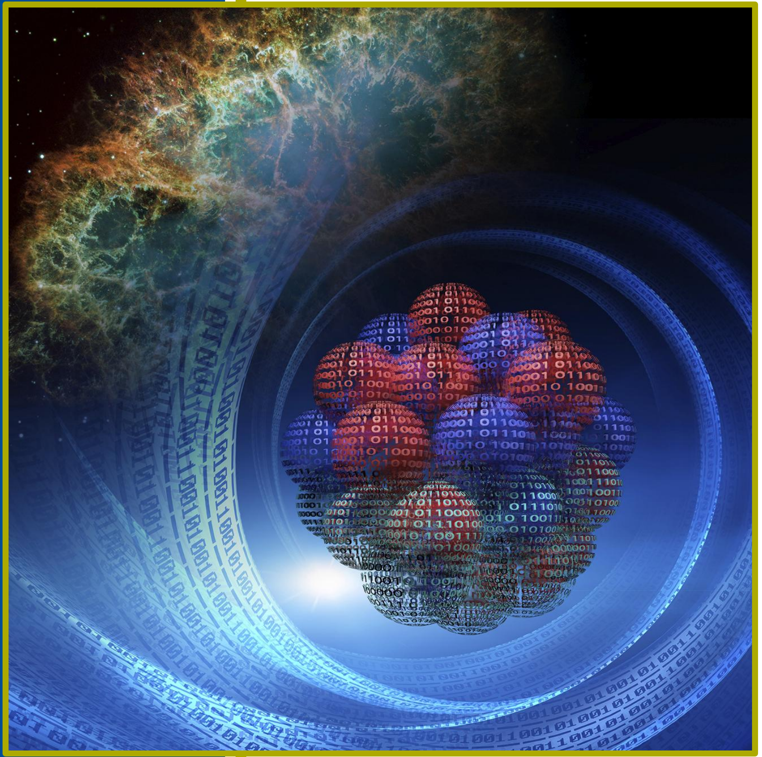
WOUTER RYSSENS



Andy Sproles, ORNL

BSkG models versus experiments

Wouter Ryssens

4th of December 2023

wryssens.com

wryssens@ulb.be

ULB

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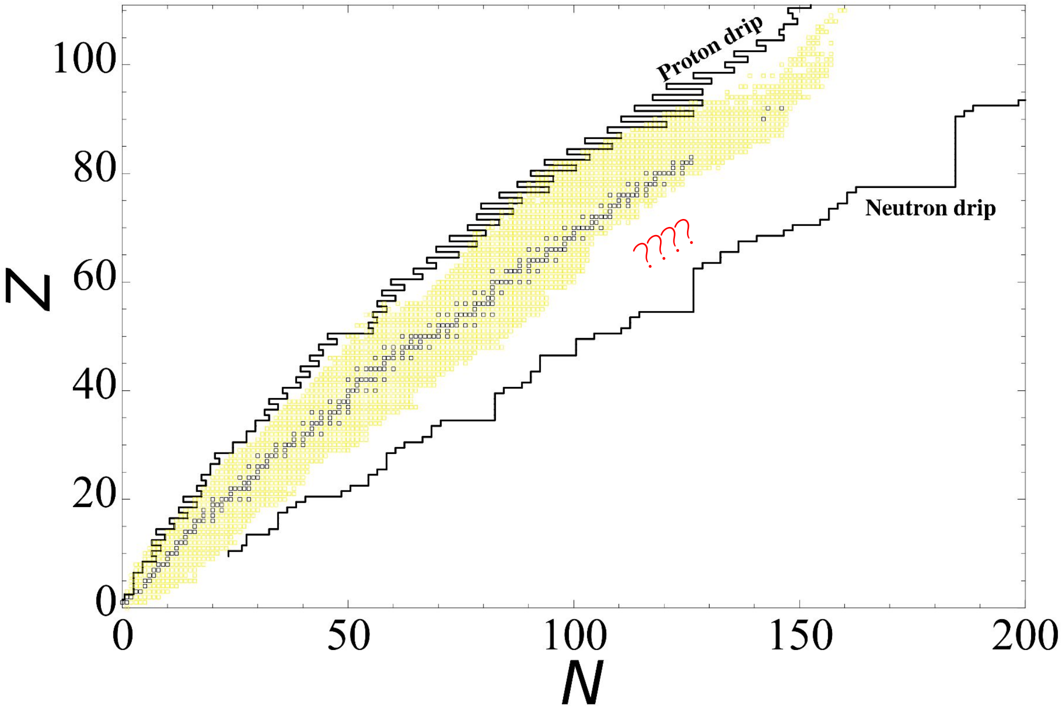
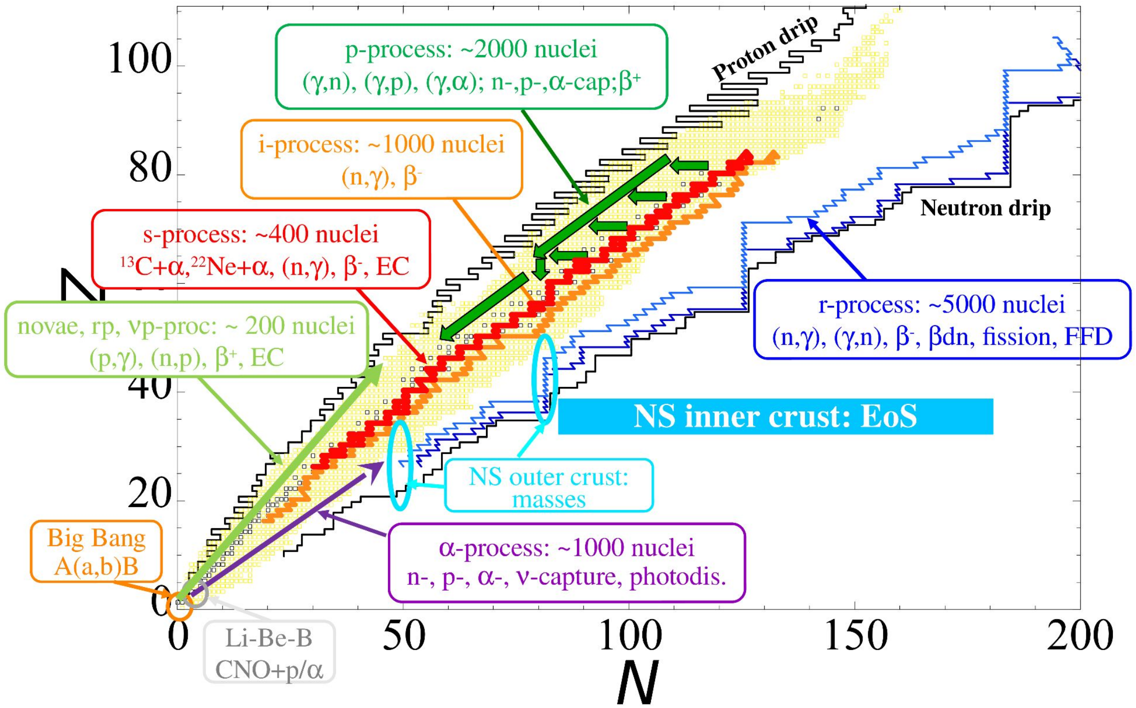
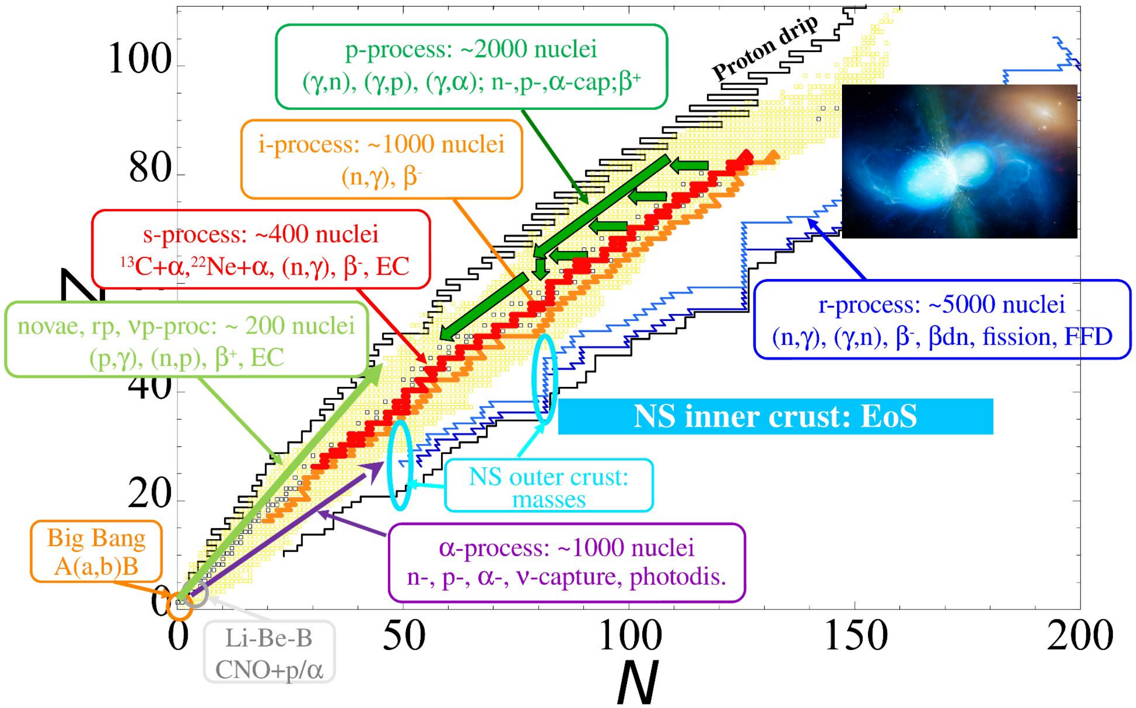
The nuclear chart...



The nuclear chart and the processes traversing it



The nuclear chart and the processes traversing it



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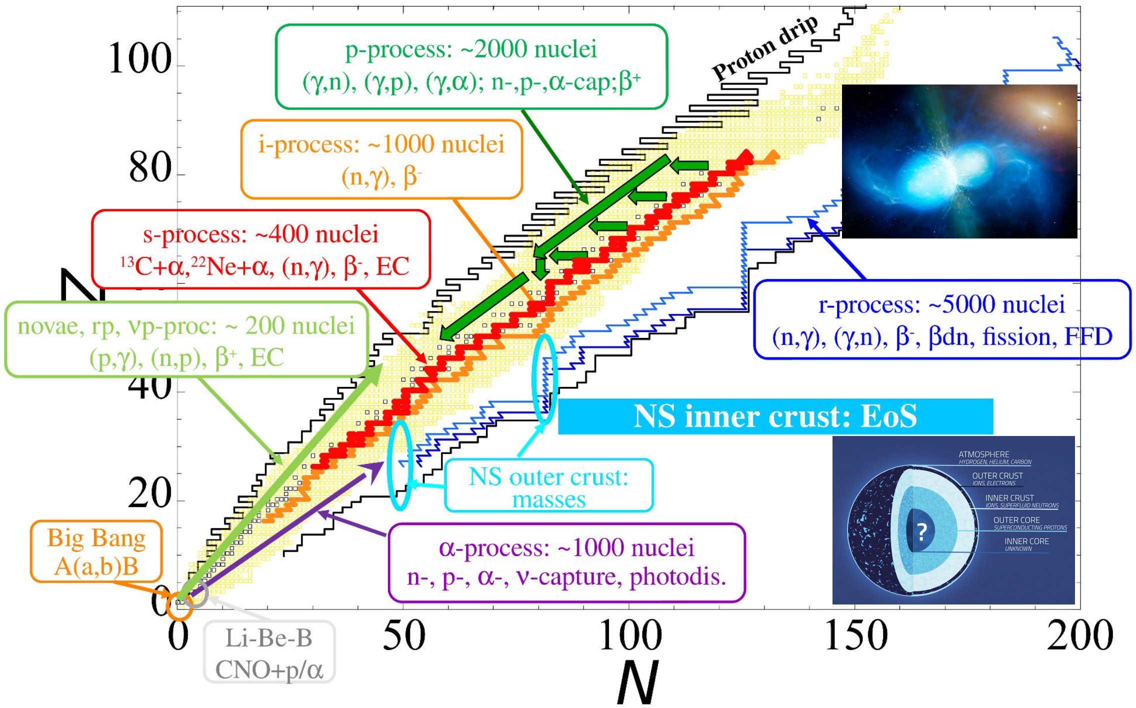
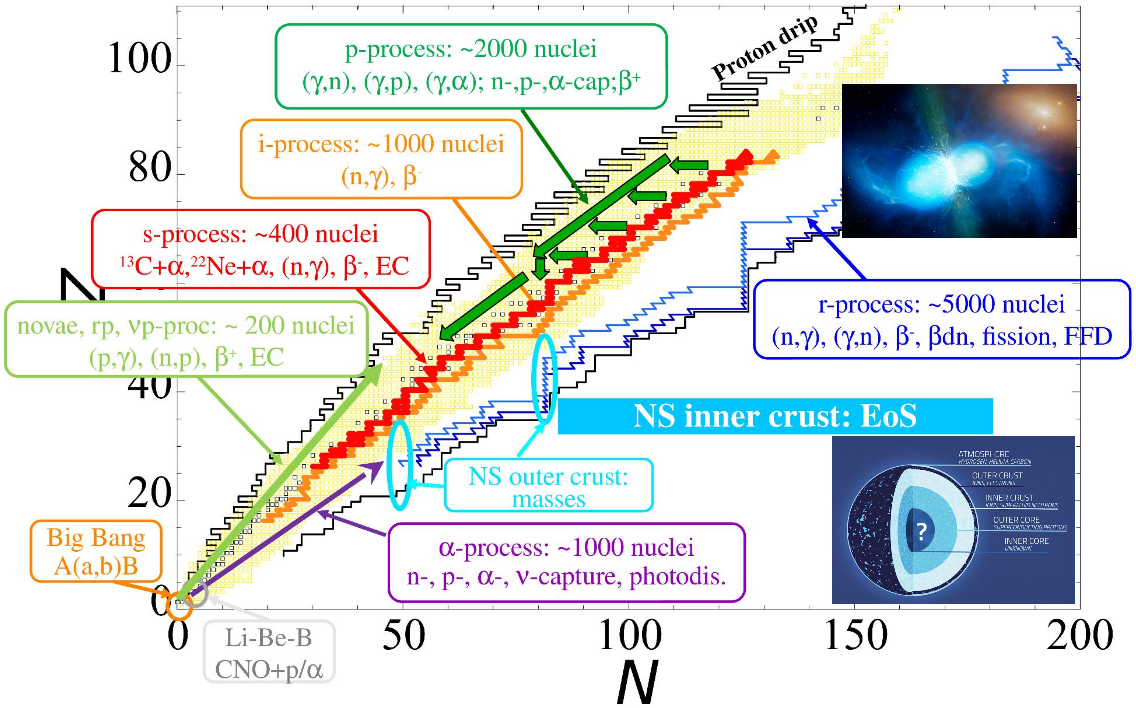


The nuclear chart and the processes traversing it

Extrapolations in N,Z,E, T, ρ, …
for **~7000** nuclei and **many** reactions!

We need is models that should be

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



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1. **predictive....**
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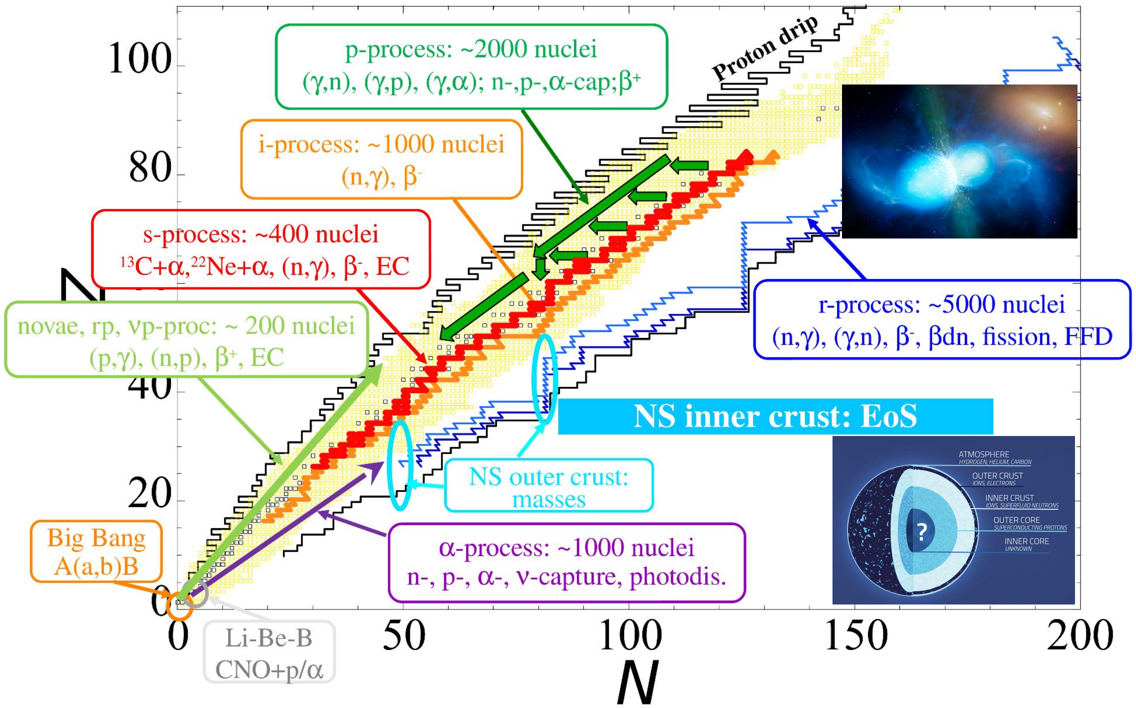
Energy Density Functional models

- ≅ 25 parameters fitted to data
- ✅ based on “in-medium” interaction
- ✅ wavefunctions with nucleons
- ✅ many observables accessible
- ✅ feasible for **~7000** nuclei
- ✅ symmetry-breaking => 3D shapes



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

BSkG1: G. Scamps et al., EPJA **57**, 333 (2021).
BSkG2: W. Ryssens et al., EPJA **58**, 246 (2022).
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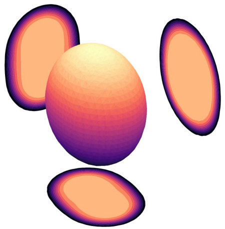
BSkG1 (2021)

- fitted to 2457 masses
- fitted to 884 charge radii
- includes triaxial deformation



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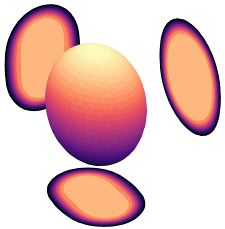
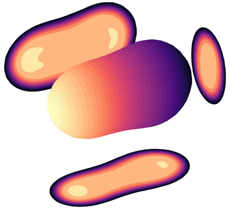


BSkG2 (2022)

- fitted to 45 fission barriers
- includes spins, currents,...



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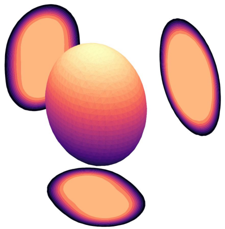

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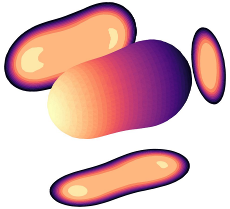
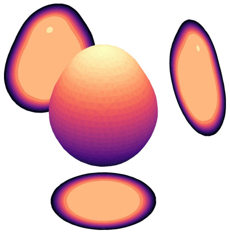


BSkG3 (2023)

- larger max. neutron star mass
- includes octupole deformation



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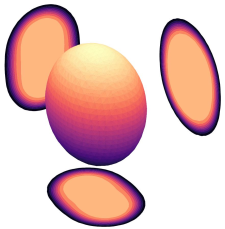

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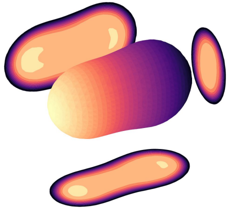

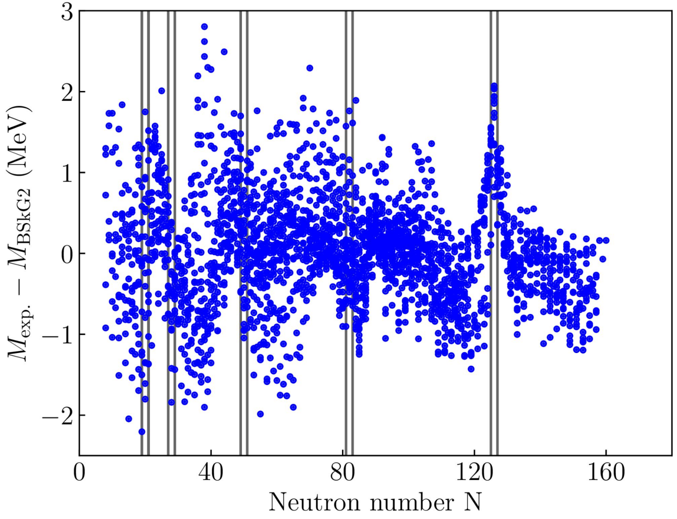

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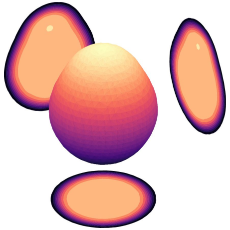

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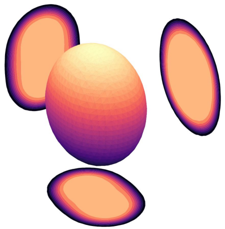

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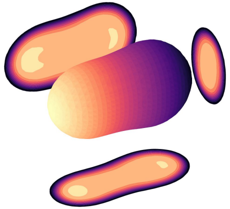

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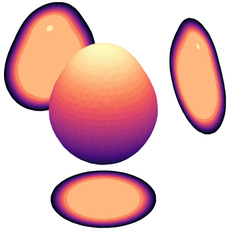

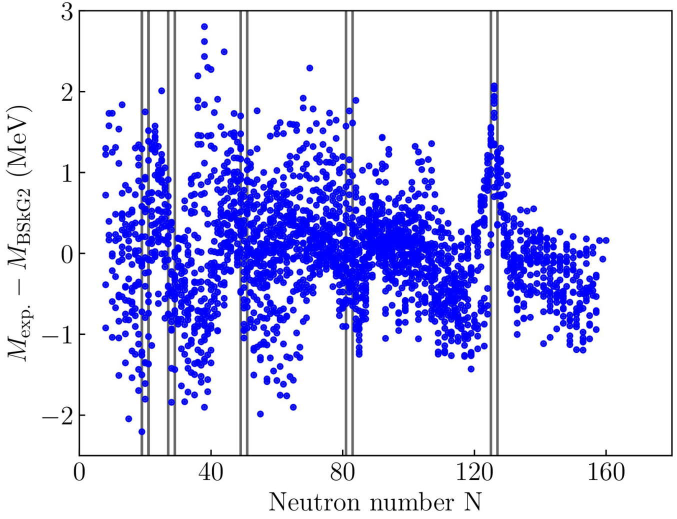

Rms σ	BSkG1	BSkG2	BSkG3
Masses [MeV]	0.741	0.678	0.631
Radii [fm]	0.024	0.027	0.024
Prim. barriers [MeV]	0.88	0.44	0.33
Secon. barriers [MeV]	0.87	0.47	0.51
Fission isomers [MeV]	1.0	0.49	0.34
Max. NS mass [$M_\odot$]	1.8	1.8	2.3

Masses

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

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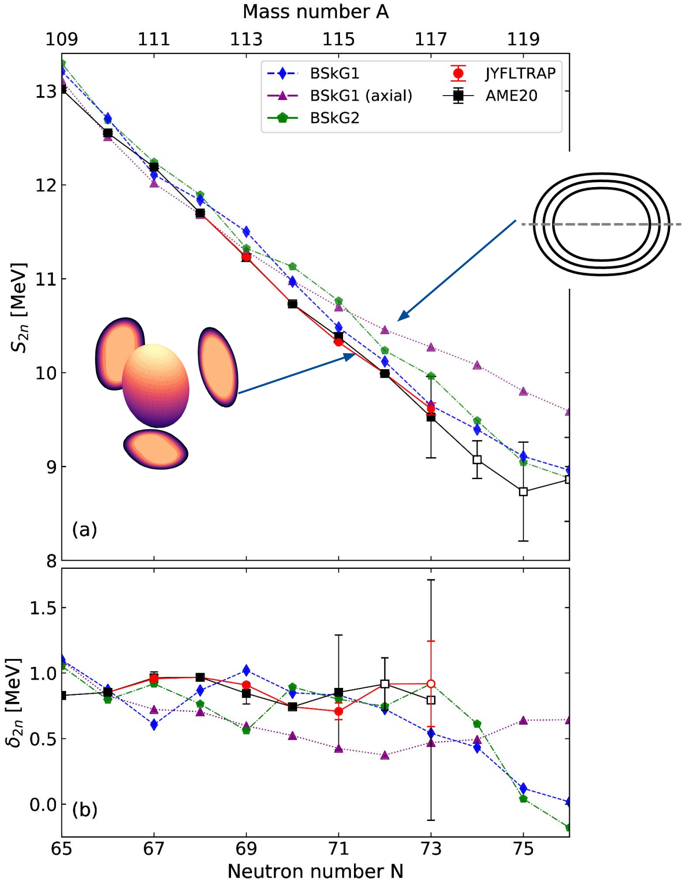

JYFLTRAP mass measurements

- neutron-rich Rh & neutron-rich Ru
  - triaxiality from spectroscopy
  - … and (indirectly) from masses

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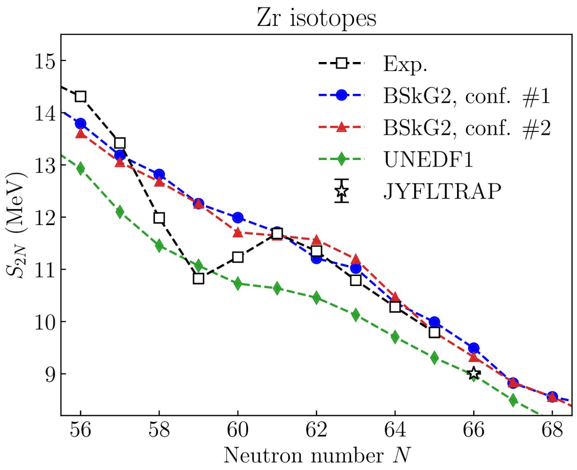

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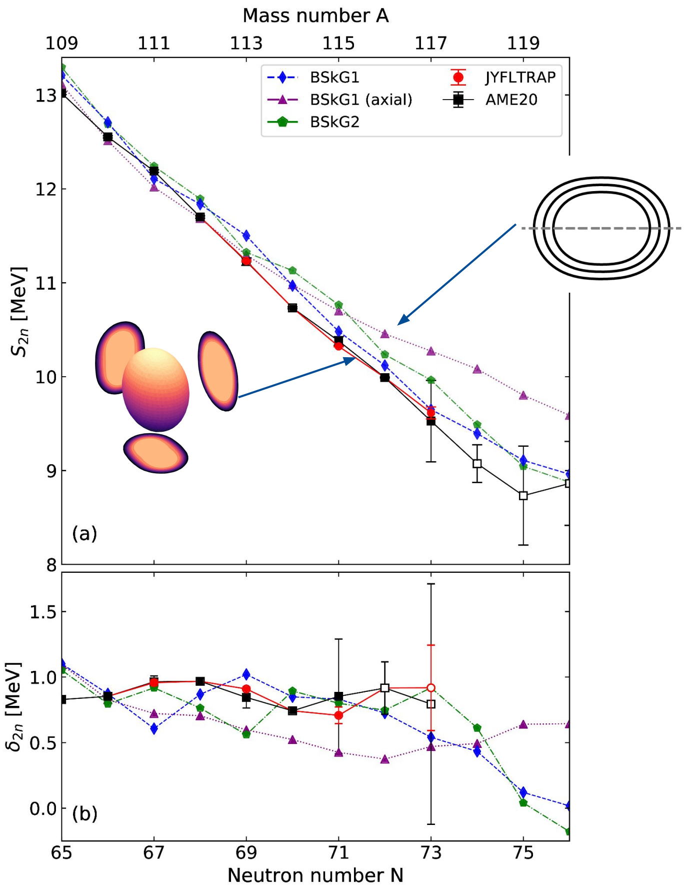

JYFLTRAP mass measurements

- neutron-rich Rh & neutron-rich Ru
  - triaxiality from spectroscopy
  - … and (indirectly) from masses
- neutron-rich Y,Zr, Nb, Mo
  - shape coexistence
  - failure to get details right

Isomers

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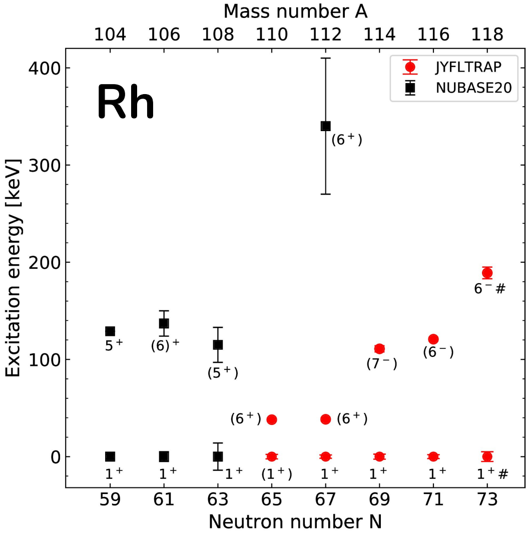

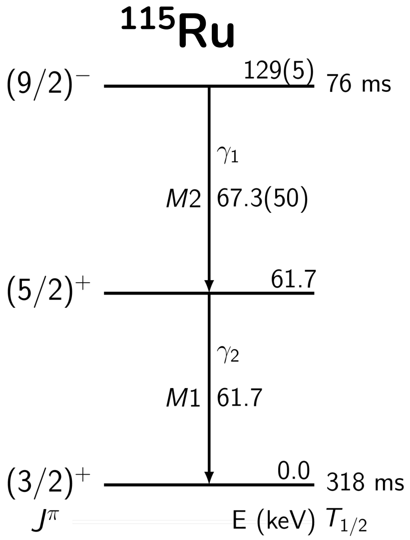

..... with Phase-Imaging-ICR!

- massive resolving power for isomers
- set of low-lying isomers in Rh
- new low-lying isomer in Ru

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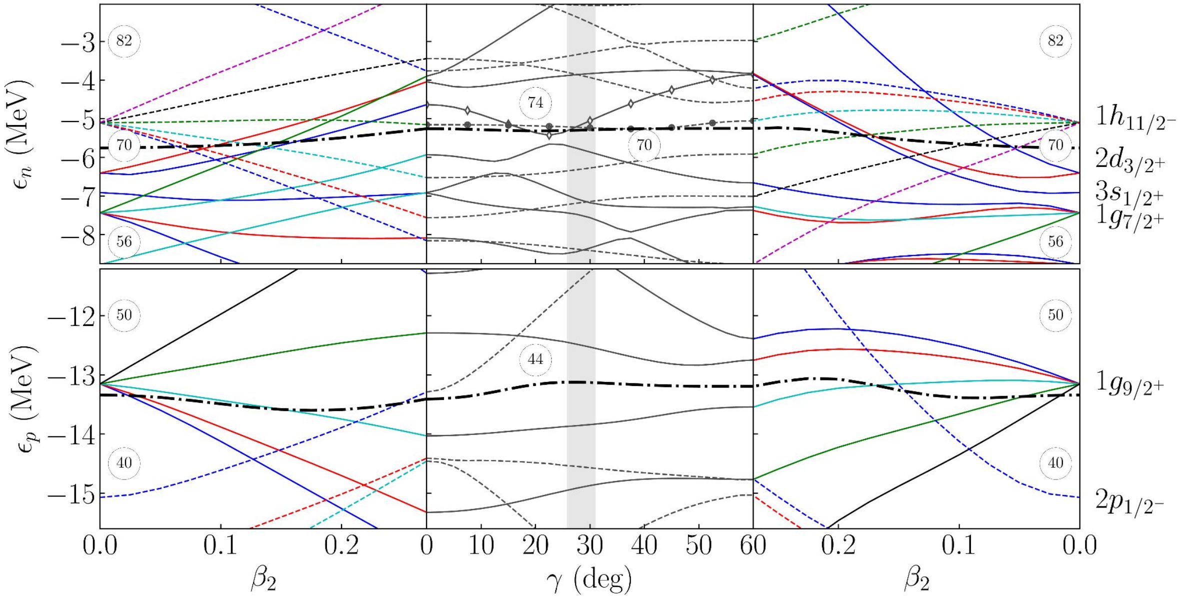

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- massive resolving power for isomers
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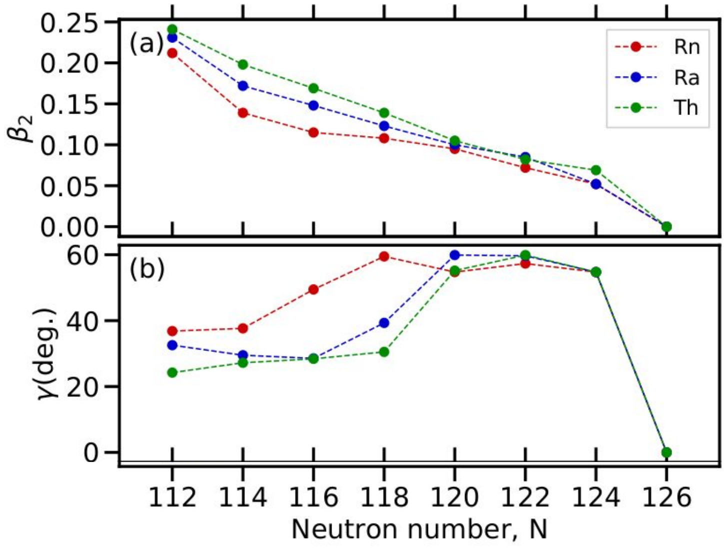
- new low-lying isomer in Ru
- qualitatively interpreted with BSkG's!

Spectroscopy

J. Heery et al, in preparation.



Neutron-deficient Radium isotopes

- in-beam γ-ray spectroscopy @ JYFL
- looking for highly-deformed states

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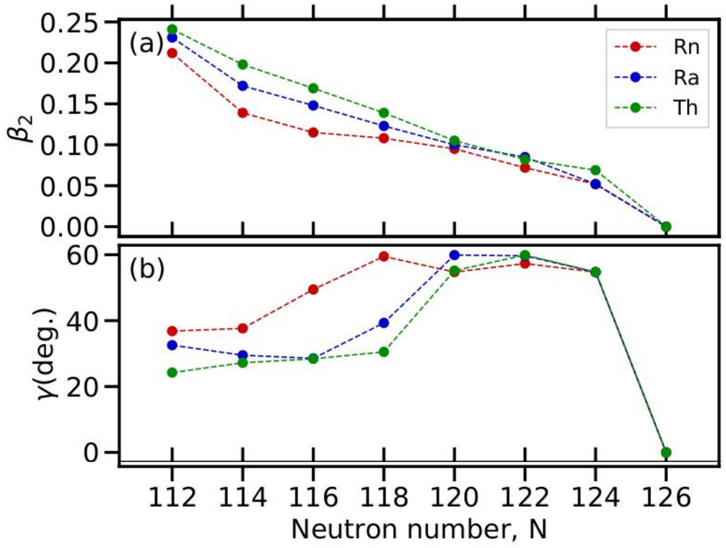

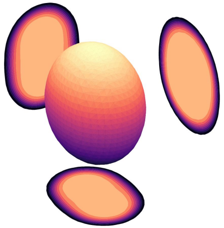

$$+ \quad \hat{H}_{\mathrm{rot}} = \sum_{\mu=x,y,z} \frac{\hat{J}_\mu^2}{2\mathcal{I}_\mu} .$$

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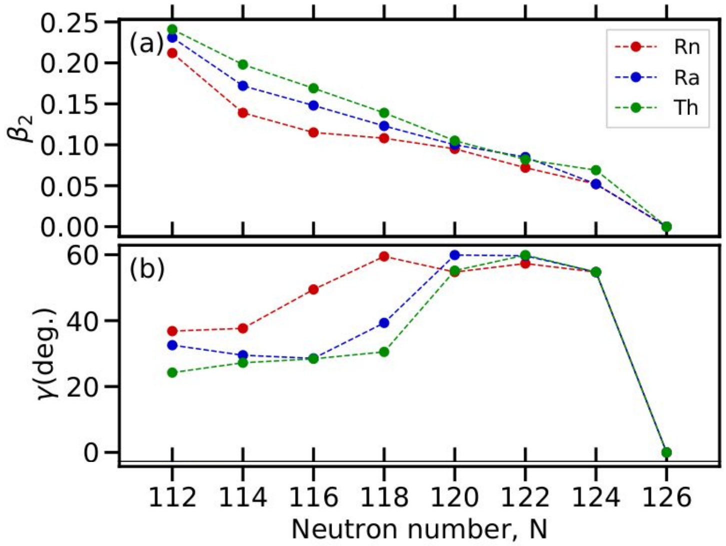

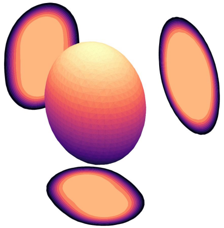

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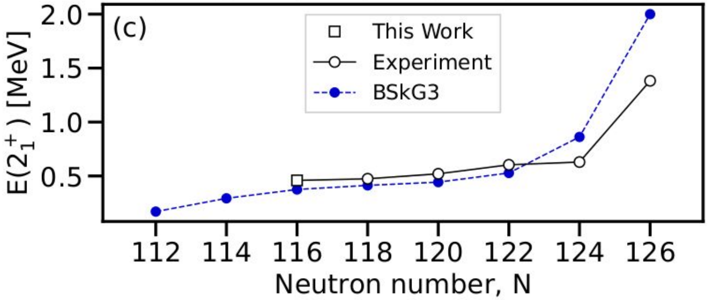
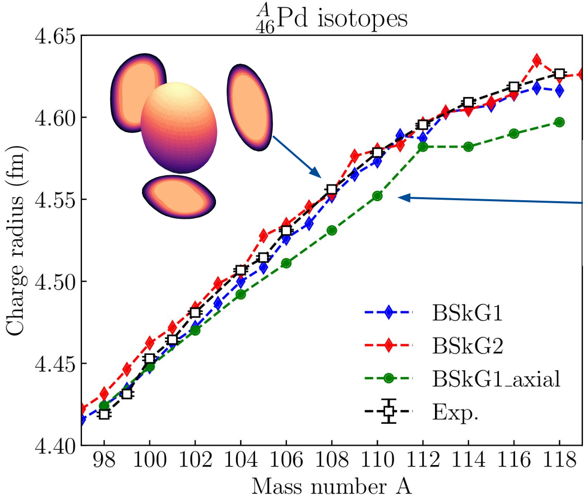
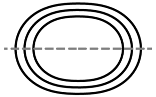


Neutron-deficient Radium isotopes

- in-beam γ-ray spectroscopy @ JYFL
- looking for highly-deformed states
- no immediate evidence for that
  (as predicted by BSkG3!)

Radii





Radii of triaxial nuclei

S. Geldhof, PRL 128, 152501 (2022).

- **all** deformation impact radii
- not just β_{20}, but also β_{22}, β_{30}, β_{40}, ...!

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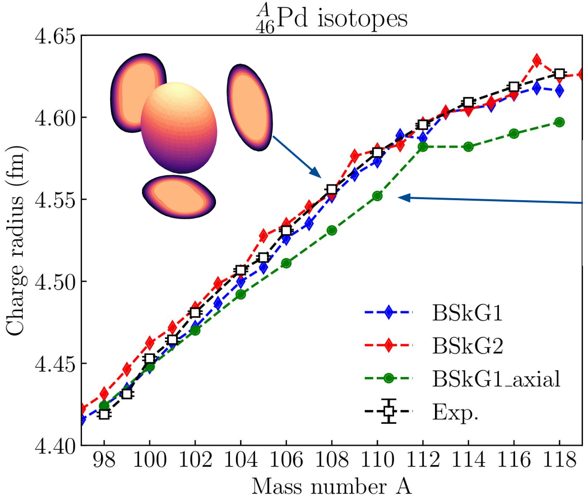

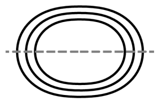

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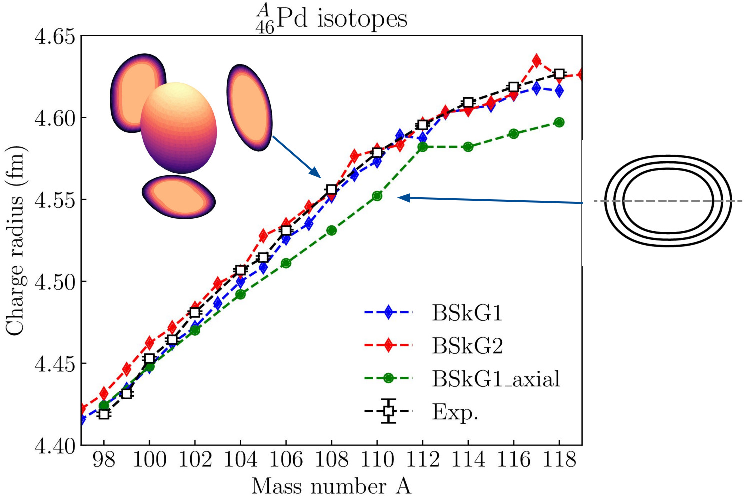

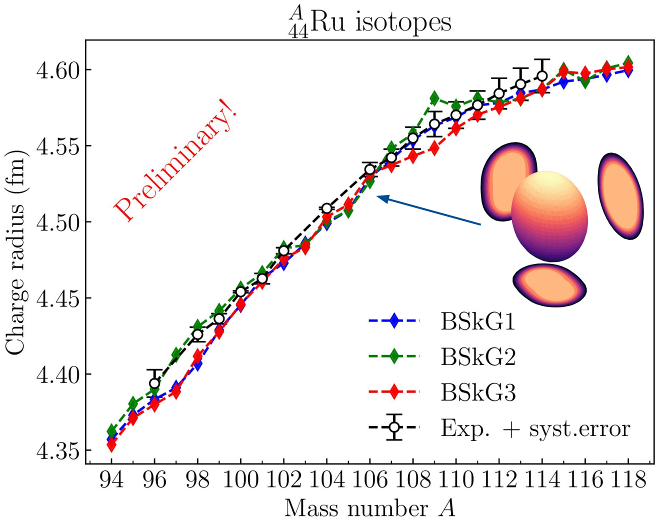

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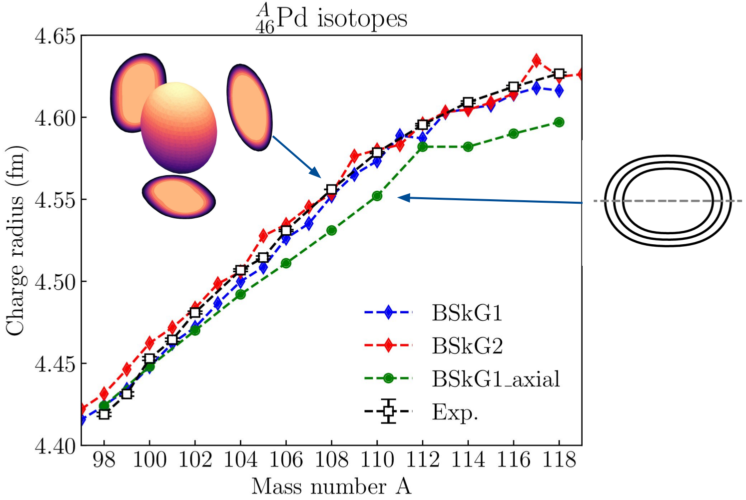

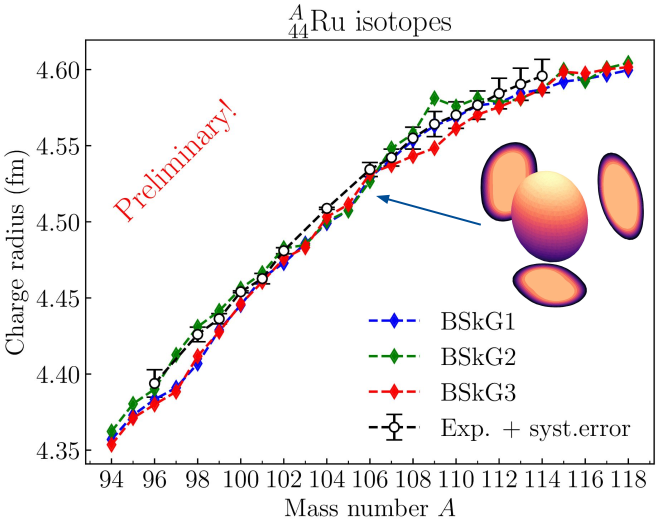

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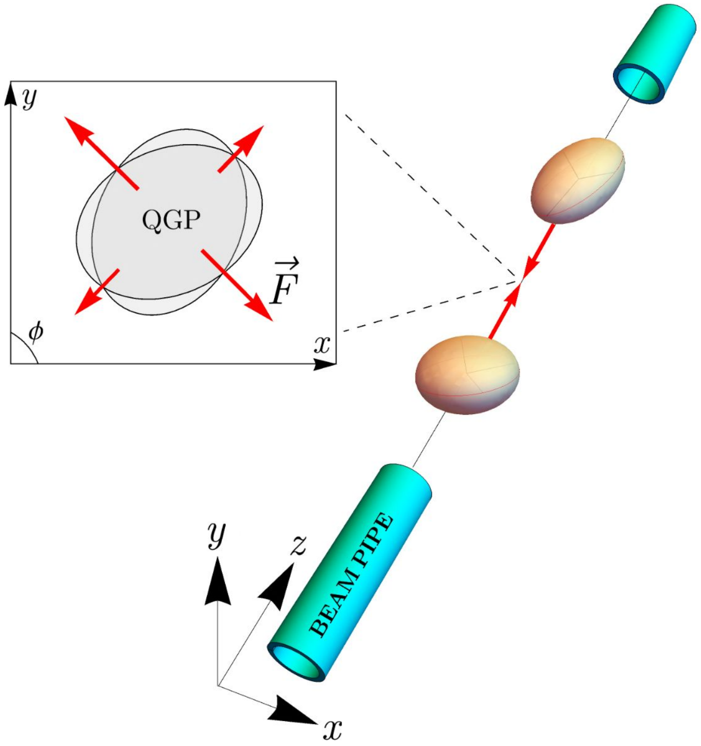
Other projects ongoing

- onset of deformation in Y & Nb chains
- radii of superheavies: Fm

Deformation



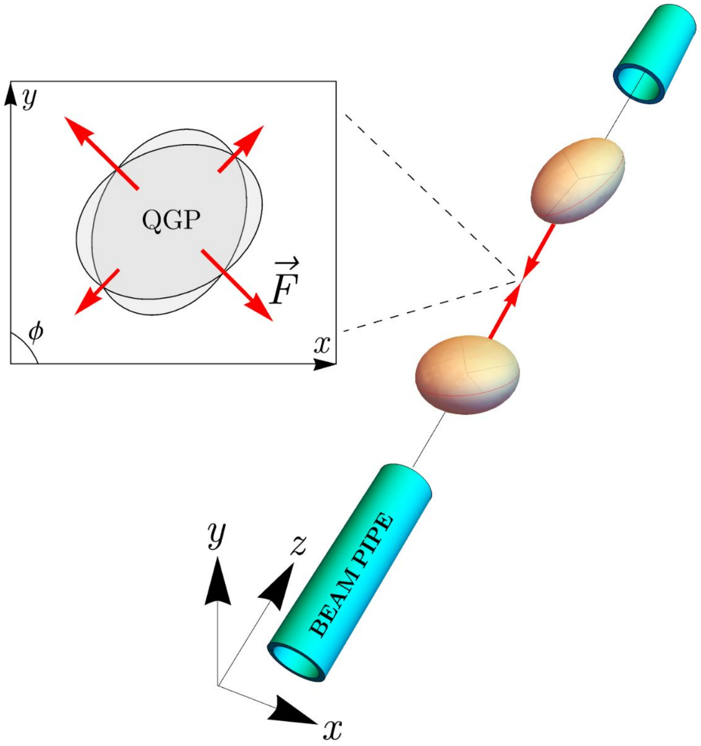
Relativistic collisions probe structure

- ^{238}U, ^{197}Au @BNL => deformation
- ^{208}Pb @ CERN => neutron skin

Deformation

$$\rho^{\mathrm{WS}}(\mathbf{r}) = \frac{\rho_0}{1 + \exp\left([r - R(\theta, \phi)]/a\right)},$$

$$R(\theta, \phi) = R_d \left[1 + \sum_{\ell=2}^{\ell_{\max}} \sum_{m=-\ell}^{\ell} \beta_{\ell m}^{\mathrm{WS}} Y_{\ell m}(\theta, \phi) \right],$$



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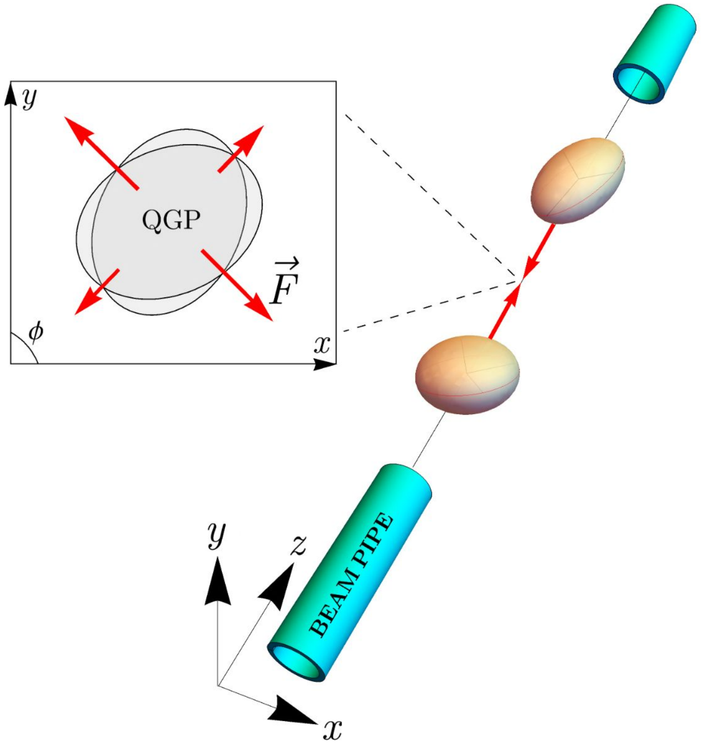

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  - with naive input from B(E2) rates

Deformation

W.R. et al., Phys. Rev. Lett. **130**, 212302 (2023)

Volume deformation

$$\beta_{20} = \frac{R_d^2}{R_0^2}\left[\beta_{20}^{\mathrm{WS}} + \frac{2}{7}\sqrt{\frac{5}{\pi}}(\beta_{20}^{\mathrm{WS}})^2 + \frac{12}{7\sqrt{\pi}}\beta_{20}^{\mathrm{WS}}\beta_{40}^{\mathrm{WS}}\right],$$

Surface deformation

.... but this misses low-energy physics!

- low-energy experiments measure **volume deformation!**

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.... but this misses low-energy physics!

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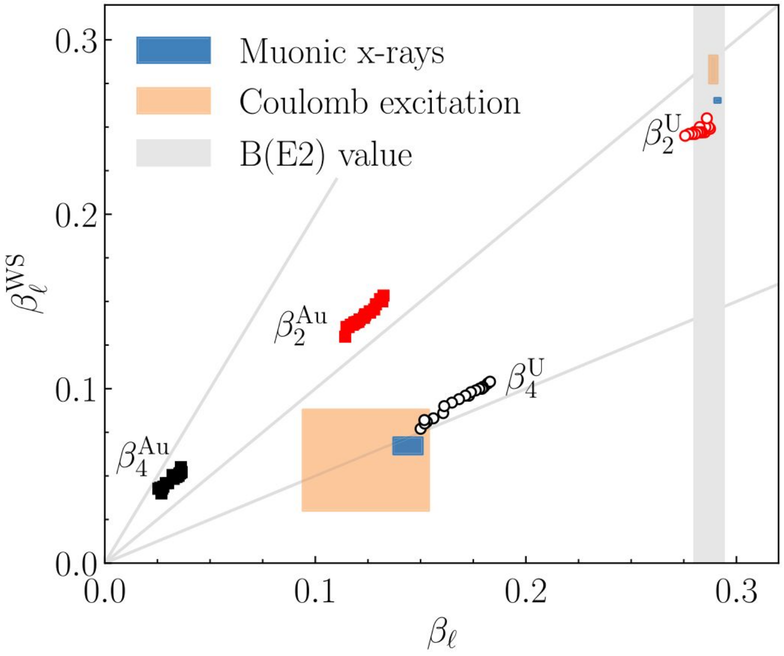
- but is not equal to surface deformation!



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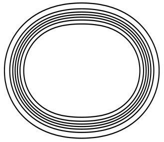

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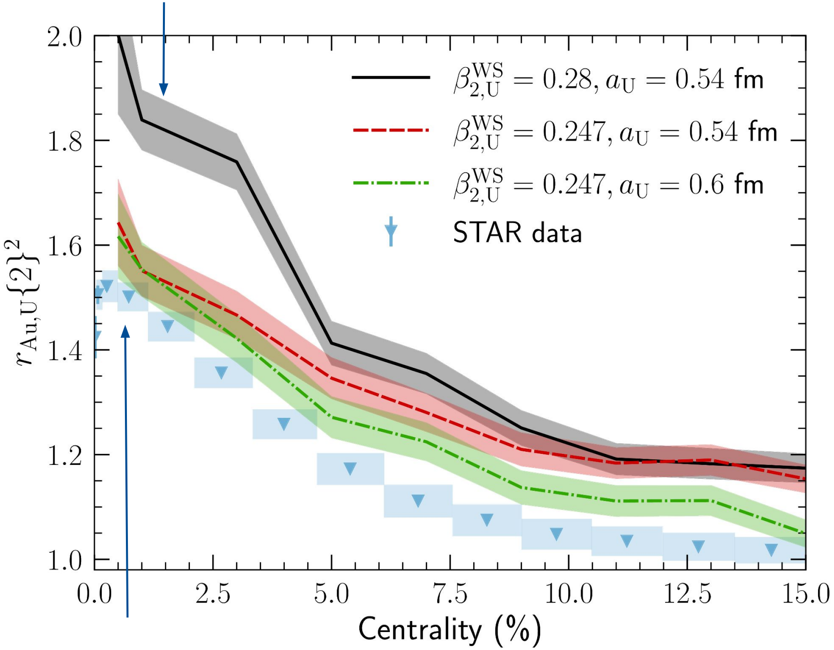
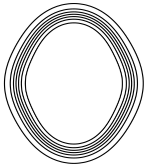
Surface deformation



β_ℓ



.... but this misses low-energy physics!

- low-energy experiments measure **volume deformation!**
- but is not equal to surface deformation!
- Taking BSkG input fixes central collisions!

W.R. et al., Phys. Rev. Lett. **130**, 212302 (2023)

Deformation

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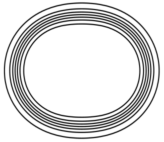

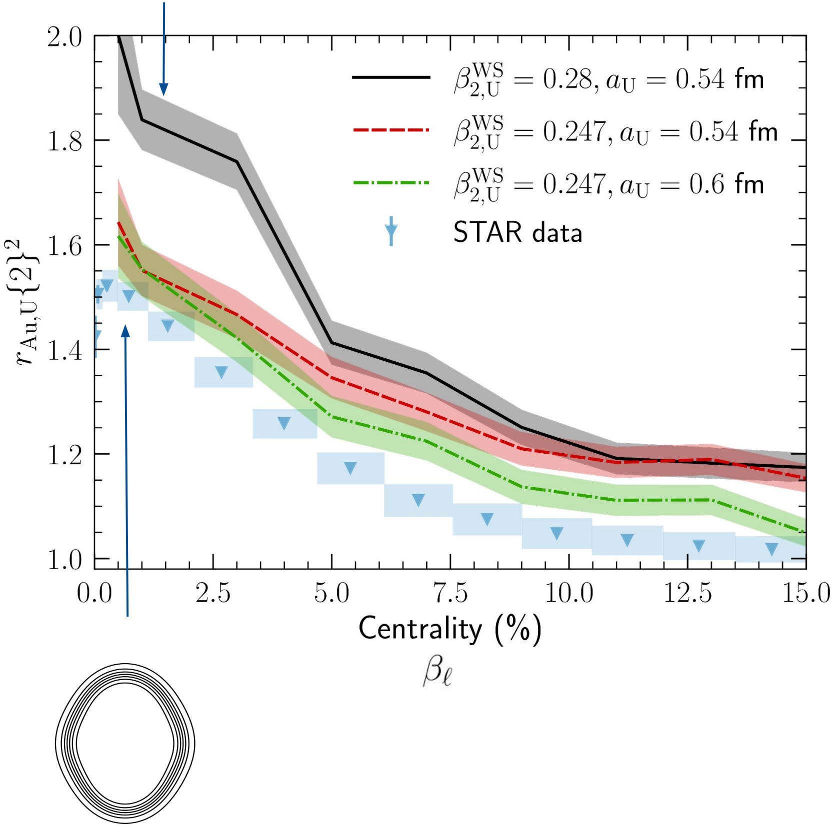

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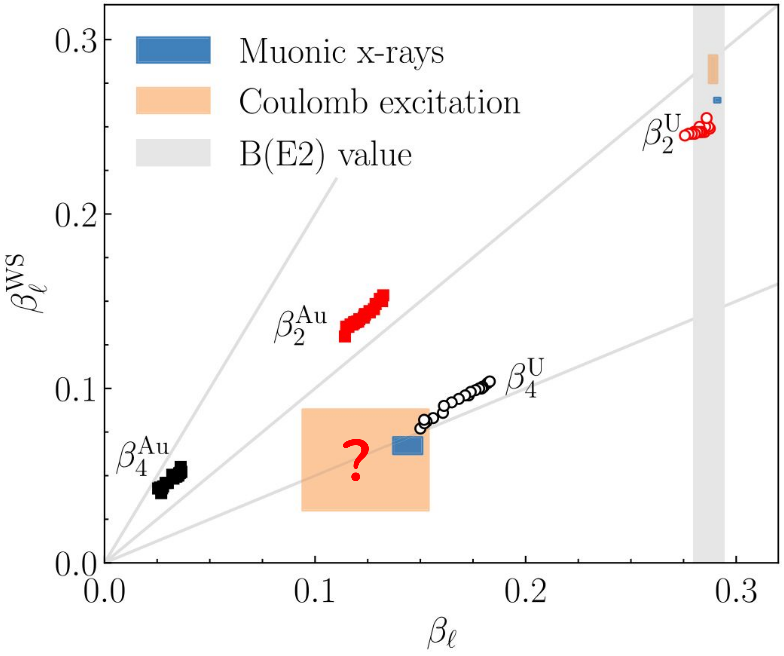

.... but this misses low-energy physics!

- low-energy experiments measure **volume deformation!**
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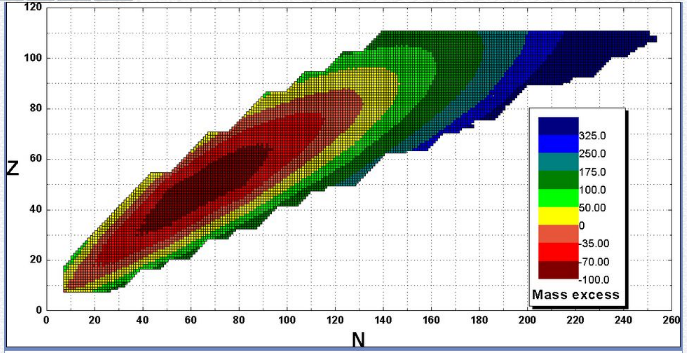
- Taking BSkG input fixes central collisions!
- First evidence of β_{40} deformation
- What will the future bring?

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

UNIVERSITÉ LIBRE DE BRUXELLES
INSTITUT D'ASTRONOMIE ET D'ASTROPHYSIQUE
BRUSLIB
the Brussels Nuclear Library for Astrophysics Applications

Q$_\beta$ | S$_n$ | S$_p$ | Spin | Parity



Ground State Properties
Single Particle Scheme
Density and Potential
Nuclear Level Density
Partition Function
E1 Strength Function
Fission Properties (90<=Z<=110)
Reaction Rates

last update: April. 30, 2015

---- Links -----------
NetGen NACRE-II NACRE
RIPL-3 EXFOR
ORNL Clemson
JINA Reaclib JCPRG
Back to IAA

Ground State Properties

- Data and Plot

Proton number Z: 8 Neutron number N: 8 Submit Reset

- Introduction

The force used in the Hartree-Fock-Bogoliubov (HFB) mass model is an extended Skyrme force (containing t_4 and t_5 terms), along with a 4-parameter delta-function pairing force derived from realistic calculations of infinite nuclear and neutron matter.
Pairing correlations are introduced in the framework of the Bogoliubov method. Deformations with axial and left-right symmetry are admitted.

The total binding energy is given by

$$E_{tot} = E_{HFB} + E_{wigner}$$

where

- E_{HFB} is the HFB binding energy including a cranking correction to the spurious rotational energy and a phenomenological vibration correction energy
- $E_{wigner}=V_W \exp(-\lambda((N-Z)/A)^2)+V_W|N-Z|\exp(-(A/A_0)^2)$ is a phenomenological correction for the Wigner energy.

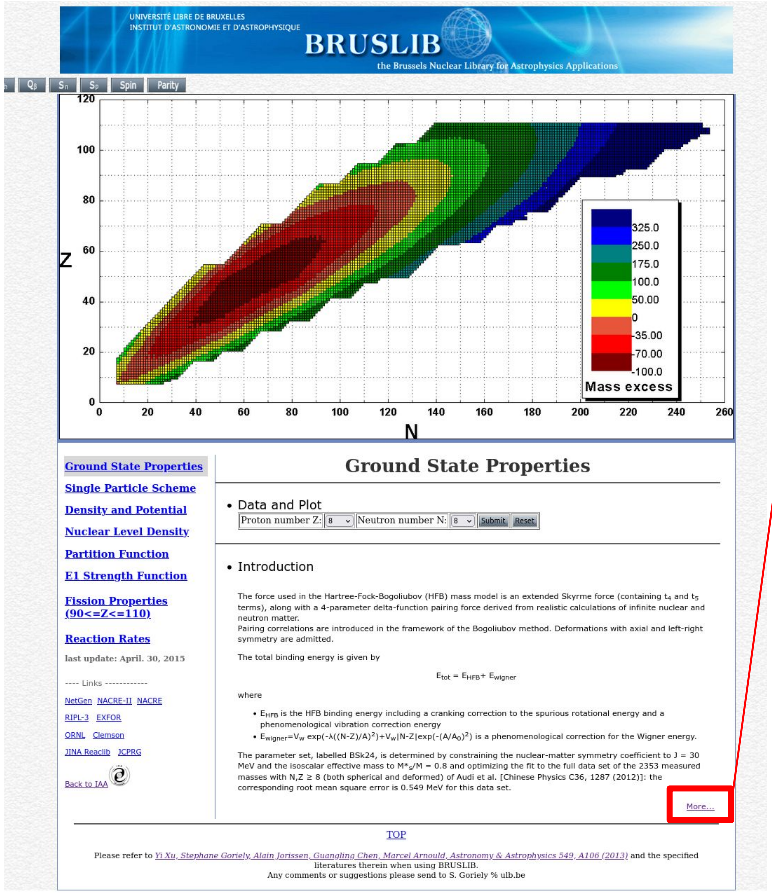
The parameter set, labelled BSk24, is determined by constraining the nuclear-matter symmetry coefficient to J = 30 MeV and the isoscalar effective mass to $M^*_s/M = 0.8$ and optimizing the fit to the full data set of the 2353 measured masses with N,Z ≥ 8 (both spherical and deformed) of Audi et al. [Chinese Physics C36, 1287 (2012)]: the corresponding root mean square error is 0.549 MeV for this data set.

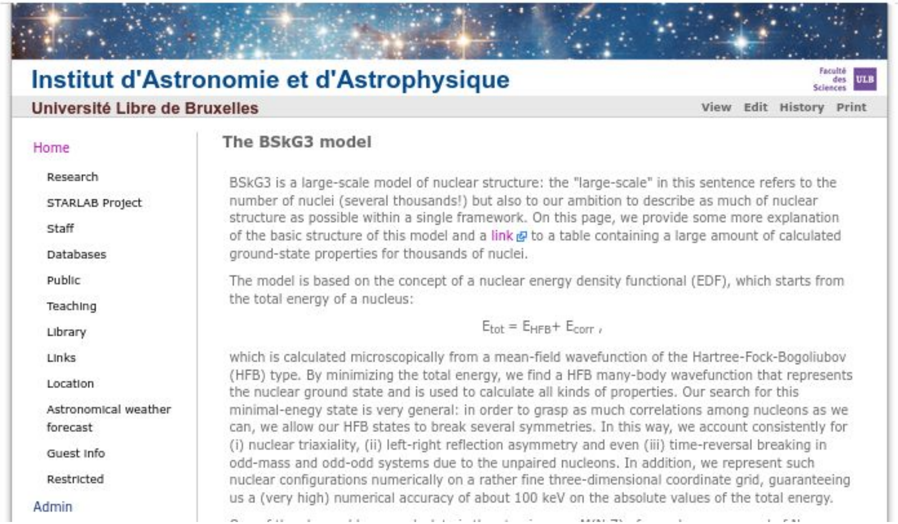
More...

TOP

Please refer to *Yi Xu, Stephane Goriely, Alain Jorissen, Guangling Chen, Marcel Arnould, Astronomy & Astrophysics 549, A106 (2013)* and the specified literatures therein when using BRUSLIB.
Any comments or suggestions please send to S. Goriely % ulb.be

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





Available right now for BSkG3:

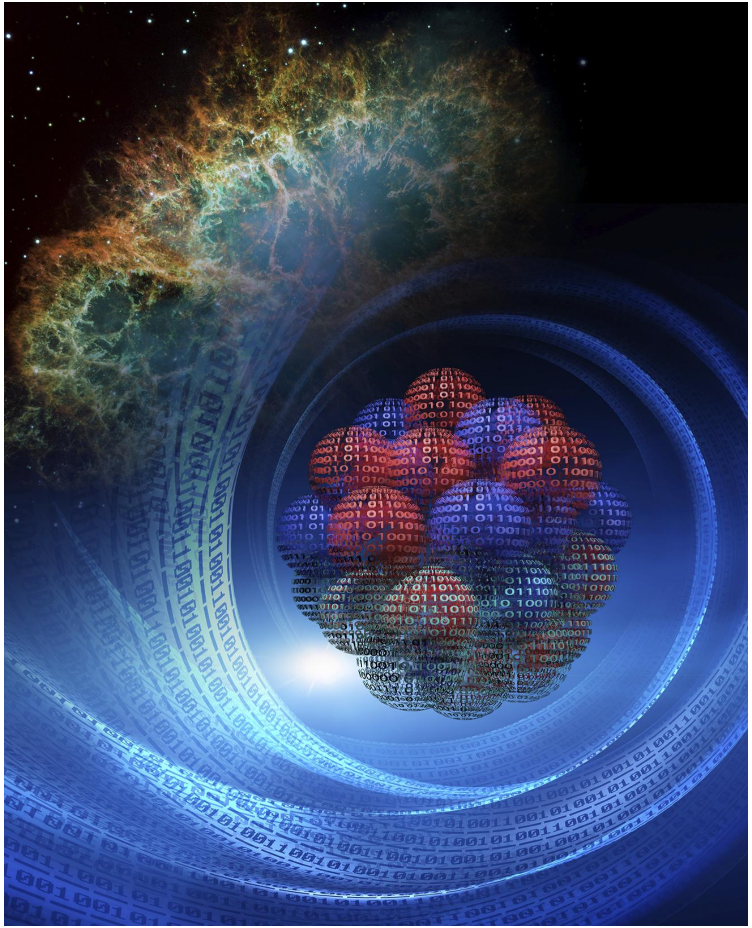
1. ground state properties for 7k nuclei
   a. masses
   b. deformations
   c. charge radii
   d. pairing properties
   e. rotational properties
2. Fission barriers for actinides

Expansion/modernisation (slowly) ongoing.

Conclusion

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

The interplay theory <-> experiment is crucial,
... and this is something we invest in!



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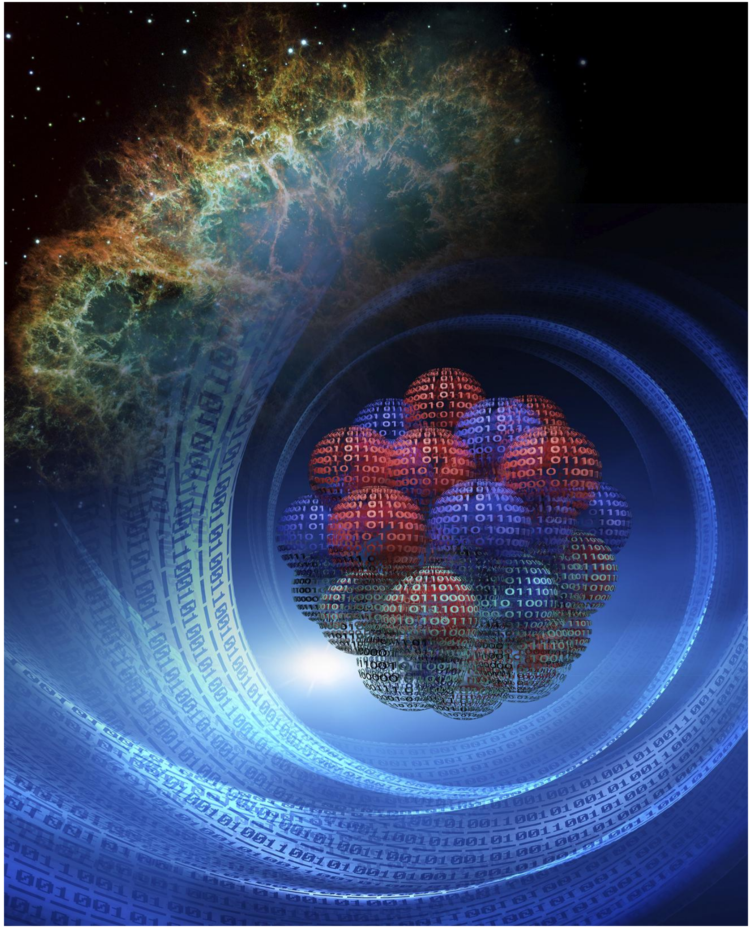

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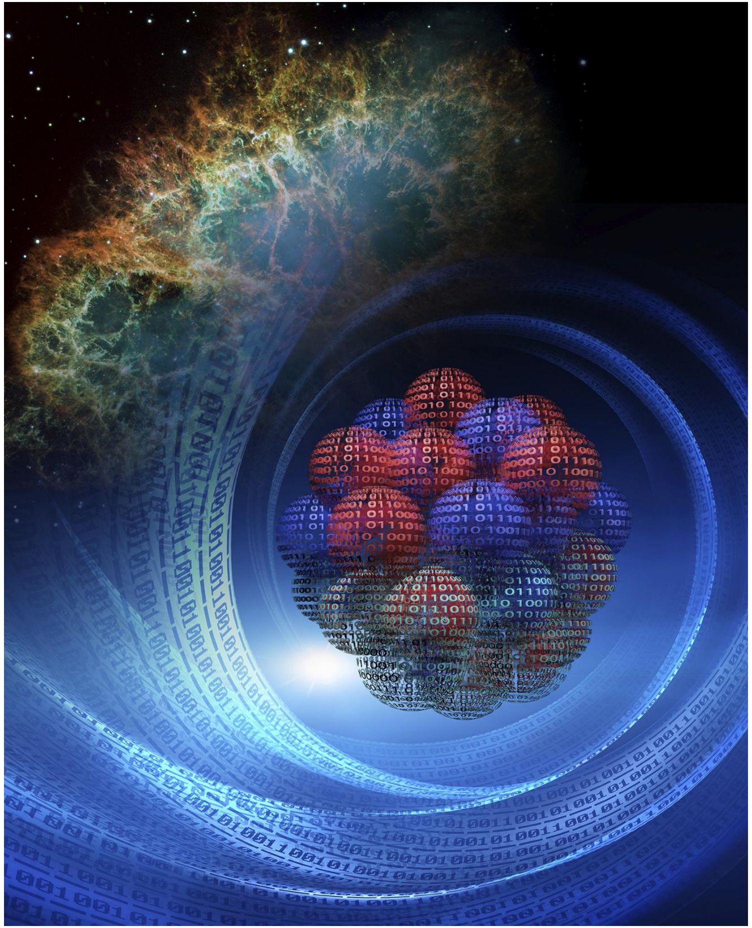
Coming up soon for comparison:

1. level densities
2. repository of nuclear level densities
3. fission properties => S. Bara



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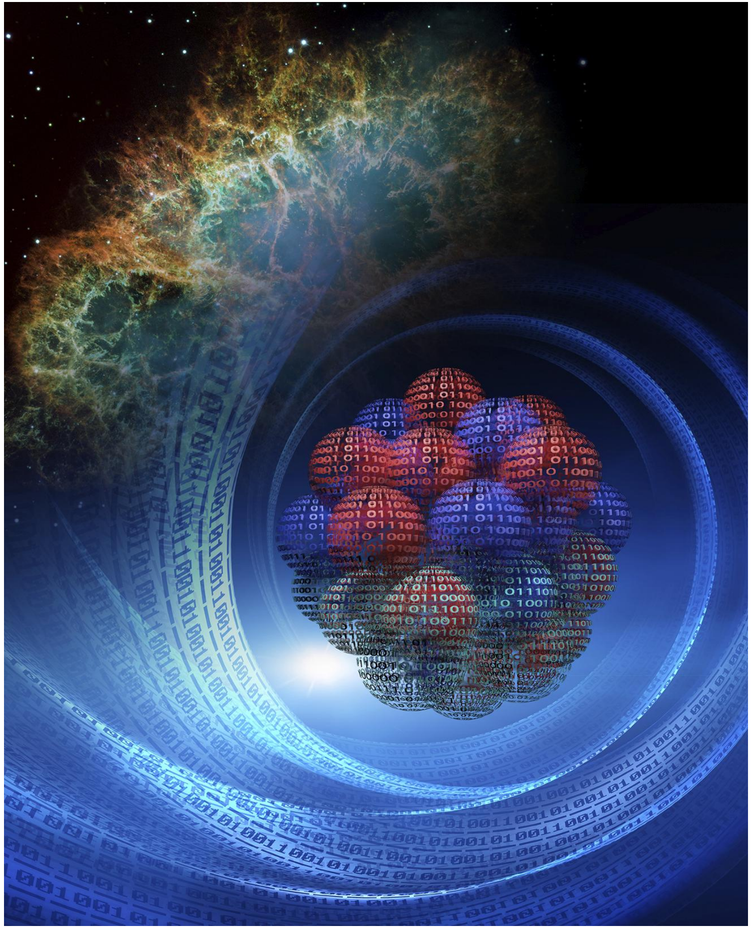
Other exciting things:

1. BSkG4 => G. Grams
2. Neutron stars => N. Shchechilin, C. Mondal



Thank you for…

…… all the wonderful work!

ULB

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N. Chamel
N. Shchechilin
C. Mondal

iP2i

M. Bender

L2IT

G. Scamps

UNIVERSITÄT HEIDELBERG ZUKUNFT SEIT 1386

G. Giacalone

KU LEUVEN

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...... the computing time!

CÉCI
Cenaero
LUMI
Vlaams Supercomputer Centrum

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Vlaams Supercomputer Centrum — Vlaanderen is supercomputing

...... the funding!

fnrs — LA LIBERTÉ DE CHERCHER
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EOS — The Excellence of Science

...... your attention!