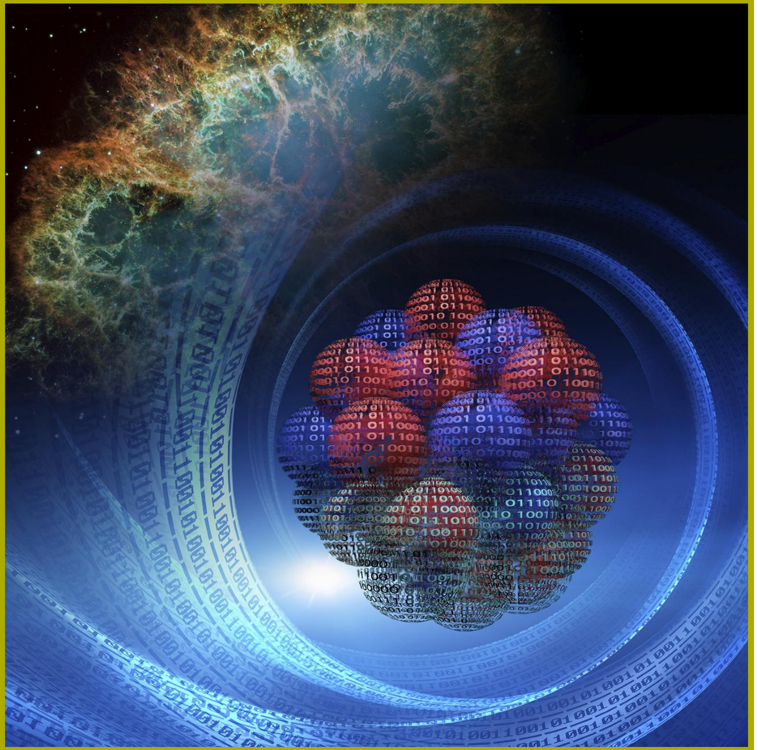
WOUTER RYSSENS



Andy Sproles, ORNL

Wood-Saxon subtleties +
Some Skyrme results from Brussels

October 12th 2022

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Reminder

- Brussels group is an astrophysics group
- mean-field with **Skyrme** EDFs

BSkG2: W. Ryssens et al., arXiv:2208.06455 [nucl-th]
BSkG1: G. Scamps et al., EPJA 57, 333 (2021).
BSk14: S. Goriely et al., PRC 75, 064312 (2007).
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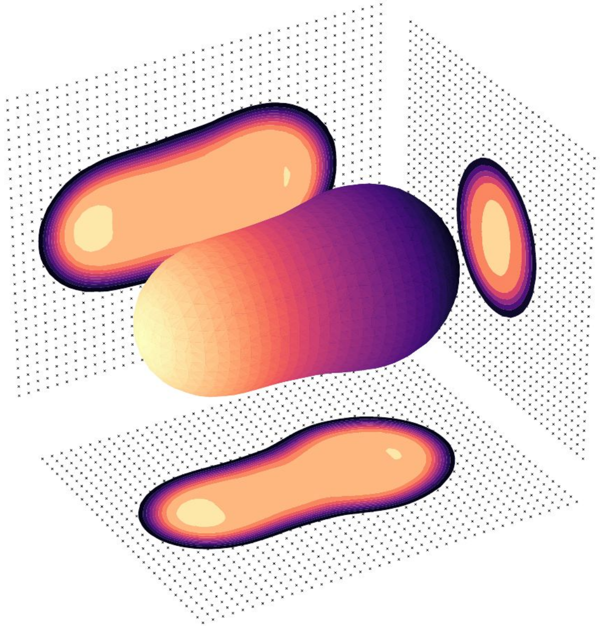

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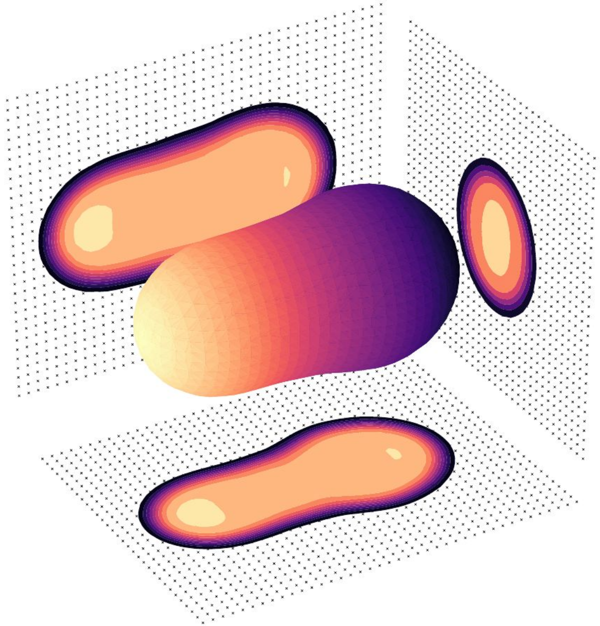
- in-house functionals: **BSkG**-s

σ (MeV)	BSkG1	**BSkG2**	HFB-14	FRLDM
2457 masses	0.741	**0.678**	0.729	0.808
884 charge radii (fm)	0.027	**0.027**	0.039	-
45 primary barriers	0.87	**0.44**	0.61	0.79
45 secondary barriers	0.86	**0.47**	0.70	1.35
28 Isomer energies	0.45	**0.49**	0.93	1.04



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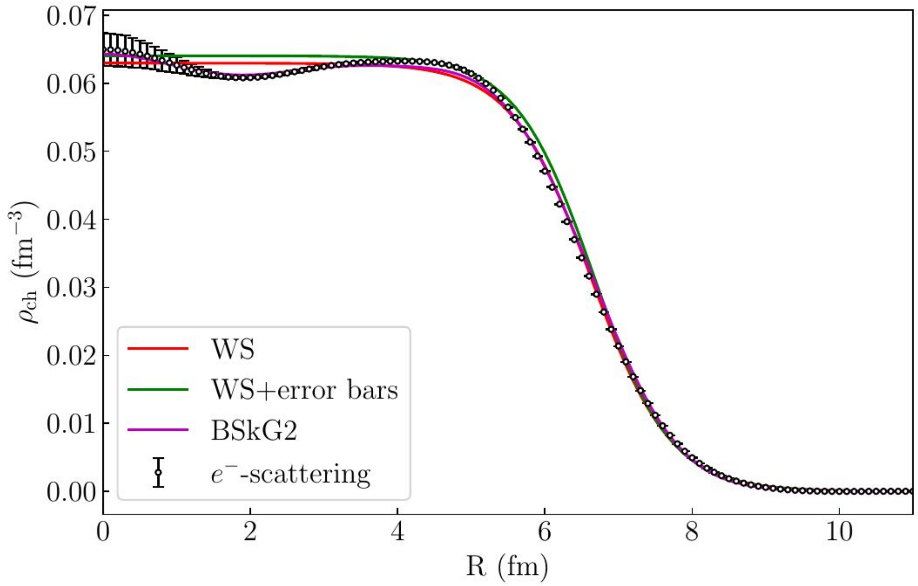
17 Skyrme parameterizations used

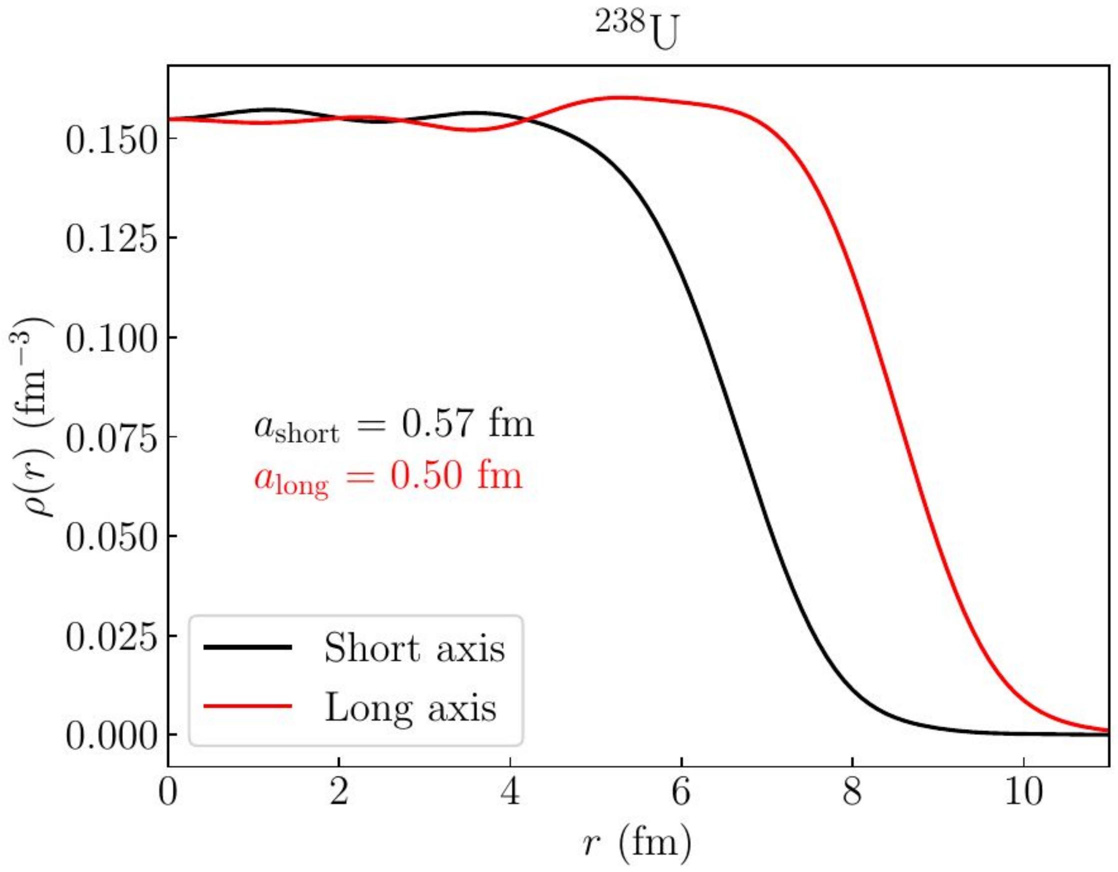
- **BSkG1, BSkG2:** Brussels group, designed with 3D in mind
- **SLy4, SLy6:** “old and venerable” parameterizations by the Lyon group
- **SLy5s1-8:** parameterizations by the Lyon group exploring the impact of surface tension
- **SV-min, SV-bas:** “best” parameterizations by the Frankfurt group
- **SV-mas07,08,10:** systematic variation of effective mass by the Frankfurt group

Wood-Saxon subtleties

Wood-Saxon: **central oscillations**



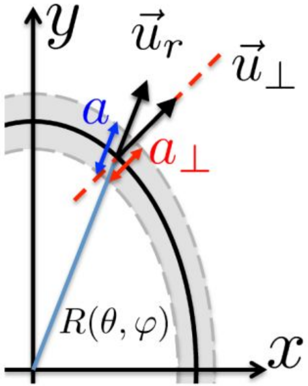
Wood-Saxon: **surface polarisation**

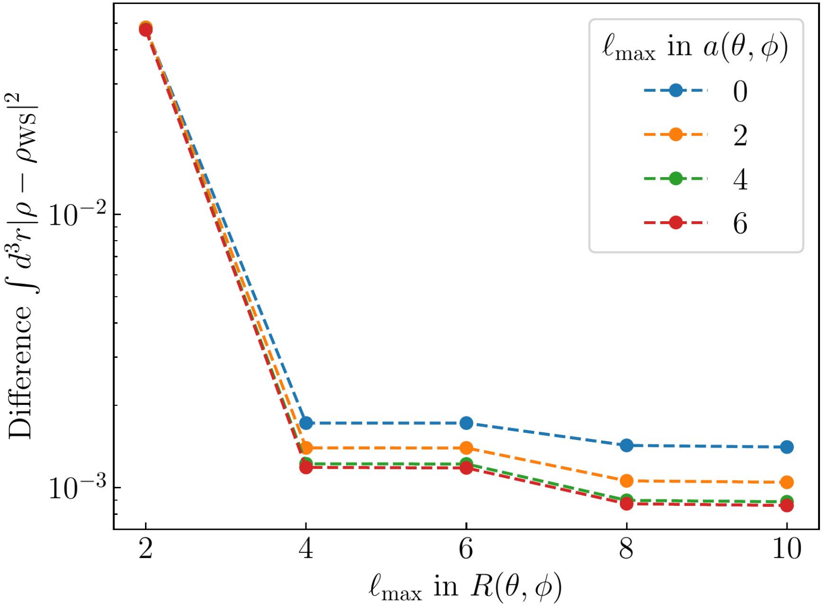


Wood-Saxon: **surface polarisation**

$$a(\theta,\phi) = a_\perp(\theta,\phi)\sqrt{1 + \left| \nabla R(\theta,\phi)|_{r=R(\theta,\phi)} \right|^2},$$

$$a_\perp(\theta,\phi) = a_0 \left[1 + \sum_{\ell m} \tilde{\beta}^{\mathrm{WS}}_{\ell m} Y_{\ell m}(\theta,\phi) \right].$$





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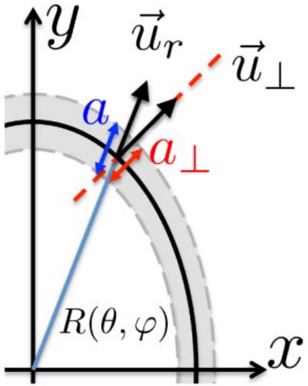

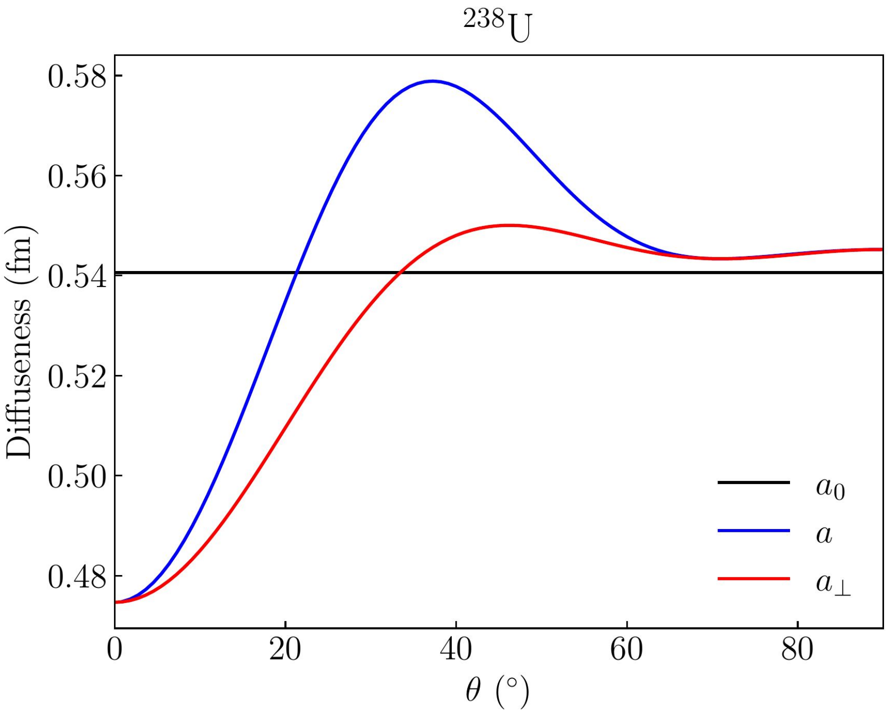

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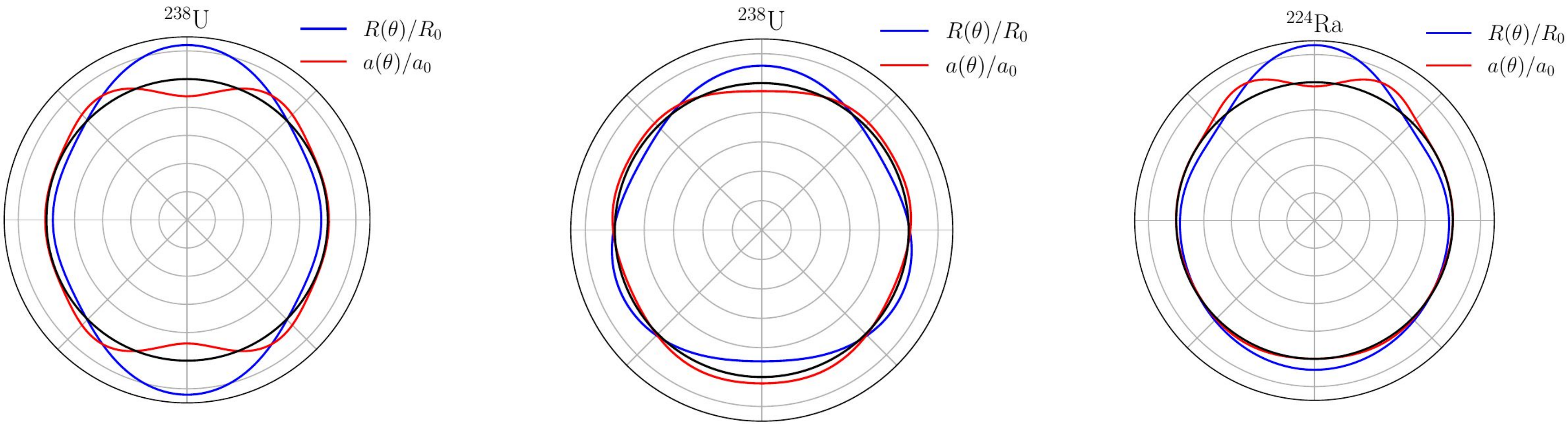


Questions

- does this meaningfully impact collision geometry?
- do we need to control this to get meaningful information on the diffuseness?

Wood-Saxon: **surface** vs. **volume** multipole moments

High-energy experiments

$$\rho(r,\theta,\phi) = \left[1 + e^{[r-R(\theta,\phi)]/a}\right]^{-1} ,$$

$$R(\theta,\phi) = R_0 \left[1 + \sum_{\ell m} \boxed{\beta^{\mathrm{WS}}_{\ell m}} Y_{\ell m}(\theta,\phi)\right] ,$$

Low-energy experiments

$$Q_{\ell m} = \int d^3\vec{r}\, \rho_{\mathrm{ch.}}(\vec{r}) r^{\ell} Y_{\ell m}(\theta,\phi) ,$$

$$\boxed{\beta_{\ell m}} = \frac{4\pi}{3R^{\ell}A} Q_{\ell m} .$$

Surface multipole moments

- characterize the nuclear radius
- practical to <u>generate</u> shapes
- not directly linked to observables (to my knowledge)

Low-energy experiments

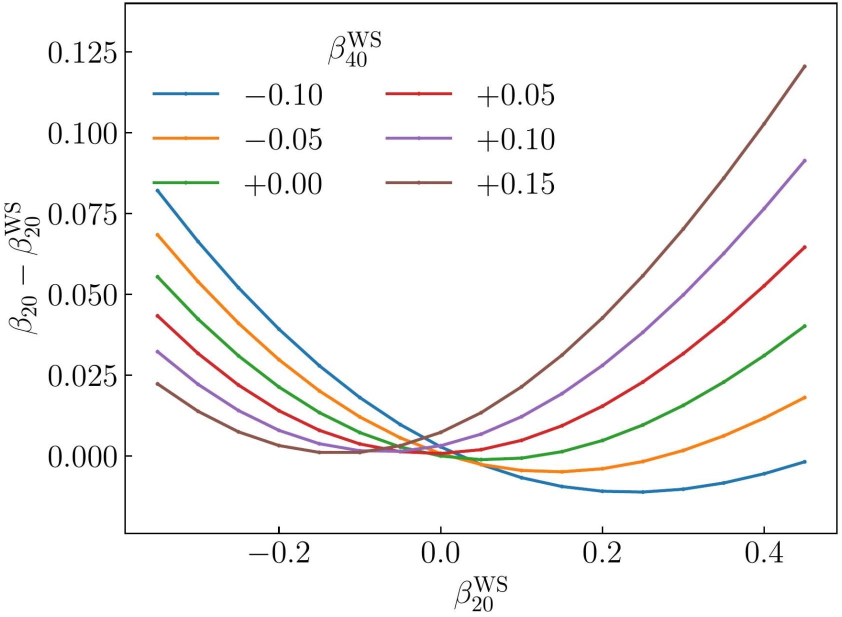
- typically γ-rays observed
- sensitive to **charge** density
- difficult to generate shapes
- multipole moments characterize interaction with external electric field
- linked to transition rates

Wood-Saxon: **things are never simple!**

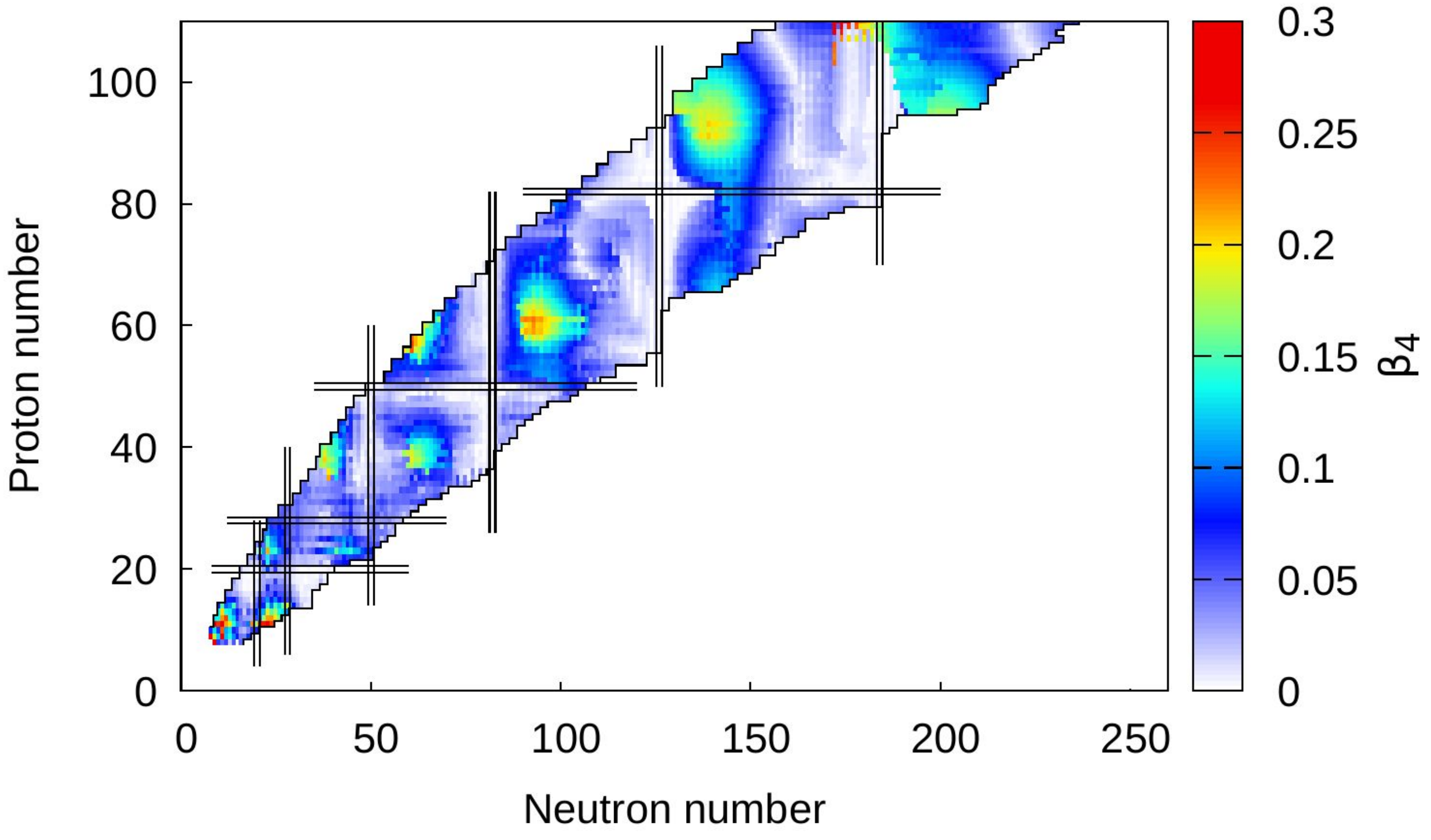
Assuming $\beta_{\ell m}(\rho_{\text{charge}}) \approx \beta_{\ell m}(\rho_{\text{matter}})$

$$\beta_2 = \beta_2^{\text{WS}} + \mathcal{O}[a] + \mathcal{O}[(\beta_2^{\text{WS}})^2] + \mathcal{O}[\beta_4^{\text{WS}}\beta_2^{\text{WS}}] + \ldots$$
$$\beta_3 = \beta_3^{\text{WS}} + \mathcal{O}[a] + \mathcal{O}[\beta_3^{\text{WS}}\beta_2] + \mathcal{O}[\beta_3^{\text{WS}}\beta_4^{\text{WS}}] + \ldots$$
$$\beta_4 = \beta_4^{\text{WS}} + \mathcal{O}[a] + \mathcal{O}[(\beta_2^{\text{WS}})^2] + \mathcal{O}[\beta_2^{\text{WS}}\beta_4^{\text{WS}}] + \ldots .$$

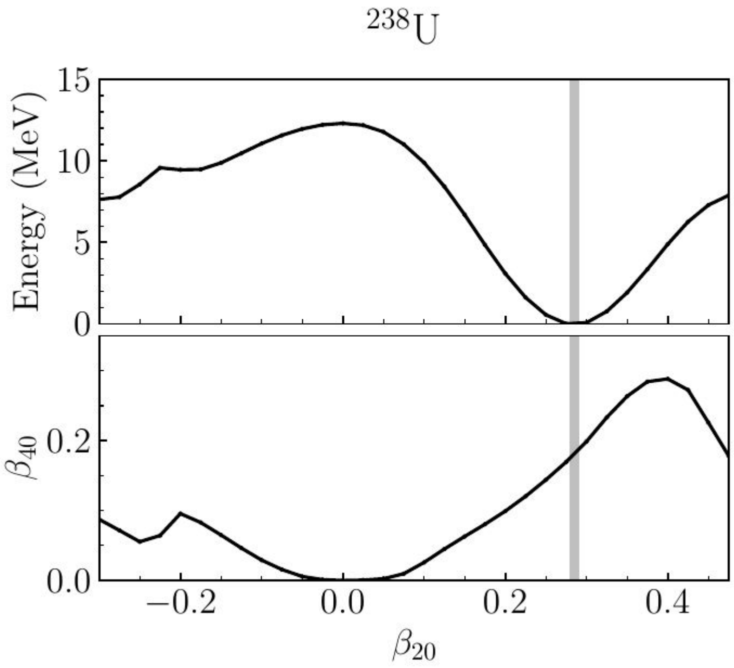
Q. Y. Shou et al., PLB **749**, 215 (2015).

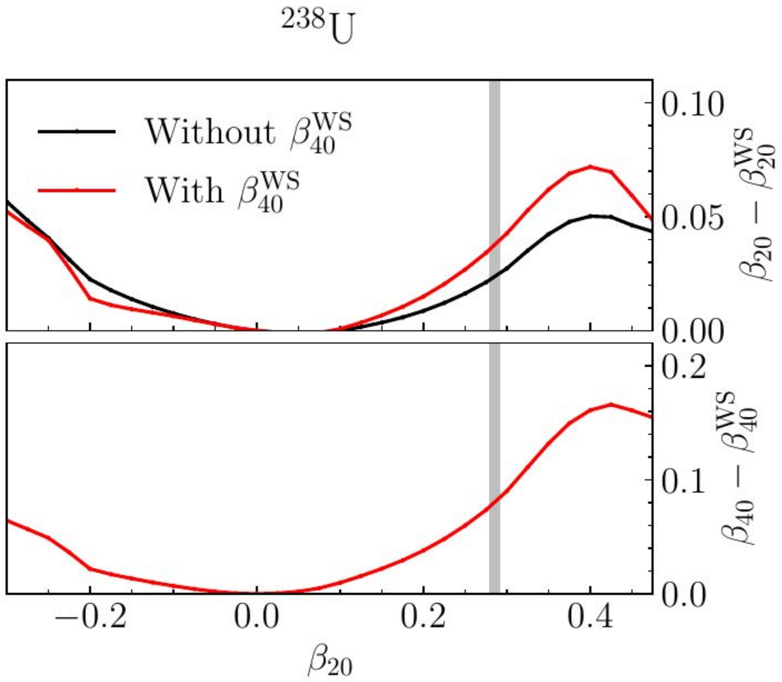


Wood-Saxon: **hexadecapole deformation**



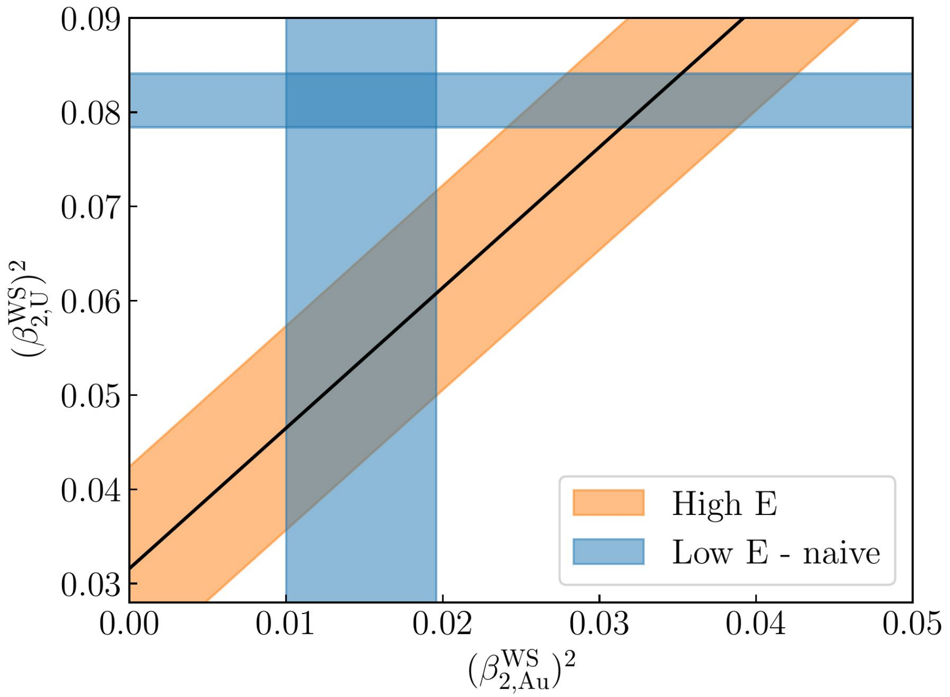
Wood-Saxon: **hexadecupole non-trivial in ^{238}U**





Wood-Saxon: ^{238}U+^{238}U vs ^{197}Au+^{197}Au

- Low-E and high-E experiment not entirely consistent for “easy” nuclei



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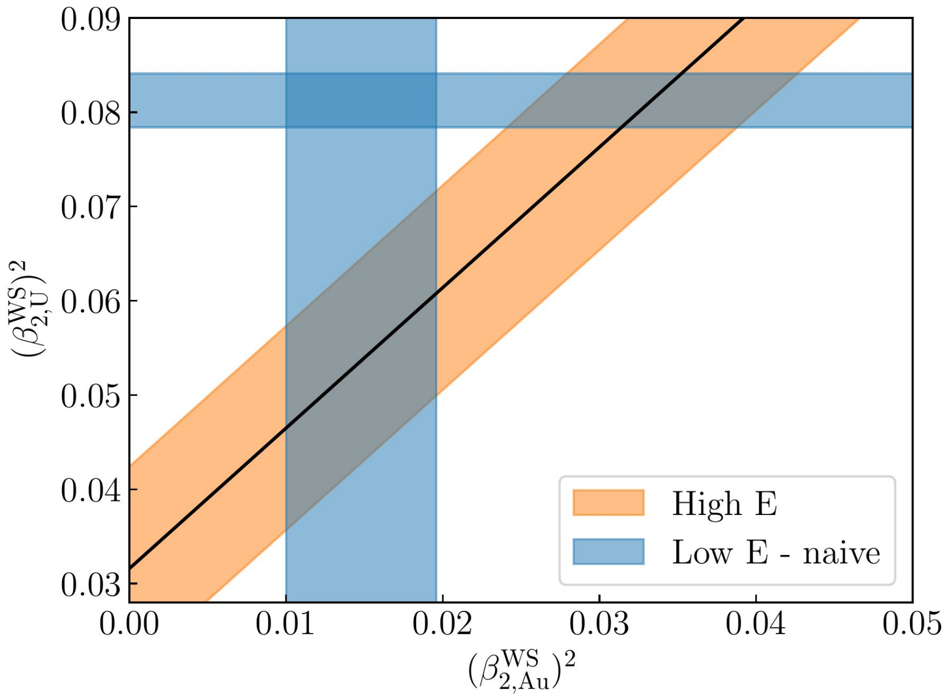

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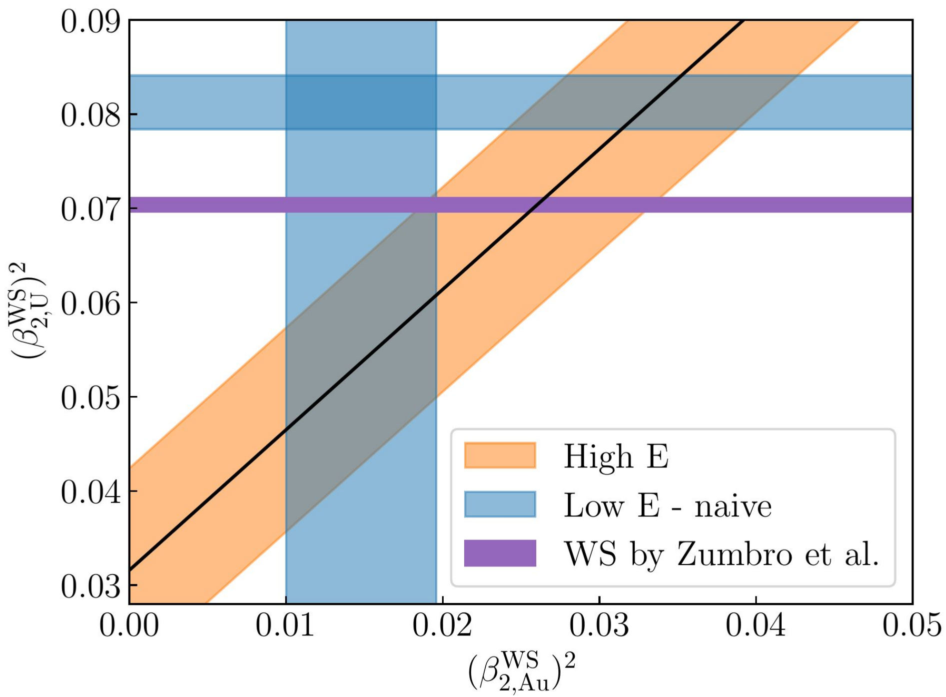

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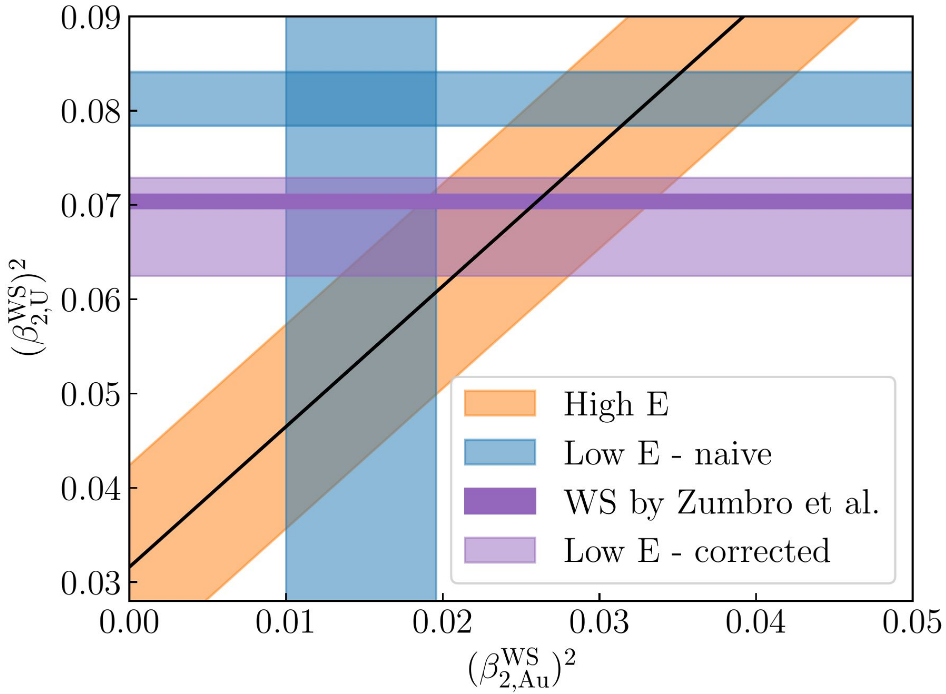

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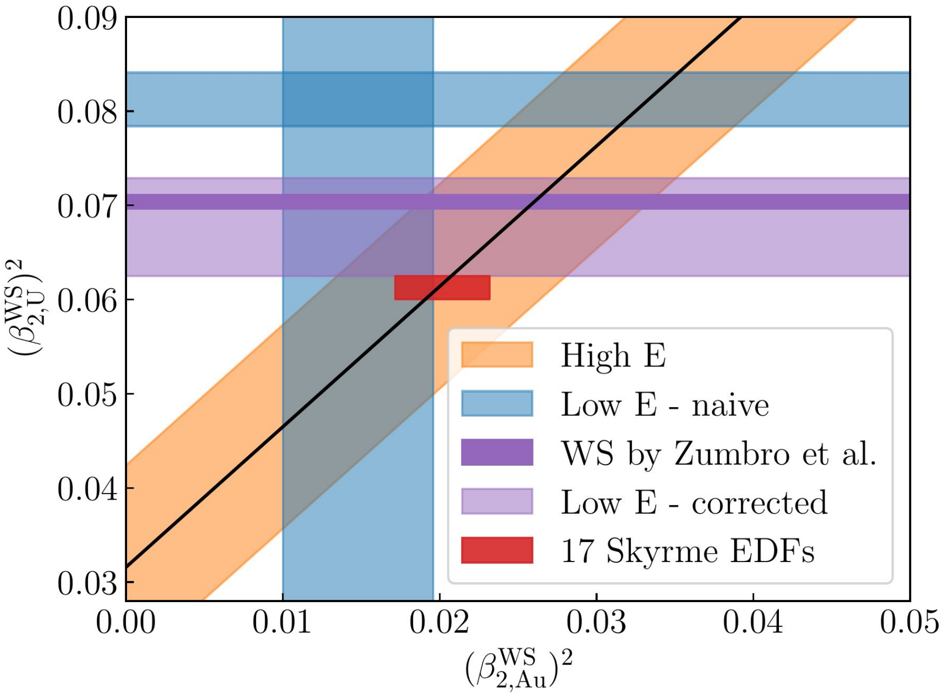
- NO data on B4 for ^{197}Au
- Skyrme produces WS-parameters on TOP of high-E experiment



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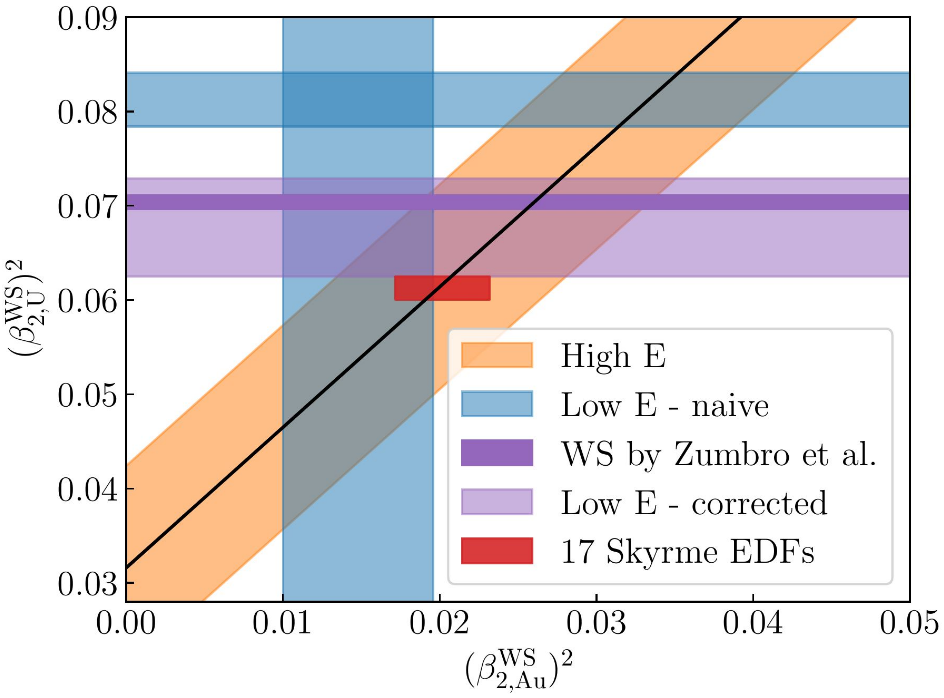
Three things are thus consistent:

- Skyrme EDFs
- High-E experiment
- Low-E experiment (almost)

RHIC “sees” hexadecupole deformation.



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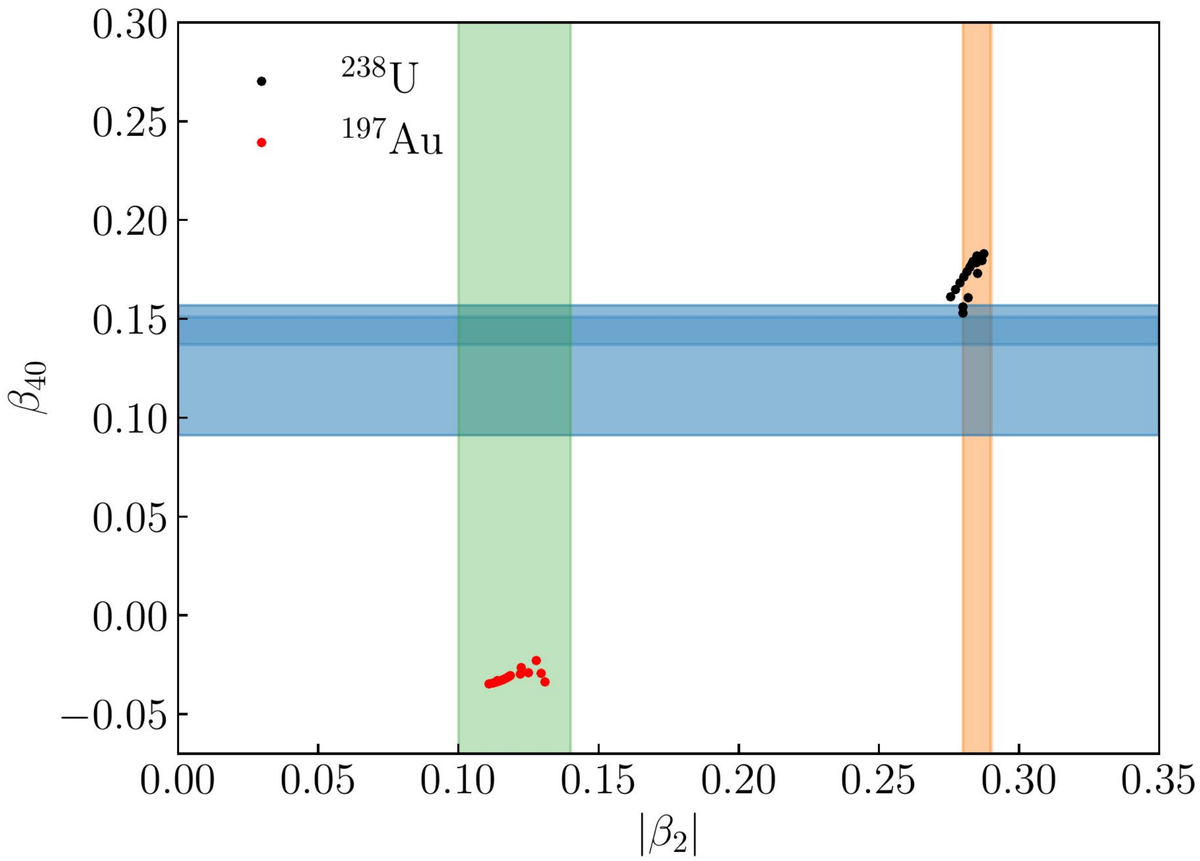
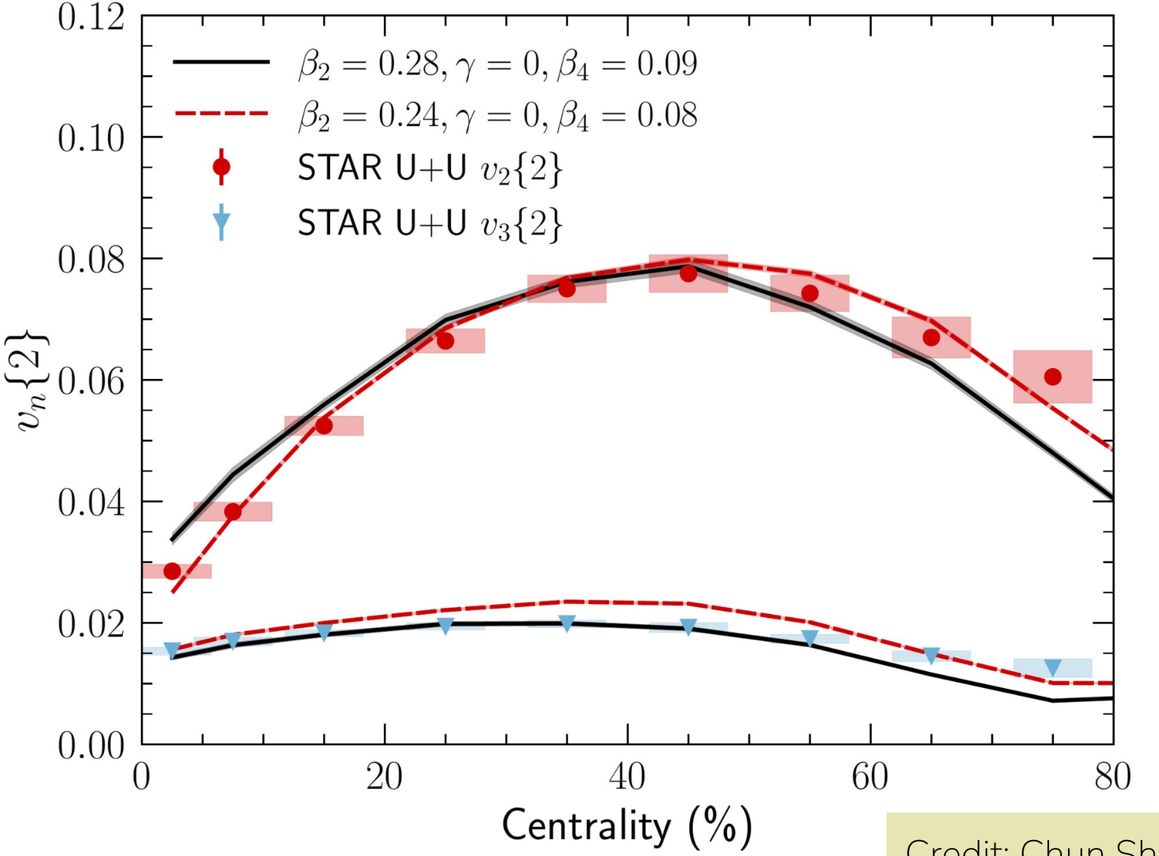
Wood-Saxon: **Skyrme deformations**



Wood-Saxon: **hydrodynamic simulations**



Credit: Chun Shen

Skyrme Results for A=96

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High-energy evidence for

- 96Ru > 96Zr in quadrupole deformation
- 96Zr strongly octupole deformed

But, one has to be careful!

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High-energy evidence for

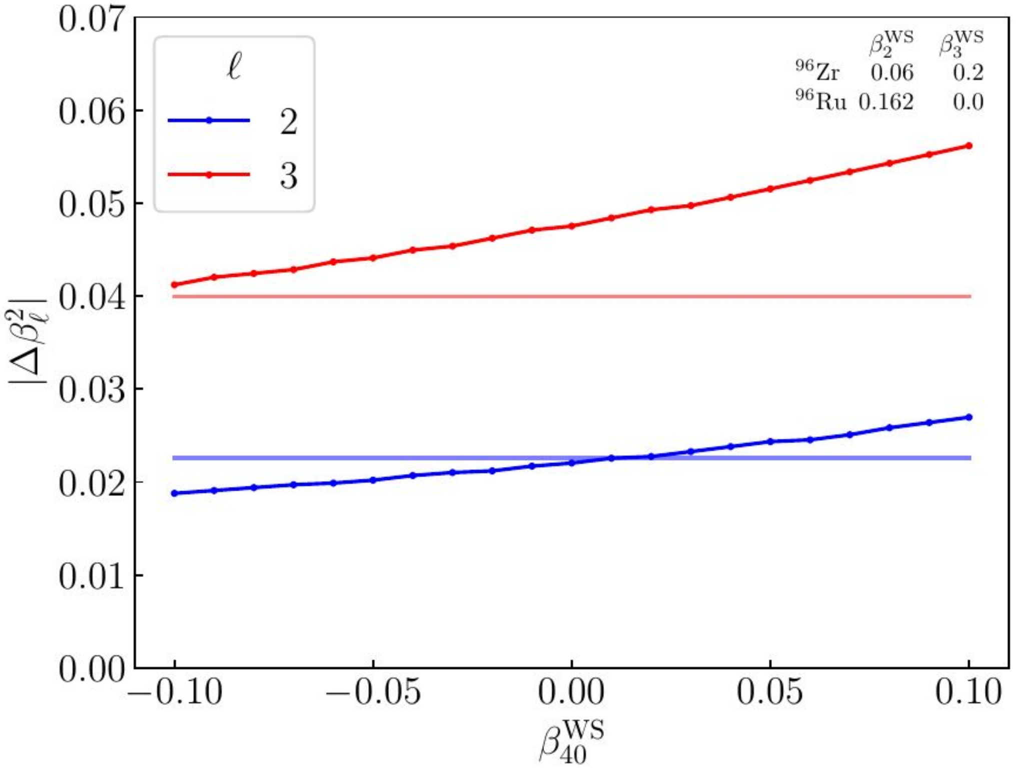
- 96Ru > 96Zr in quadrupole deformation
- 96Zr strongly octupole deformed

But, one has to be careful!

- with fixed WS parameters, the implied octupole deformation is **even larger**!

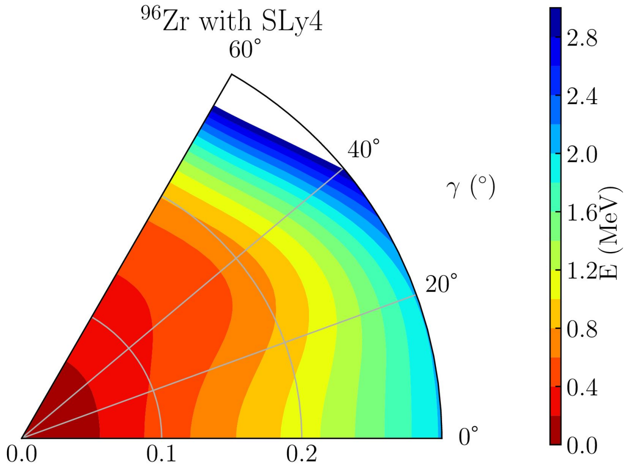
Parameters from Zhang & Jia, PRL 128 022301 (2022)

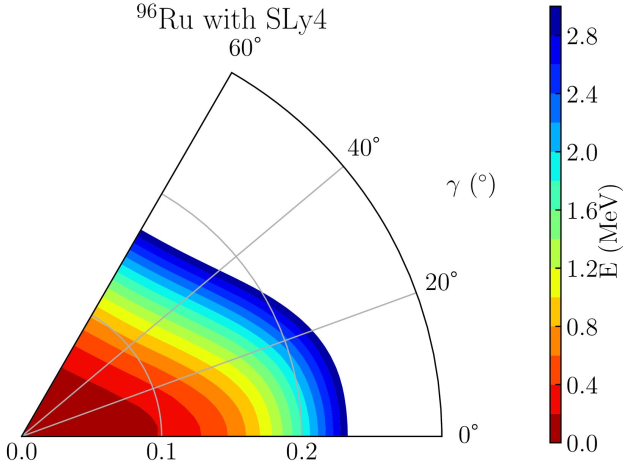
$$\beta_3 = \beta_3^{\mathrm{WS}} + \mathcal{O}(a) + \mathcal{O}(\beta_3\beta_2) + \mathcal{O}(\beta_3\beta_4) + \dots$$



Skyrme results for **A=96**

- almost all parameterizations fail
  - either no octupole minimum for ^{96}Zr
  - OR wrong quadrupole ordering





Skyrme results for **A=96**

- almost all parameterizations fail
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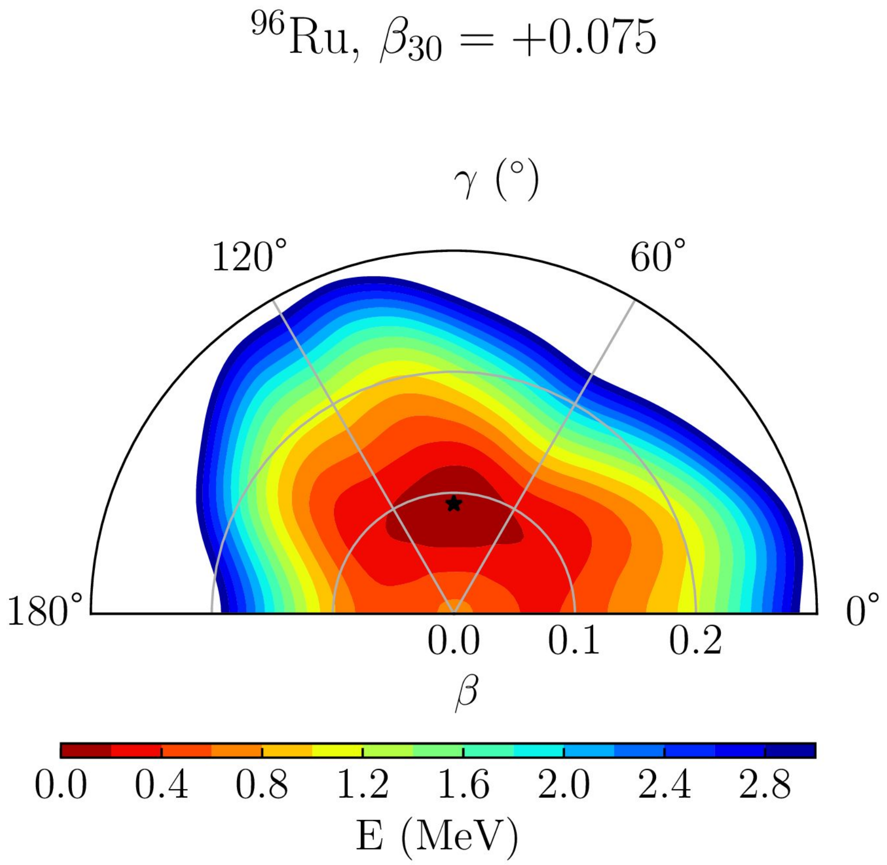
- BSkG's fail in a very special way
  - octupole deformation for **BOTH**
  - comparable quadrupole
  - Triaxial + octupole shapes



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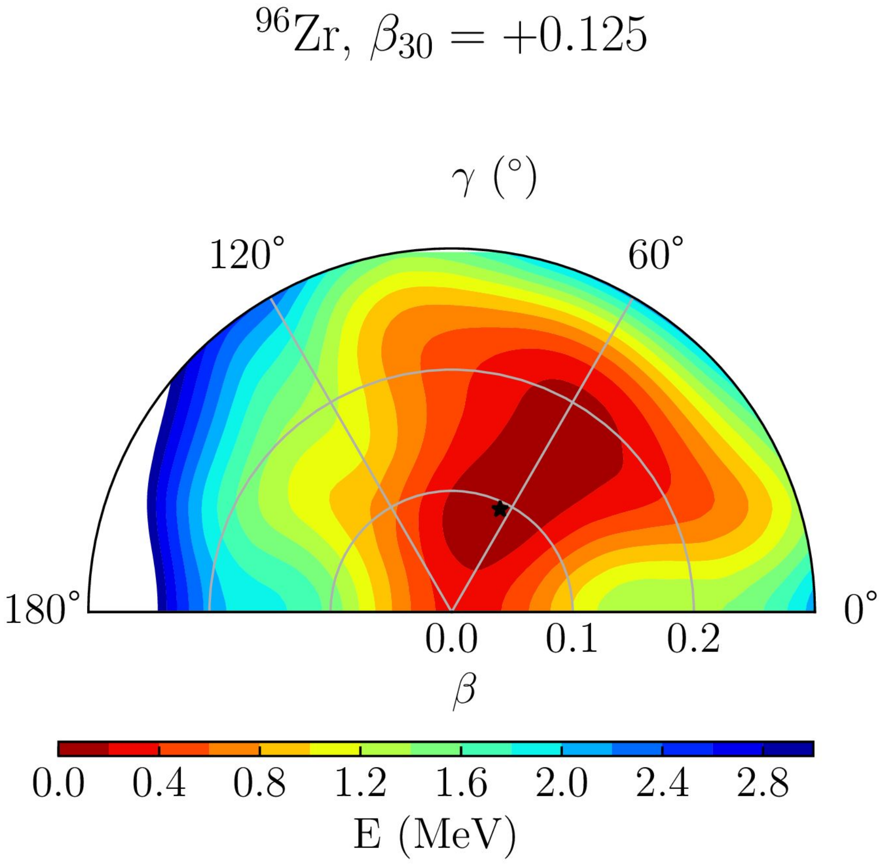

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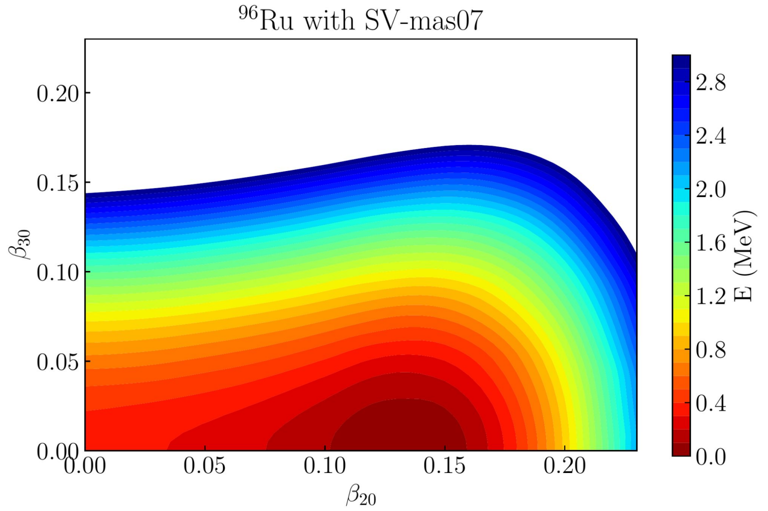
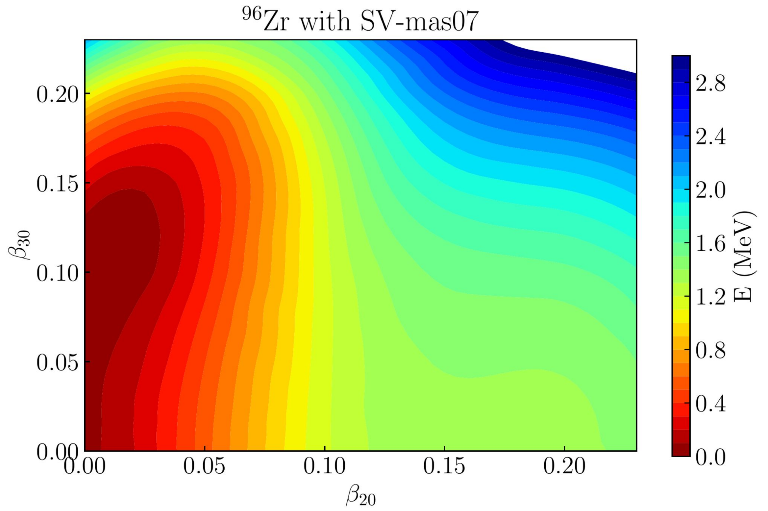
- Except SV-mas07
  - octupole deformation in ^{96}Zr without quadrupole deformation
  - quadrupole deformation in ^{96}Ru without octupole deformation
  - different s.p. structure?

- **All octupole** deformations too small
  - $\square_3$ > 0.2 is very large
  - max produced ~ 0.1
  - Beyond MF surely important
  - Other systematics unaccounted for?





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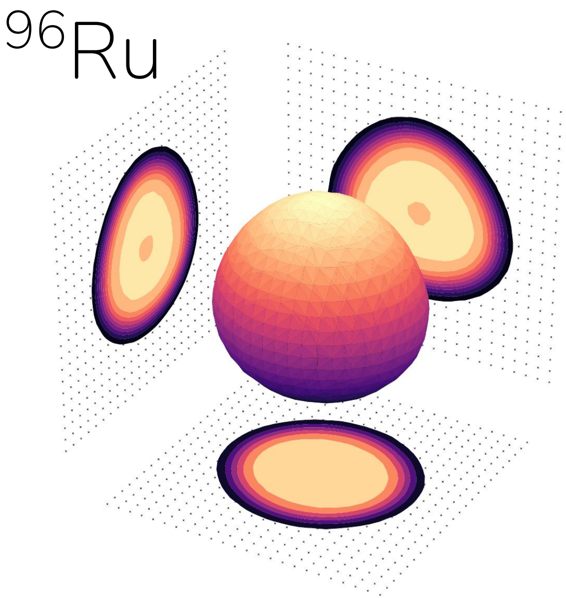

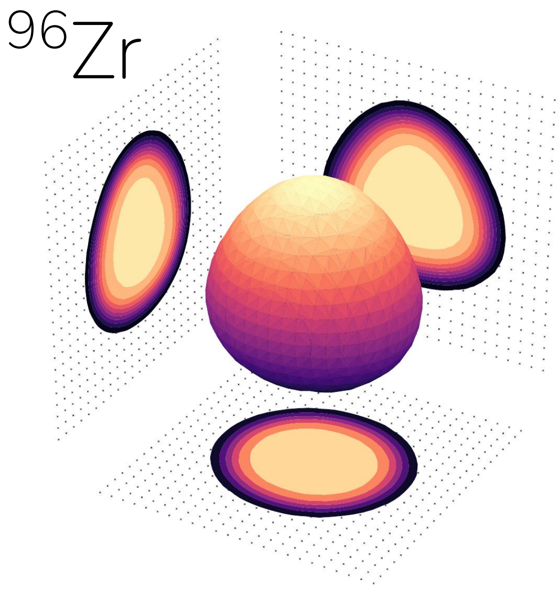

	^{96}Ru	^{96}Zr
R_0 [fm]	5.077	5.035
a_0 [fm]	0.509	0.546
ρ_0 [fm^{-3}]	0.160	0.161
β_{20}	+0.002	+0.037
β_{22}	+0.065	+0.059
β_{30}	+0.079	+0.120
β_{32}	−0.006	−0.024
β_{40}	+0.005	+0.006
β_{42}	−0.002	−0.001
β_{44}	+0.007	−0.001

Conclusion

Wood-Saxon subtleties

- central oscillations (probably not so relevant)
- surface polarisation (relevant?)
- <u>**volume ≠ surface** multipole moments</u>

U+U vs. Au+Au

- nuclear theory, low-E and high-E consistent
  (with some room for larger Q40-measurement)

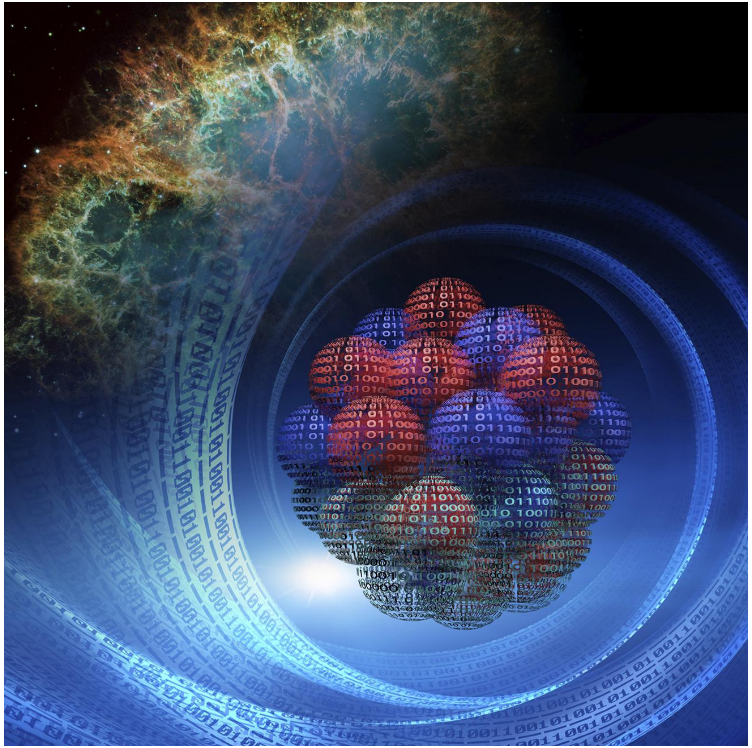

Image credit: Andy Sproles, ORNL

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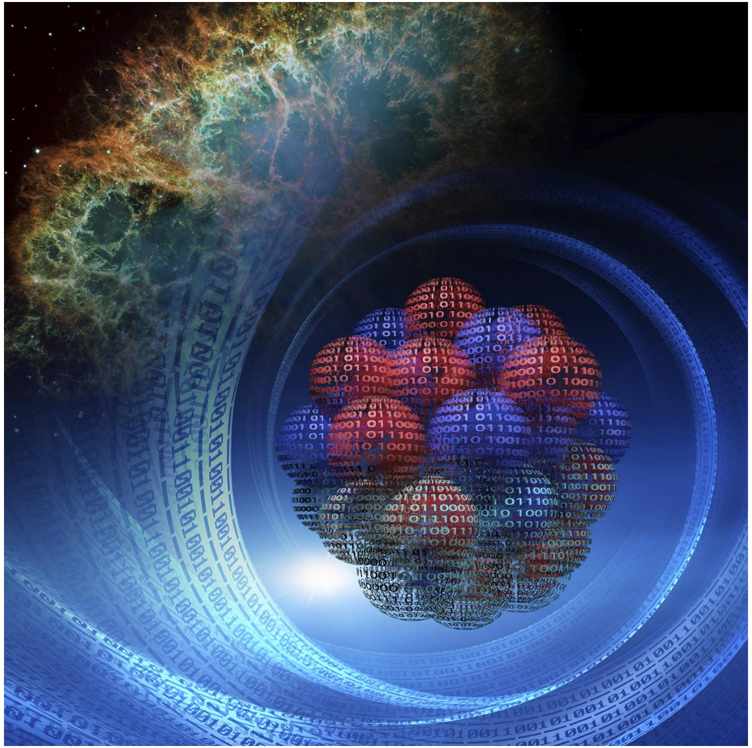

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By-product:
- Python scripts for creating crazy Wood-Saxon shapes
- that can easily be coupled to 3D-codes

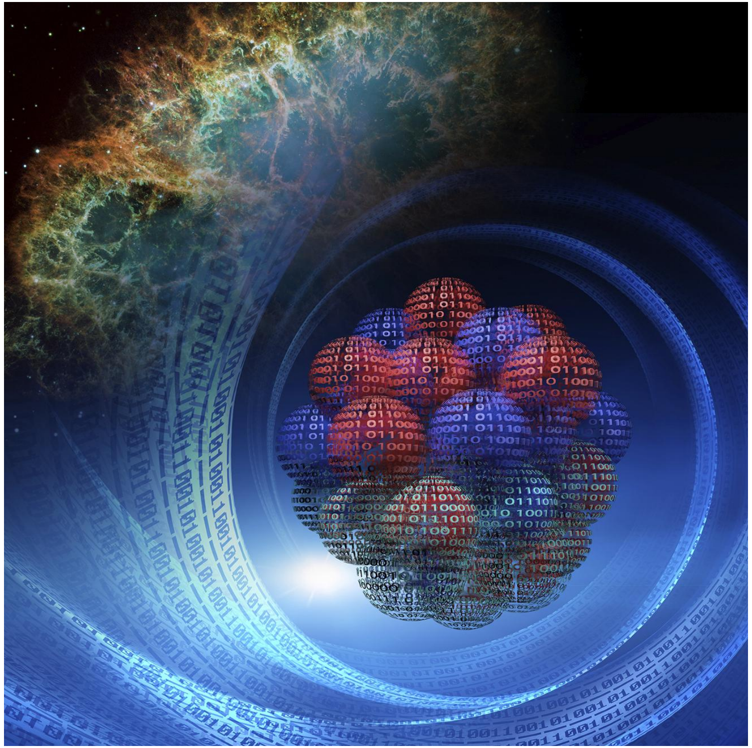

Image credit: Andy Sproles, ORNL

Thank you for…

…… the collaboration!

S. Goriely
G. Grams
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V. Allard
L. Perot

G. Scamps

S. Hilaire
J.-F. Lemaître

M. Bender

…… the computing time!

…… the funding!

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