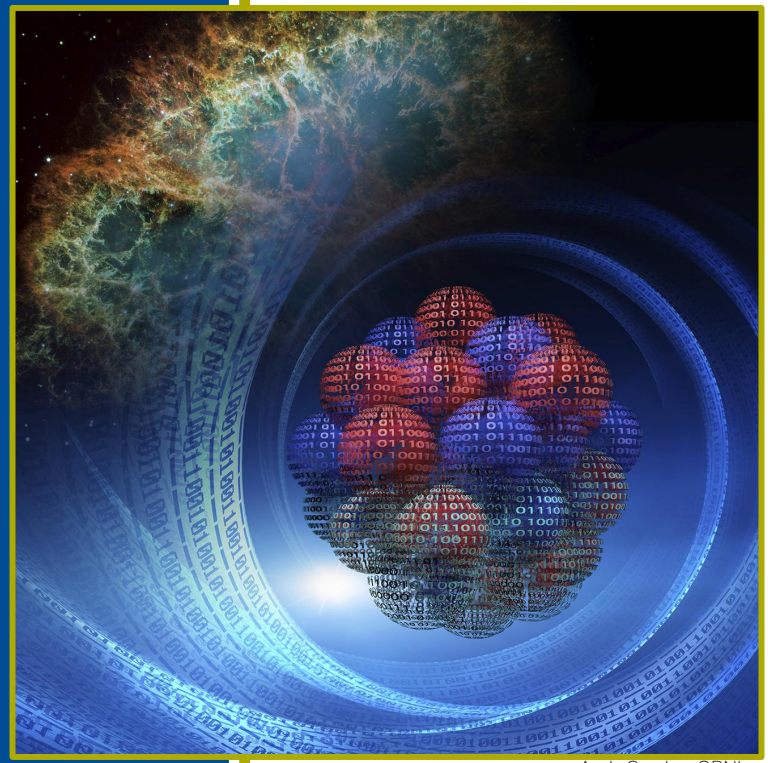
WOUTER RYSSENS



Andy Sproles, ORNL

Dense matter in the cosmos: nuclei, pasta and explosions.

W. Ryssens

November 6th 2023

wryssens.com

wryssens@ulb.be

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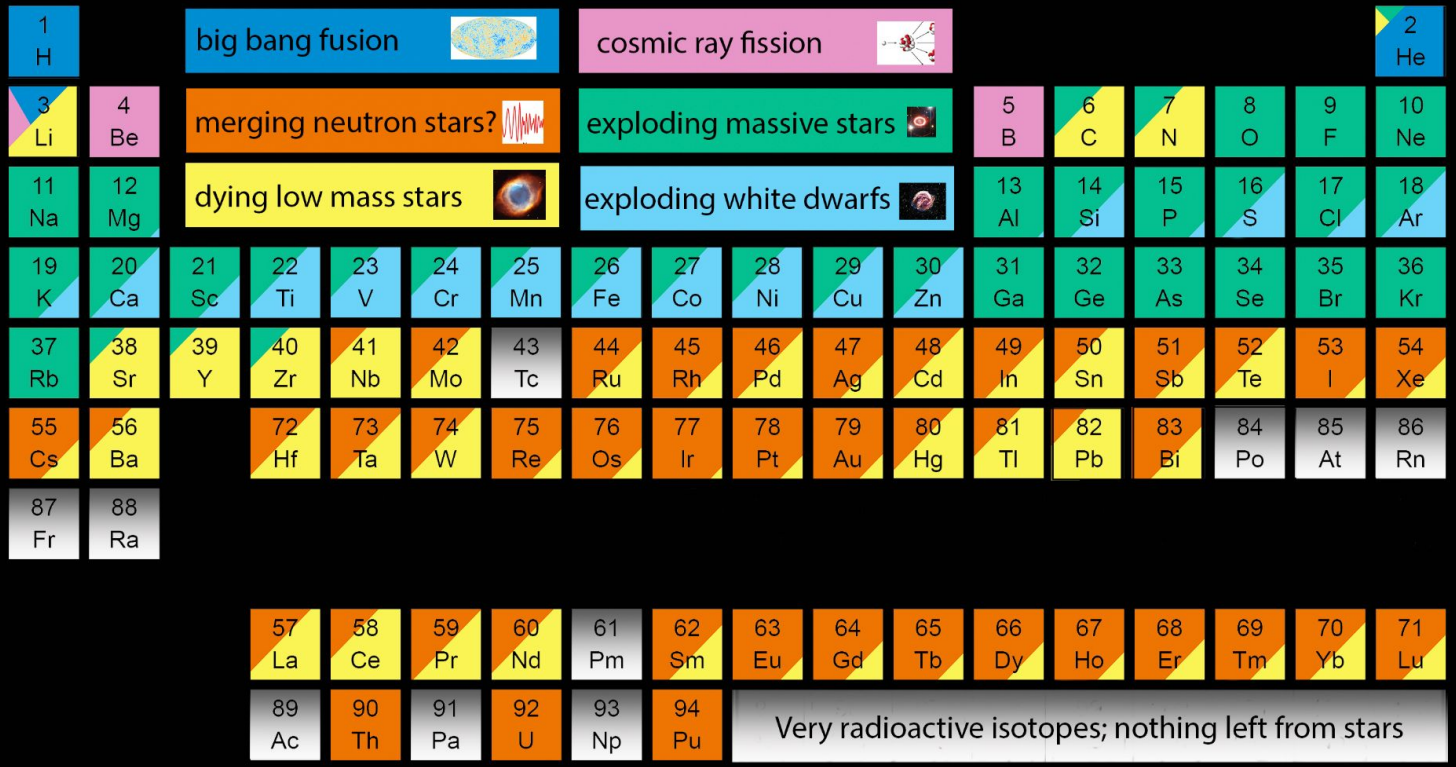
Contents

1. Nuclear astrophysics
    a. the origin of the elements
    b. the Belgian landscape

2. Simulating dense matter
    a. atomic nuclei
    b. nuclear fission
    c. nuclear pasta

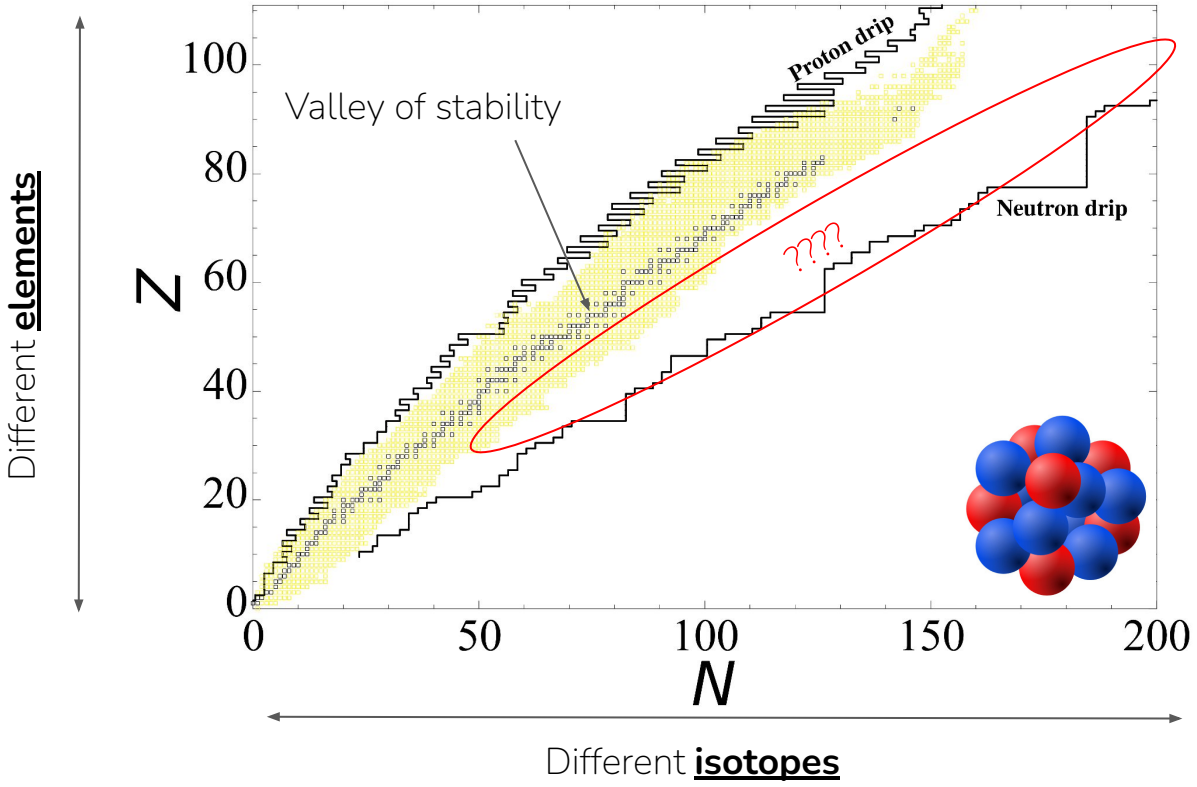
3. What will we be doing on LUMI?



Graphic created by Jennifer Johnson
http://www.astronomy.ohio-state.edu/~jaj/nucleo/

Astronomical Image Credits:
ESA/NASA/AASNova

The nuclear chart…



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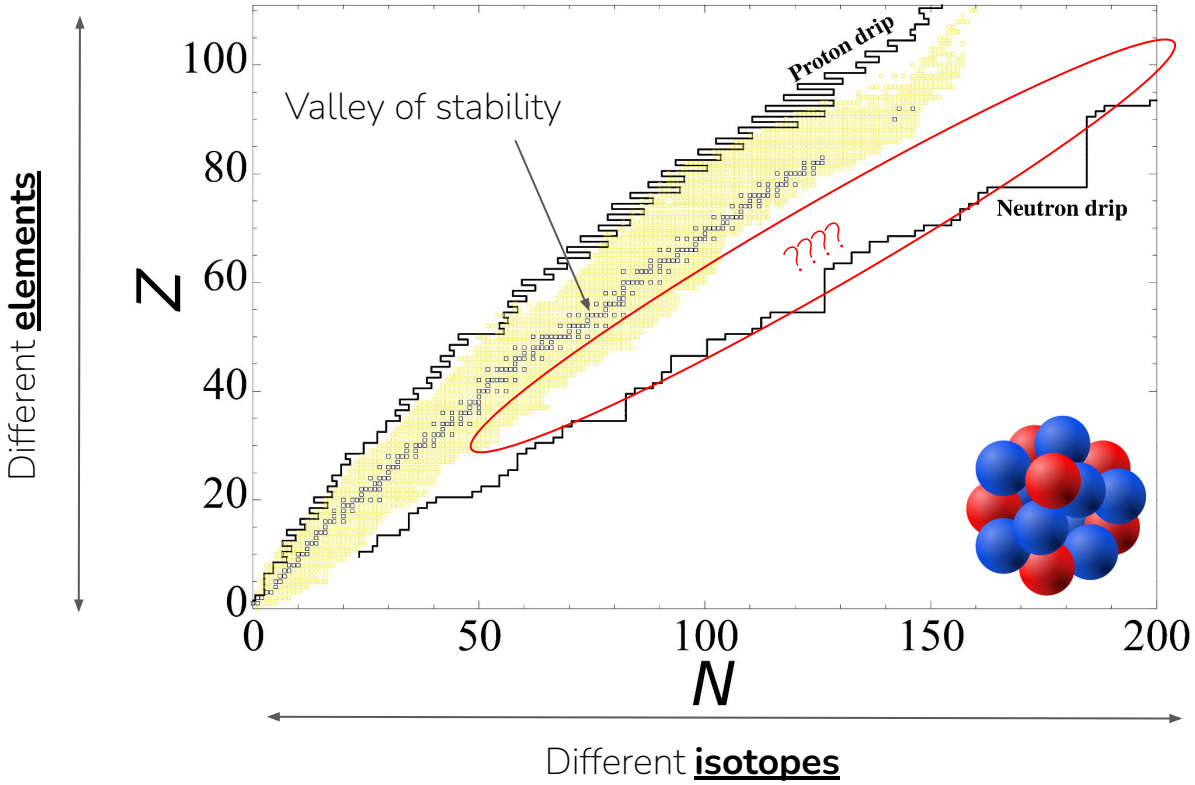
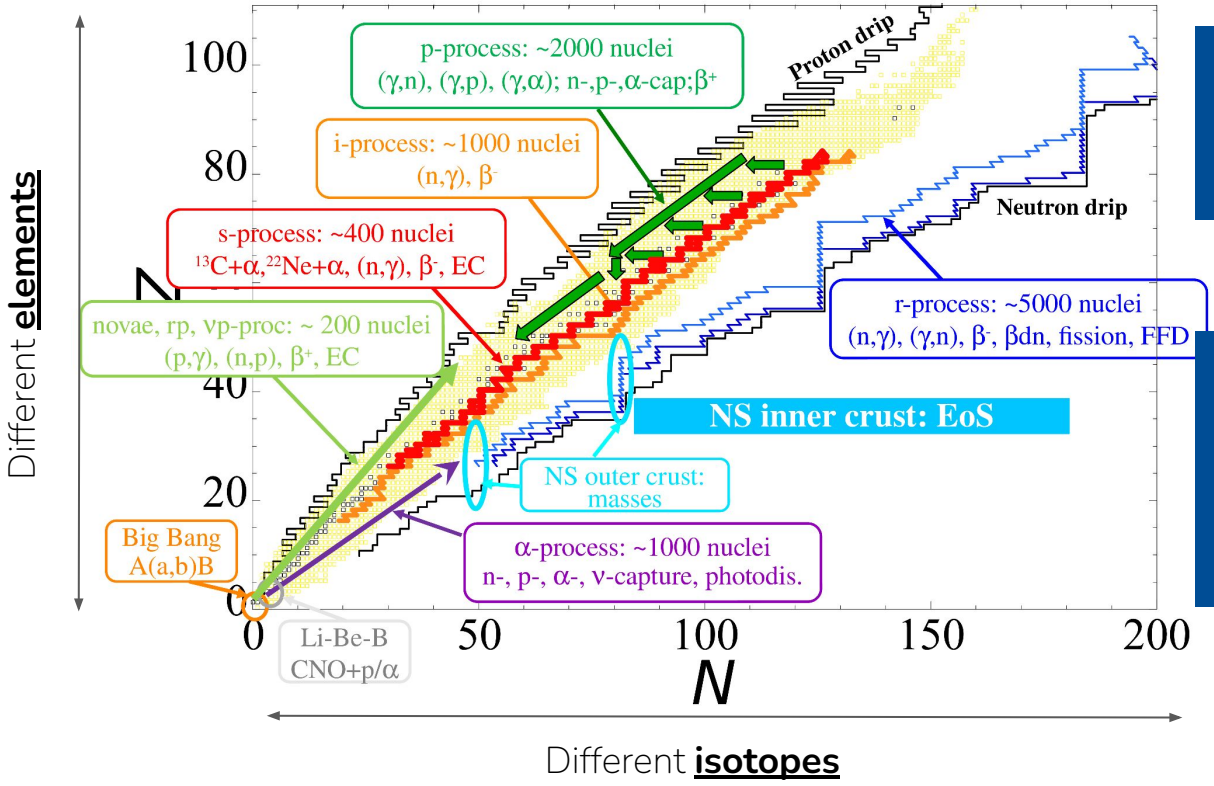


Transmutation

1. neutron capture
2. β+ and β- decay
3. different types of fission

and many others…

The nuclear chart and the processes traversing it



Transmutation

1. neutron capture
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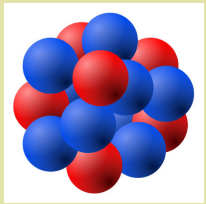
and many others...

Need for theory!

1. many astrophysical processes
   - r-process, s-process, ...
2. operating in different conditions
   - temperature, density, ...
3. properties of 1000s of nuclei
   - masses, sizes, ...
   - reaction rates

Nuclear physics



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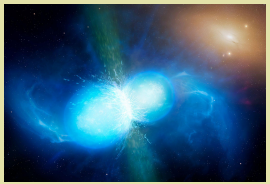
Masses, reaction and decay rates

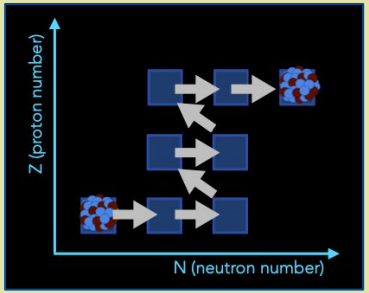
Neutron star properties

Hydrodynamic simulations



Temperature, densities, ...

Reaction networks



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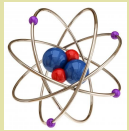
Atomic Theory



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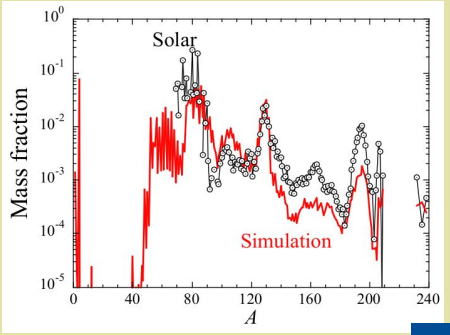
Opacities

Observables!



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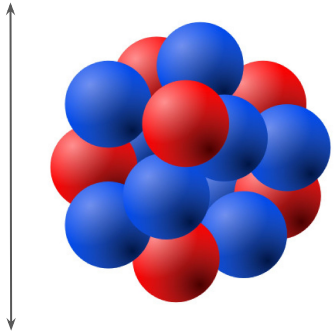
Dense matter: simulating **nuclei**

L ~ 5 fm = 5e-15 m
ρ ~ 2e**+14** g/cm^3



The nuclear many-body problem

- **quantum** N-body problem
- … for A~10 - 300 particles
- … with Coulomb interaction
- … with strong nuclear interaction

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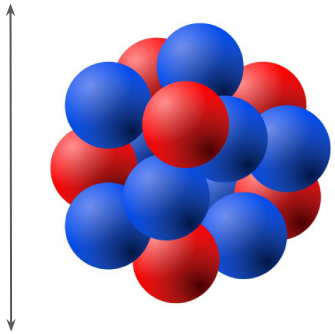

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Density Functional Theory with MOCCa

- Brussels-built functionals
- **non-linear** optimisation problem

Dense matter: simulating **nuclei**

Typical job: 0.3-1h, < 2GB, 1 CPU
Extreme job: 6 - 7h , ~ 4GB, 1 CPU

L ~ 5 fm = 5e-15 m
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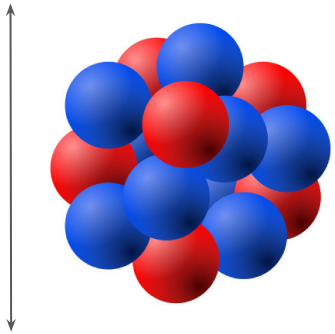

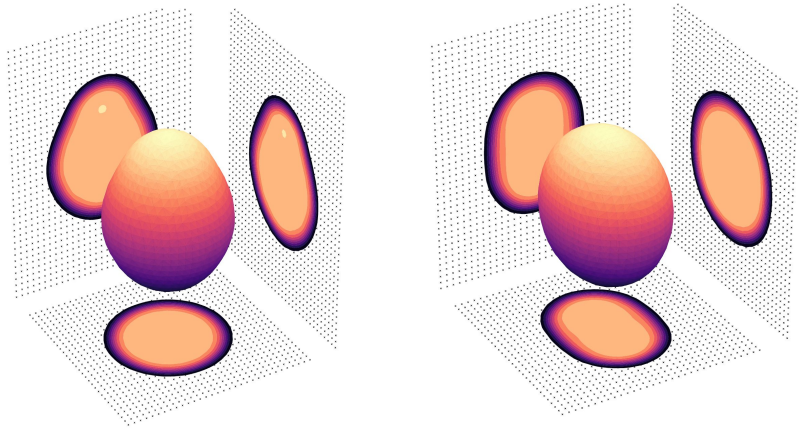

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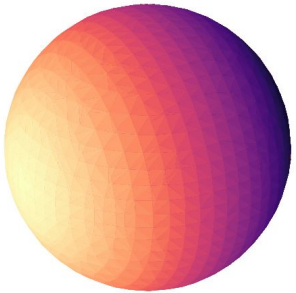
Density Functional Theory with MOCCa

- Brussels-built functionals
- **non-linear** optimisation problem
- 3D coordinate space representation
- need to explore different shapes

Dense matter: **fission**



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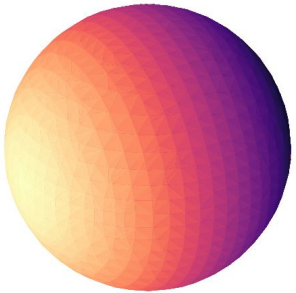

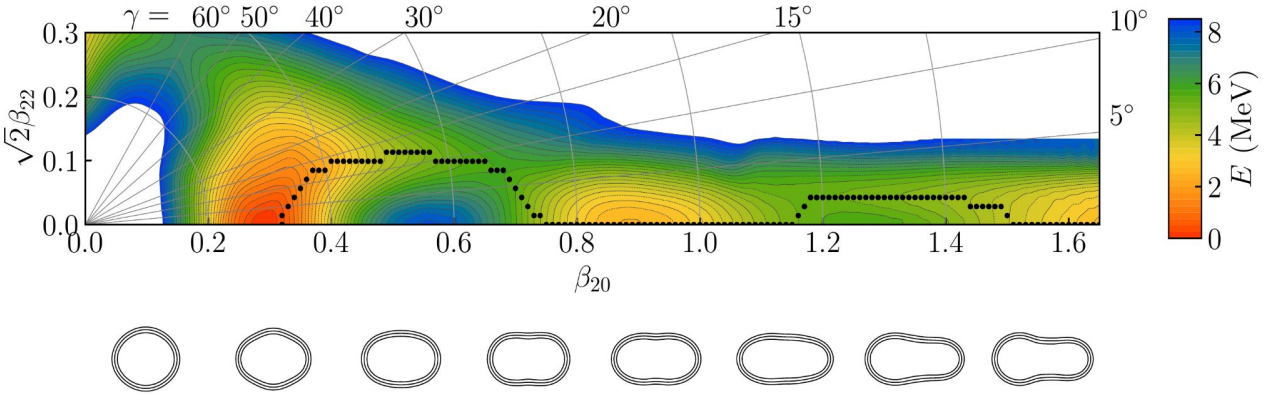

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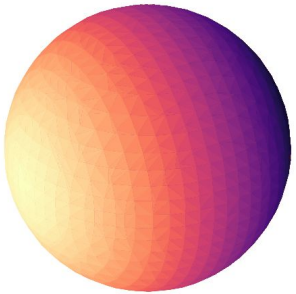

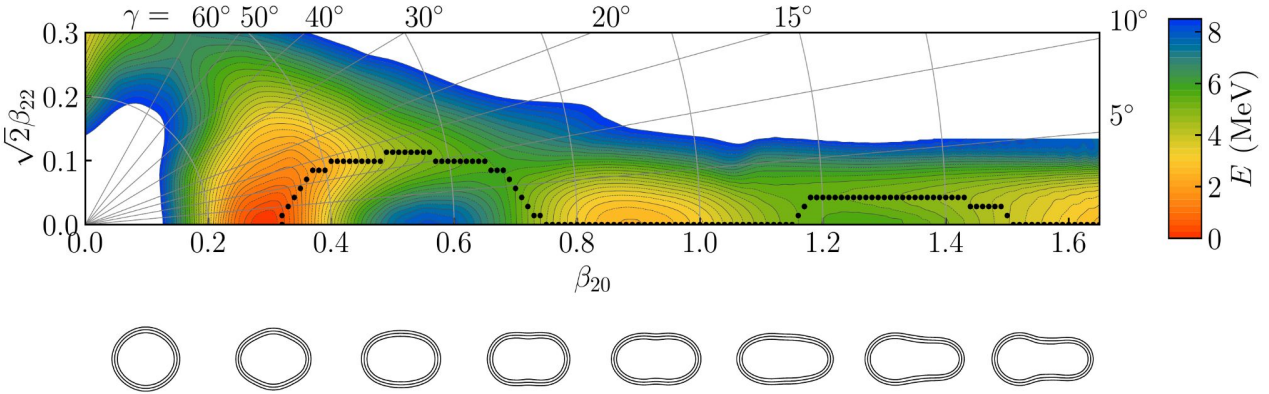

Challenges

- properties required for **thousands of nuclei**
- rates depend **exponentially** on energy!
- **relevant shapes** depend on nucleus

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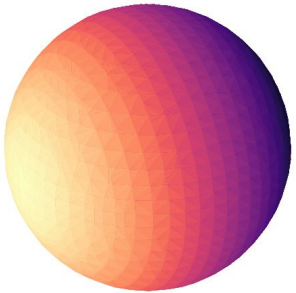
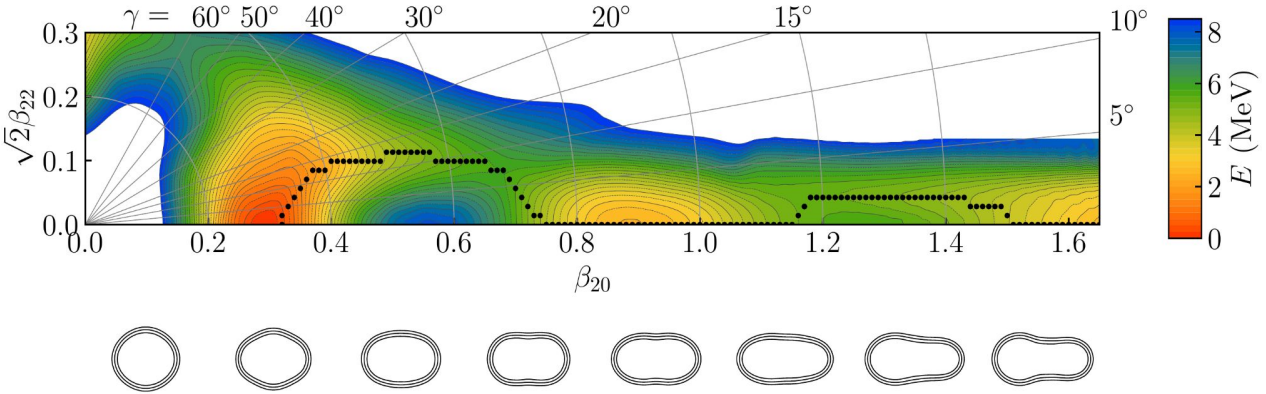




Challenges

- properties required for **thousands of nuclei**
- rates depend **exponentially** on energy!
- **relevant shapes** depend on nucleus

Research goals

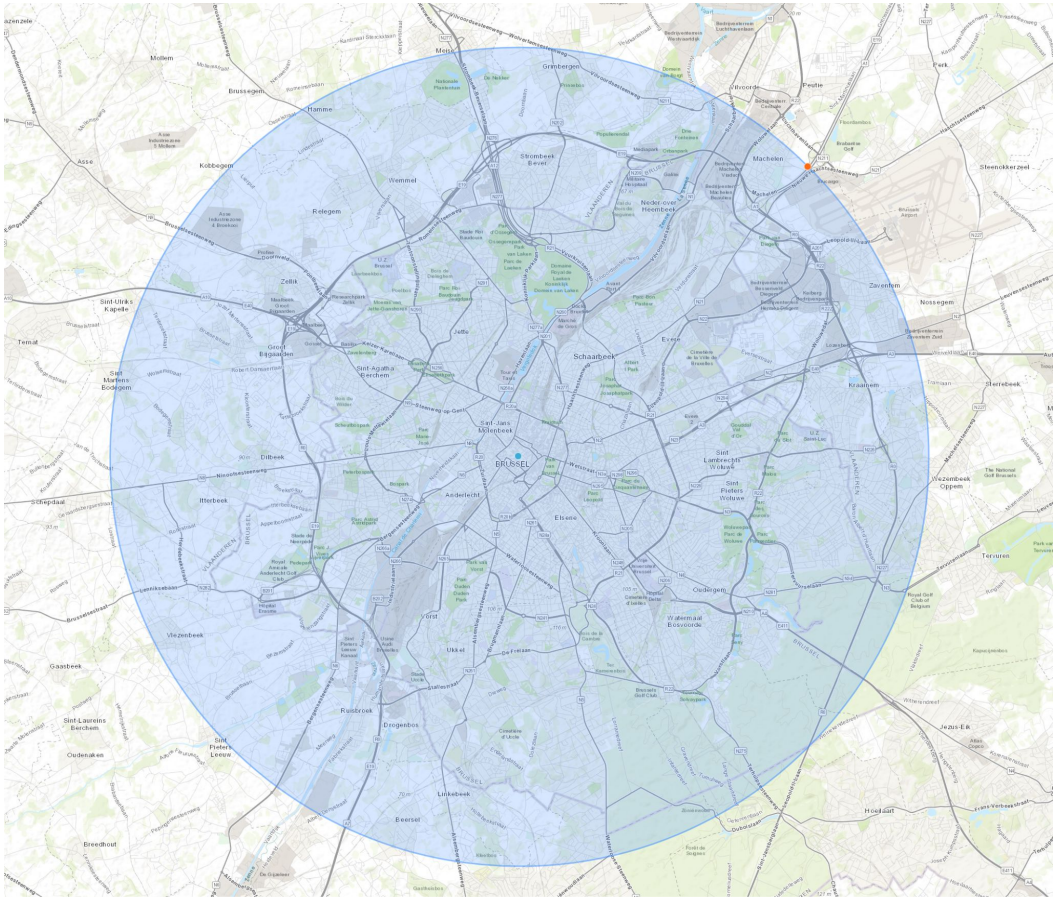
1. Can we scale to 3D fission trajectories?
2. What are the “best” 3 shape d.o.f.s?
3. What is the impact on nucleosynthesis?

Dense matter: **neutron stars**

Image credit: NASA Goddard

L ~ 20 km = 2e+3 m
ρ ~ 10e+14 g/cm^3 (?)

Dense matter: **neutron stars**



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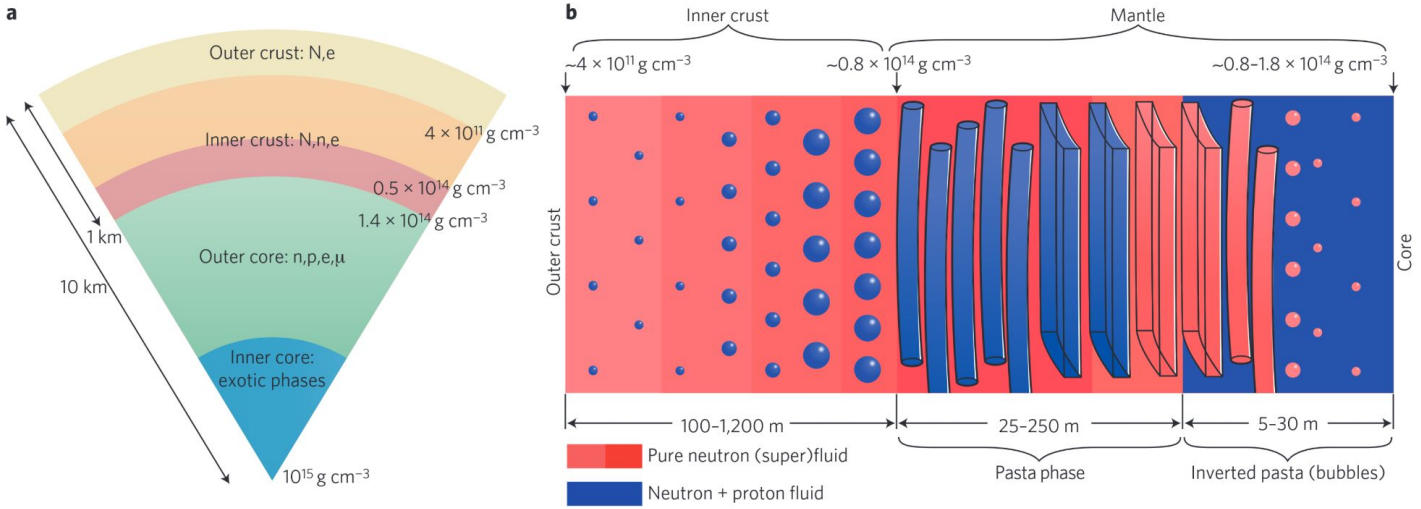

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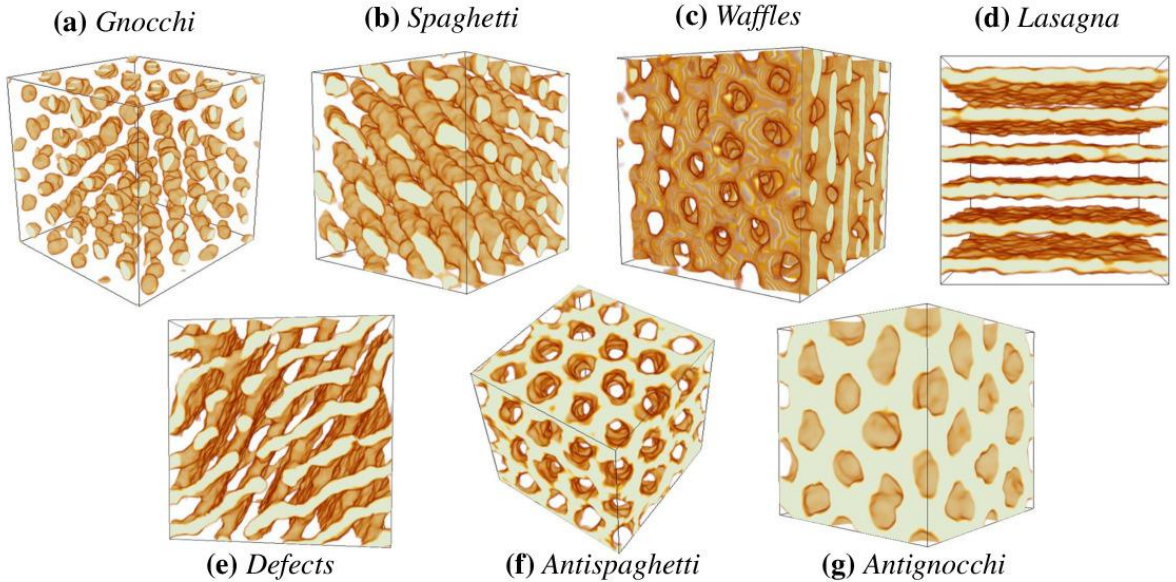

Challenges

- simulations in large volumes
- thousands of particles
- extremely complicated phase-space

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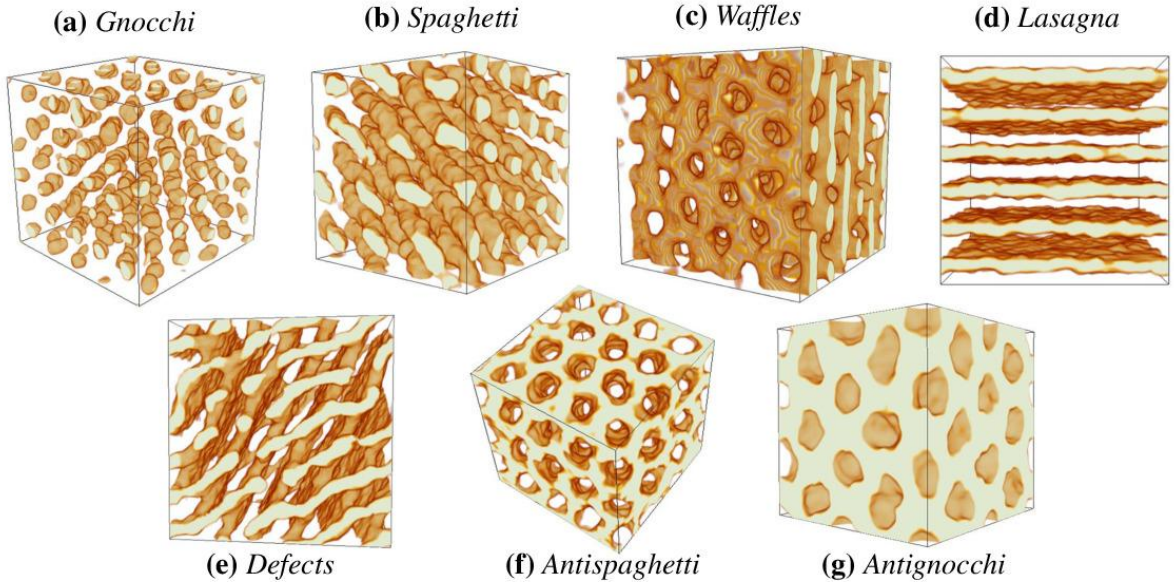


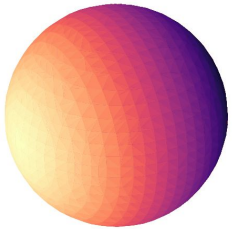
Challenges

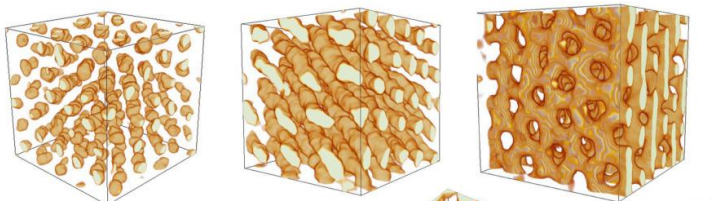
- simulations in large volumes
- thousands of particles
- extremely complicated phase-space

Research goals

1. Can we scale to “thermodynamic” limit?
2. Does pasta survive quantum mechanics?
3. Can we build a unified picture?

Dense matter: **LUMI preparatory project**



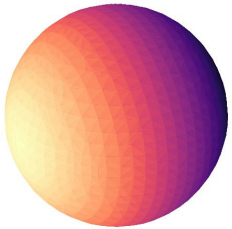


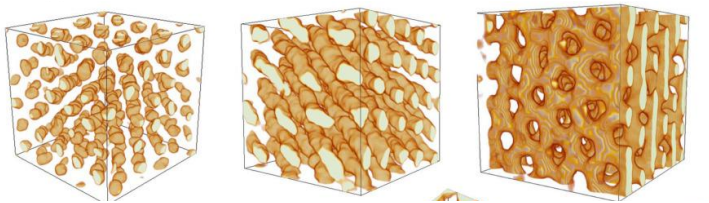
Fission & pasta

- phenomena at different scales …
- different computational requirements
- with common physics origin
- targeted with a single tool!

Dense matter: **LUMI preparatory project**

@





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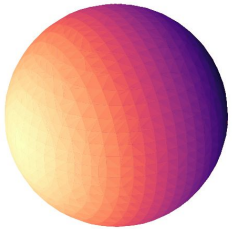

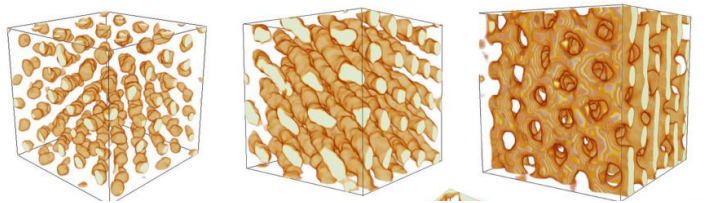

Fission & pasta

- phenomena at different scales …
- different computational requirements
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- targeted with a single tool!

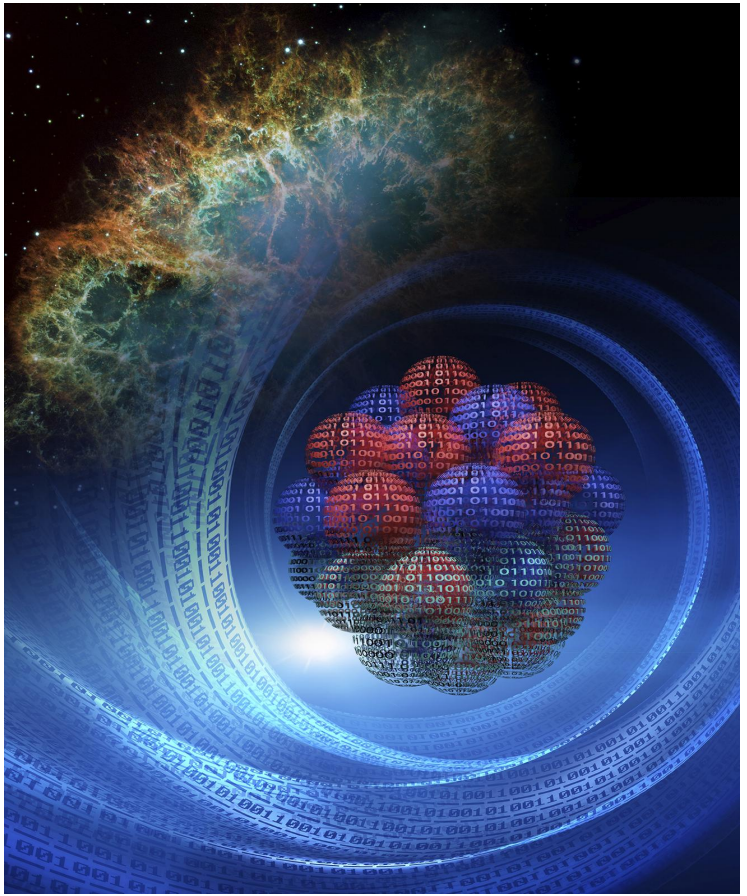
We are …

1. optimizing the MPI implementation
2. adapting solution strategies
3. developing proof-of-concept for pasta

Conclusion

From the **microscopic** description of **nuclei**...

- What shapes do they take?
- How do they react to deformation/fission?



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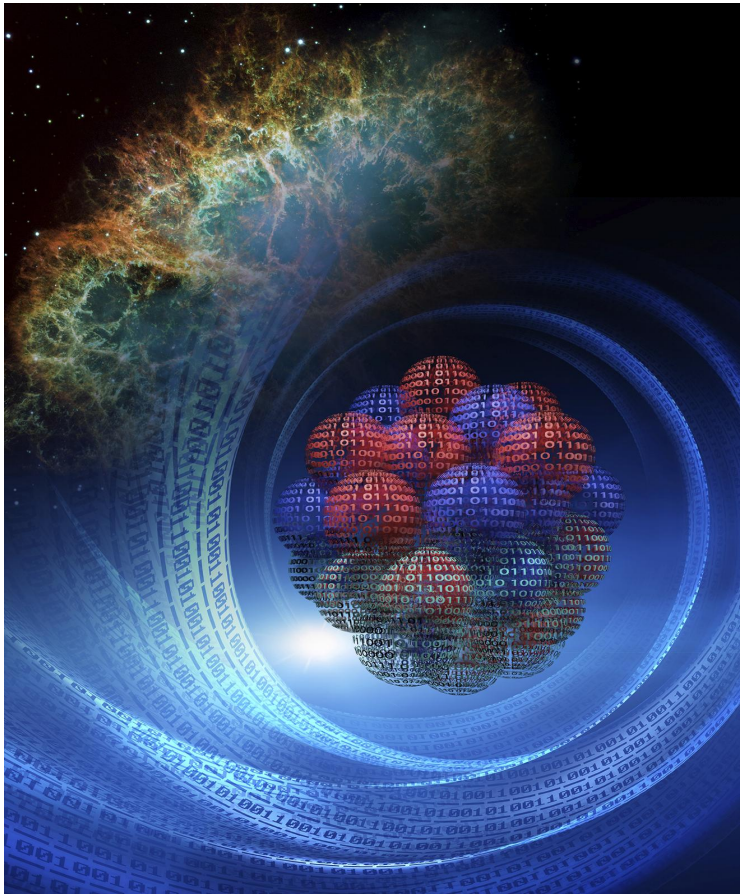

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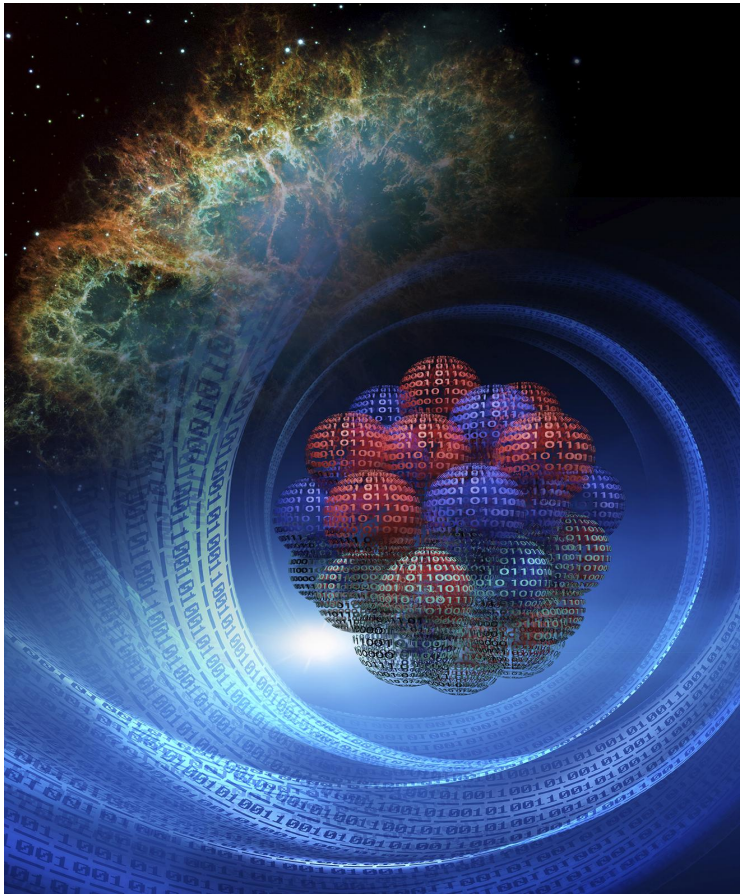

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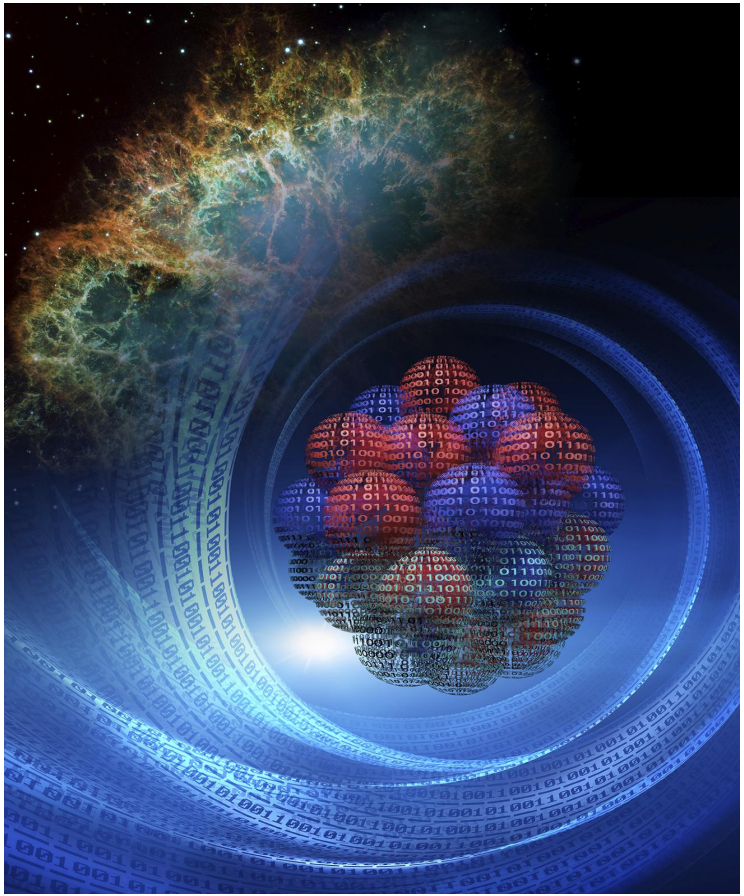

Thank you ....

..... to all our Belgian collaborators!

ULB

S. Goriely, N. Chamel, M. Godefroid, S. Van Eck, G. Grams, L. Batail, N. Shchechilin, L. Perot, V. Allard, A. Choplin, S. Martinet, R. Giribaldi, J. De Prince

KU LEUVEN

P. Van Duppen, T. Cocolios, R. Raabe, G. Neyens, R. De Groote

UMONS

P. Quinet, P. Palmeri

..... to our international partners!

..... to you, for your attention!

... for the computing time!

...and the patient user support!

Cenaero

CÉCI

LUMI

..... for the funding!

EOS THE EXCELLENCE OF SCIENCE

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