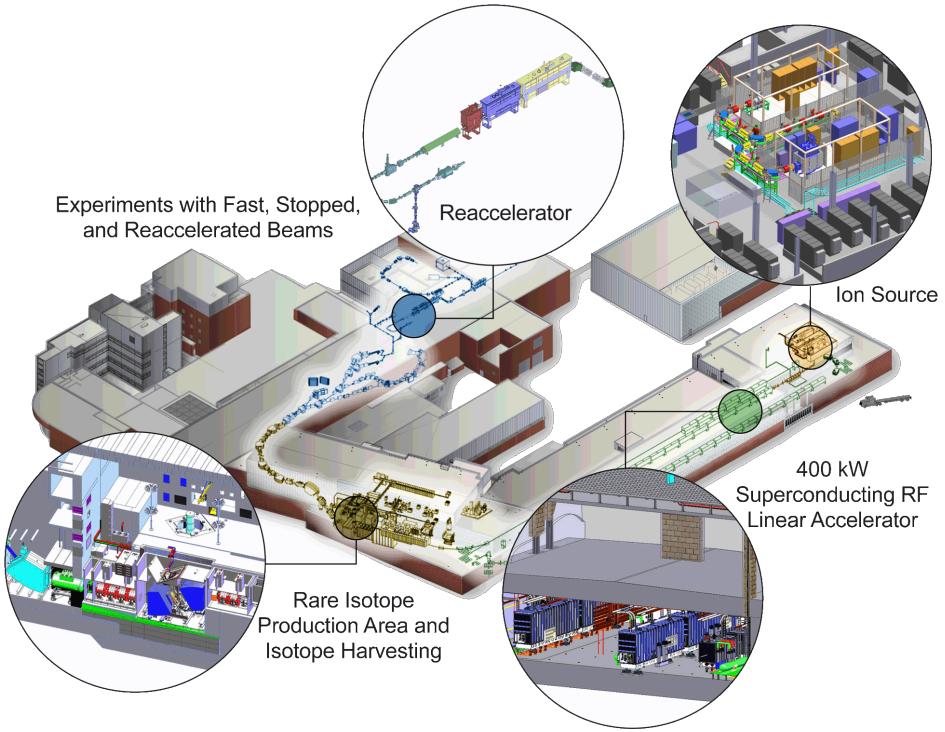
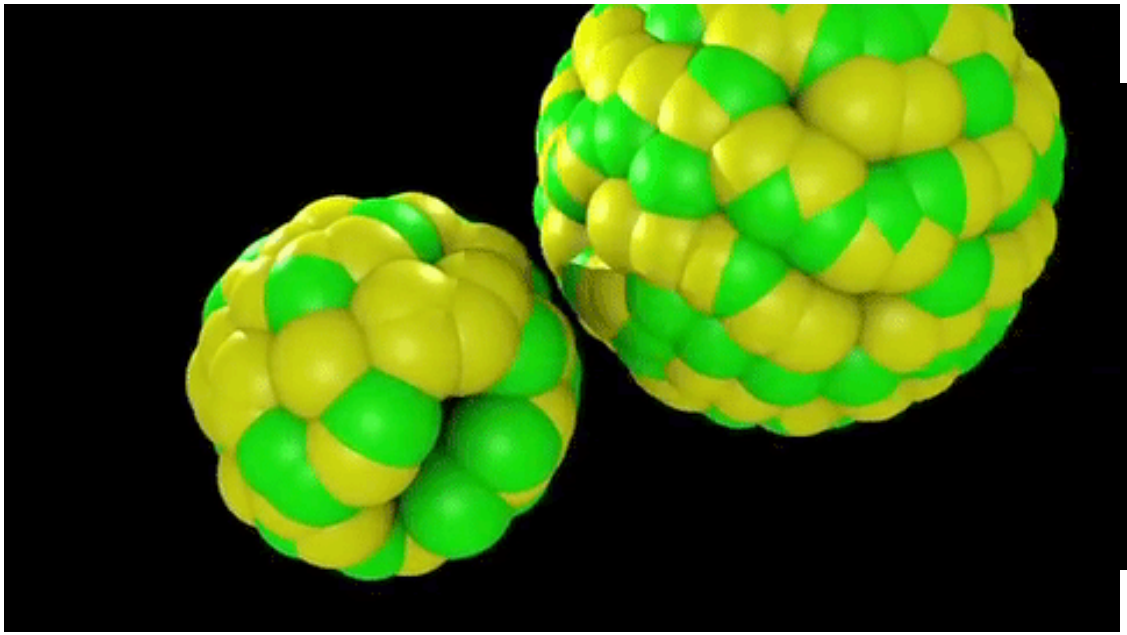
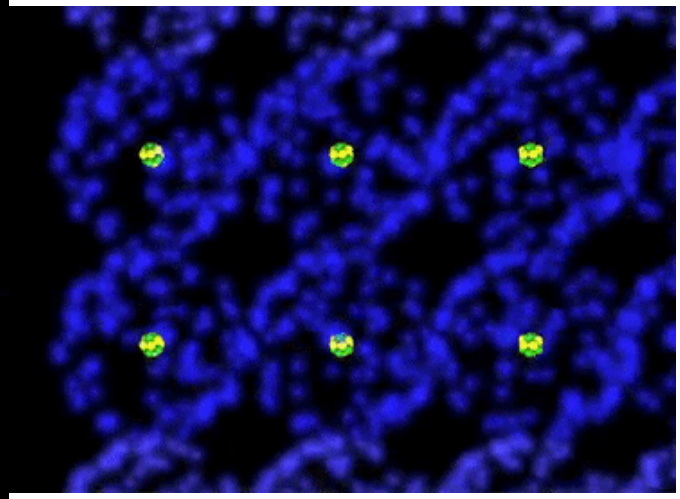
Rare Isotopes

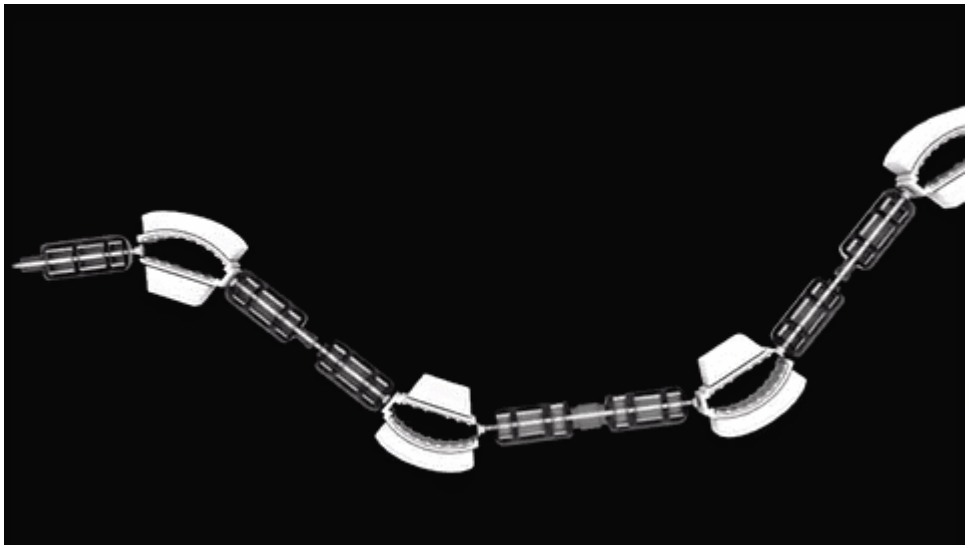


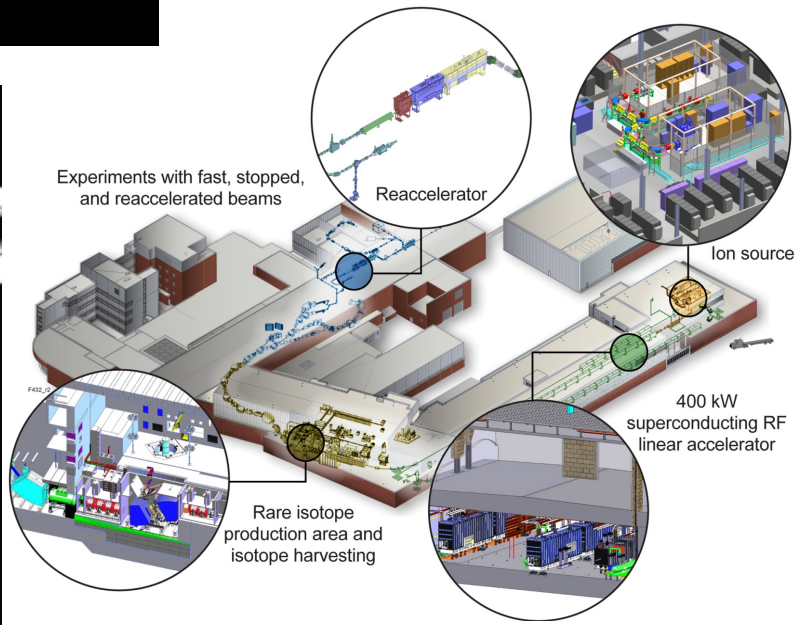
ISOTOPES discovery

https://www.youtube.com/watch?v=ZvuMRwvJhHw&spfreload=10

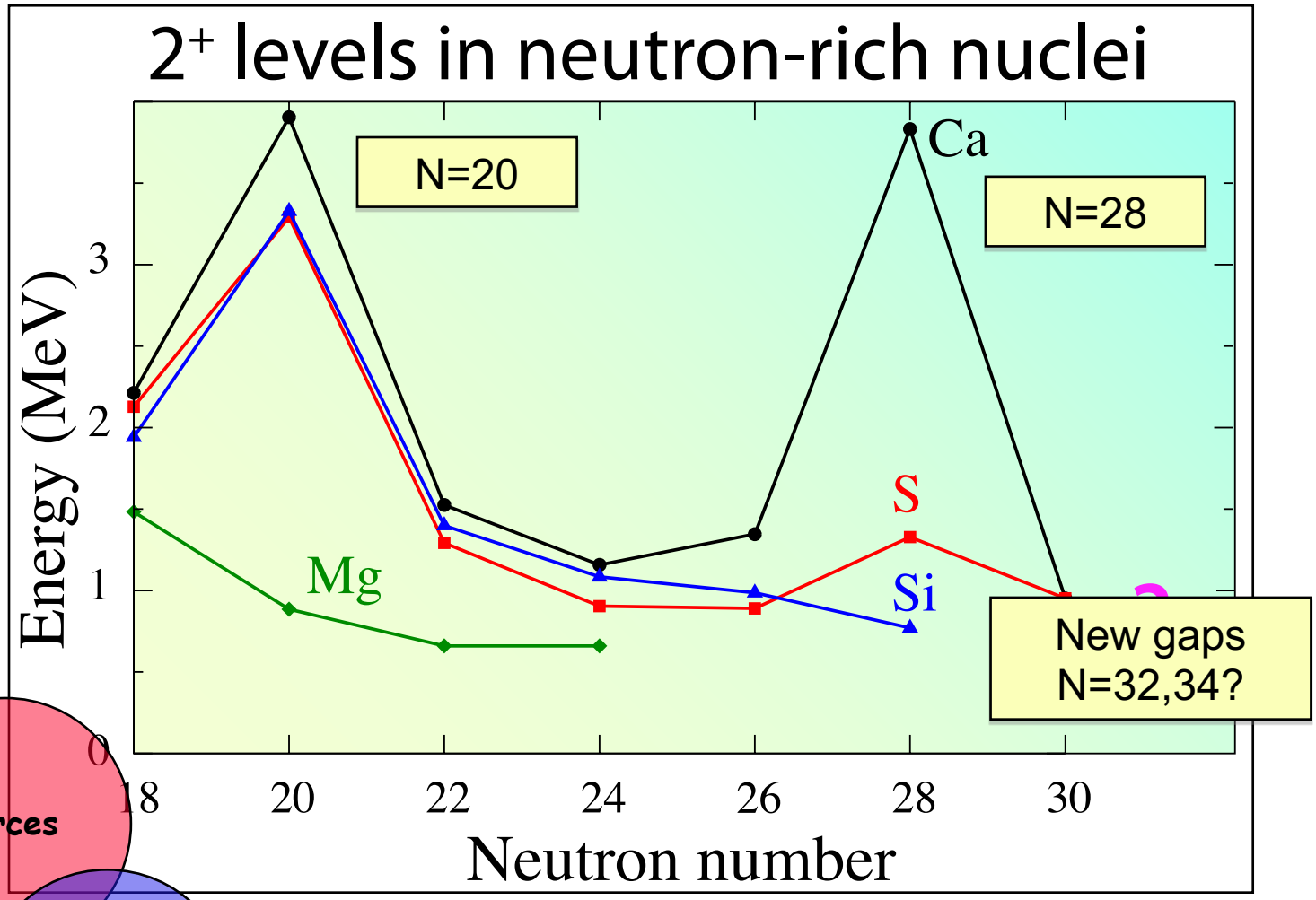


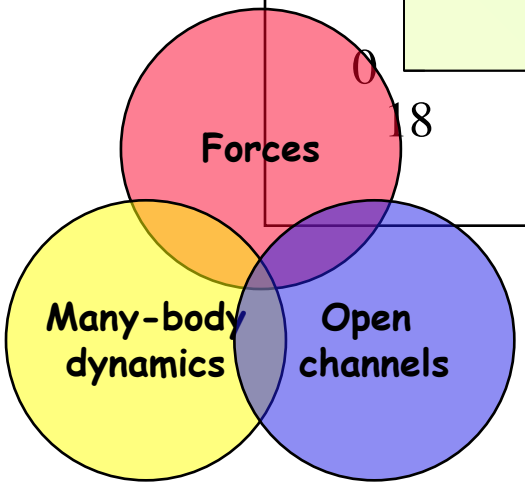





Experiments with fast, stopped, and reaccelerated beams
Reaccelerator
Ion source
400 kW superconducting RF linear accelerator
Rare isotope production area and isotope harvesting

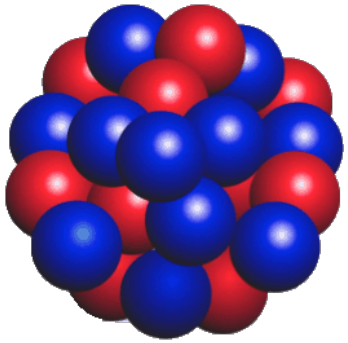
Nuclear Structure: Revision of textbook knowledge



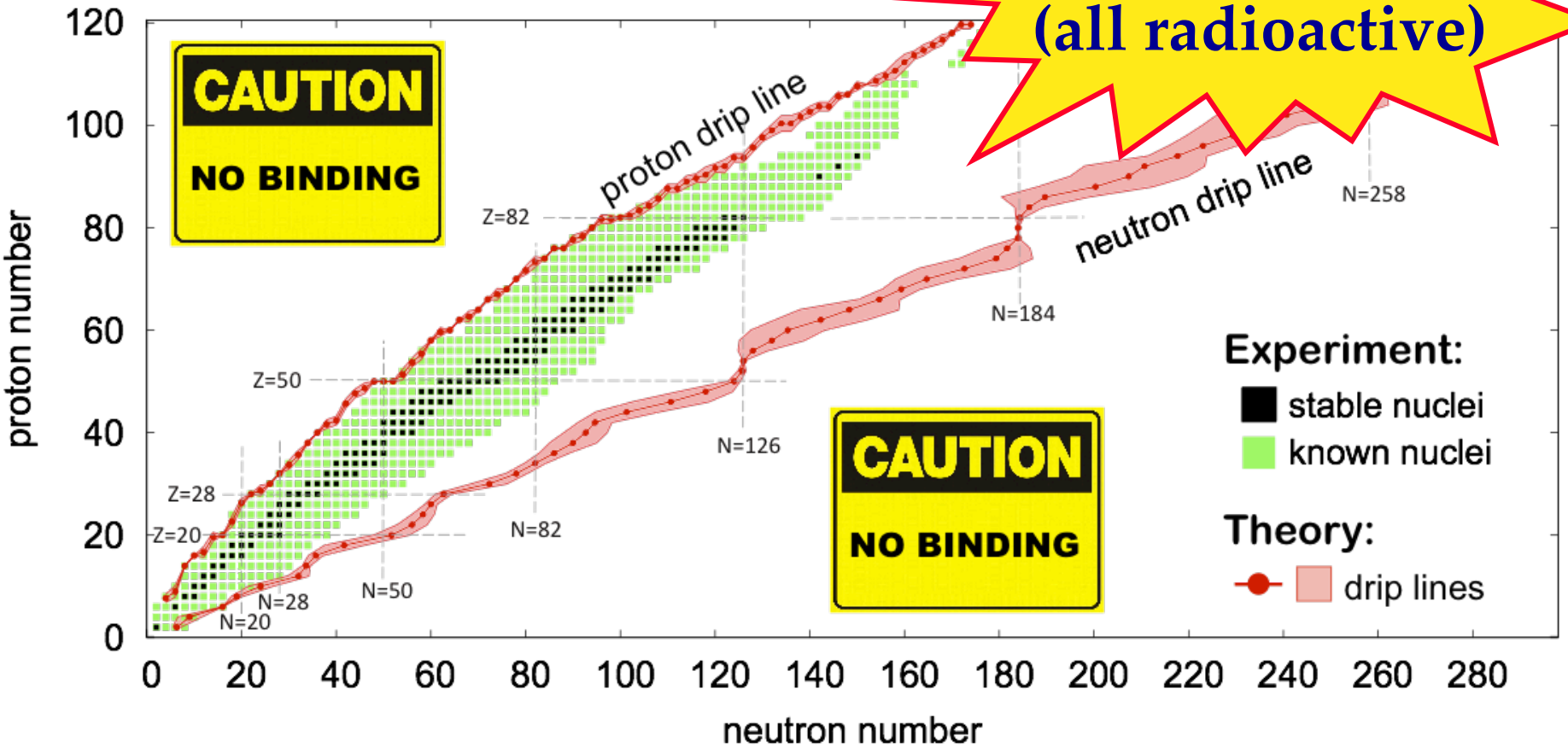


from A. Gade

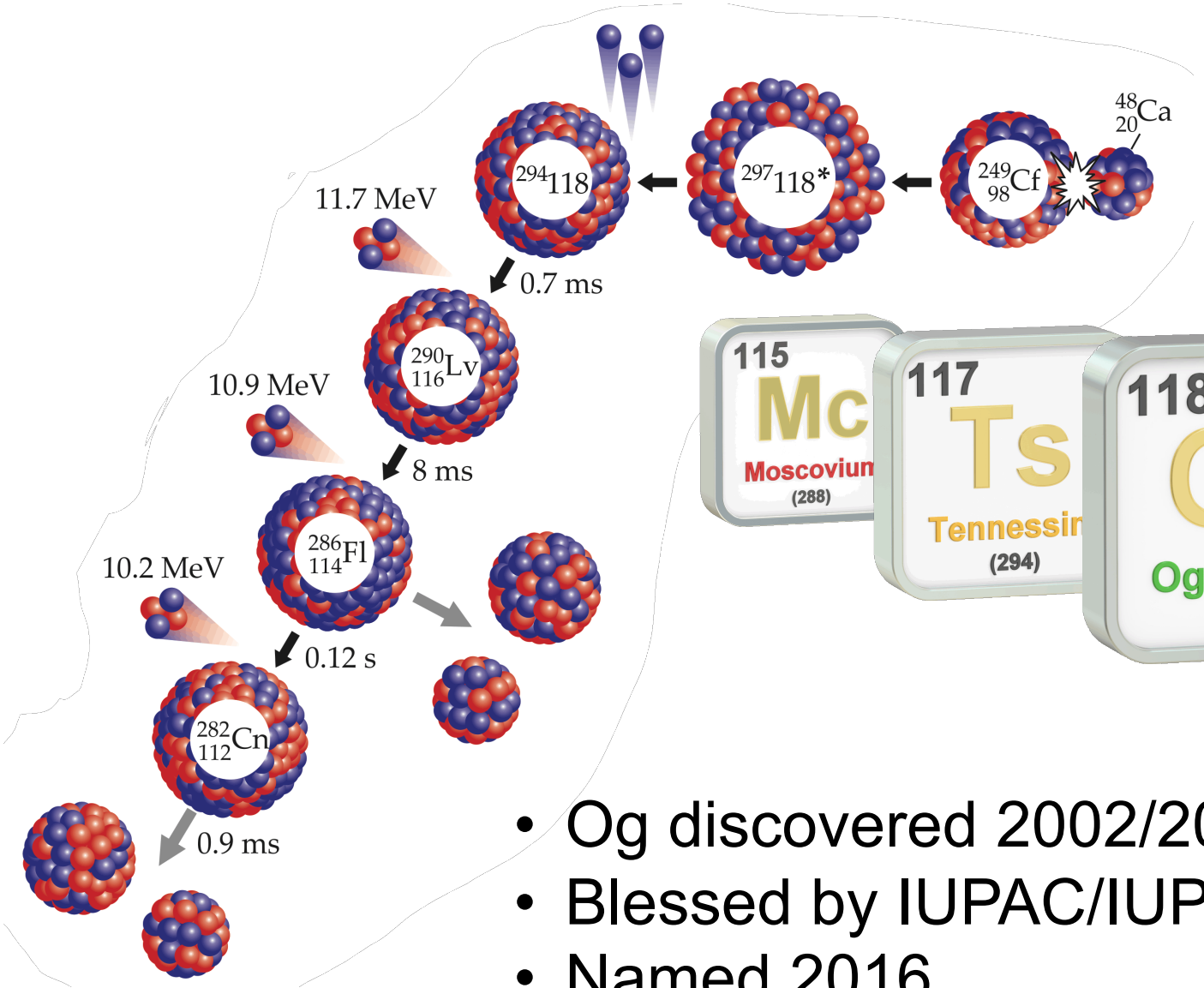
The Nuclear Landscape



superheavy Nuclei (all radioactive)



A short story of oganesson



- Og discovered 2002/2006
- Blessed by IUPAC/IUPAP 2015
- Named 2016

Physics Today **68**, 32 (2016)

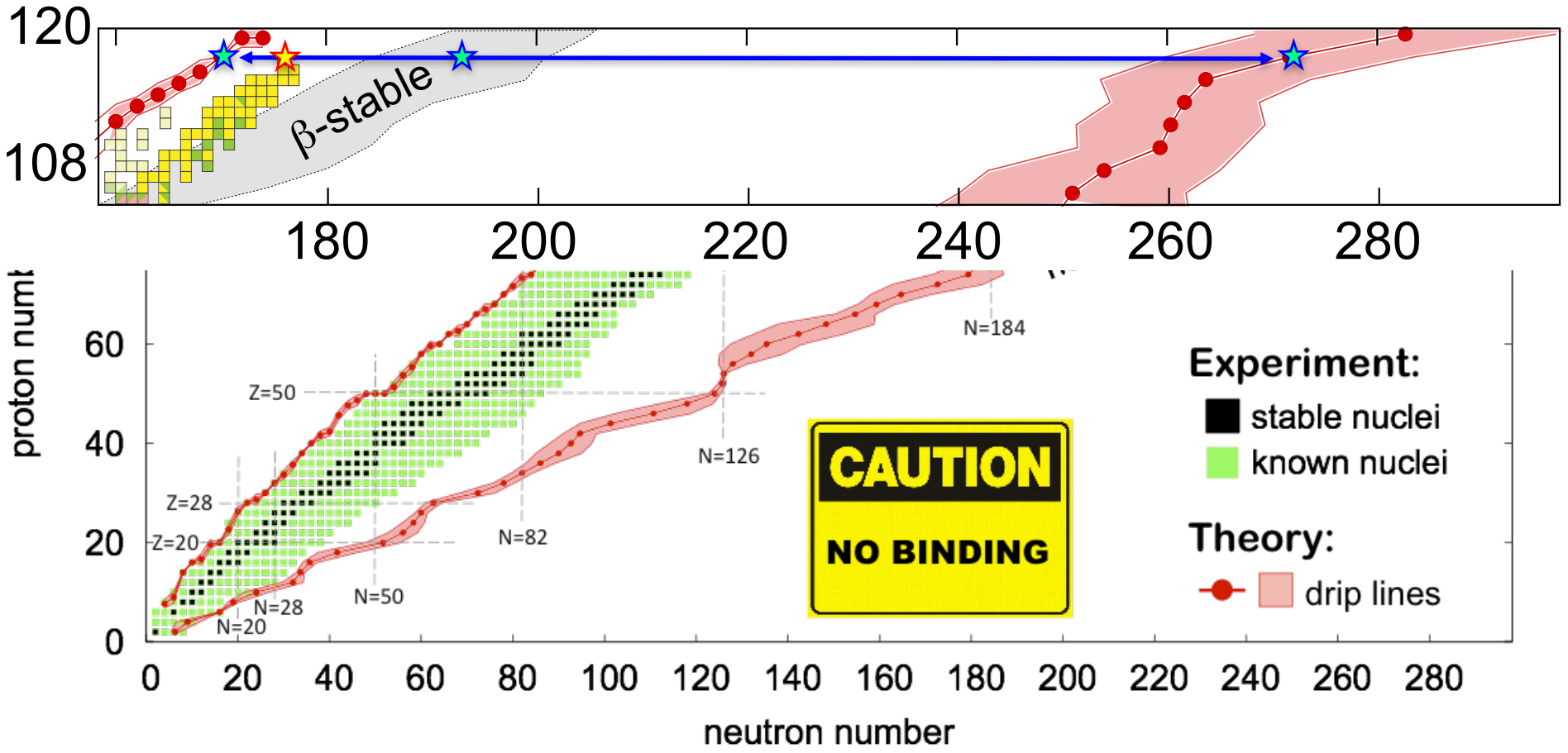
Physical properties of oganesson

≈100 isotopes of Og

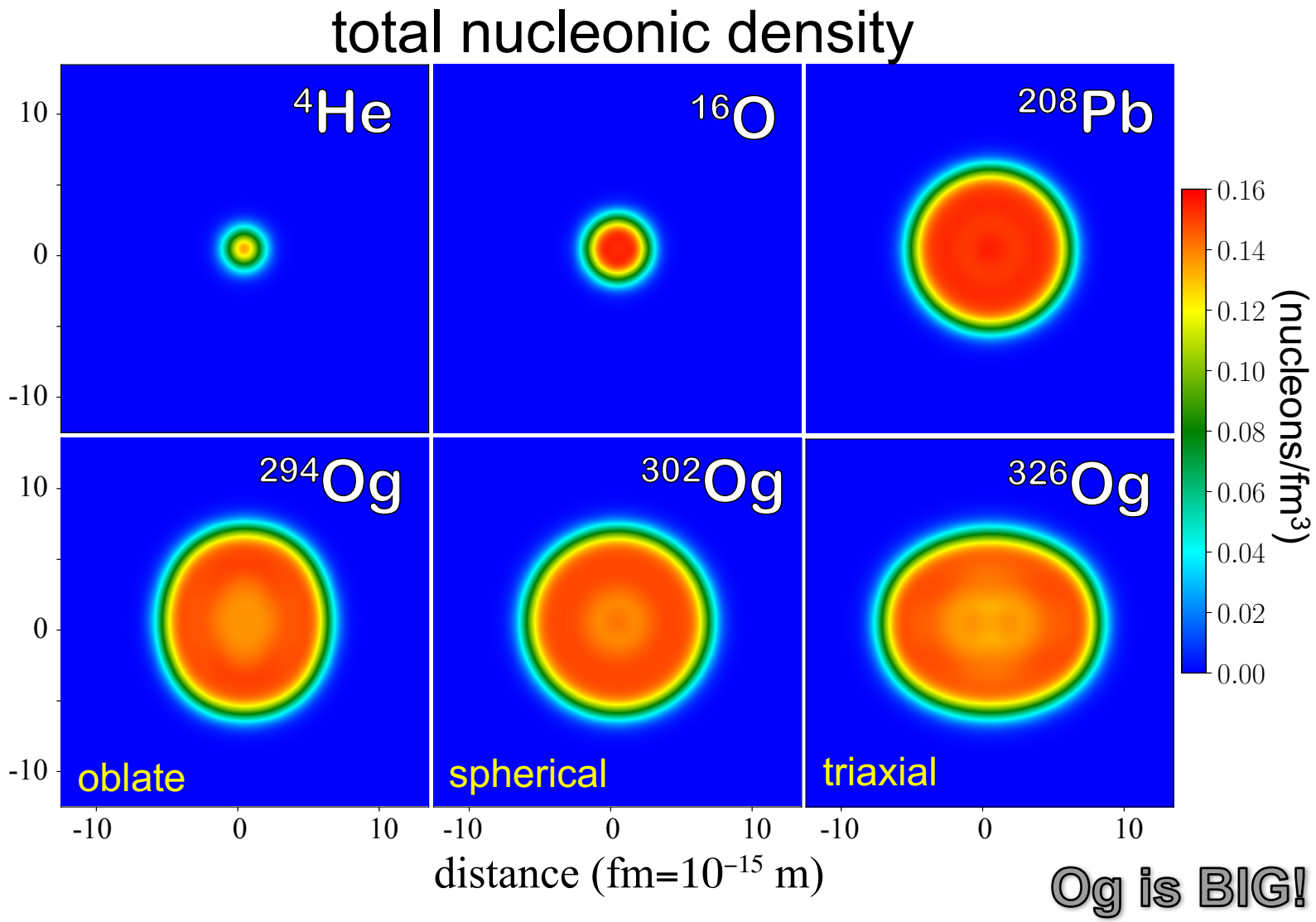
proton drip line
N=170

beta stable
N≈192

neutron drip line
N≈270



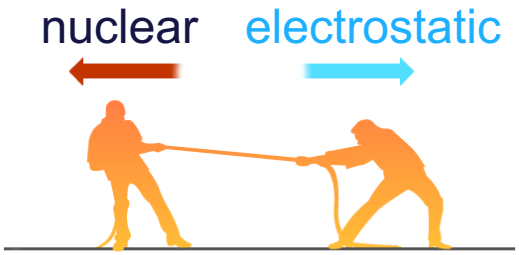
Nuclear properties of Og (predicted)



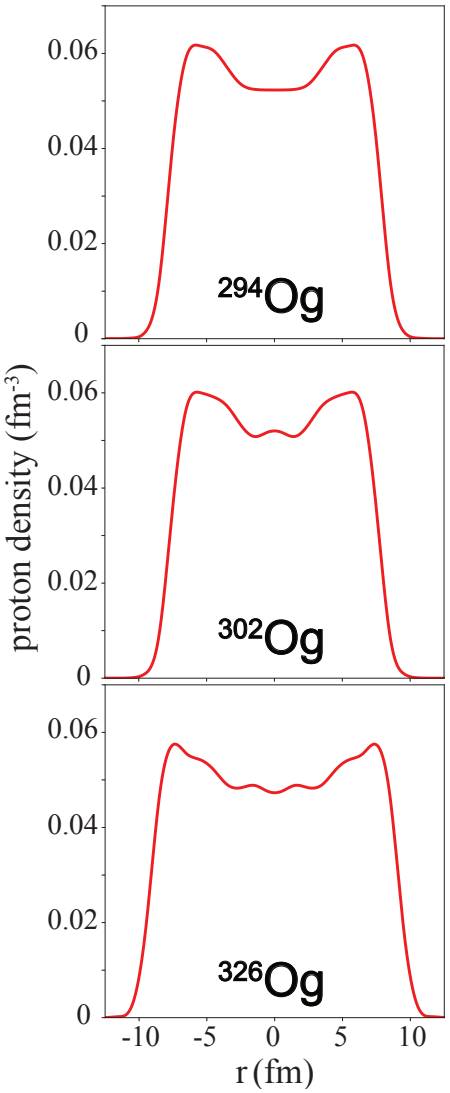
Og is BIG!

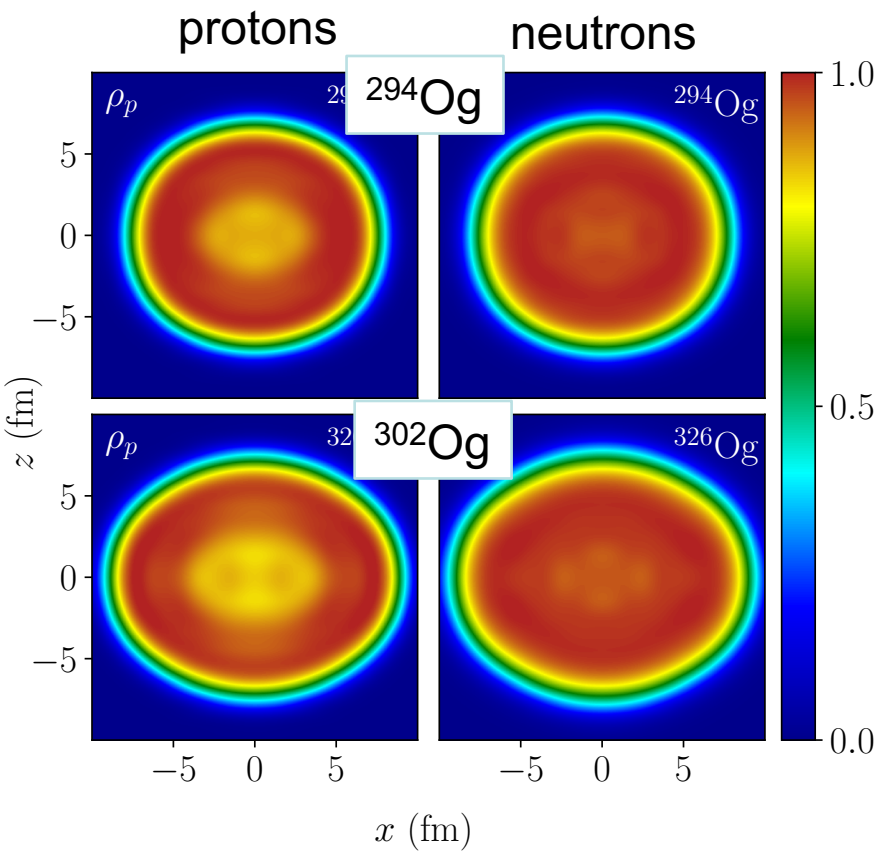
^{294}Og is expected to be a deformed semi-bubble!

B. Schuetrumpf et al., Phys. Rev. C 96, 024306 (2017)



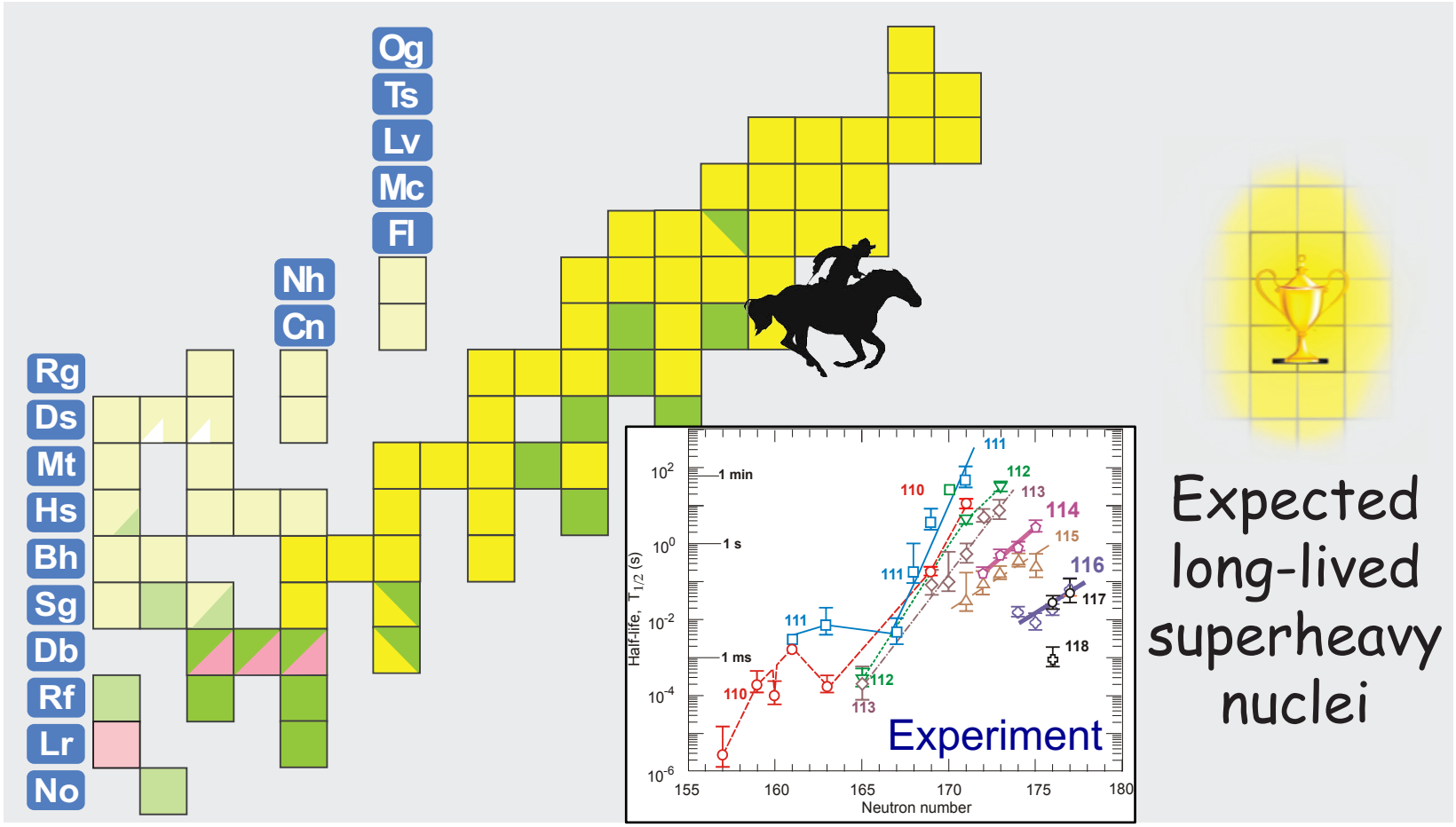
Og is a strongly frustrated system: a competition between long-range Coulomb and short-range nuclear interactions gives rise to exotic distributions of protons



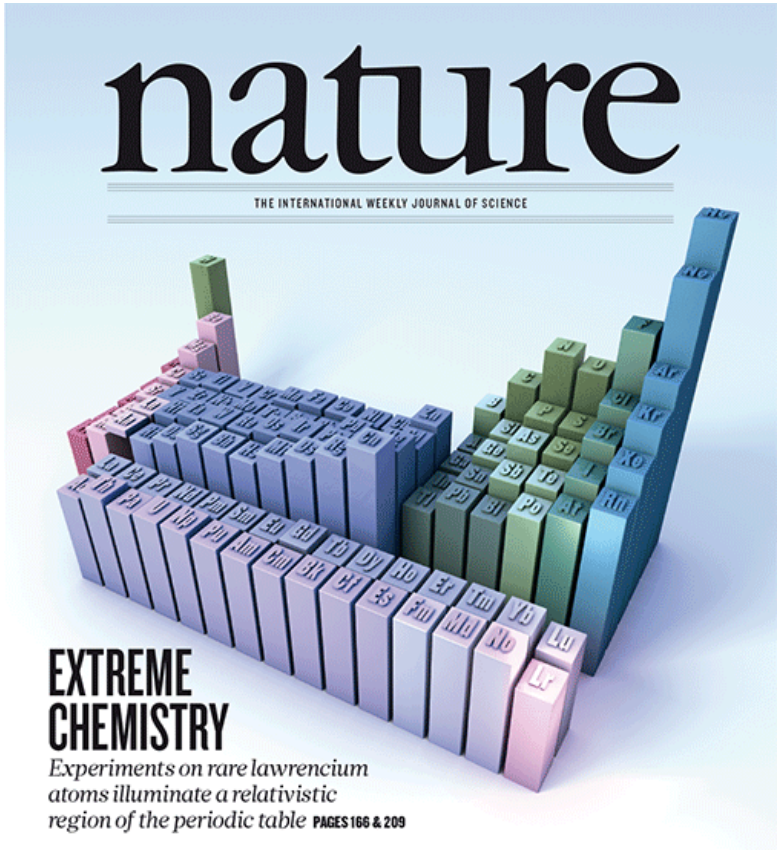


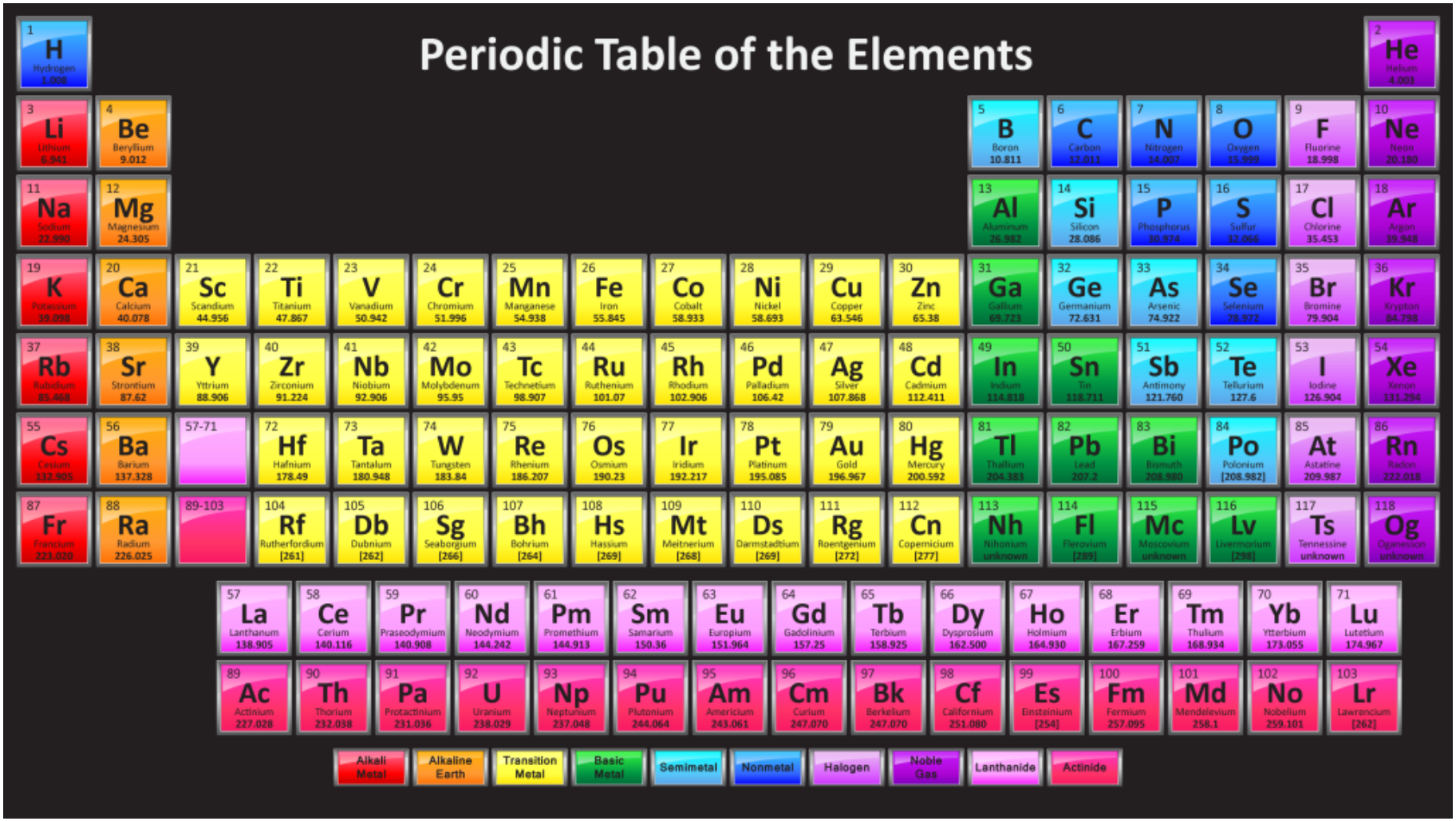
The end of the nuclear chart as of 2017

... is governed by alpha decay and fission



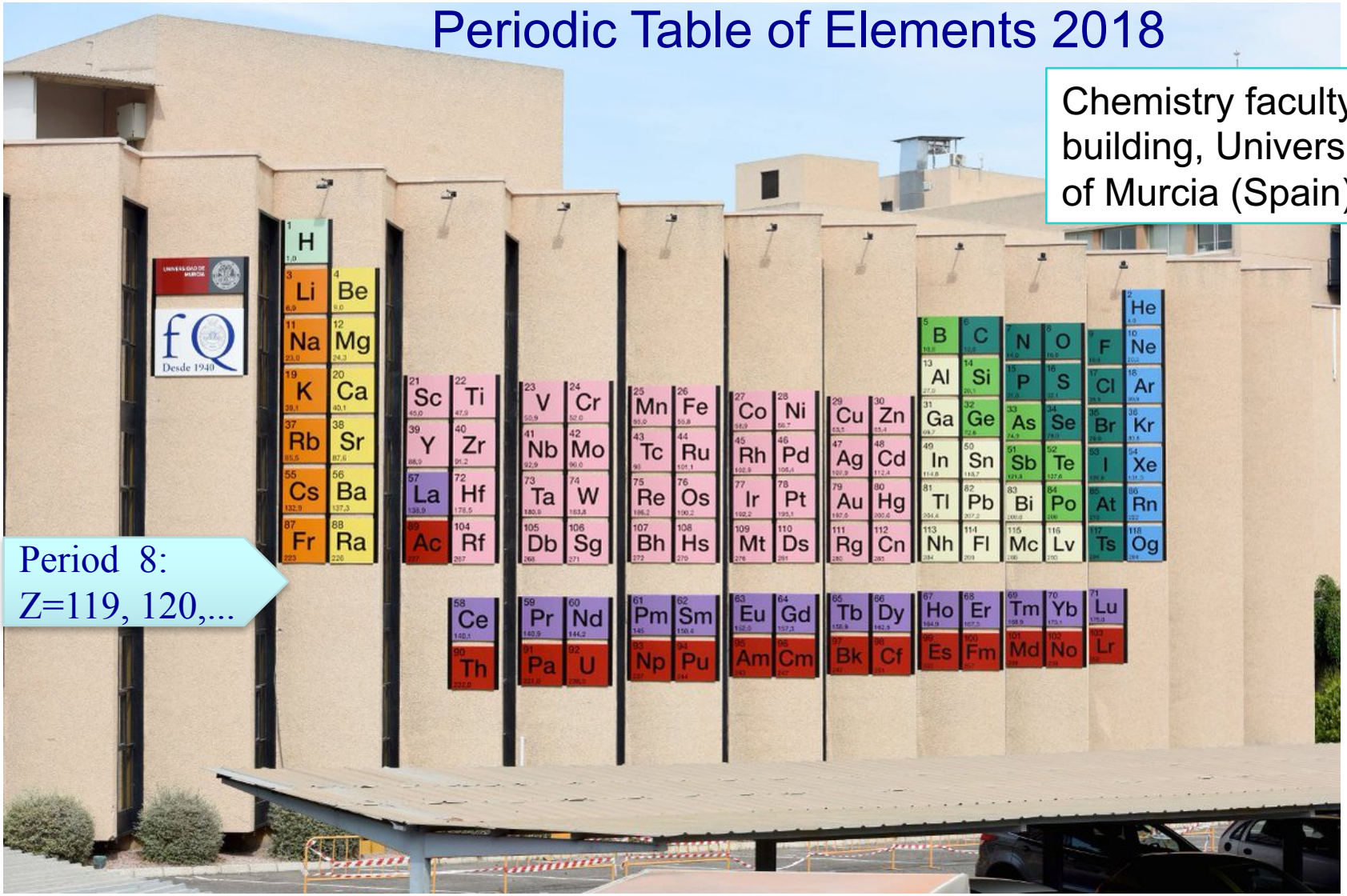
What are chemical properties of superheavy elements?





http://sciencenotes.org

Periodic Table of Elements 2018



- **Og**: The end of the line, your millisecond half-life brings down the curtain
- **Z=119**: Will the curtain rise? Will you open the eighth act? Claim the center stage?

Elemental haiku: http://science.sciencemag.org/content/357/6350/461

The Dirac equation in the Coulomb field of a point charge -Ze:

$$E_{n,\kappa} = \frac{mc^2}{\sqrt{1 + \frac{\alpha^2 Z^2}{\left(n - |\kappa| + \sqrt{\kappa^2 - \alpha^2 Z^2}\right)^2}}}$$

κ=*j*+1/2

From *LS* to *jj*

$\kappa = 1$ for $1S_{1/2}$ electrons ⟹ *Z*>137 catastrophe

Would element 137 (feynmanium) really spell the end of the periodic table?

$$Z\alpha = 0.86 \text{ for Og}$$

When $Z\alpha \to 1$, QED becomes strongly nonperturbative!

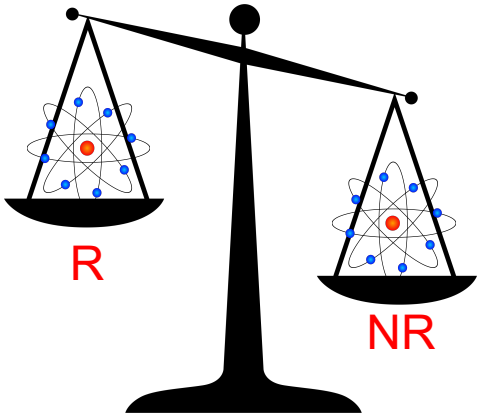
Atomic properties of Og

Peter Schwerdtfeger, Massey U., Auckland

atomic mass $M_{\rm at} = M_{\rm nucl} + Zm_e - B_e/c^2$

relativistic (R): B_e=1.487 MeV (0.57 MeV in Pb)
nonrelativistic (NR): B_e=1.260 MeV (0.53 MeV in Pb)

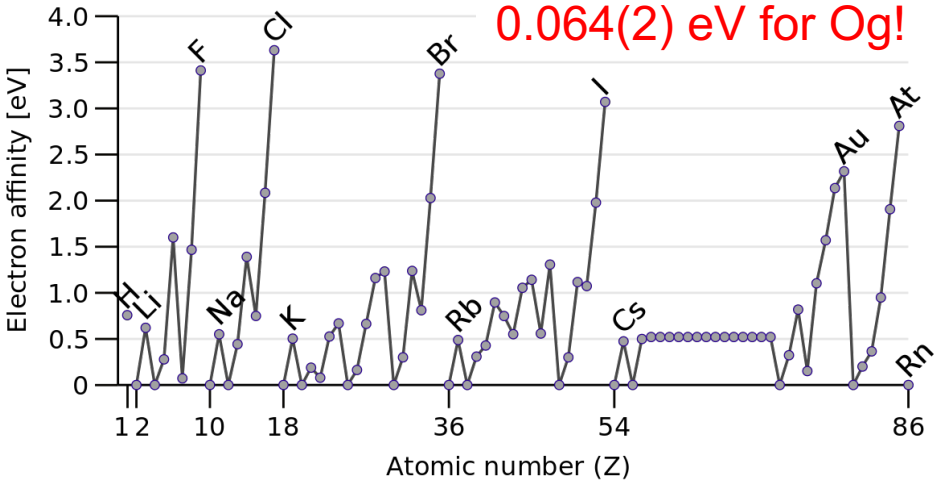
$\Delta M_{\rm at}$=227 keV (40 keV in Pb)



ground state: $5f^{14}6d^{10}7s^27p^6$

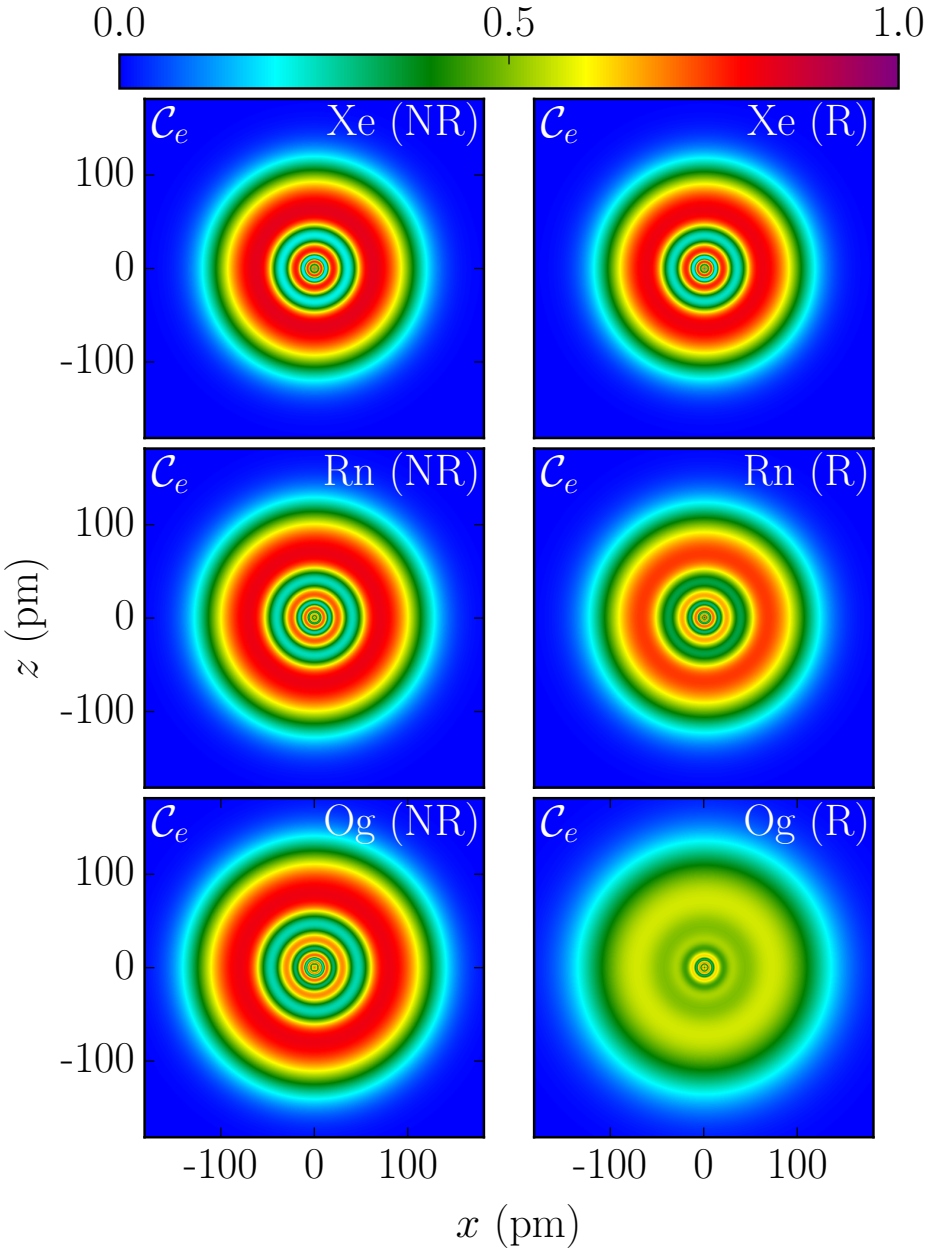
excited state: at 4.3 eV $5f^{14}6d^{10}7s^27p^58s$

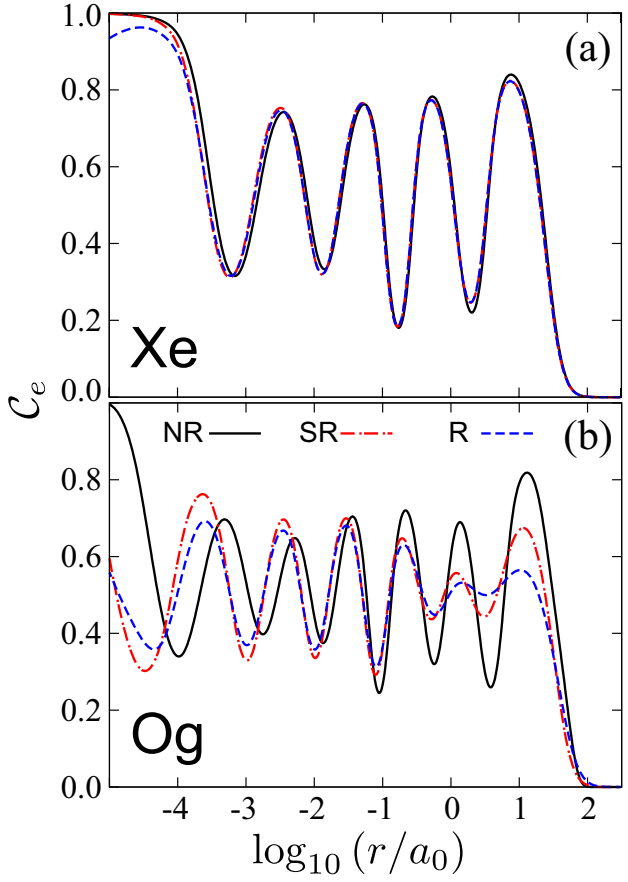
Og is predicted to be the first rare gas with positive electron affinity, due to dramatic stabilization effect on the 8s orbital (including significant QED correction of 0.006 eV)
NPA 944, 518 (2015)



Electron Localization Functions

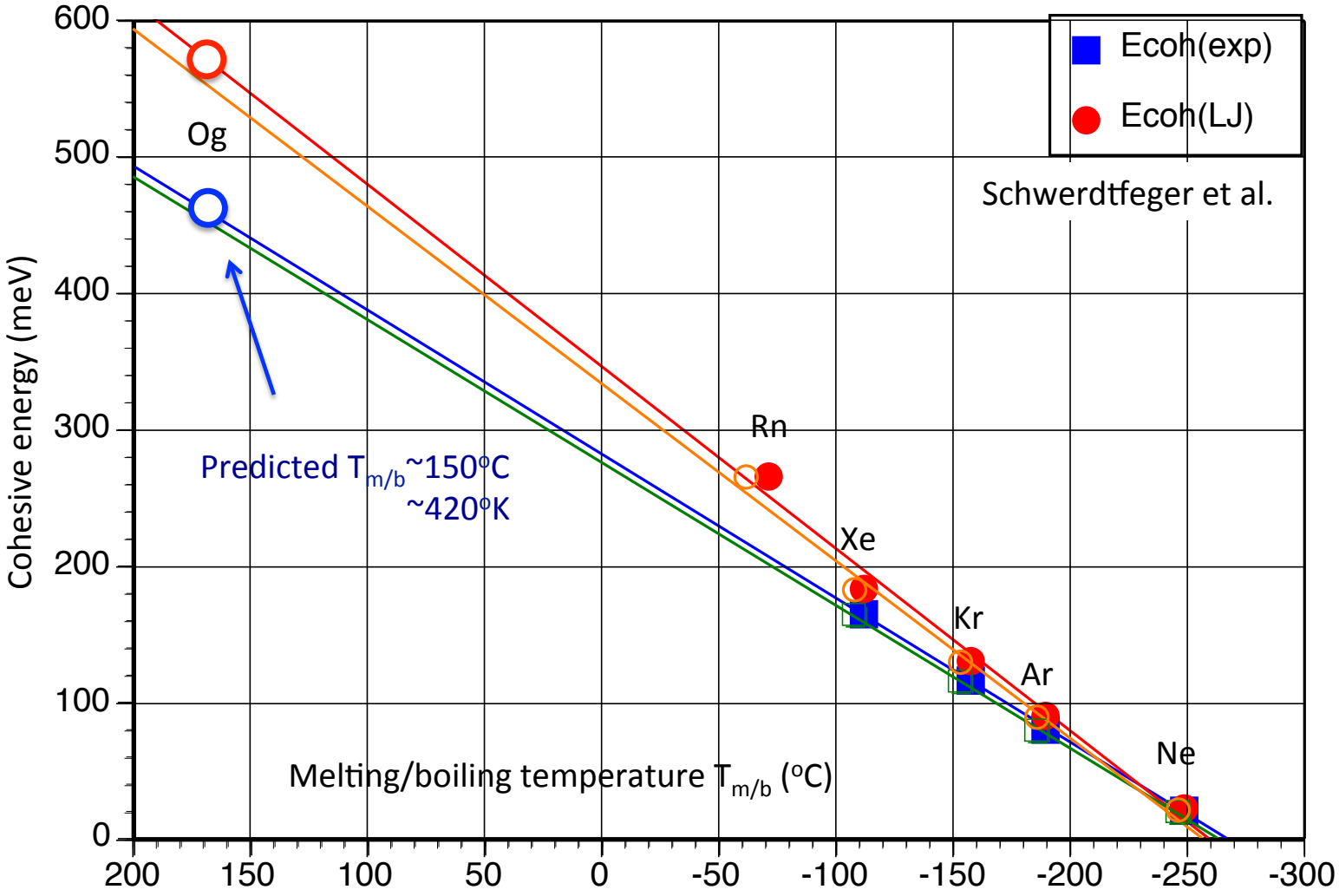
P. Jerabek et al., Phys. Rev. Lett. 120, 053001 (2018)





Og is expected to have an enormous polarizability (more than 58 a.u.; 44 a.u in NR), almost double that of Rn (33 a.u.). Thus, for Og one expects an increase in van-der-Waals interactions compared to the lighter rare gases.

Og is rare but not a gas at room temperature



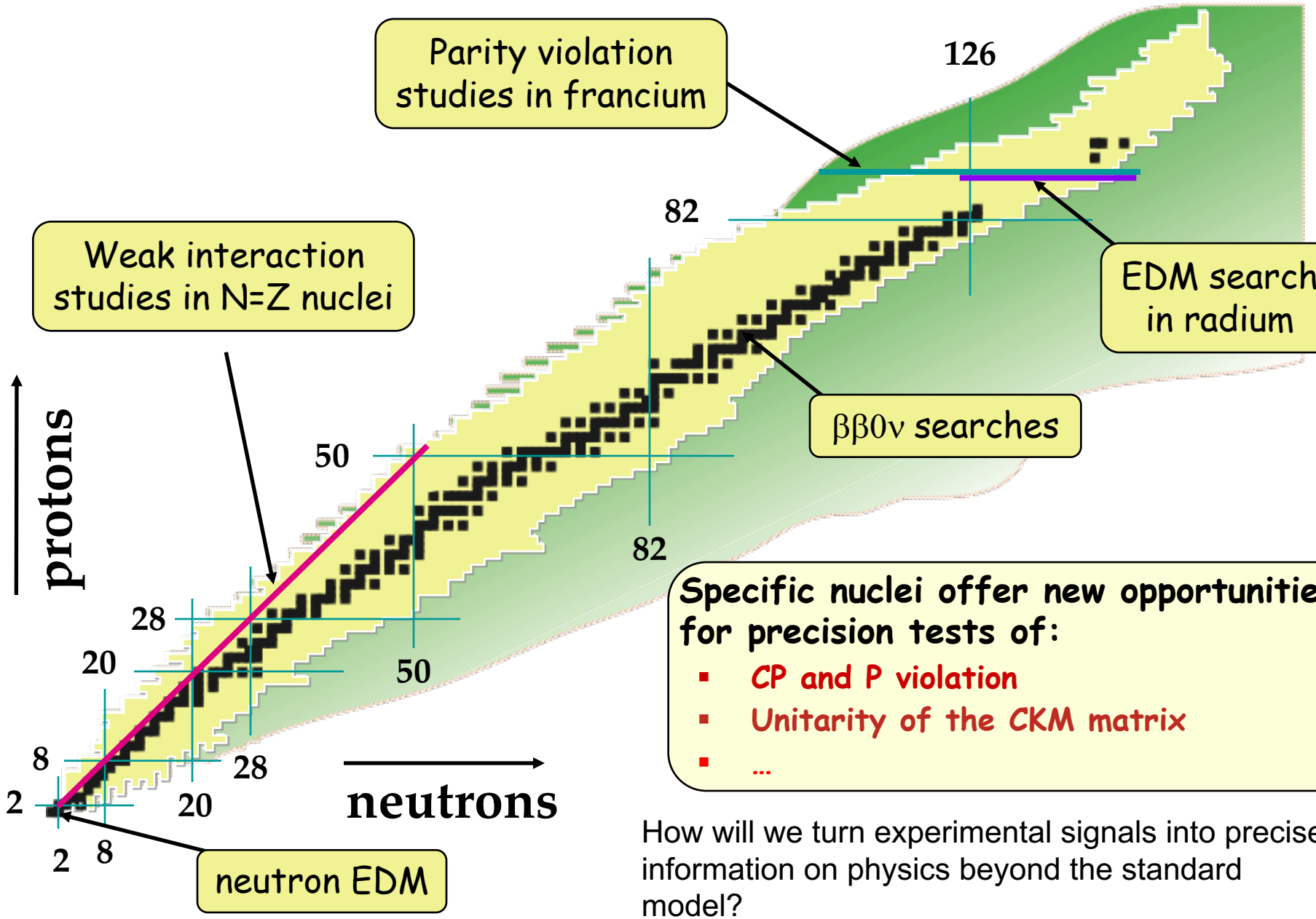
THE UNITED NATIONS PROCLAIMS THE INTERNATIONAL YEAR OF THE PERIODIC TABLE OF CHEMICAL ELEMENTS

28 December 2017

On 20 December 2017, during its 74th Plenary Meeting, the United Nations (UN) General Assembly 72nd Session has proclaimed 2019 as the International Year of the Periodic Table of Chemical Elements (IYPT 2019). In proclaiming an International Year focusing on the Periodic Table of Chemical Elements and its applications, the United Nations has recognized the importance of raising global awareness of how chemistry promotes sustainable development and provides solutions to global challenges in energy, education, agriculture and health. Indeed, the resolution was adopted as part of a more general Agenda item on Science and technology for development. This International Year will bring together many different stakeholders including UNESCO, scientific societies and unions, educational and research institutions, technology platforms, non-profit organizations and private sector partners to promote and celebrate the significance of the Periodic Table of Elements and its applications to society during 2019.

The development of the Periodic Table of the Elements is one of the most significant achievements in science and a uniting scientific concept, with broad implications in Astronomy, Chemistry, Physics, Biology and other natural sciences. The International Year of the Periodic Table of Chemical Elements in 2019 will coincide with the 150th anniversary of the discovery of the Periodic System by Dmitry Mendeleev in 1869. It is a unique tool enabling scientists to predict the appearance and properties of matter on Earth and in the Universe. Many chemical elements are crucial to enhance the value and performance of products necessary for humankind, our planet, and industrial endeavors. The four most recent elements (115-118) were fully added into the Periodic Table, with the approval of their names and symbols, on 28 November 2016.

Testing the fundamental symmetries of nature



Specific nuclei offer new opportunities for precision tests of:

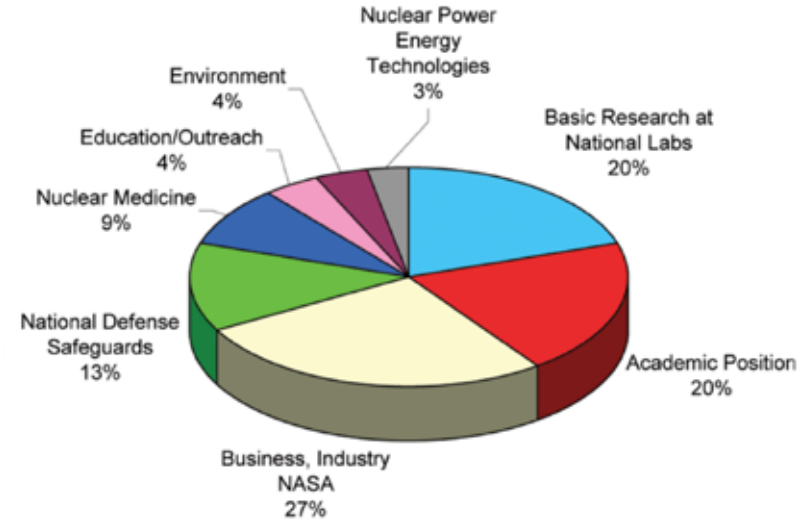
- CP and P violation
- Unitarity of the CKM matrix
- …

How will we turn experimental signals into precise information on physics beyond the standard model?

Societal Benefits

- Energy, transmutation of waste…
- Medical and biological research
- Materials science
- Environmental science
- Stockpile stewardship
- Security
- …

http://science.energy.gov/~/media/np/pdf/Accelerating_Innovation_9_01142011.pdf



The pie chart above shows that many scientists who receive Ph.D.s in nuclear science go on to apply their knowledge working in professions outside the field after five to 10 years.

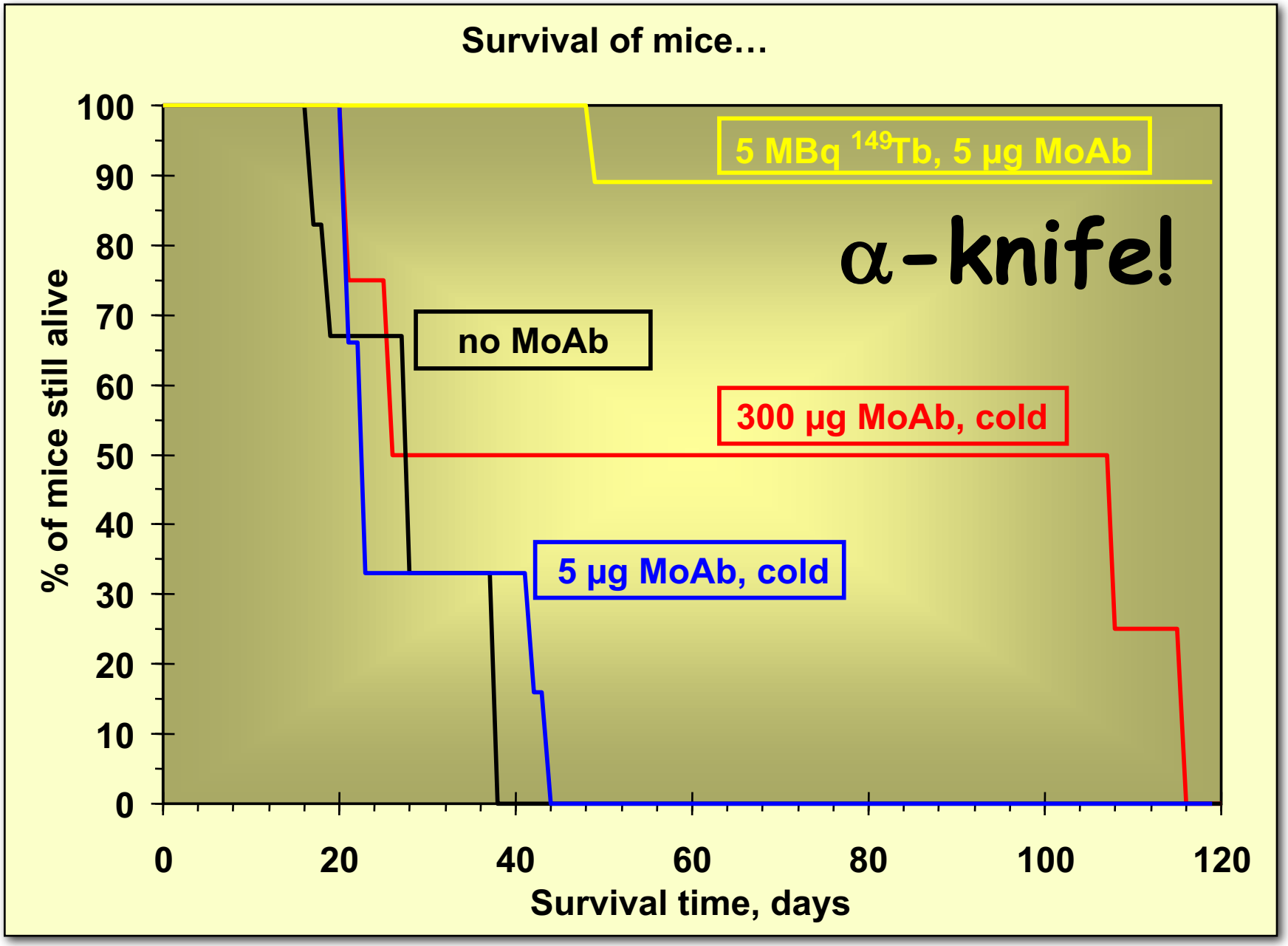
What are the next medically viable radioisotopes required for enhanced and targeted treatment and functional diagnosis?

Example: Targeted Alpha Therapy in vivo

G.-J. Beyer et al. Eur. J. Nucl. Med. and Molecular Imaging **33**, 547 (2004)

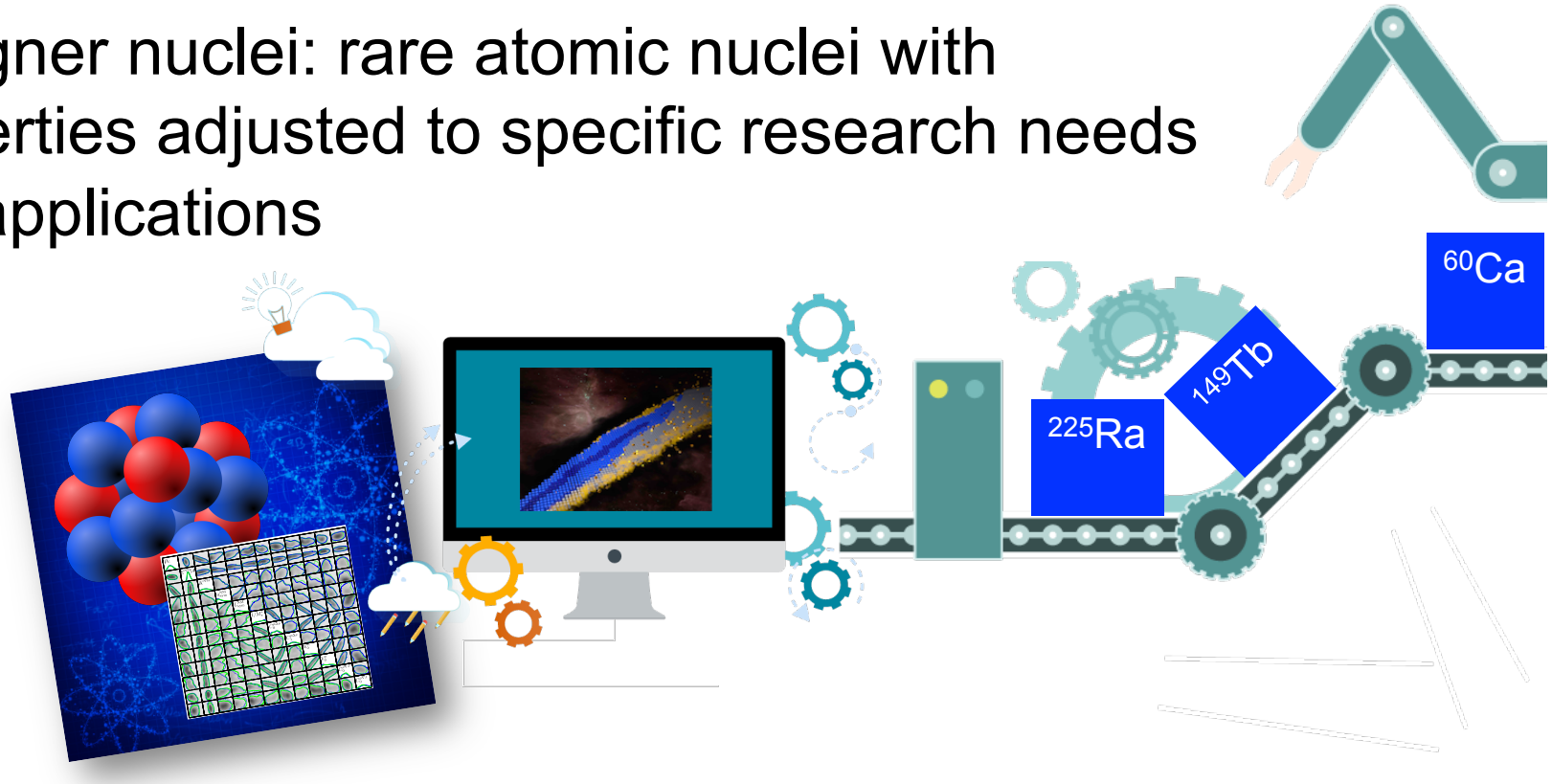
The radionuclide ^{149}Tb decays to alpha particles 17 percent of the time and has a half-life of 4.1 hours, which is conveniently longer than some other alpha-emitting radionuclides. Low-energy alpha particles, such as in ^{149}Tb decays, have been shown to be very efficient in killing cells, and their short range means that minimal damage is caused in the neighborhood of the target cells.

- 5 million lymphoma cells injected into mice
- 2 days later the mice have been divided into 4 groups:
    a. No treatment
    b. 5 μg of Monoclonal Antibody (MoAb Rituximab)
    c. 300 μg of MoAb
    d. 5 MBq of ^{149}Tb + 5 μg of MoAb


Survival of mice…
100
90
80
70
60
50
40
30
20
10
0
% of mice still alive
0
20
40
60
80
100
120
Survival time, days
5 MBq 149Tb, 5 µg MoAb
α-knife!
no MoAb
300 µg MoAb, cold
5 µg MoAb, cold

Some nuclei are more important than others

Designer nuclei: rare atomic nuclei with properties adjusted to specific research needs and applications



CONCEPT PREDICTION FABRICATION

http://iopscience.iop.org/article/10.1088/0954-3899/43/4/044002

Rare Isotope Rap

https://www.youtube.com/watch?v=677ZmPEFIXE