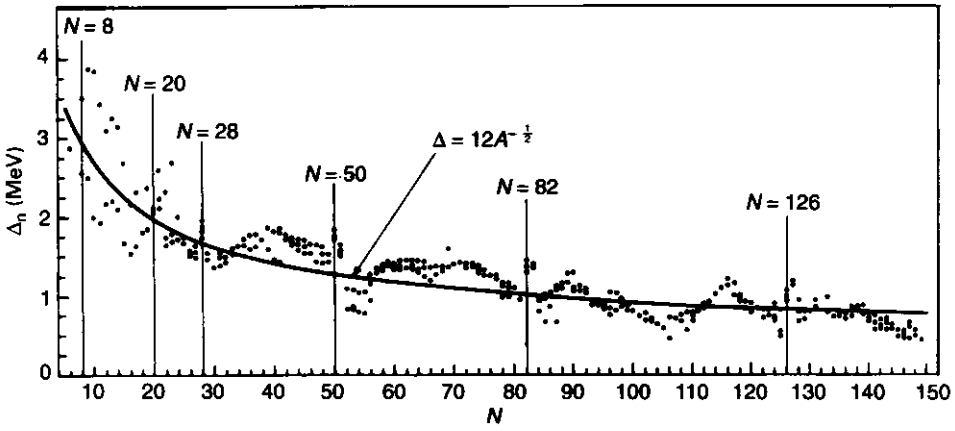
Pairing energy

$$\Delta_n = \frac{B(N+1,Z)+B(N-1,Z)}{2} - B(N,Z)$$

N-odd

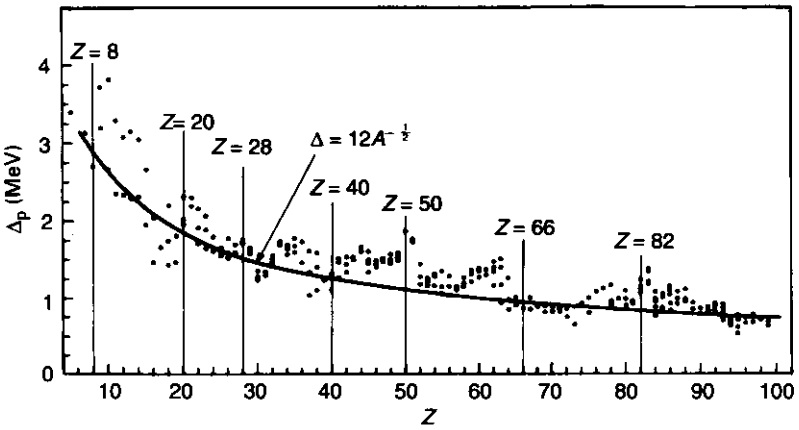
$$\Delta_p = \frac{B(N,Z+1)+B(N,Z-1)}{2} - B(N,Z)$$

Z-odd

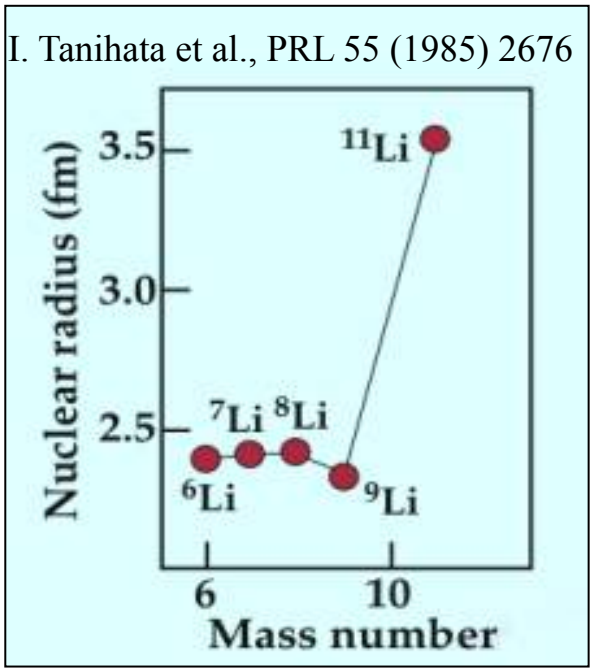


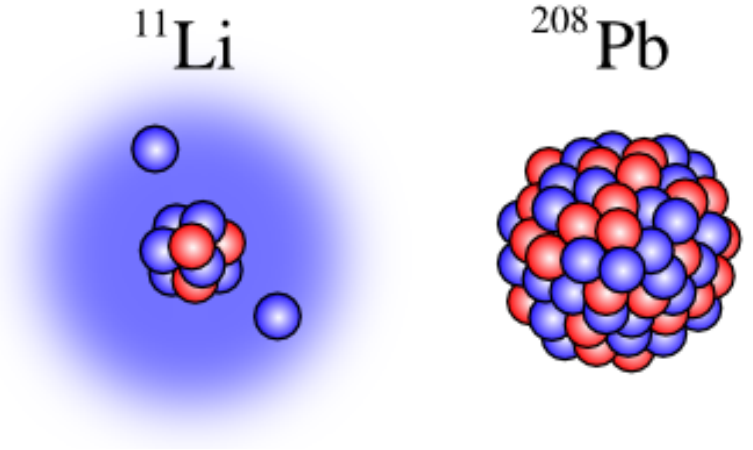
A common phenomenon in mesoscopic systems!

Example: Cooper electron pairs in superconductors…



Halos





For super achievers:

Consider a spherical square-well potential such as in the figure. The energy of the last occupied neutron state is $\varepsilon < 0$ and its quantum numbers are n and $\ell = 0$. We assume: $\varepsilon \approx 0$.

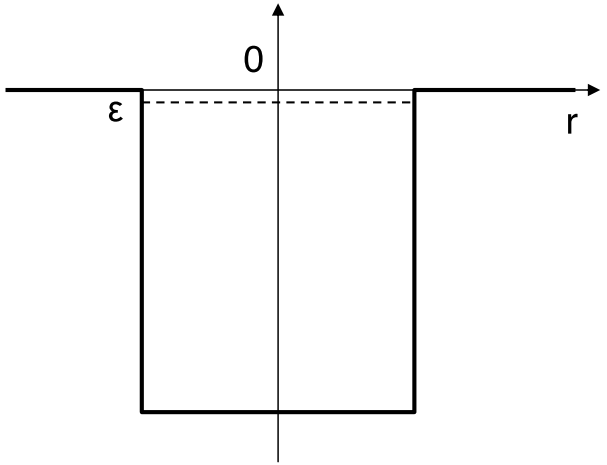
Prove that the r.m.s radius of the neutron orbit, defined as

$$R_{rms} = \sqrt{\langle \hat{r}^2 \rangle}$$

obeys the following relation:

$$R_{rms} \sim (-\varepsilon)^{-1/2}$$

Discuss the result.



Hint: The asymptotic behavior of the Bessel function at large distance is:

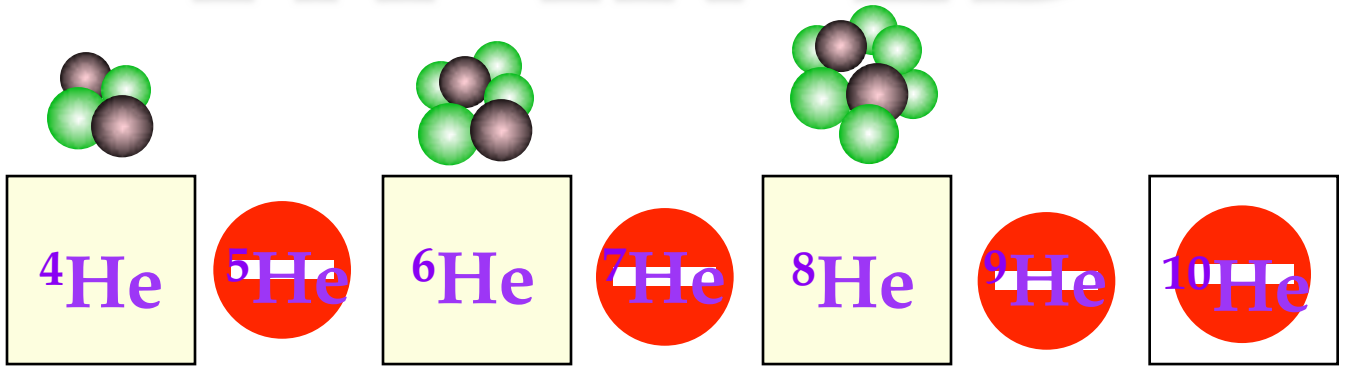
$$H_\ell(z) \underset{r\to+\infty}{\longrightarrow} 1 \times 3 \times \ldots \ (2\ell - 1) z^{-\ell-1}$$

Neutron Drip line nuclei

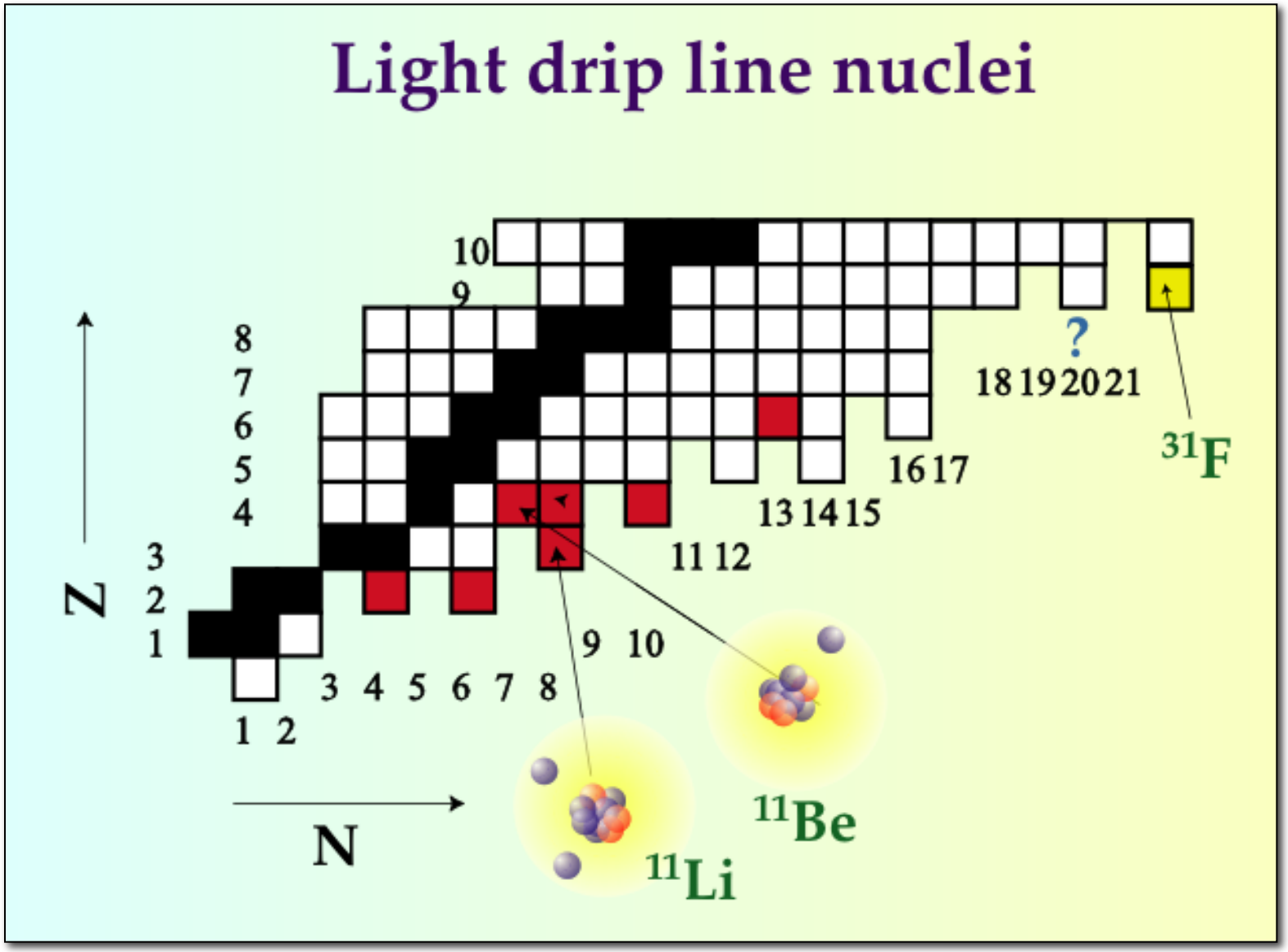
HUGE

Diffused

PAIRED

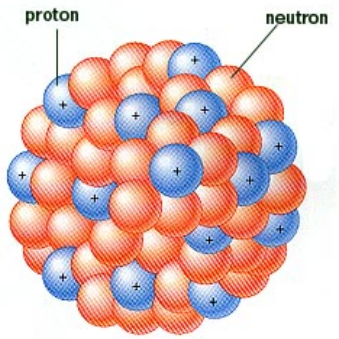


Pairing and binding



The Grand Nuclear Landscape

(finite nuclei + extended nucleonic matter)



superheavy nuclei

Z=118, A=294

known up to Z=91

protons

known nuclei

proton drip line

82

126

terra incognita

50

82

neutron drip line

stable nuclei

28

20

50

8

28

2

20

probably known only up to oxygen

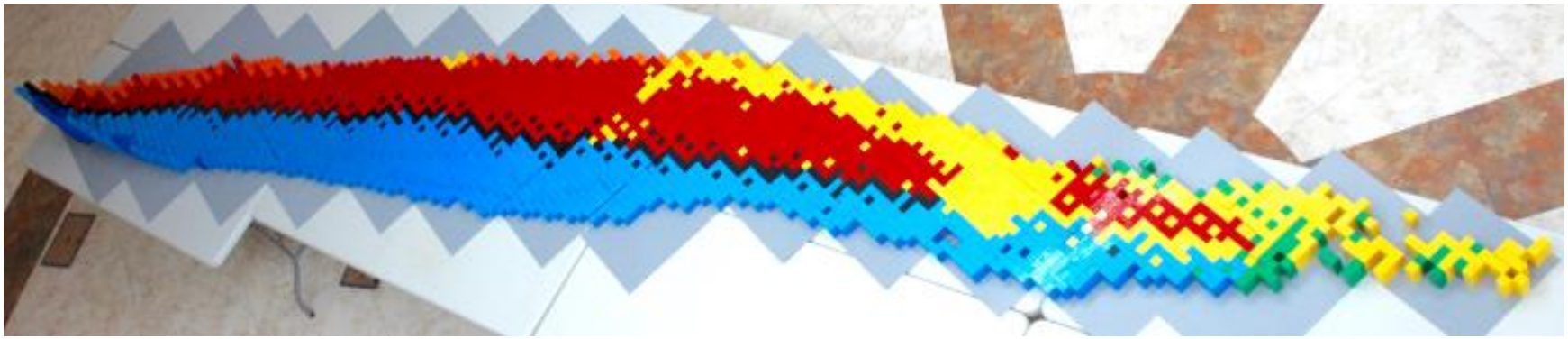
2 8

neutrons

neutron stars

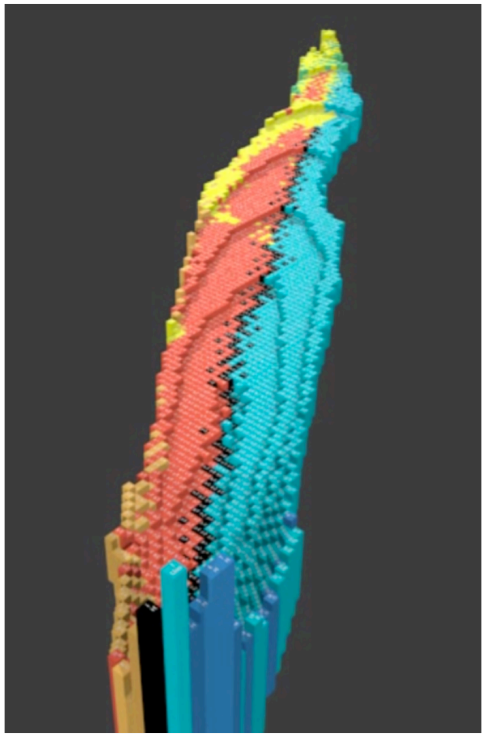
Binding Blocks

http://www.york.ac.uk/physics/public-and-schools/schools/secondary/binding-blocks/



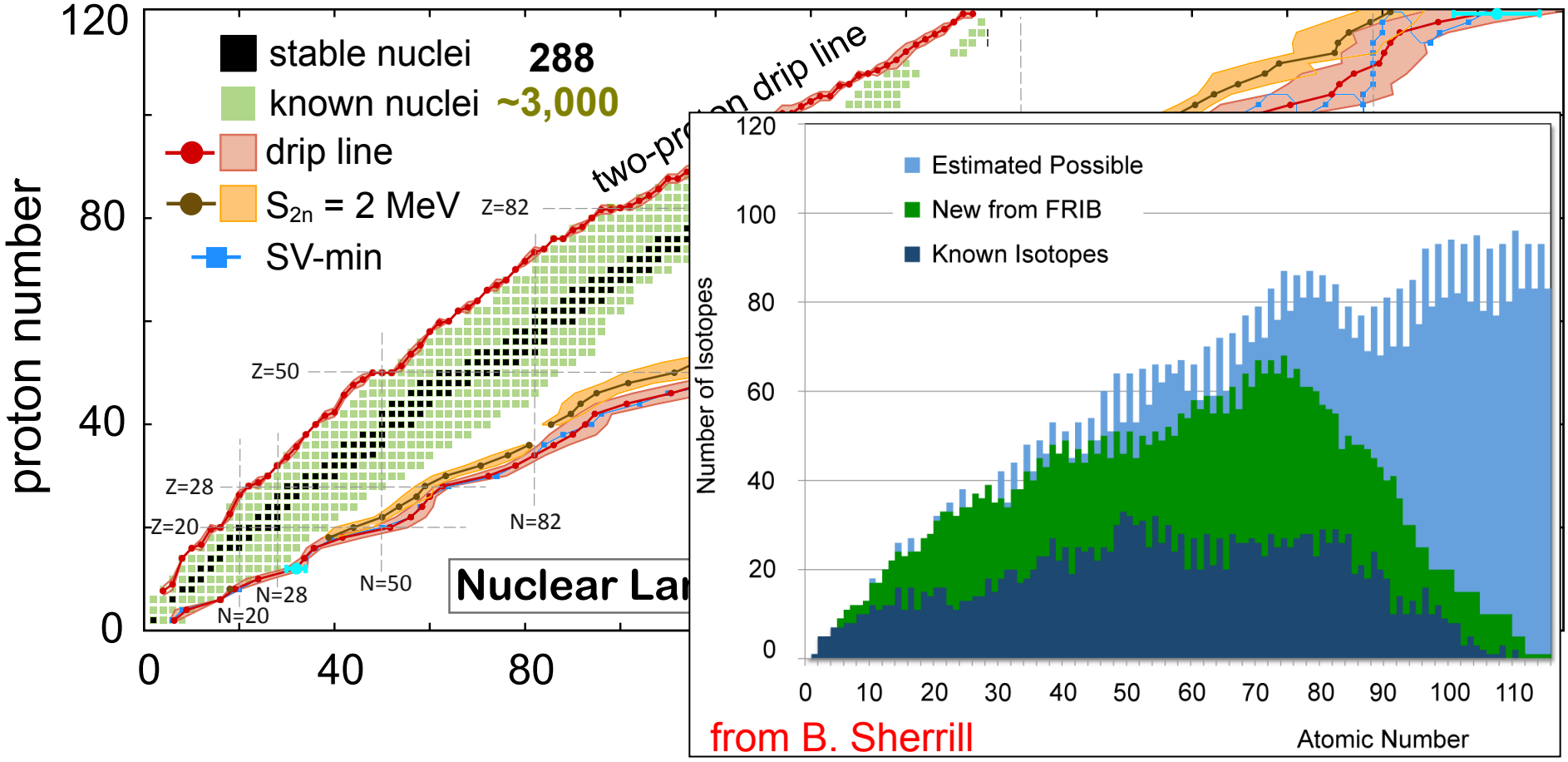
http://www.york.ac.uk/physics/public-and-schools/schools/secondary/binding-blocks/interactive/

https://arxiv.org/abs/1610.02296



http://www.nishina.riken.jp/enjoy/kakuzu/kakuzu_web.pdf

The limits: Skyrme-DFT Benchmark 2012



How many protons and neutrons can be bound in a nucleus?

Literature: 5,000-12,000

Erler et al.
Nature 486, 509 (2012)

Skyrme-DFT: 6,900±500$_{syst}$

HW:

a) Using http://www.nndc.bnl.gov/chart/ find one- and two-nucleon separation energies of ^{5}He, ^{24}O, ^{25}O, ^{26}O, ^{48}Ni, ^{56}Ni and ^{208}Pb. Discuss the result.

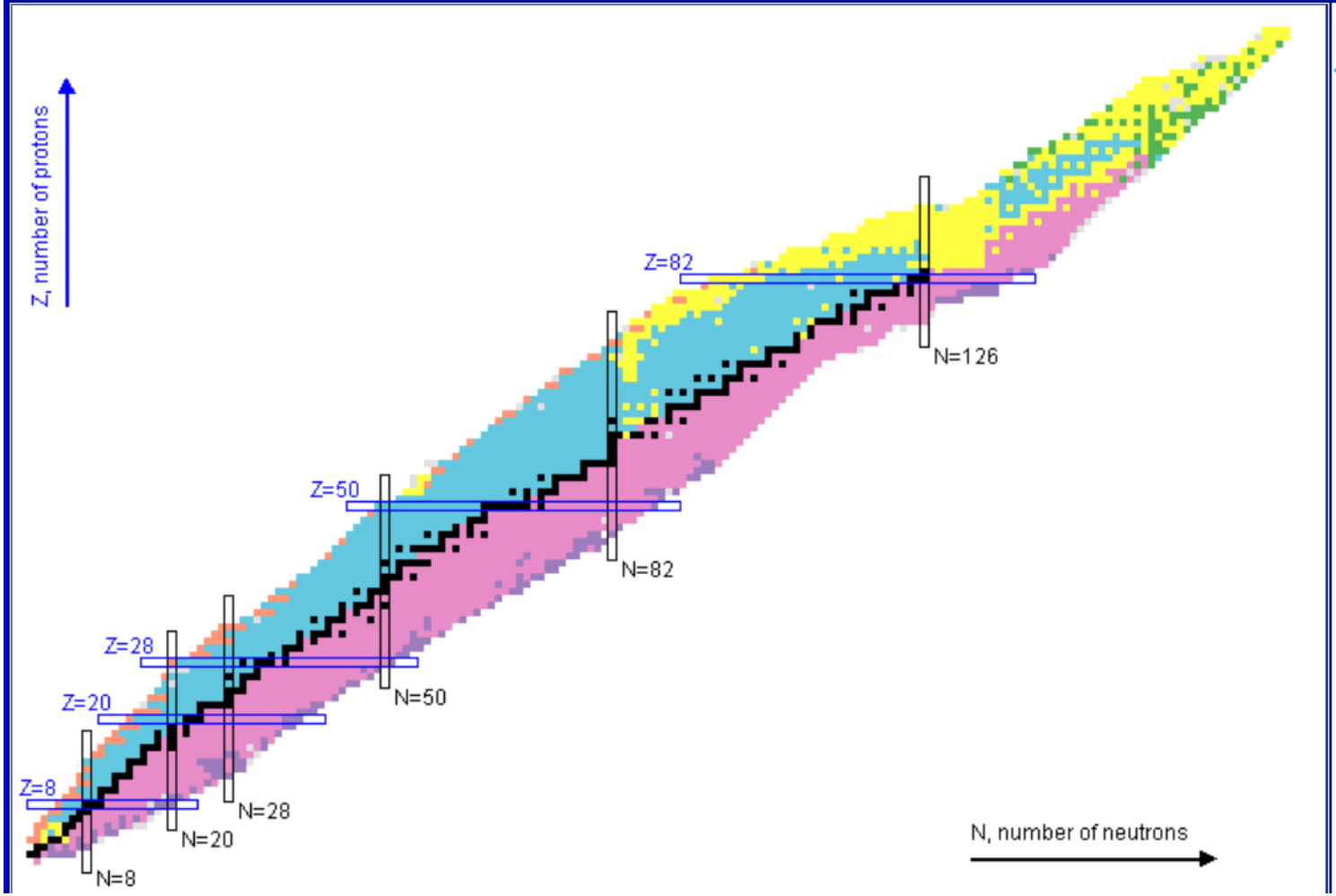
b) Find the relation between the neutron pairing gap and one-neutron separation energies. Using http://www.nndc.bnl.gov/chart/ plot neutron pairing gaps for Yb (Z=70) isotopes as a function of N.

Chart of Nuclides

NNDC

Click on a nucleus for information

Color code	Half-life	Decay Mode	$Q_{\beta-}$	Q_{EC}	$Q_{\beta+}$	S_n	S_p	Q_α	S_{2n}	S_{2p}	$Q_{2\beta-}$	Q_{2EC}	Q_{ECp}
$Q_{\beta-n}$	BE/A	(BE-LDM Fit)/A	$E_{1st\ ex.\ st.}$	E_{2+}	E_{3-}	E_{4+}	E_{4+}/E_{2+}	β_2	$B(E2)_{42}/B(E2)_{20}$	$\sigma(n,\gamma)$	$\sigma(n,F)$	235U FY	239Pu FY



Tooltips
On
Off

Zoom
1
2
3
4
5
6
7

Uncertainty
NDS
Standard

Screen Size
Narrow
Wide

Nucleus
go

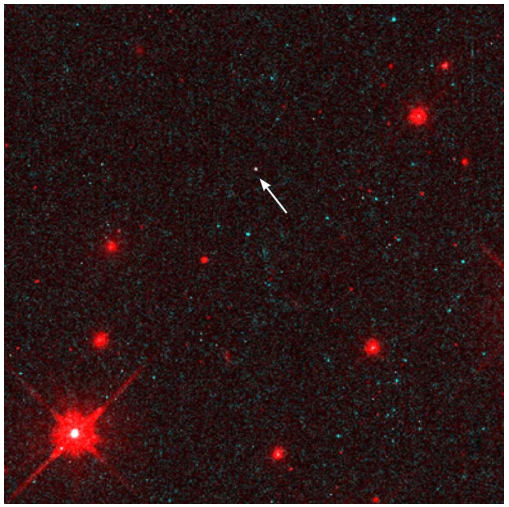
Stable
EC+β+
β-
α
P
N
SF
Unknown

Search options:

Levels and Gammas
Nuclear Wallet Cards
Decay Radiation

Help - Glossary

Neutron star, a bold explanation



A lone neutron star, as seen by NASA's Hubble Space Telescope

$$B = a_{vol}A - a_{surf}A^{2/3} - a_{sym}\frac{(N-Z)^2}{A} - a_C\frac{Z^2}{A^{1/3}} - \delta(A) + \frac{3}{5}\frac{G}{r_0 A^{1/3}}M^2$$

Let us consider a giant neutron-rich nucleus. We neglect Coulomb, surface, and pairing energies. Can such an object exist?

$$B = a_{vol}A - a_{sym}A + \frac{3}{5}\frac{G}{r_0 A^{1/3}}(m_n A)^2 = 0$$

limiting condition

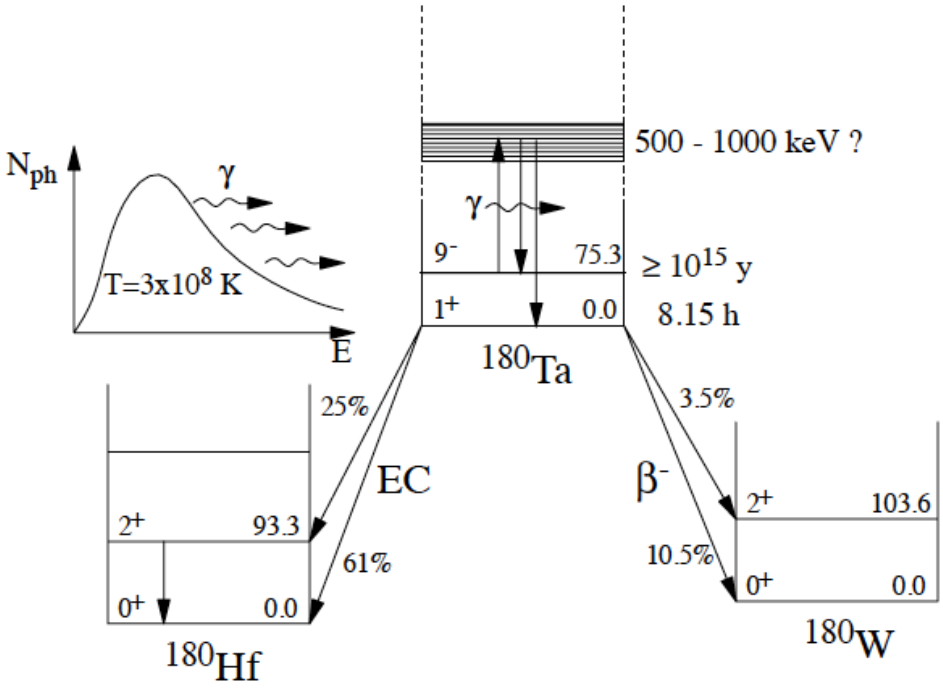
$$\frac{3}{5}\frac{G}{r_0}m_n^2 A^{2/3} = 7.5\,\text{MeV} \Rightarrow A \cong 5\times10^{55},\ R \cong 4.3\,\text{km},\ M \cong 0.045 M_\odot$$

More precise calculations give M(min) of about 0.1 solar mass ($M_\odot$). Must neutron stars have

$$R \cong 10\,\text{km}, M \cong 1.4\,M_\odot$$

Nuclear isomers

The most stable nuclear isomer occurring in nature is ^{180m}Ta. Its half-life is at least 10^{15} years, markedly longer than the age of the universe. This remarkable persistence results from the fact that the excitation energy of the isomeric state is low, and both gamma de-excitation to the ^{180}Ta ground state (which itself is radioactive by beta decay, with a half-life of only 8 hours), and direct beta decay to hafnium or tungsten are all suppressed, owing to spin mismatches. The origin of this isomer is mysterious, though it is believed to have been formed in supernovae (as are most other heavy elements). When it relaxes to its ground state, it releases a photon with an energy of 75 keV.



VOLUME 83, NUMBER 25 PHYSICAL REVIEW LETTERS 20 DECEMBER 1999

Photoactivation of ^{180}Ta^{m} and Its Implications for the Nucleosynthesis of Nature's Rarest Naturally Occurring Isotope

Discovery of a Nuclear Isomer in ^{65}Fe with Penning Trap Mass Spectrometry

http://journals.aps.org/prl/abstract/10.1103/PhysRevLett.100.132501