LABORATÓRIO DE INSTRUMENTAÇÃO
E FÍSICA EXPERIMENTAL DE PARTÍCULAS
partículas e tecnologia

Ciências ULisboa
Faculdade de Ciências da Universidade de Lisboa

Exotic Nuclei

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LIP Internships 2023

Lisbon, July 6th 2023

Overview

- What are **exotic** nuclei?
- Why are they **important**?
- How can they be **produced**?
- **Facilities** for exotic nuclei research

Exotic …

Exotic

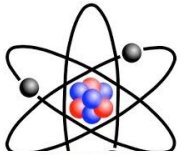
Definition:

(Cambridge Dictionary)

English:
unusual and exciting because of coming (or seeming to come) from far away, especially a tropical country

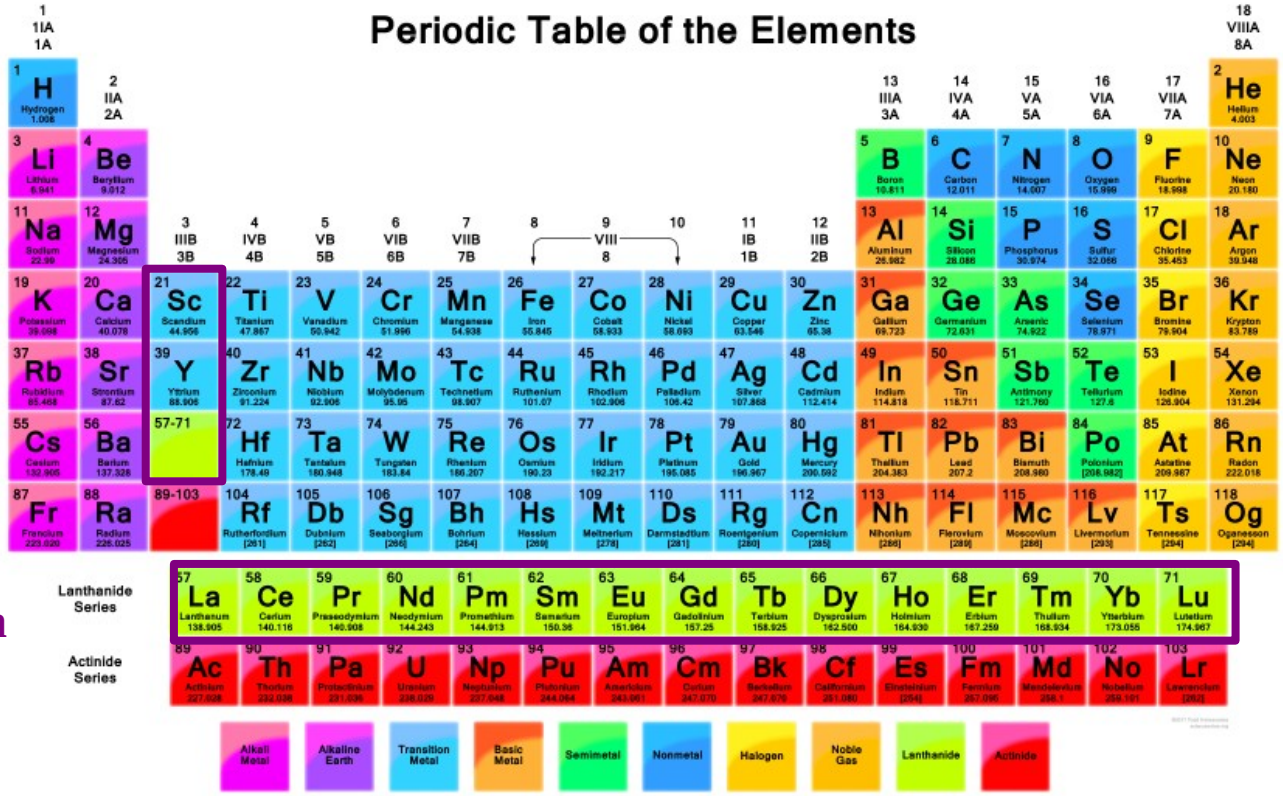
American:
unusual and specially interesting because of coming from a country that is far away

Atomic Nuclei



Exotic Nuclei?

Table of elements



Rare Earth Elements

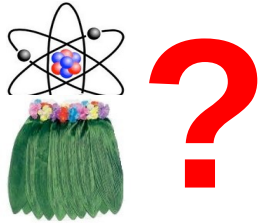


Chart of isotopes

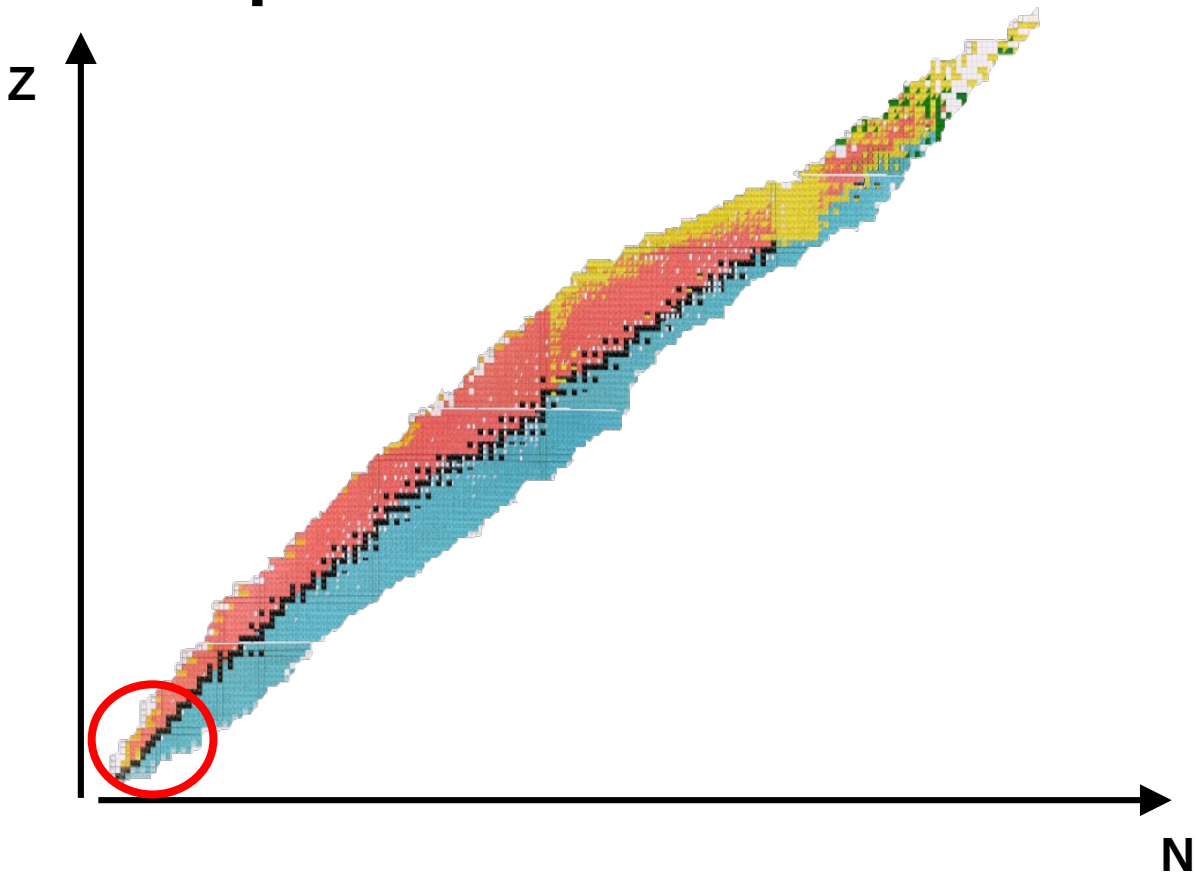


Chart of isotopes (zoom)

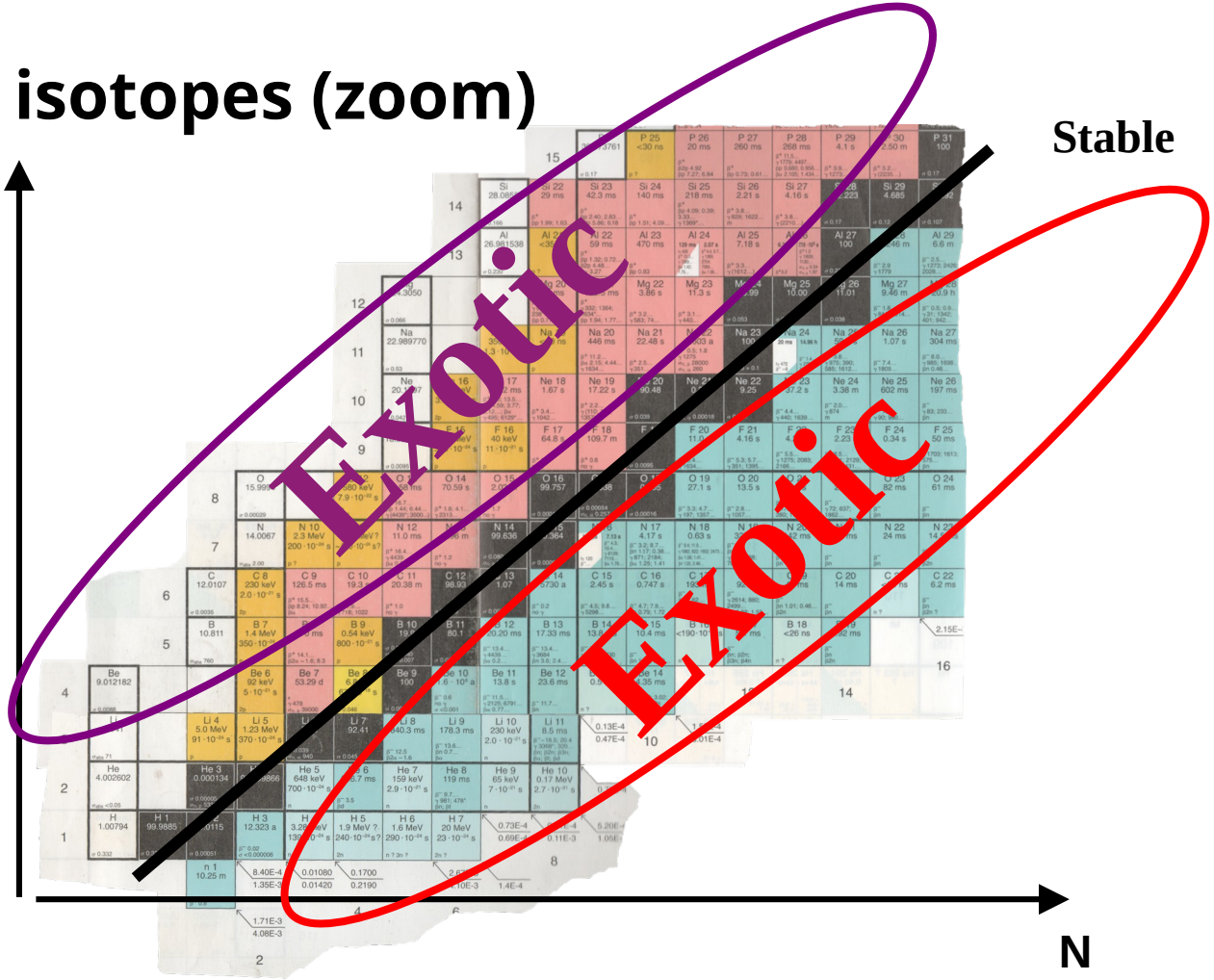
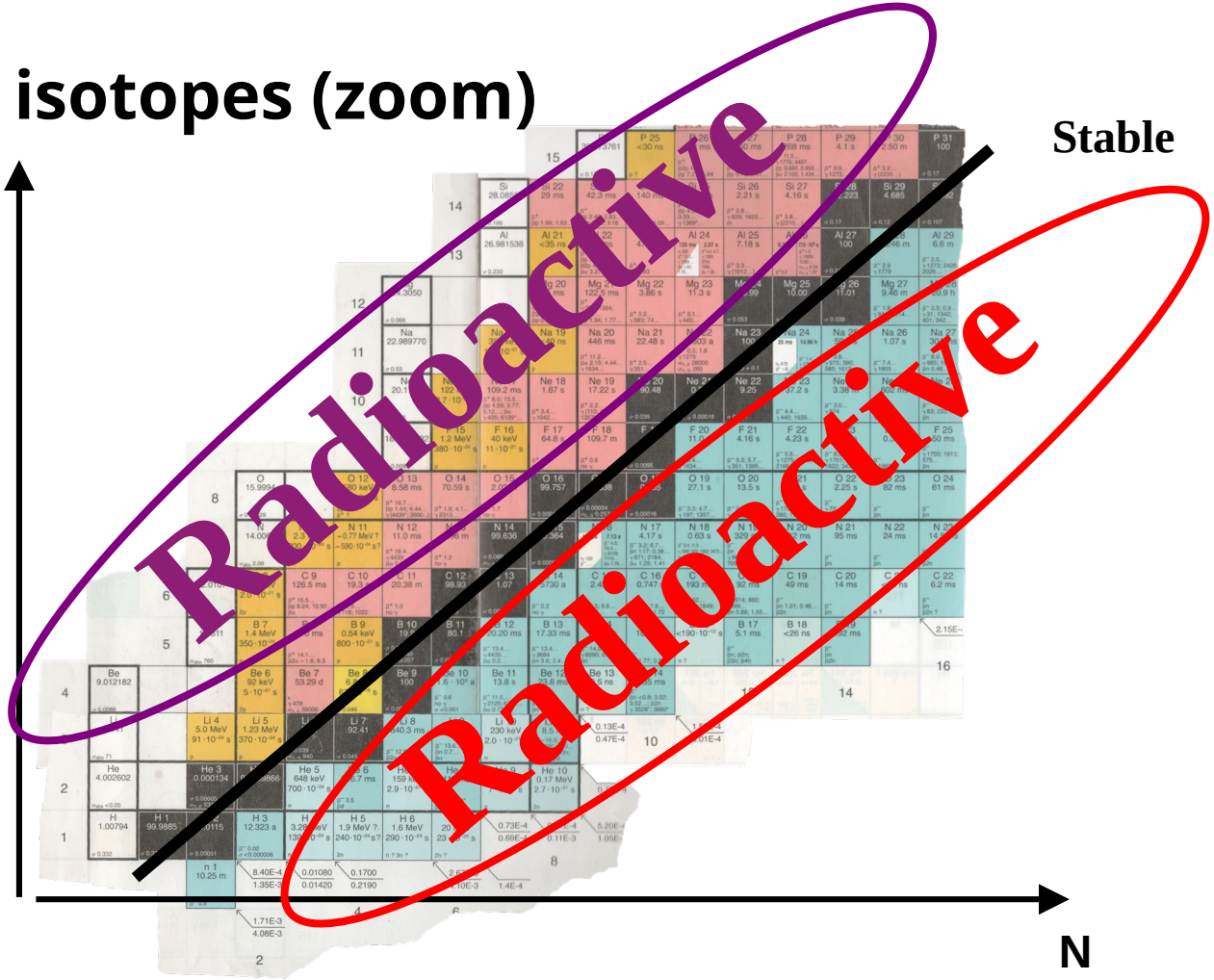
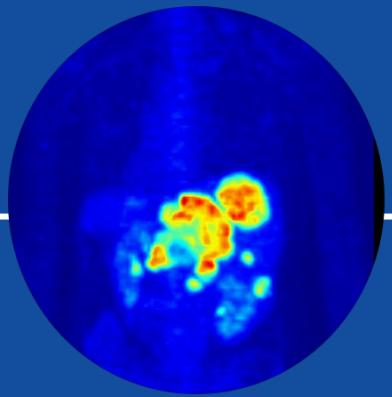


Chart of isotopes (zoom)



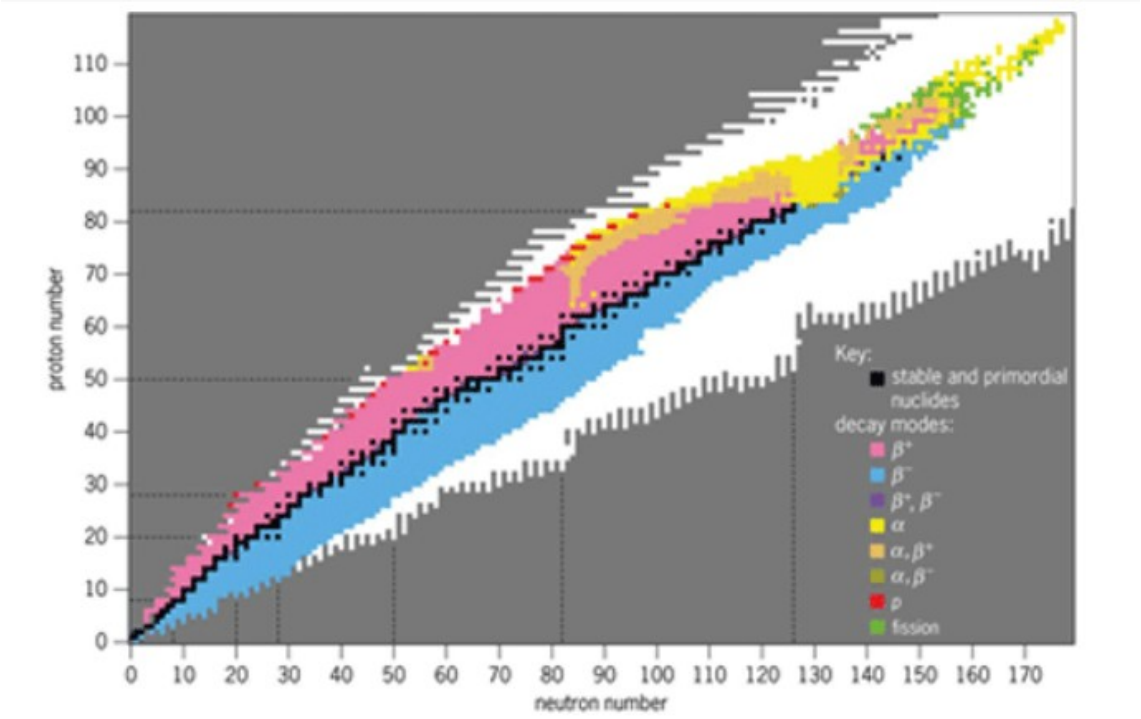
Why are they important?



Fundamental level

★ **How many nucleons** can hold the strong force inside a nucleus?

Fundamental level



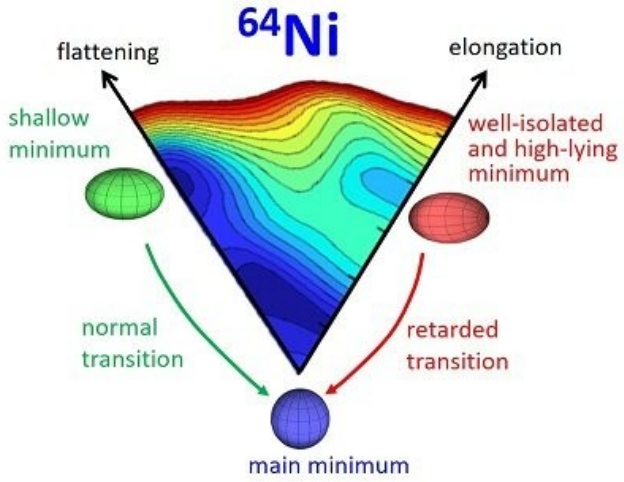
https://doi.org/10.1036/1097-8542.551325

Fundamental level

- **How many nucleons** can hold the strong force inside a nucleus?
- What kind of **shapes** do nuclei adopt?

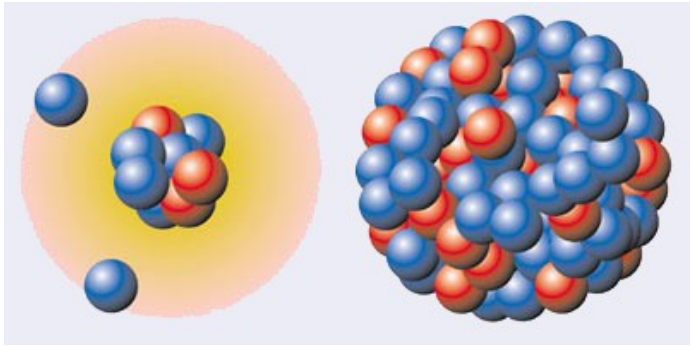
Fundamental level

Deformation



N. Mărginean et al, Physical Review Letters (2020)

Halo nucleons



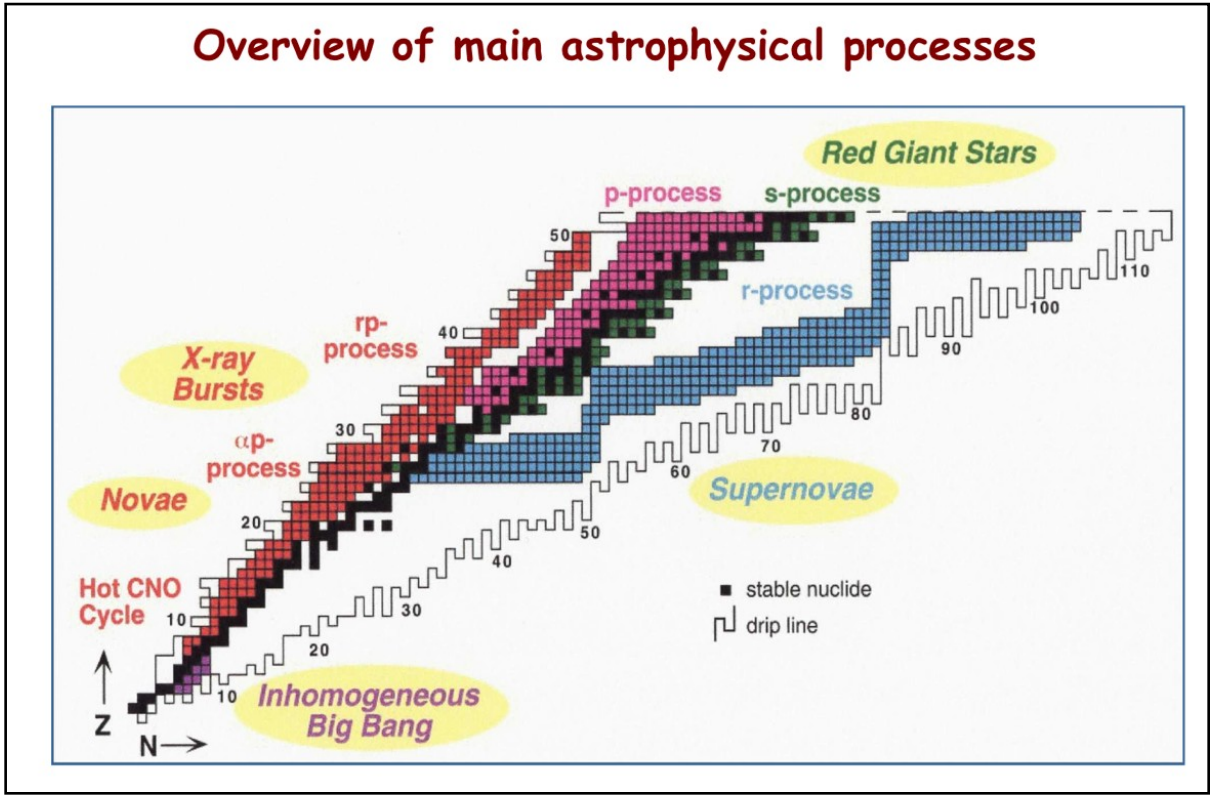
^{11}Li ^{208}Pb

https://cerncourier.com/a/isolde-goes-on-the-trail-of-superlatives/

Fundamental level

- **How many nucleons** can hold the strong force inside a nucleus?
- What kind of **shapes** do nuclei adopt?
- How are **natural elements** synthesized in the Universe?

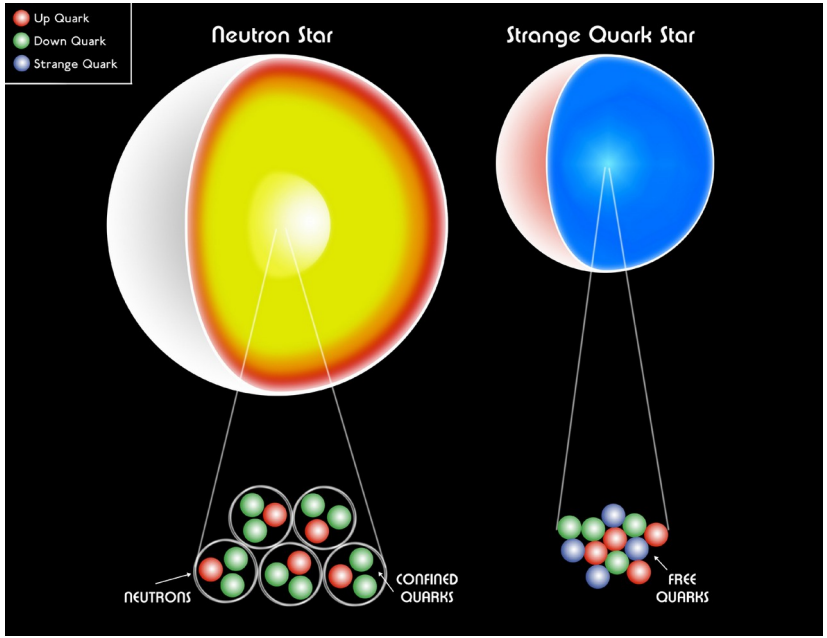
Fundamental level



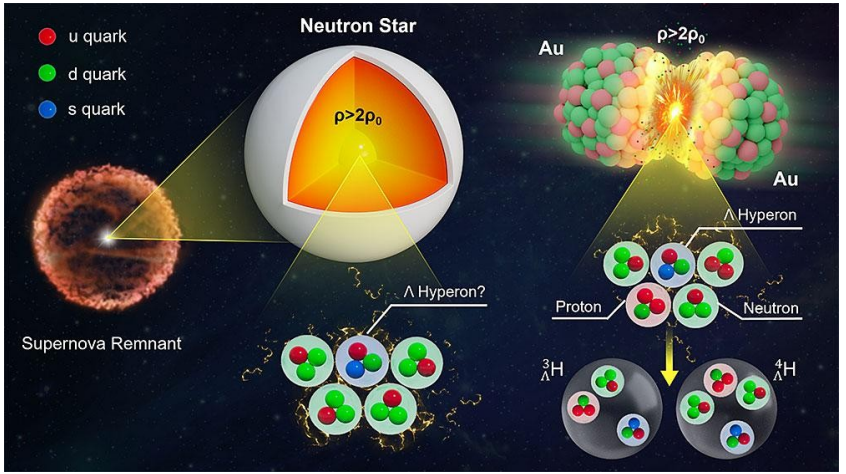
Fundamental level

- **How many nucleons** can hold the strong force inside a nucleus?
- What kind of **shapes** do nuclei adopt?
- How are **natural elements** synthesized in the Universe?
- How do ***gigantic nuclei*** behave?

Fundamental level



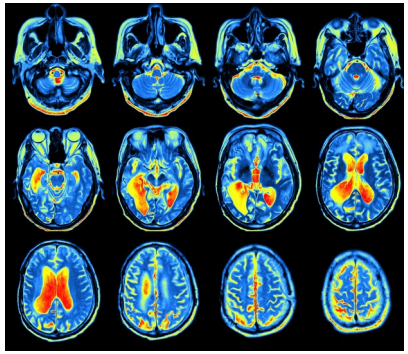
https://www.esa.int/Science_Exploration/Space_Science/XMM-Newton_gives_new_insight_into_neutron_stars



https://www.bnl.gov/newsroom/news.php?a=121192

Applied level

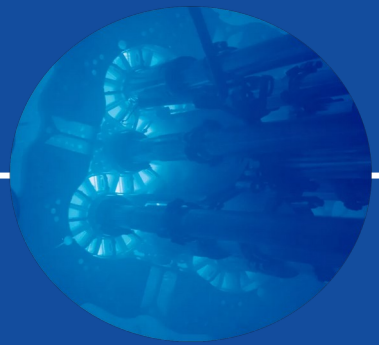
- Radiopharmaceuticals (^{123}I, ^{131}I, ^{99m}Tc, ^{18}F)
- Gammagraphy (^{60}Co, ^{137}Cs)
- Dating (^{14}C, ^{87}Rb)



https://alzheimersnewstoday.com/news/fdg-pet-scan-accurately-assesses-cognitive-decline-severity-alzheimers-disease/

https://www.sciencephoto.com/media/317009/view/male-skeleton-gamma-scan

How can we produce them?



Exotic nuclei in nature?

★ Isotopes with half-live > Solar System:

^{235}U, ^{238}U, ^{232}Th, ^{40}K, ^{36}Cl

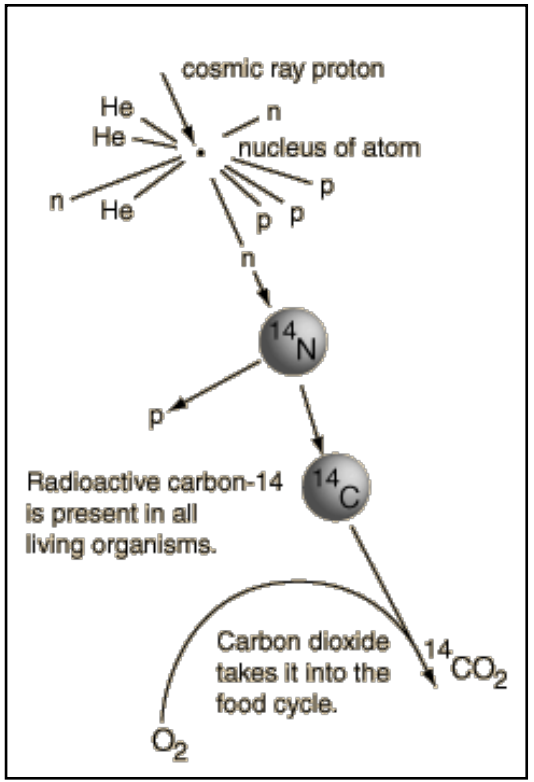
Exotic nuclei in nature?

★ Isotopes with half-live > Solar System:

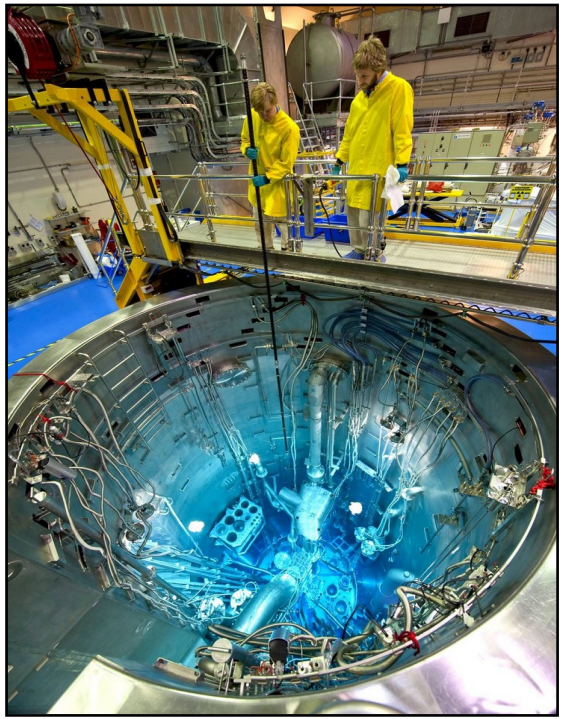
^{235}U, ^{238}U, ^{232}Th, ^{40}K, ^{36}Cl

★ Isotopes continously produced on Earth:

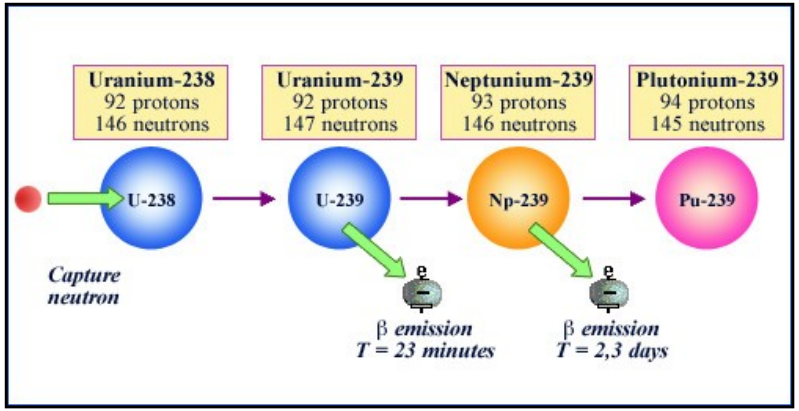
^{14}C



Nuclear reactors

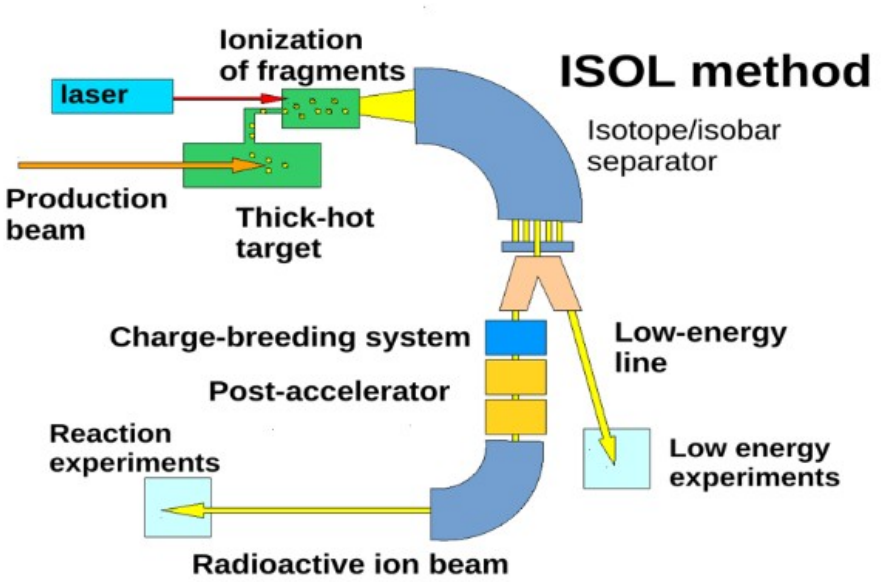


Neutron capture reactions, followed by **beta decay**



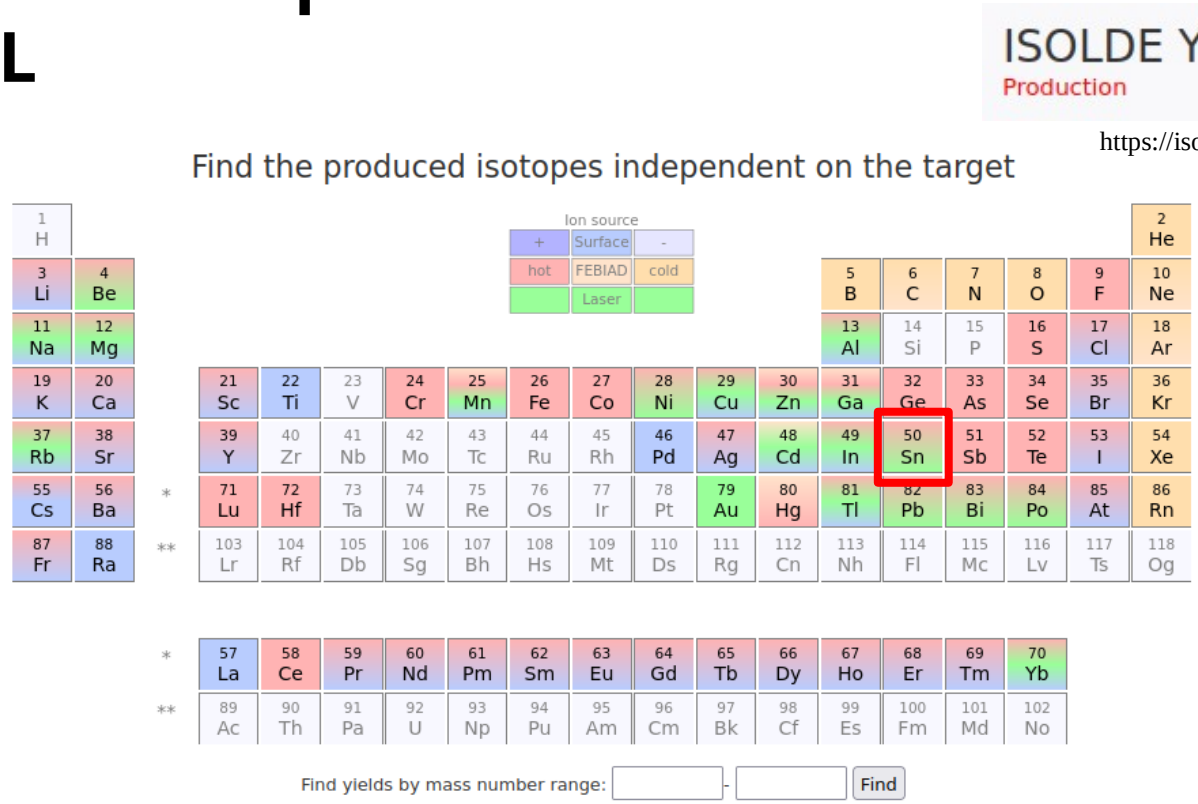
Accelerator production methods: ISOL

- **Light** beam (protons)
- **Heavy** targets (W,U)
- **High purity** secondary beams
- Relatively **long** half-lives (ms)



Taken from M.J.G. Borge (IEM/CSIC, Spain)

Accelerator production methods: ISOL



Accelerator production methods: ISOL

ISOLDE Yield Database
Production

https://isoyields2.web.cern.ch/

Tin - Yield Overview

Filter by driver beam: PSB only | Show All

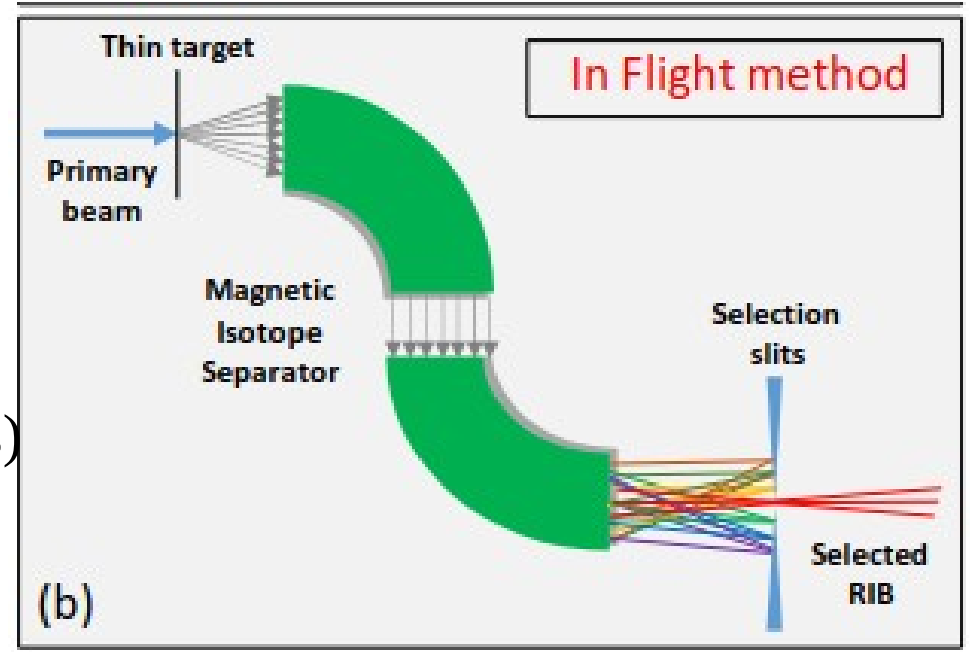
Hidden: 14 non-PSB yields.

Isotope	Half life	Driver	Yield / µC	Target
^{105}Sn	31 s 6	PSB	8.00e+4	U Carbide
^{106}Sn	115 s 5	PSB	1.60e+6	La Carbide
^{107}Sn	2.90 m 5	PSB	6.00e+6	La Carbide
^{108}Sn	10.30 m 8	PSB	1.40e+8	La Carbide
^{109}Sn	18.0 m 2	PSB	1.00e+9	La Carbide
^{110}Sn	4.11 h 10	PSB	1.80e+9	La Carbide
^{113}Sn	21.4 m 4	PSB	6.00e+9	U Carbide
^{132}Sn	39.7 s 5	PSB	3.00e+8	U Carbide
^{133}Sn	1.45 s 3	PSB	1.50e+7	U Carbide
^{134}Sn	1.12 s 8	PSB	2.00e+6	U Carbide
^{135}Sn		PSB	1.00e+5	U Carbide
^{136}Sn		PSB	4.00e+3	U Carbide
^{137}Sn		PSB	1.00e+2	U Carbide

In the ISOLDE Yield Database the beam intensities for isotopes of the elements measured at ISOLDE PSB (PS Booster with 1.0 or 1.4 GeV protons) are presented. For isotopes where no new yields are listed yet from the PSB, one can get an idea from looking at the available SC yields (0.6 GeV protons).

Accelerator production methods: In-Flight

- **Heavy** beams (O → U)
- **Light** targets (Be)
- **Low purity** secondary beams (cocktails)
- Much **shorter** half-lives (μs)



https://hal.archives-ouvertes.fr/hal-02899285

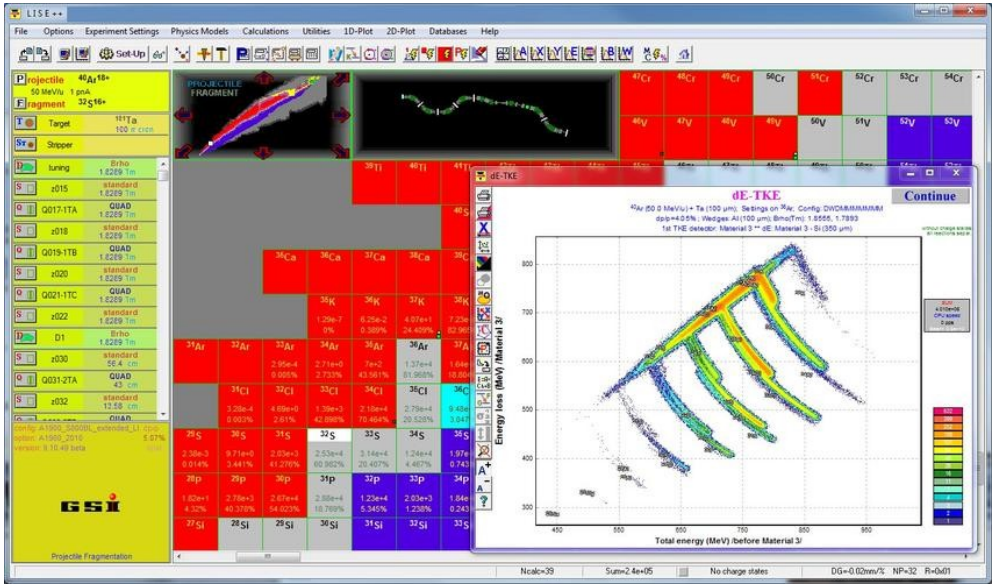
Production methods: In-Flight

CCF PRIMARY BEAM

An estimate of the yield of rare isotopes produced at NSCL can be calculated with the program LISE++. an estimate of the beam rates. The facility does not guarantee that rates and purities will be in exact agr to continuously improve the LISE++ calculations.

- Instructions for downloading and using LISE^{++} to calculate rare isotope yields at NSCL are availal
- General information on LISE^{++} is available here

A	Element	Energy (MeV/nucleon)	Intensity (pnA)
16	O	150	175
18	O	120	150
20	Ne	170	80
22	Ne	120	80
22	Ne	150	100
24	Mg	170	60
28	Si	160	10
32	S	150	60
36	Ar	150	75
40	Ar	140	75
40	Ca	140	50
48	Ca	90	15



https://lise.nscl.msu.edu/lise.html

https://nscl.msu.edu/users/beams.html#a1

Exotic nuclei in the World

RIBs ATLAS
(for fundamental science)

FRIB - MSU

https://www.youtube.com/watch?v=EPG919lJK8s&t=253s

RIBs ATLAS
(for fundamental science)

FAIR - GSI

The Universe in the Laboratory

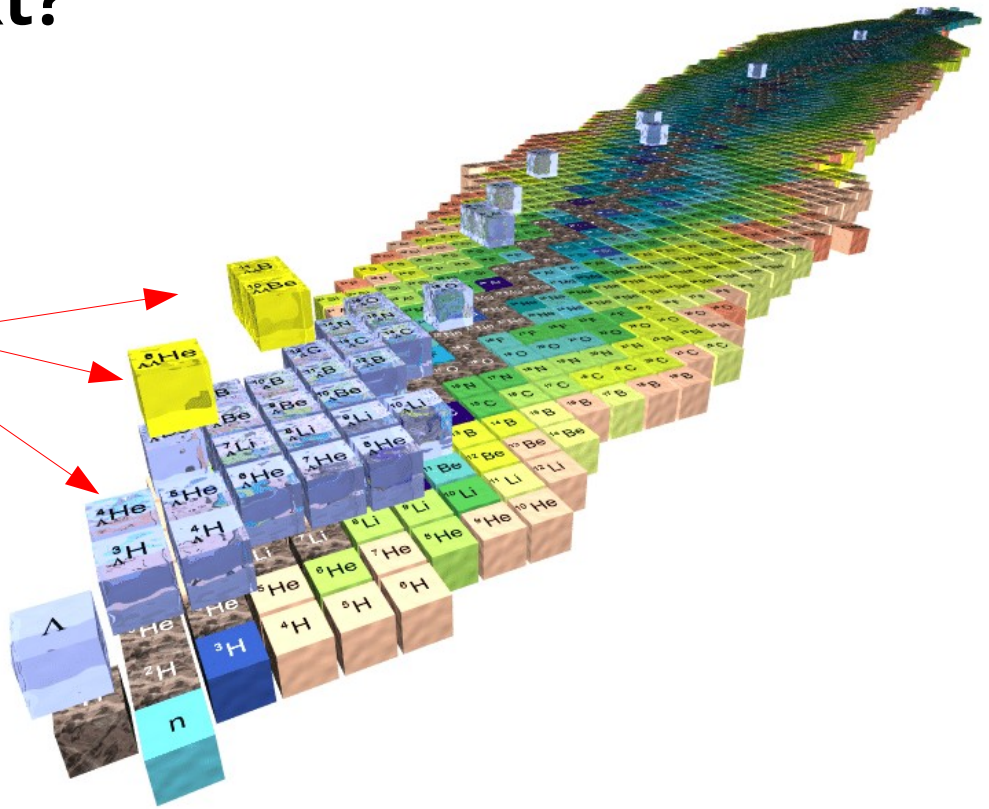
Research at the world-wide unique
international particle accelerator facility

Facility for Antiproton and Ion Research,
Darmstadt, Germany

https://www.youtube.com/watch?v=iZmC6Q6aXGY

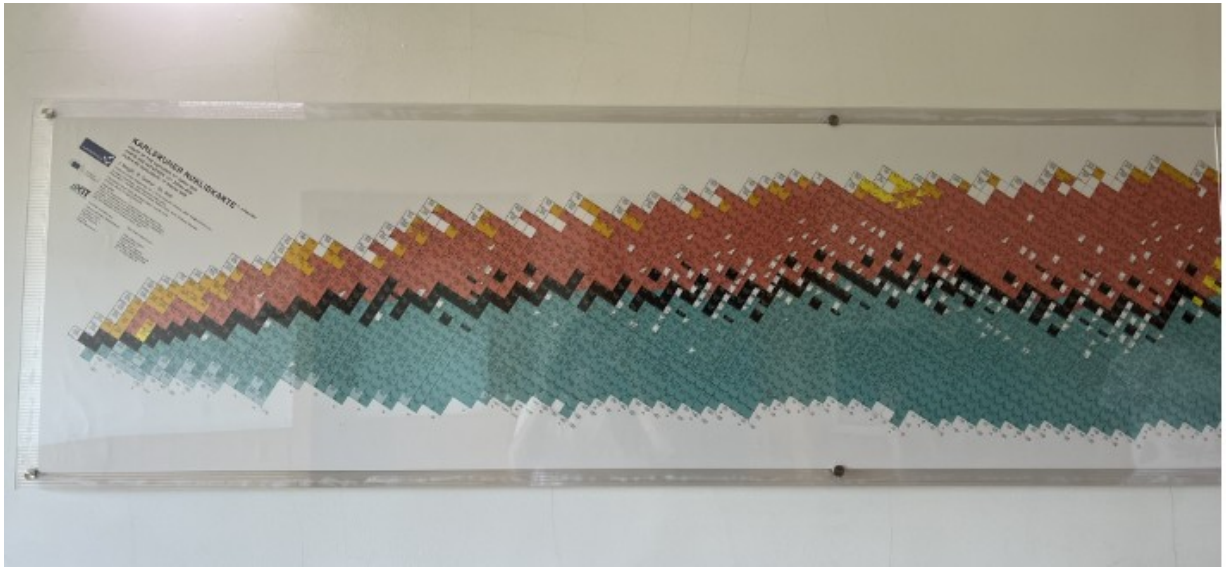
What’s next?

Hypernuclei



Closing

Freshly mounted **Table of Isotopes** at FCUL



Thanks!

REPÚBLICA
PORTUGUESA