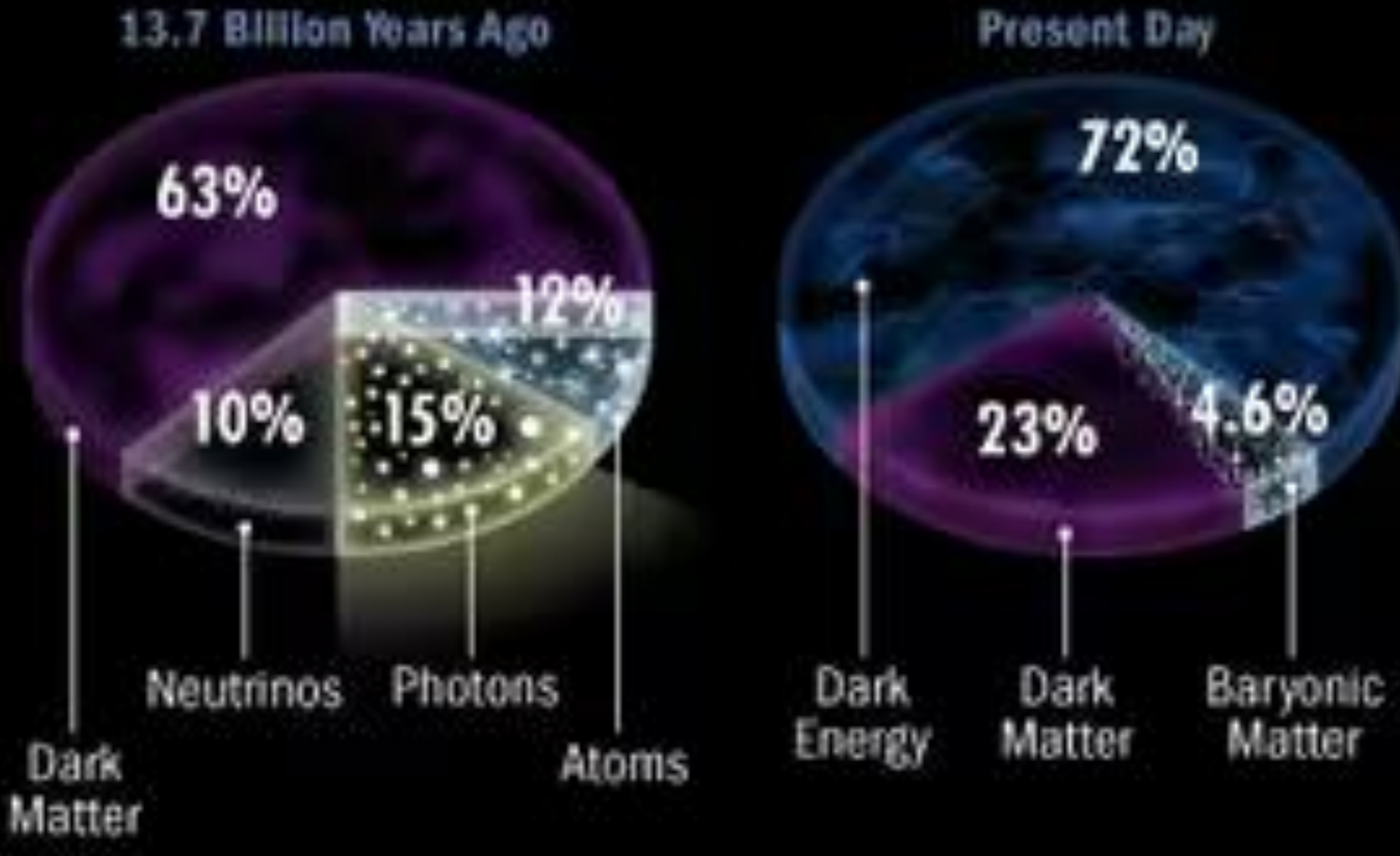
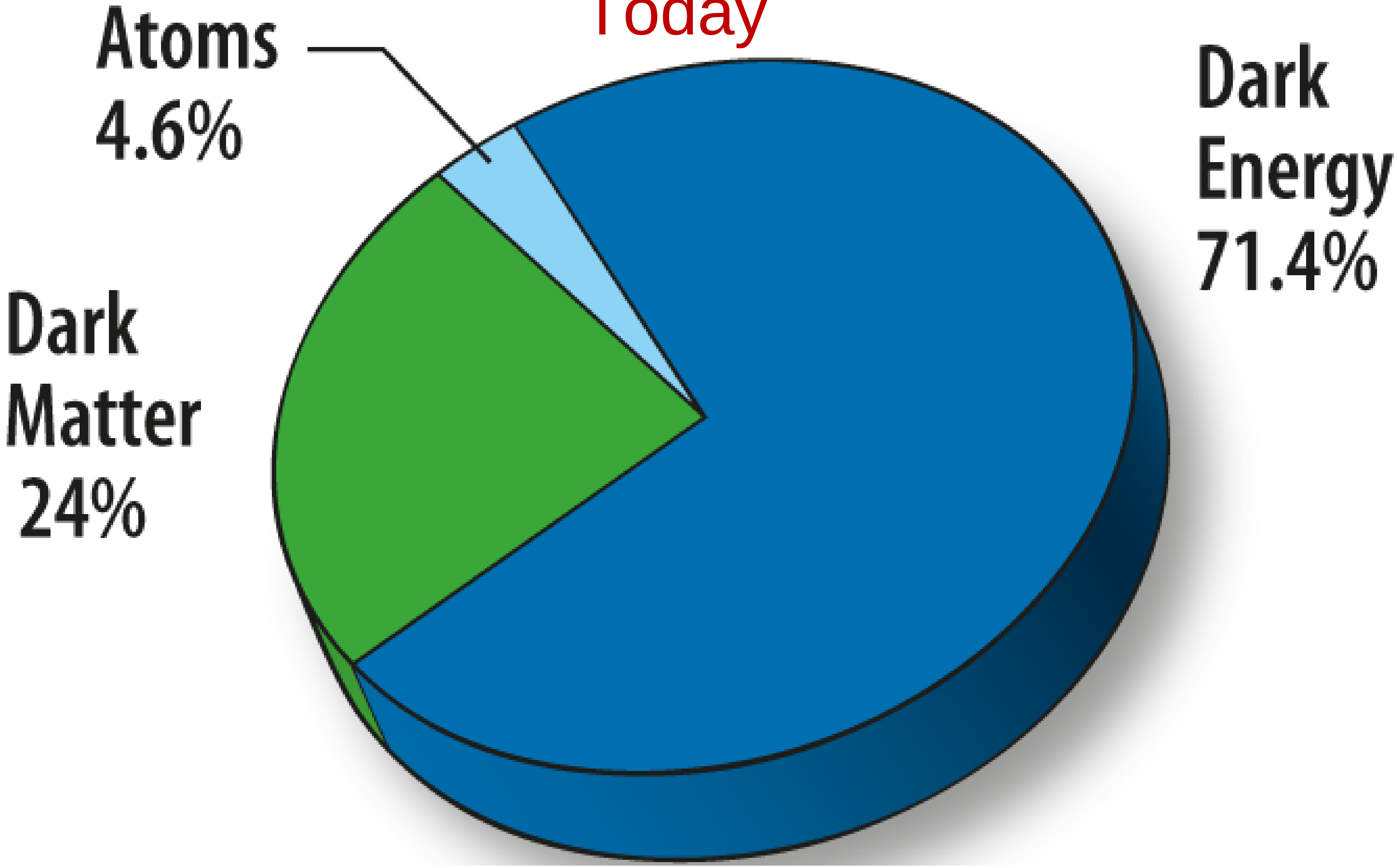
Միջուկային ֆիզիկա

What is the Universe Made of?



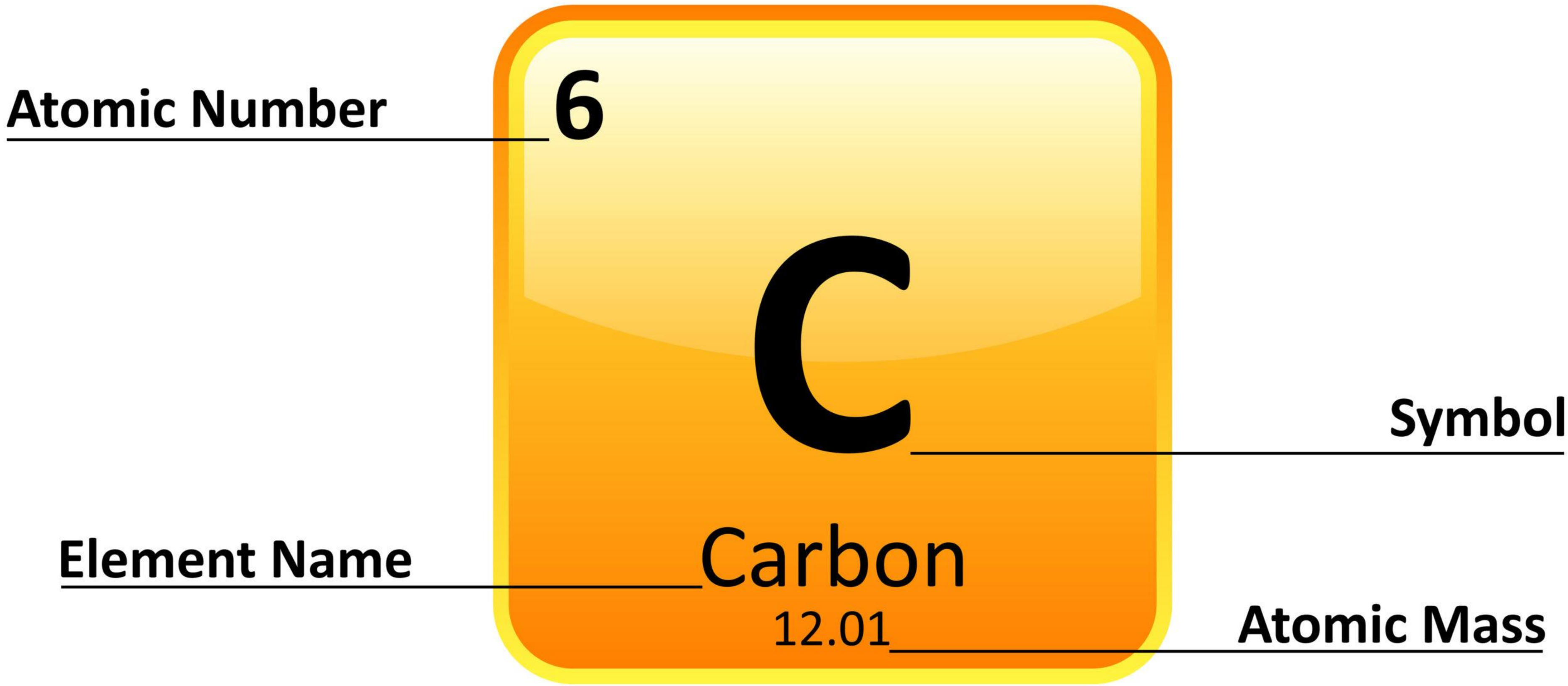
Today



Over 99.9 percent of the mass of all the universe comes from the nuclei found at the center of every atom. These nuclei are made of protons and neutrons that themselves formed a few microseconds after the big bang as the primordial liquid known as quark-gluon plasma cooled and condensed.

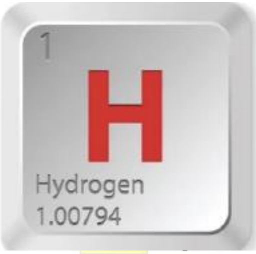
Entire history of the universe entangled with the nuclear physics….


1
H
Hydrogen
1.0079
3
Li
Lithium
6.941
4
Be
Beryllium


Atomic Number
6
C
Symbol
Element Name
Carbon
12.01
Atomic Mass

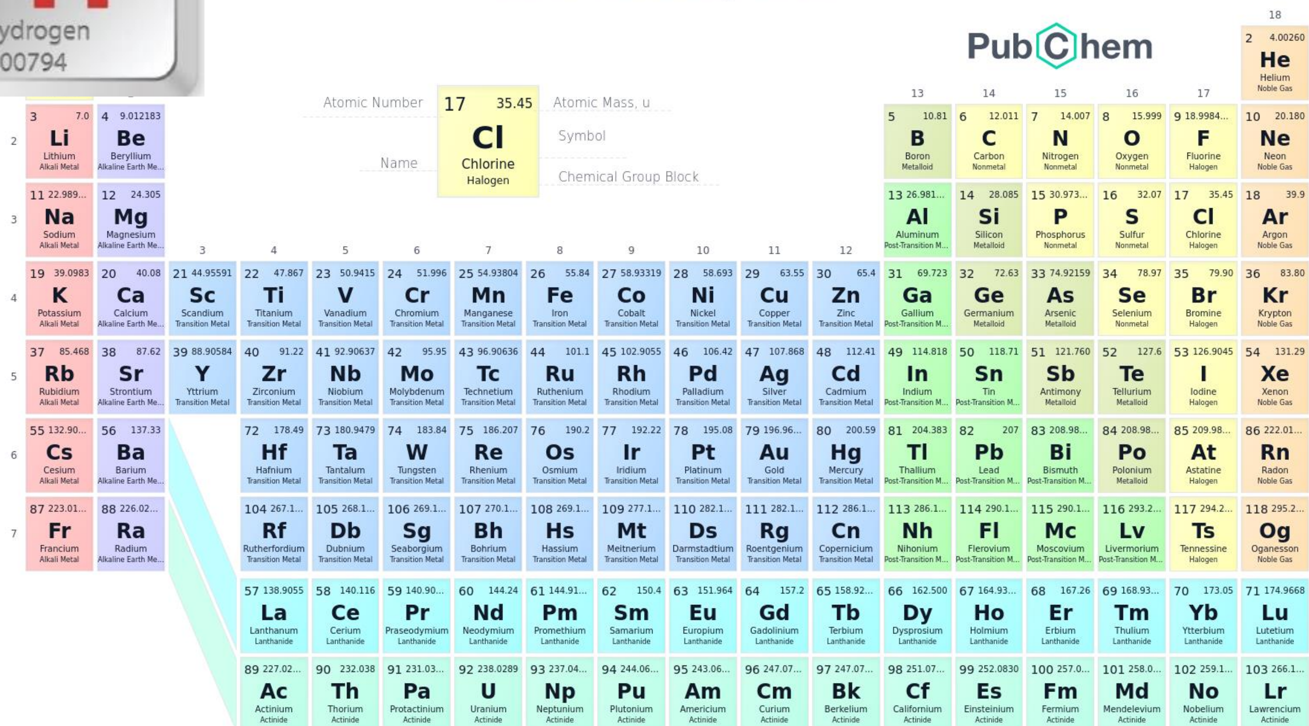

La
Ce
Cerium
90
Th
91
Pa
92
U
Uranium
93
Np
95
Am
96
Cm
97
Bk
Cf
Es
Fm

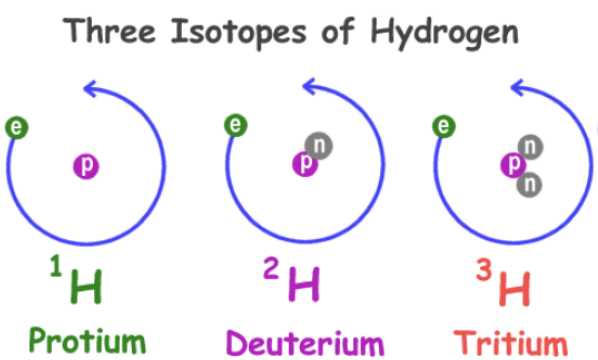
Elements and Isotopes



PERIODIC TABLE OF ELEMENTS

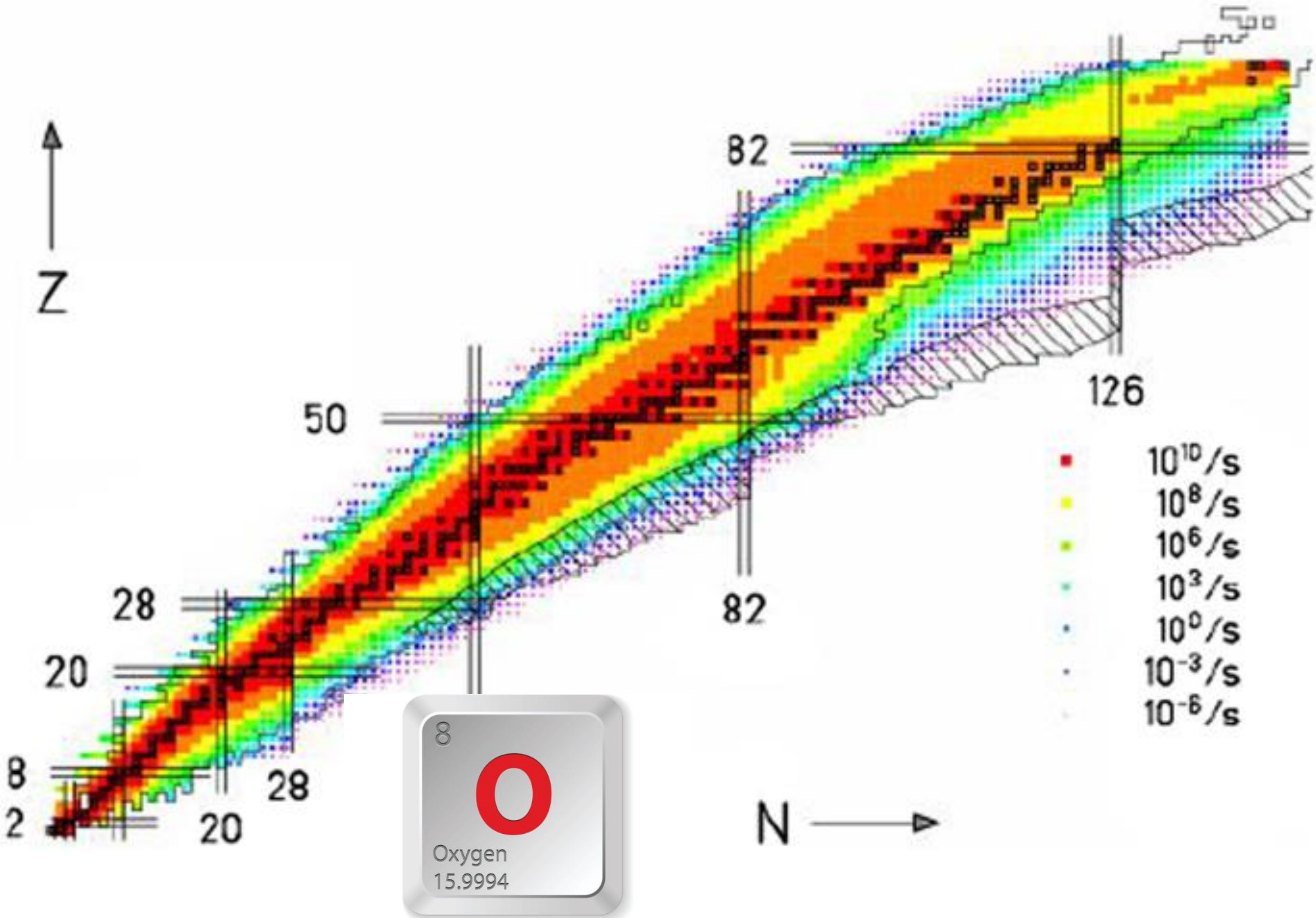
Chemical Group Block





Oxygen

8 protons
8 neutrons
8 electrons


Z
N
2
8
20
28
50
82
20
28
82
126
10^10/s
10^8/s
10^6/s
10^3/s
10^0/s
10^-3/s
10^-6/s
8
O
Oxygen
15.9994

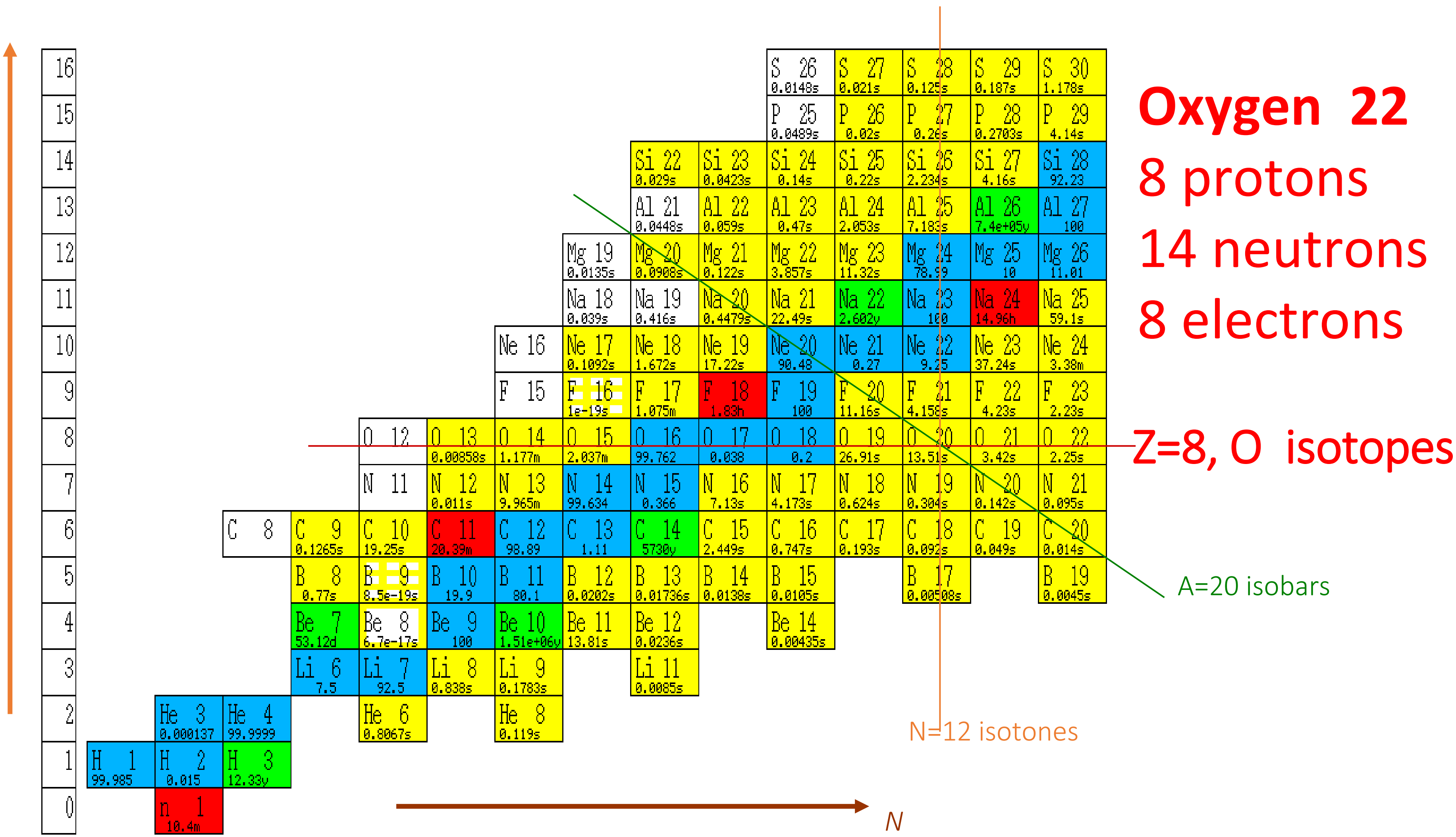
What is an isotope?

Oxygen 22

8 protons

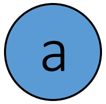
14 neutrons

8 electrons



Q value of nuclear reaction process

projectile

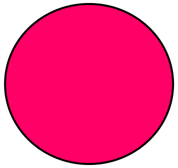


$$A + a \Rightarrow B + b$$

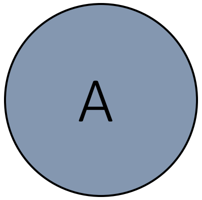
A(a,b)B

product

b



B



target

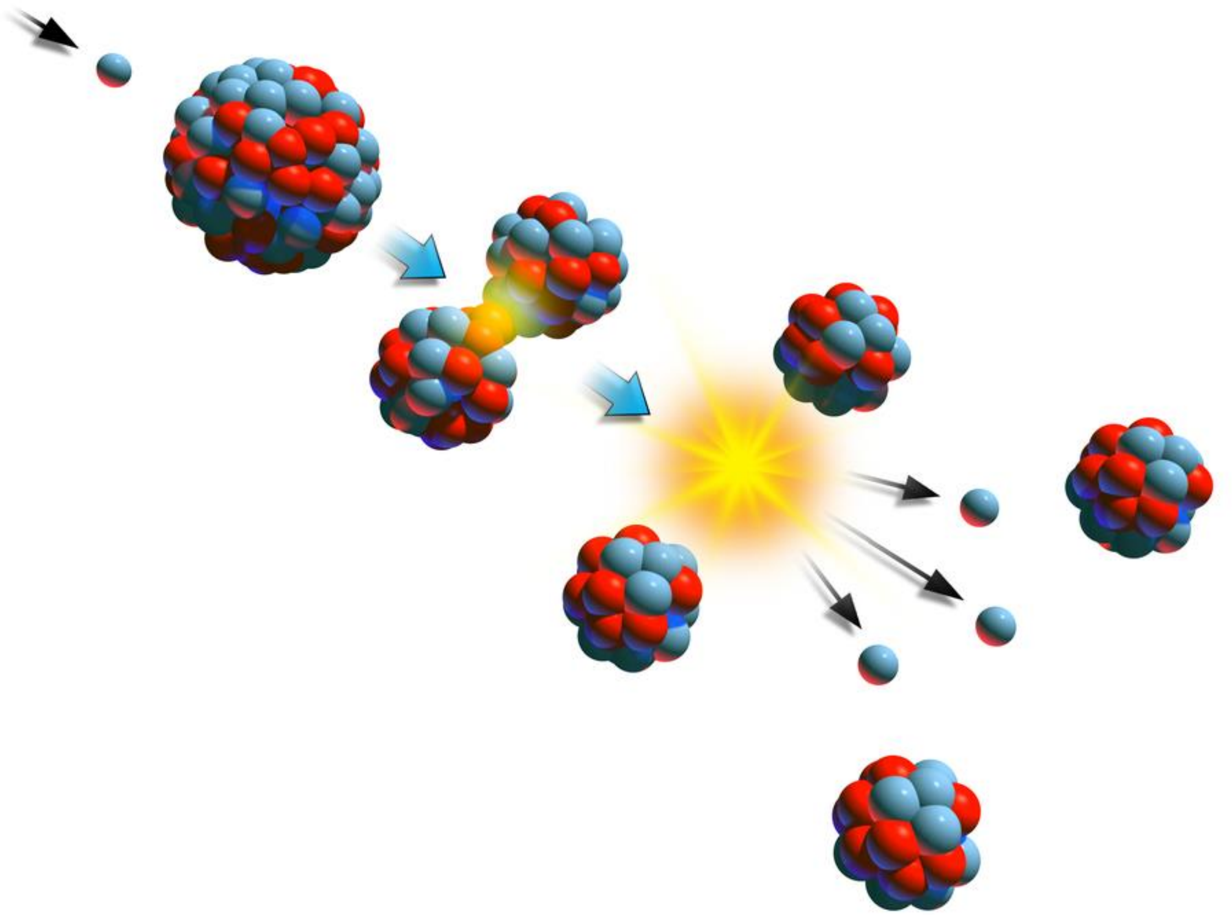
$$Q = (m_B + m_b)\cdot c^2 - (m_A + m_a)\cdot c^2$$

$$Q = (B_B + B_b) - (B_A + B_a)$$

$Q > 0$ exothermic reaction

$Q < 0$ endothermi c reaction

recoil

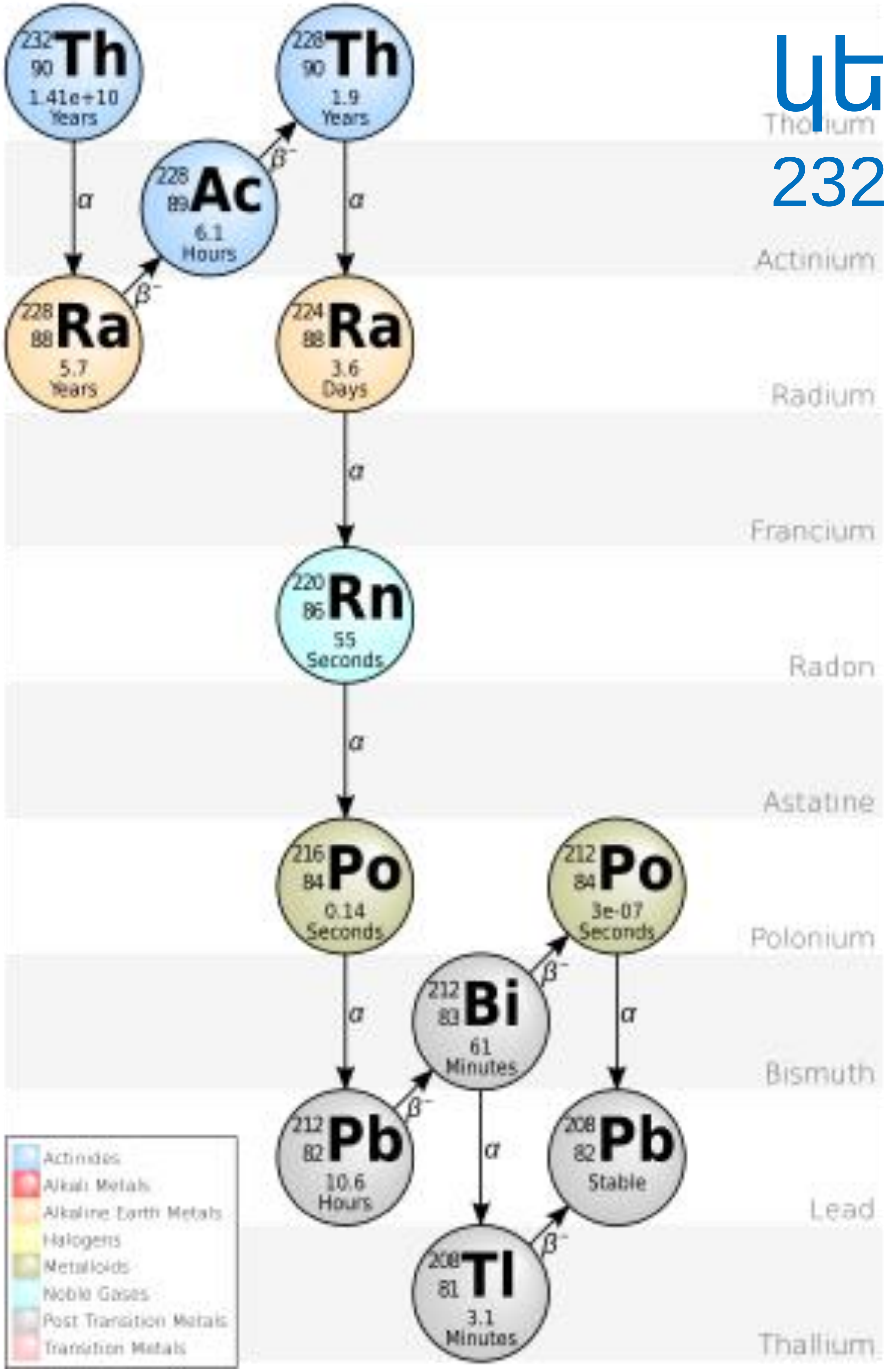


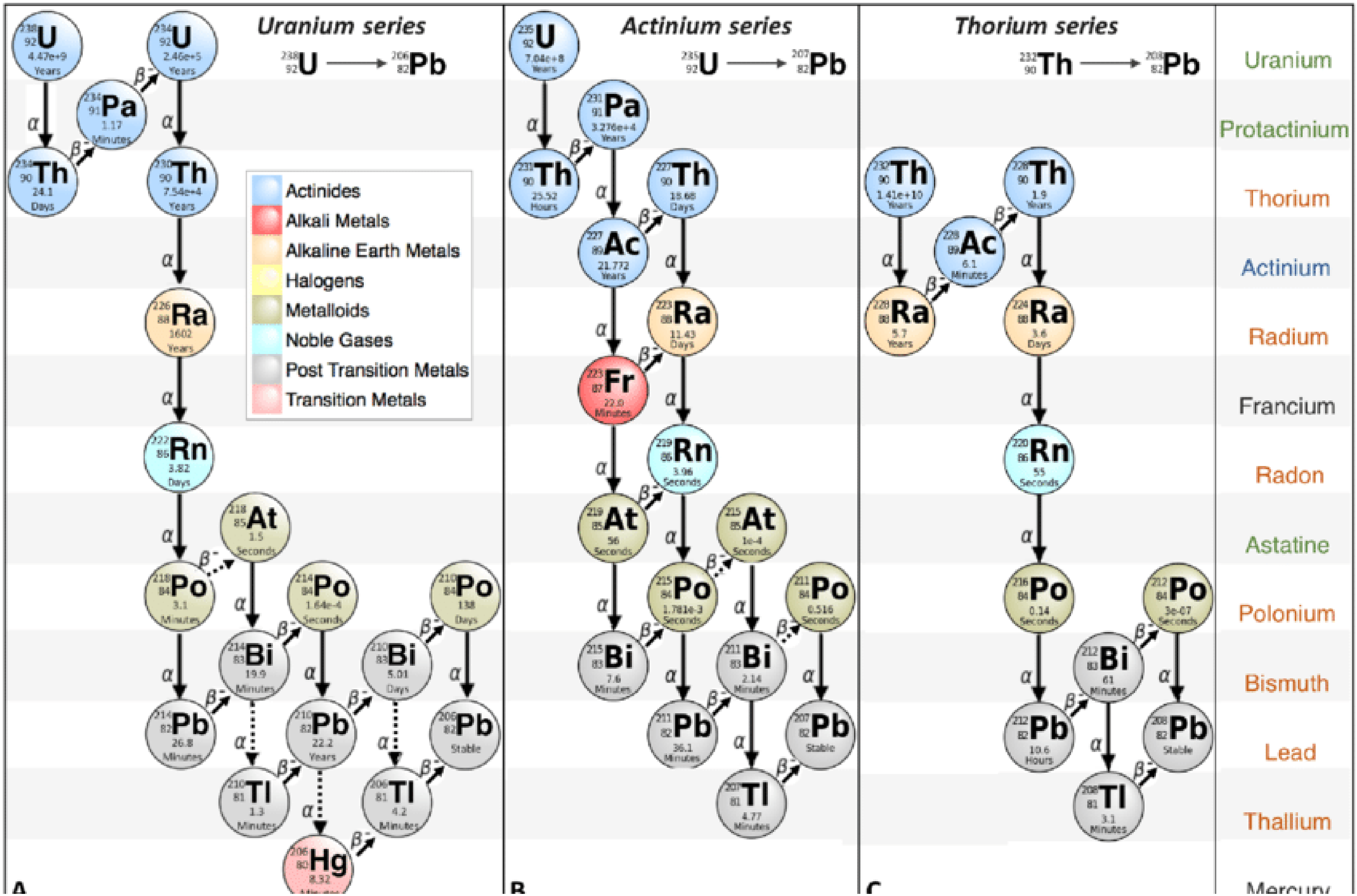
կես կյանք

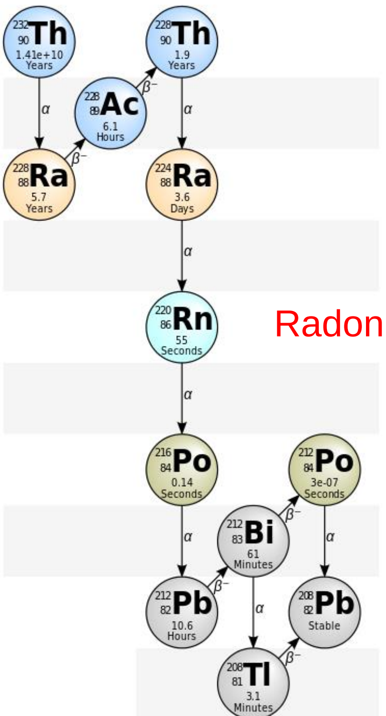
^{232}Th = 1.4x10^{10} տարի

90 պրոտոններ

142 նեյտրոններ

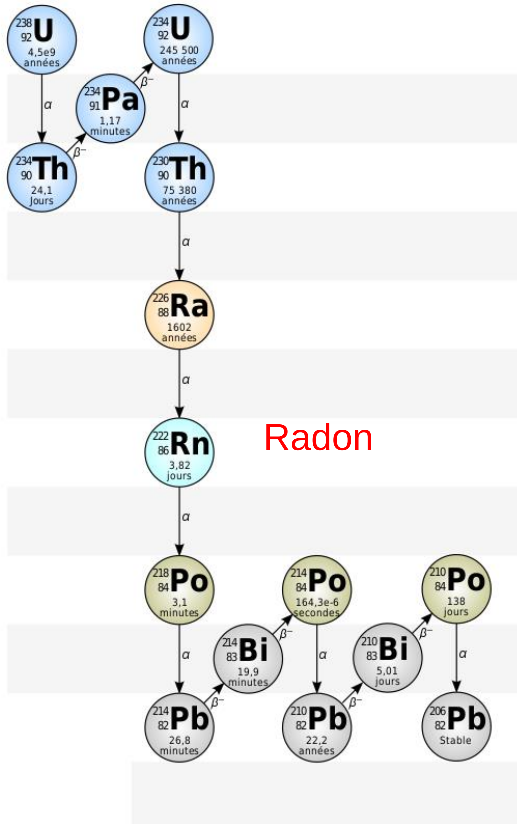


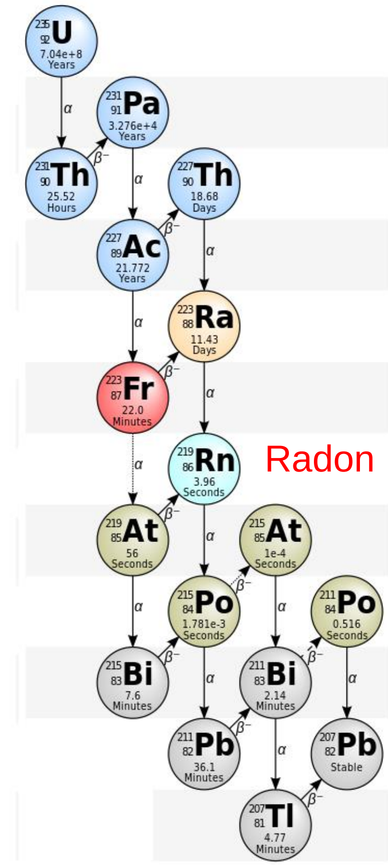

Uranium series
238 92 U → 206 82 Pb
Actinium series
235 92 U → 207 82 Pb
Thorium series
232 90 Th → 208 82 Pb
Actinides
Alkali Metals
Alkaline Earth Metals
Halogens
Metalloids
Noble Gases
Post Transition Metals
Transition Metals
Uranium
Protactinium
Thorium
Actinium
Radium
Francium
Radon
Astatine
Polonium
Bismuth
Lead
Thallium
Mercury
A
B
C



thorium-232
(half-life 14 billion years).

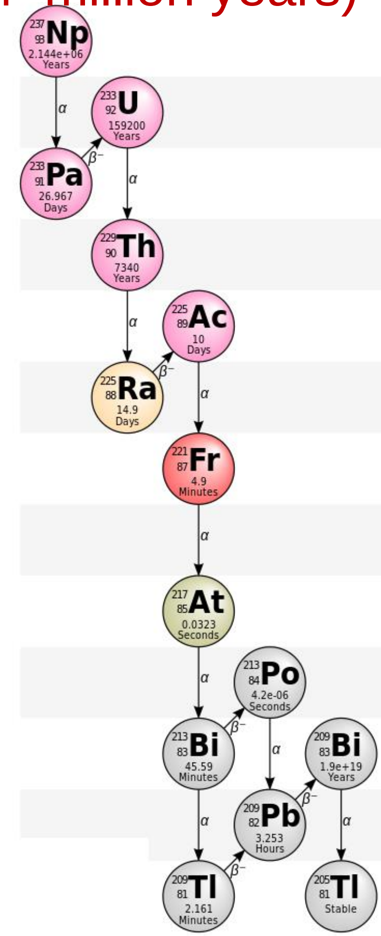
uranium-238
(half-life 4.5 billion years)





uranium-235
(half-life 700 million years)

Neptunium-238
(half-life 2.14 million years)



Radioactivity in our daily life

Radioactivity is not only an extreme phenomenon associated with nuclear bombs and nuclear reactors but also with a number of daily utensils and activities. We don't notice it, but we can detect it!

What do you think, radioactive or not ????

Dinosaur bone 70 Ma old

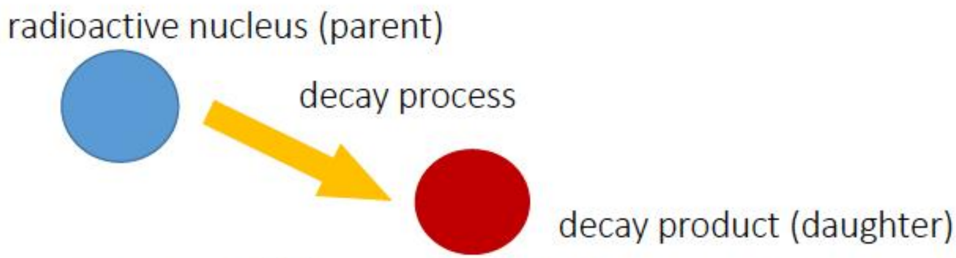
Salt from the underground US nuclear Waste Isolation Pilot Plant (WIPP) 1999-2015

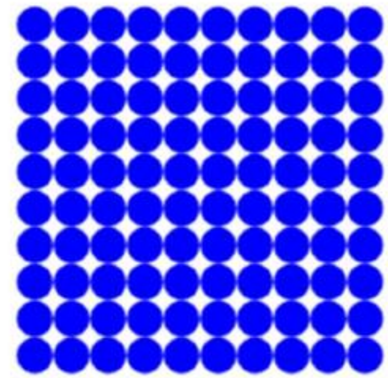
Uranium Ore I

Uranium Ore II

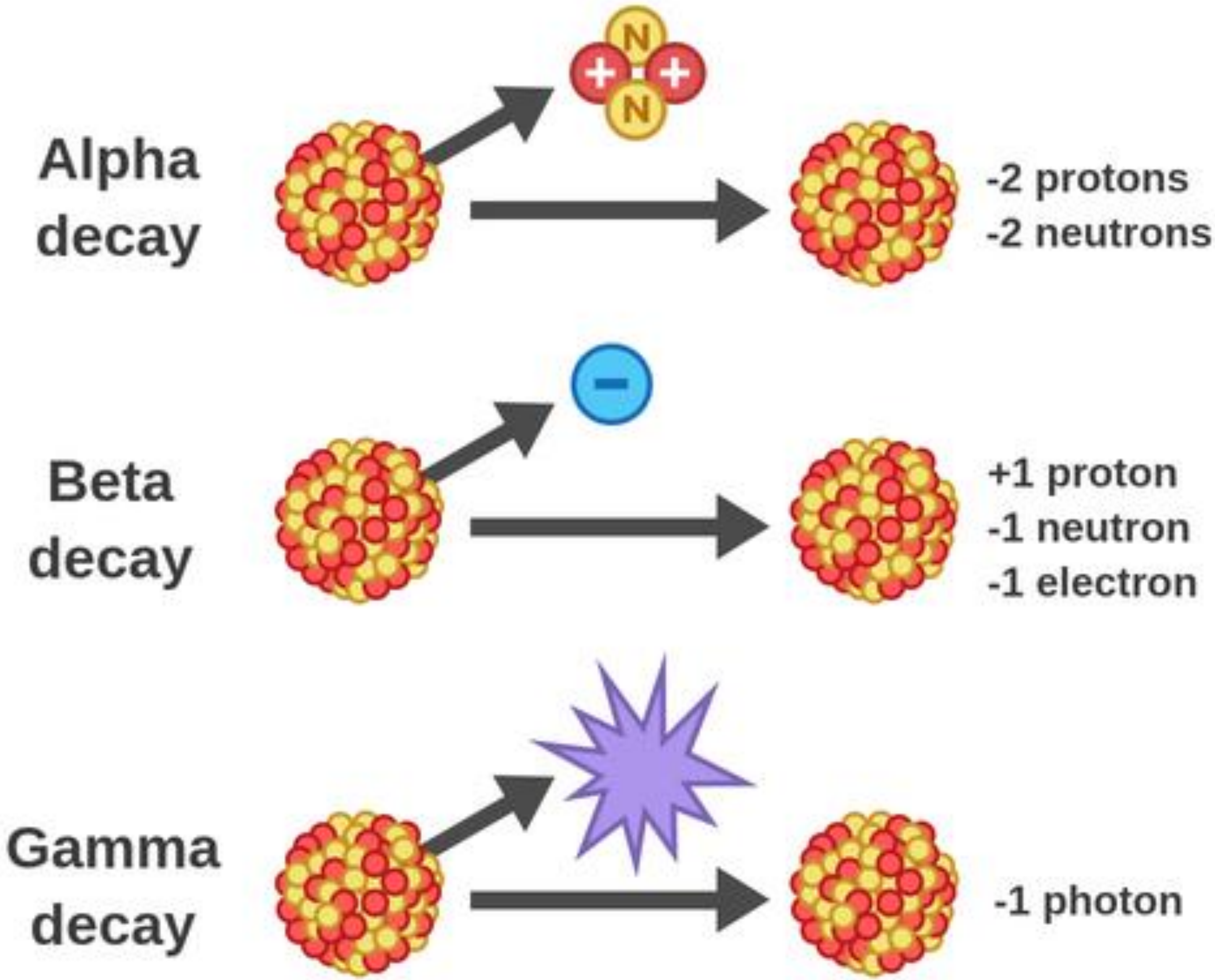
Trinitite from Nuclear Bomb test 1945

Terminology of nuclear decay

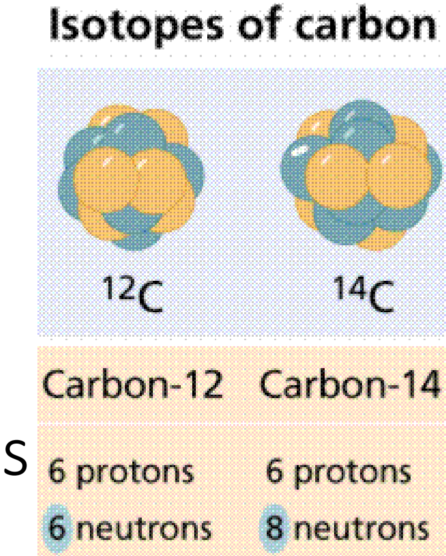




- Activity, $A(t)$: number of decay events per time
- Decay constant, λ: probability of decay
- Half life, $t_{1/2}$: time for the activity to be reduced to 50%
  - Activity corresponds to the number of sand particles dripping through hole
  - Decay constant is associated with the size of the hole


Alpha decay
N
N
-2 protons
-2 neutrons
Beta decay
+1 proton
-1 neutron
-1 electron
Gamma decay
-1 photon

Changing Z to N or N to Z



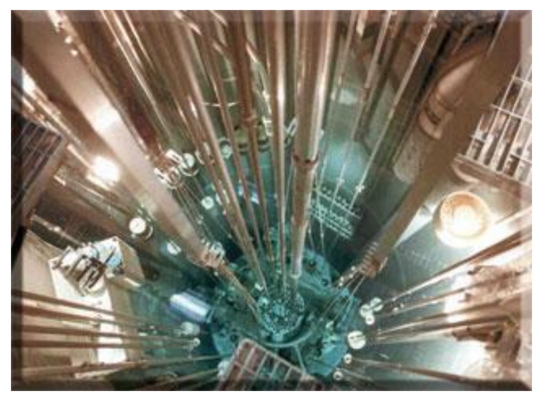
Adding a proton (electron)

Ածխածին-->ազոտ

ոսկի--> սնդիկ

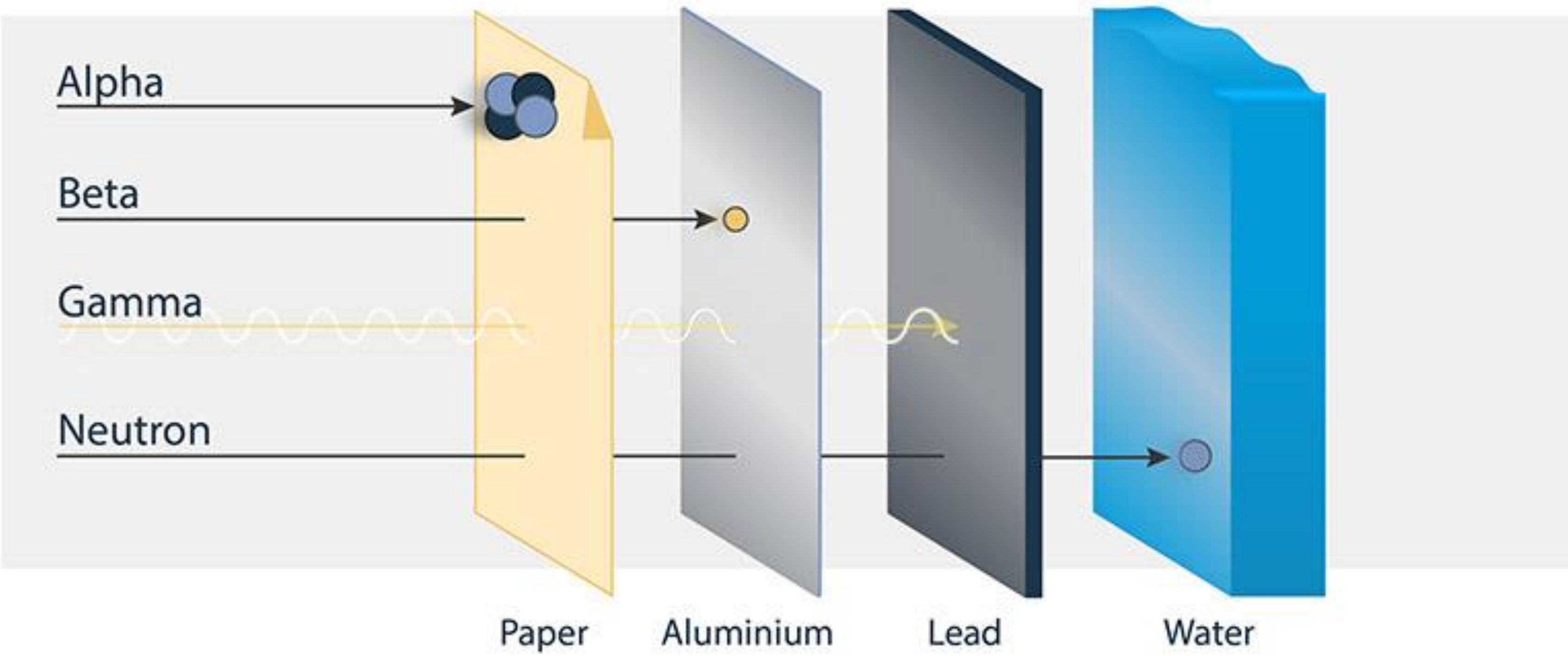
Subtracting or adding neutrons

nucleus becomes unstable and decays by internally converting neutrons to protons (beta-decay)!



What are the physical laws that govern the decay process?

Types of decay



Basics of Instruments

- A radiation detector is based on the detection of **secondary effects** caused by radiation
- Radiation effects depend on the kind of radiation, not every radiation detector is sensitive to each kind.
- Radiation ionizes material by energy deposition, ionization can be measured by electric current
- Radiation excites atoms by energy deposition, de-excitation via light emission can be measured

The collection of early instrumentation

Early Scintillator screens for visual counting

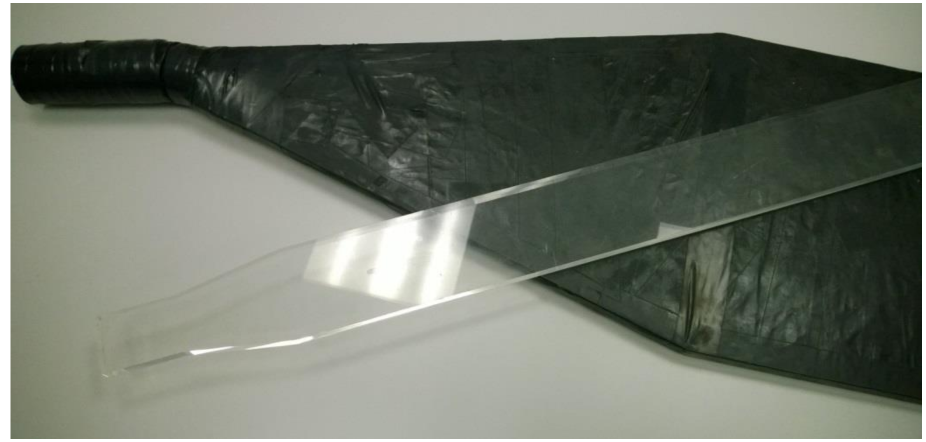
Geiger Counter 1955 version

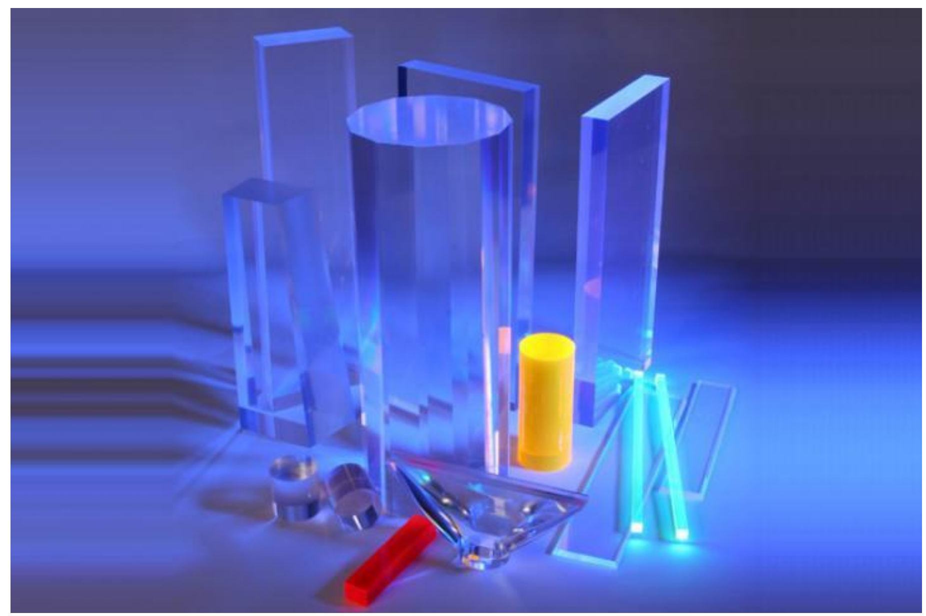
Dosimeter   1955 version

Dosimeters today

Geiger Counter 2015 version

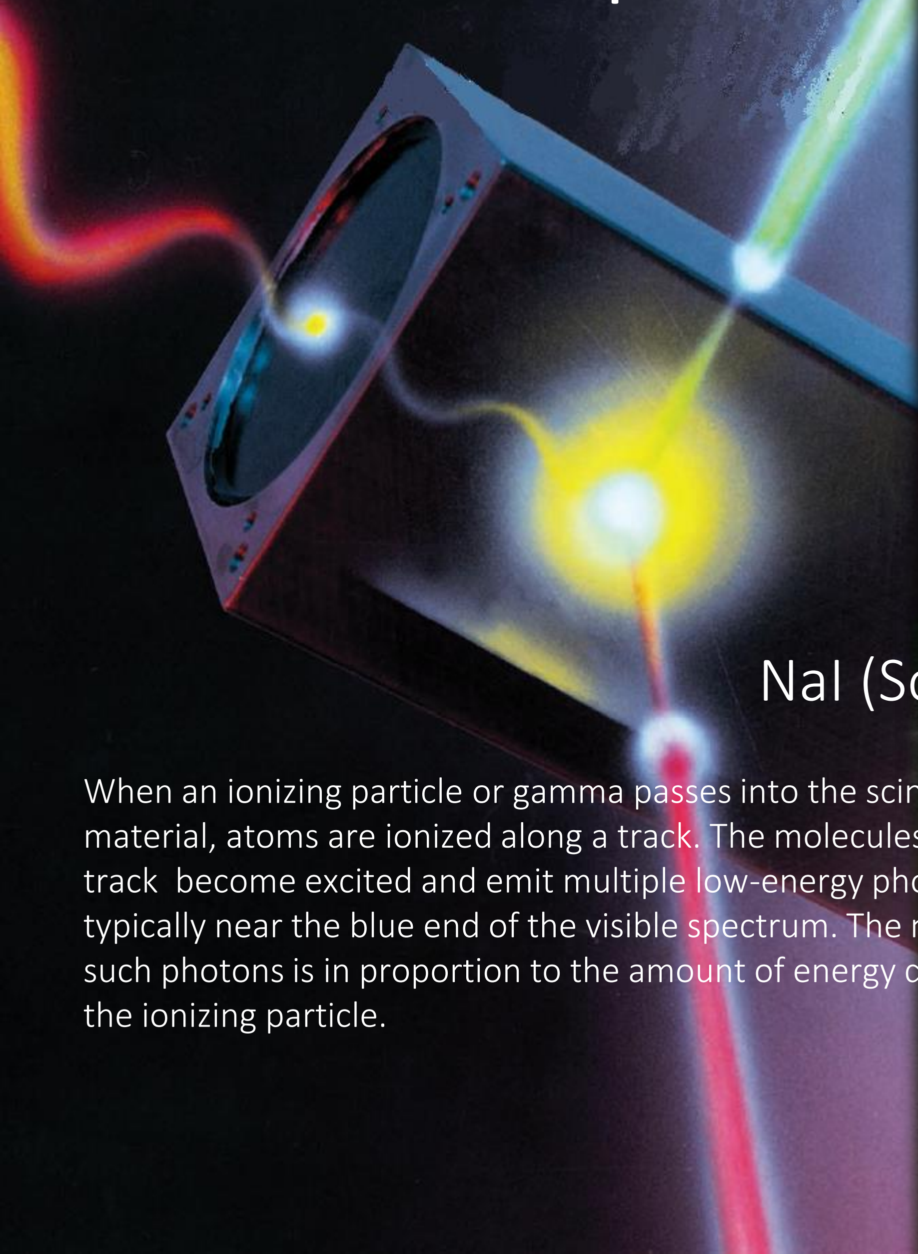
Scintillators





Mostly salt crystal, but increasingly also plastic material that emits light when hit by radiation, ZnS, NaI, CsI, BaF_2, BGO, ….

Principle of Scintillators

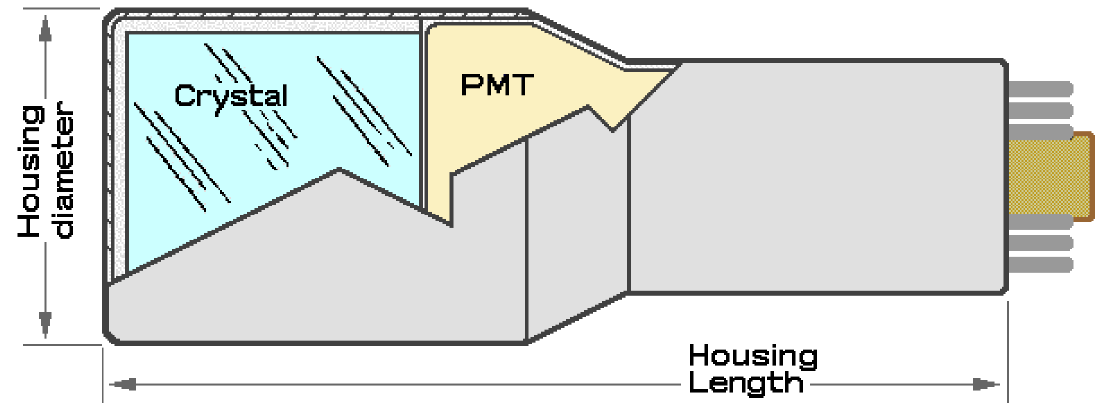


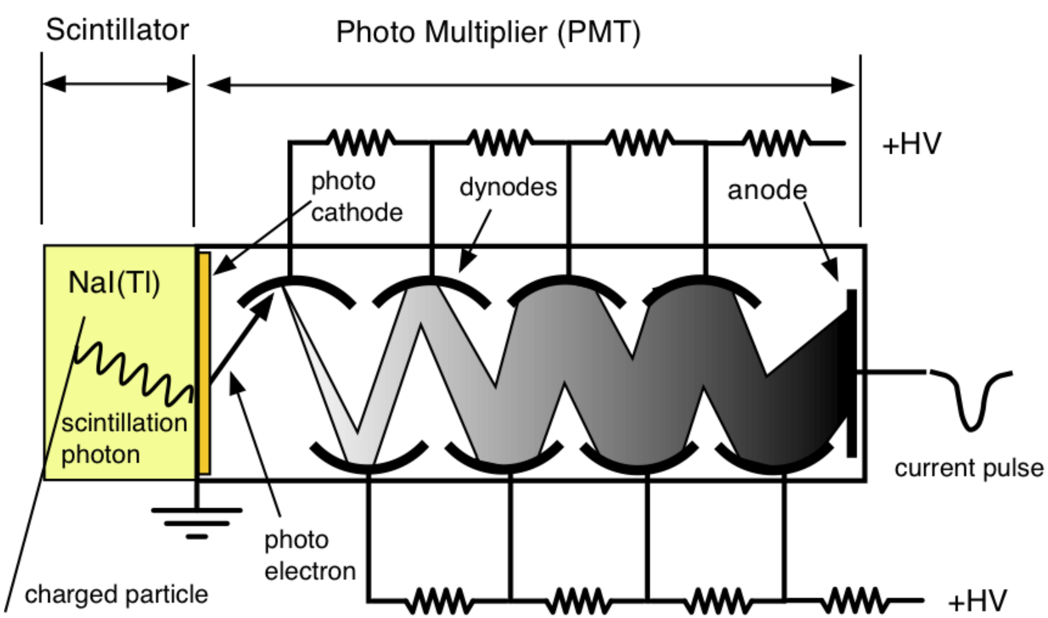
NaI (Sodium Iodide) detector for γ radiation

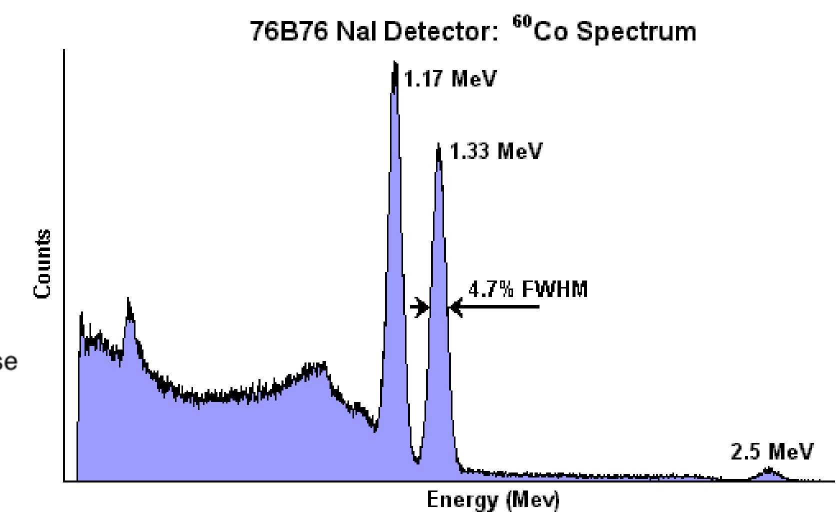
When an ionizing particle or gamma passes into the scintillator material, atoms are ionized along a track. The molecules along the track become excited and emit multiple low-energy photons, typically near the blue end of the visible spectrum. The number of such photons is in proportion to the amount of energy deposited by the ionizing particle.

Photomultiplier (PMT)

Efficient optical coupling is required between crystal and PMT

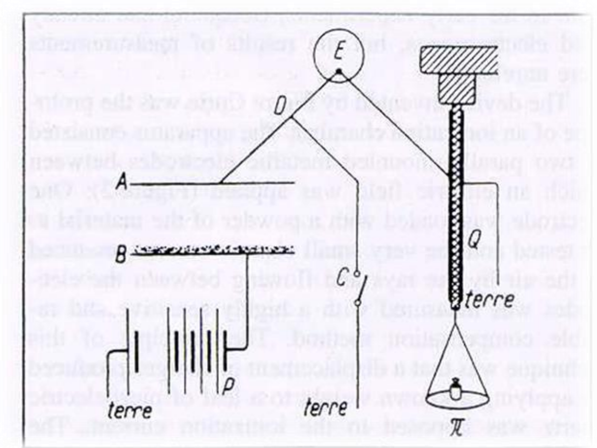






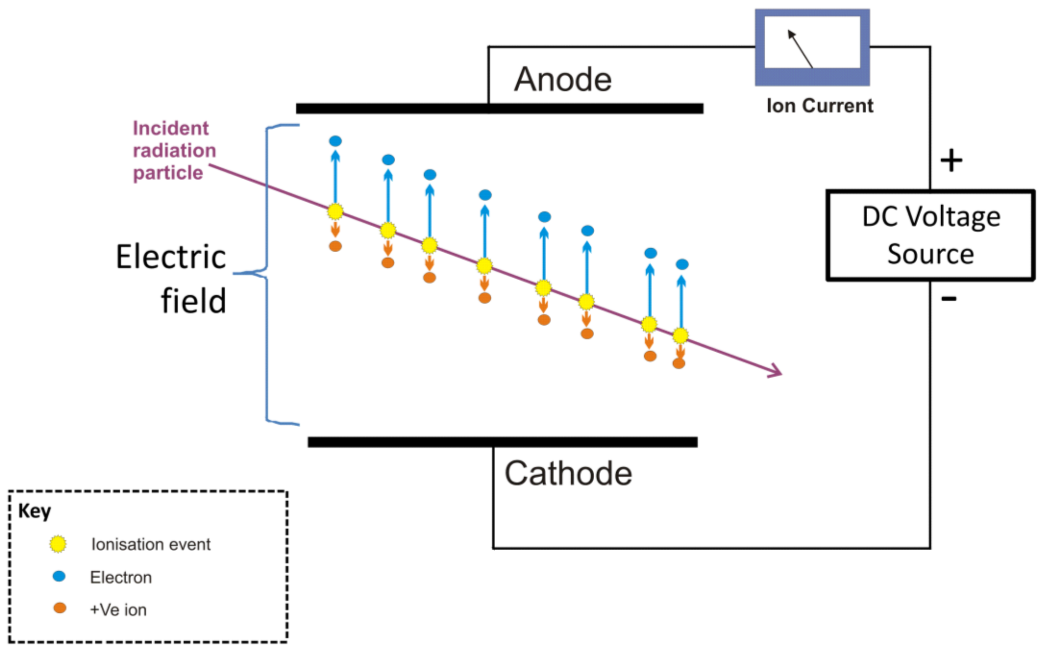
Principle of Ionization chamber

Pierre Curie invented the prototype of an ionization chamber.



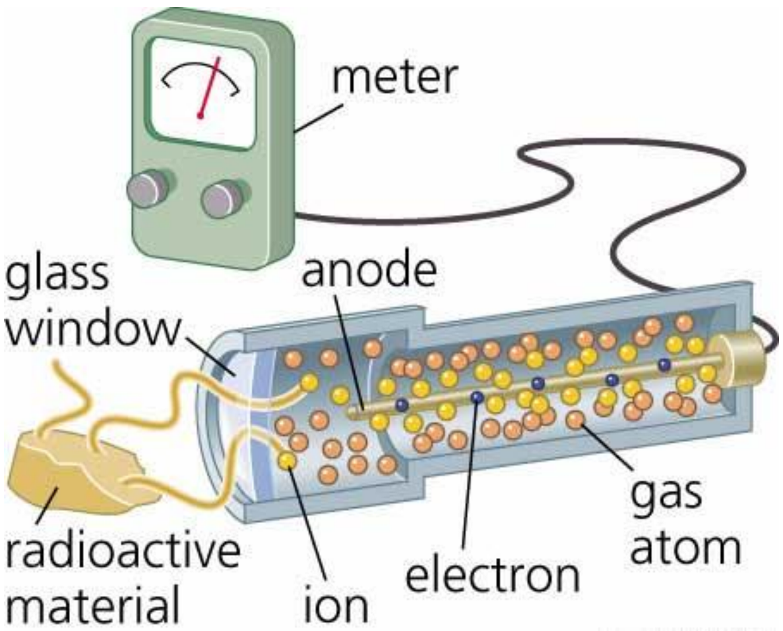
The apparatus consisted of two parallel-mounted metallic electrodes between which an electric field was applied.

Nuclear radiation has sufficient energy to ionize atoms in a gas, generating free negatively charge electrons and free positively charged ions that can be separated by electrical potential and detected.

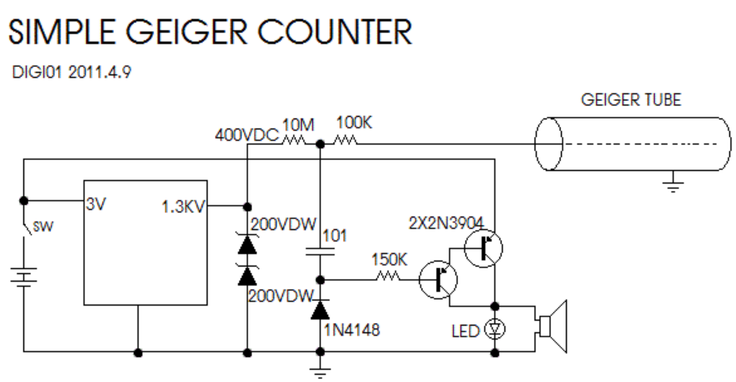


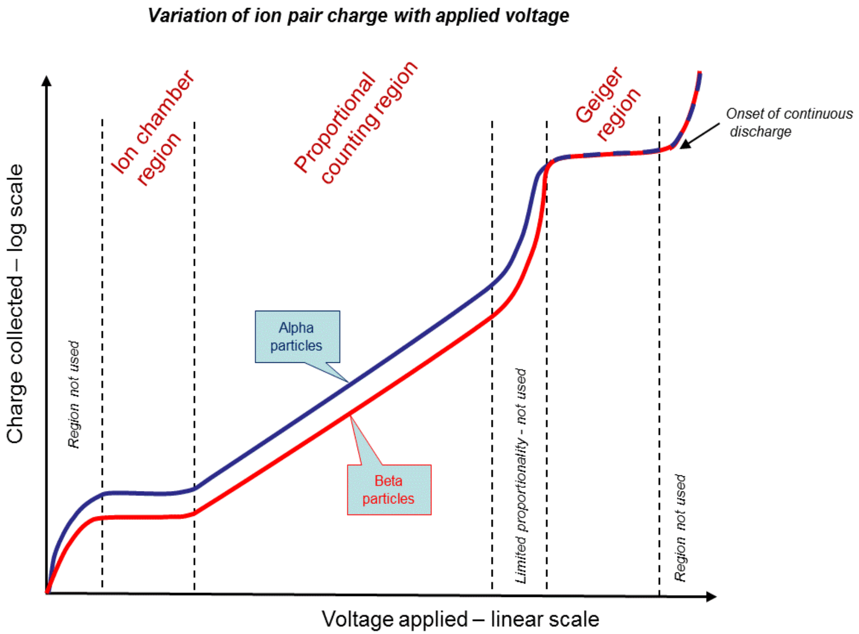
One electrode was loaded with a powder of the material to be tested and the very small electric current produced in the air by the rays and flowing between the electrodes was measured with a highly sensitive and reliable weight compensation method. Today the electrical current can be directly measured and corresponds to the level of radioactivity.

Geiger or Geiger-Müller Counter



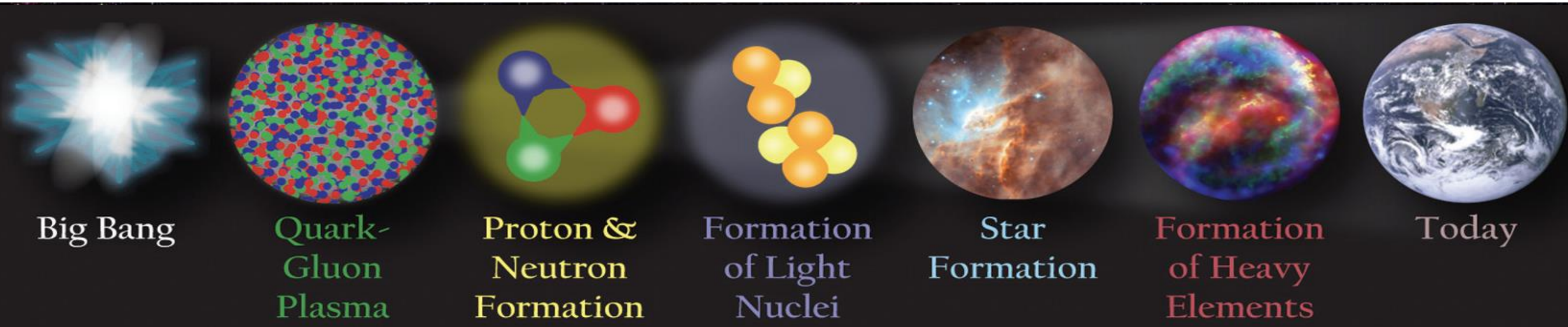
Variation of ionization counter, instead of two parallel plates, cathode (-) and anode (+) the anode is now a central wire in a cylindrical geometry, attracting electrons from the ionized gas and measuring the current proportional to the ionization, which is proportional to the intensity of the radiation. There ate different modes of operation depending on the applied voltage for charge collection.





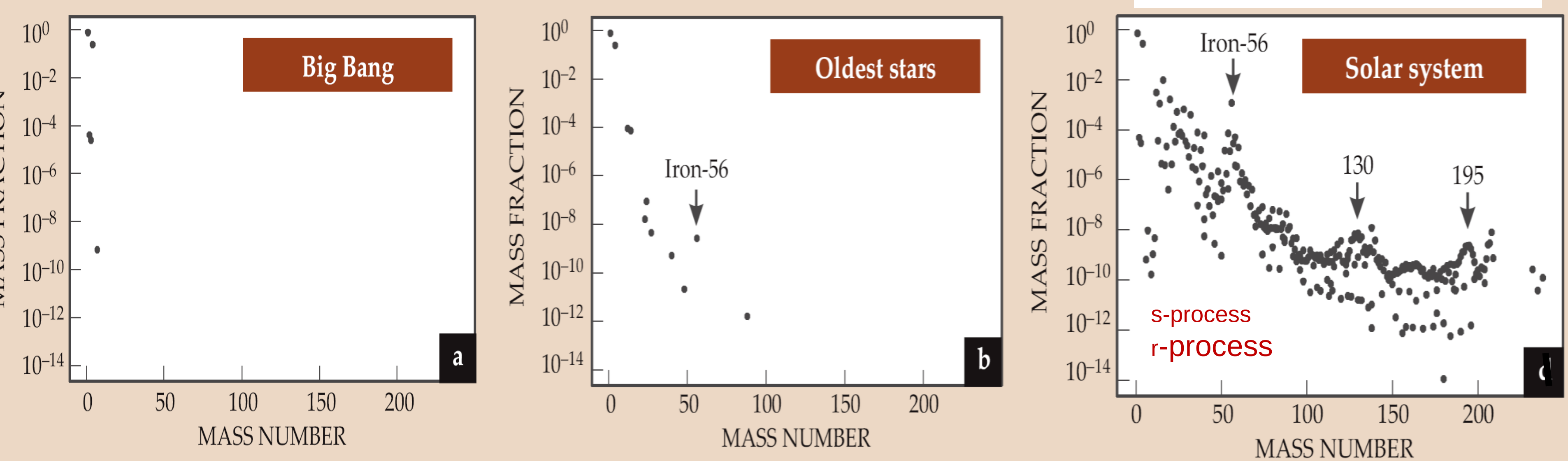
տարրական առասրությւններ

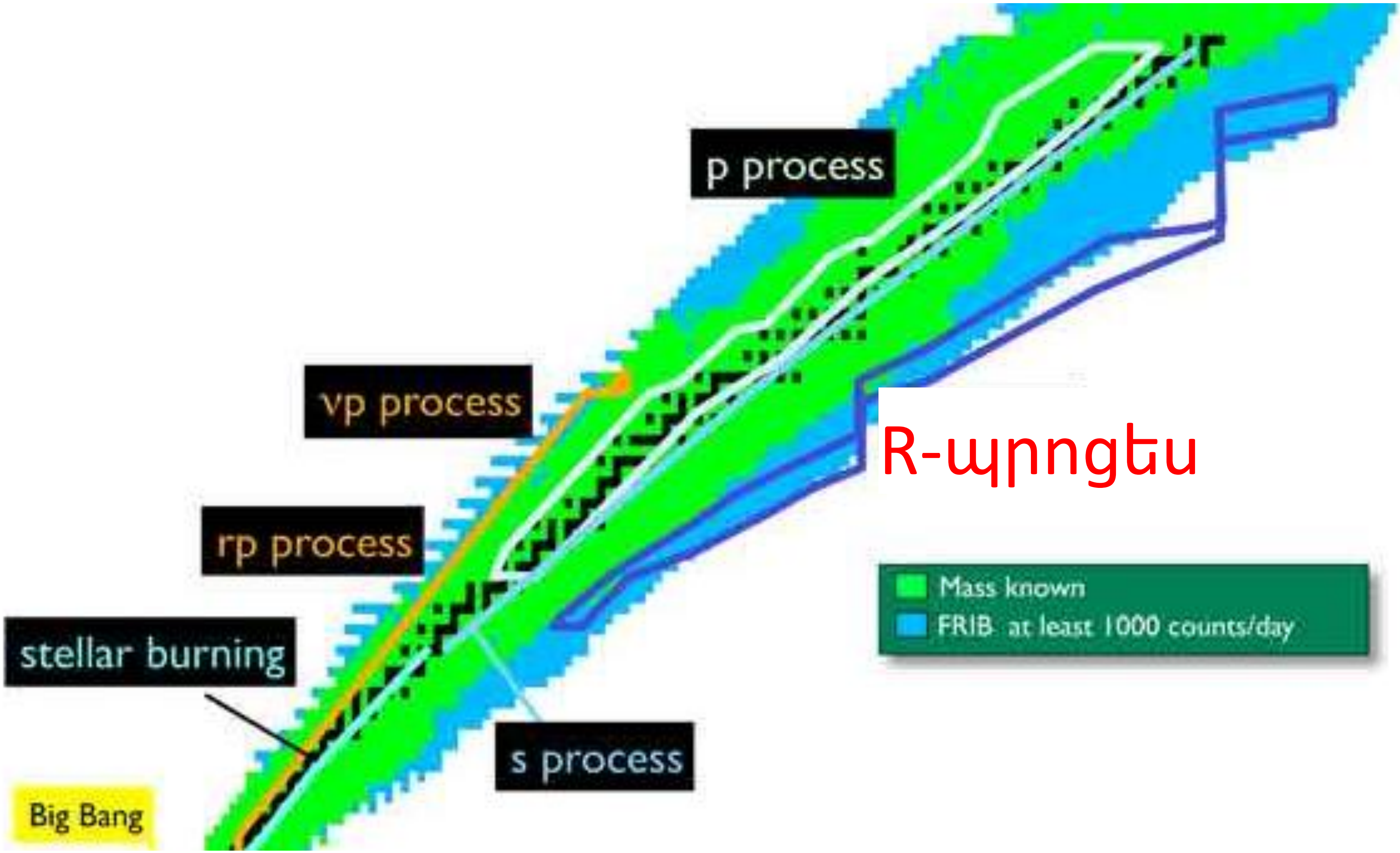
=տիեզերքի պատմություն + միջուկային ֆիզիկա



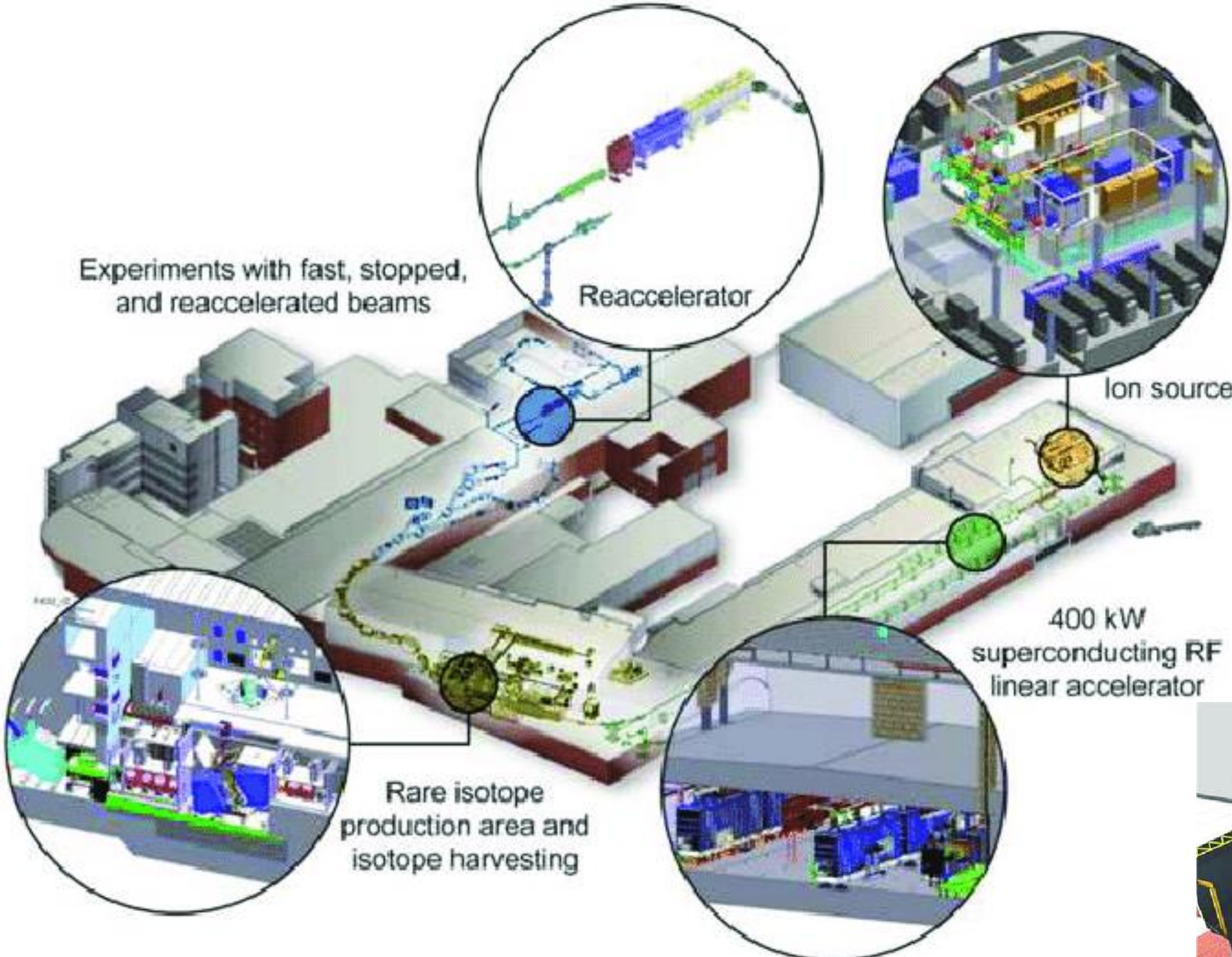
- How were elements Fe to U made?

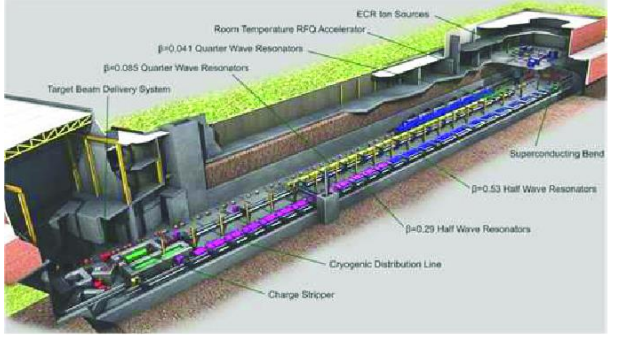
արեգակնային համակարգ




p process
νp process
rp process
stellar burning
Big Bang
s process
R-պրոցես
Mass known
FRIB at least 1000 counts/day


Ferrari

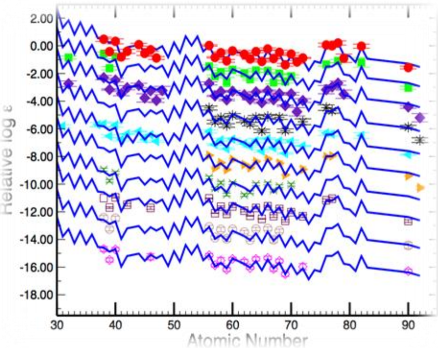




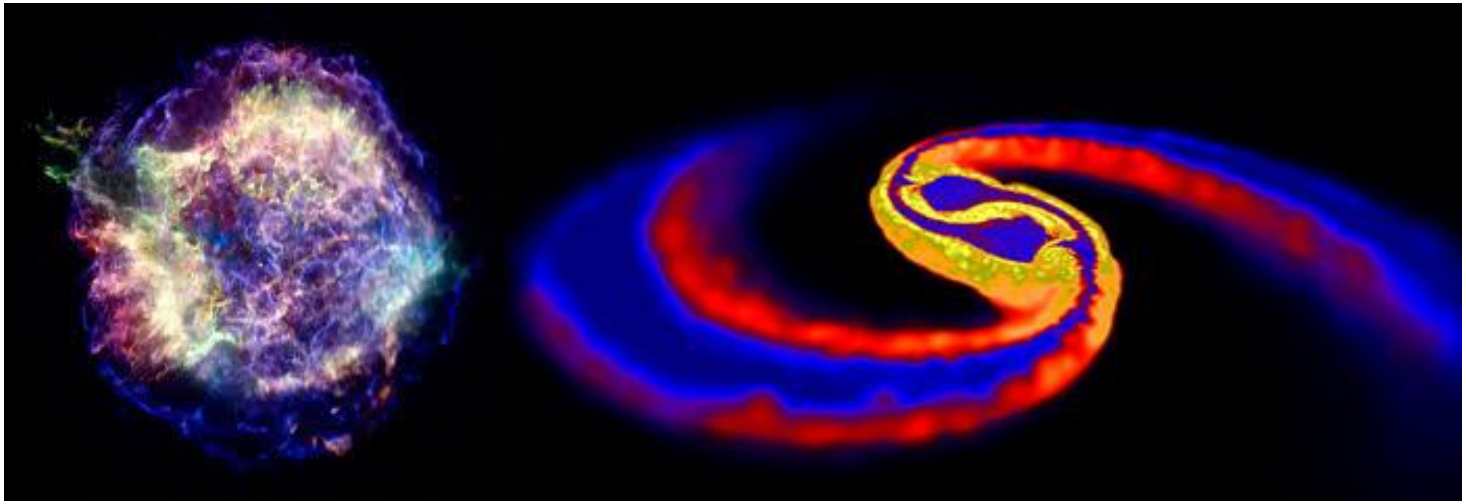
Facility for Rare Isotope Beams: 2022
Michigan State University

R-պրոցես

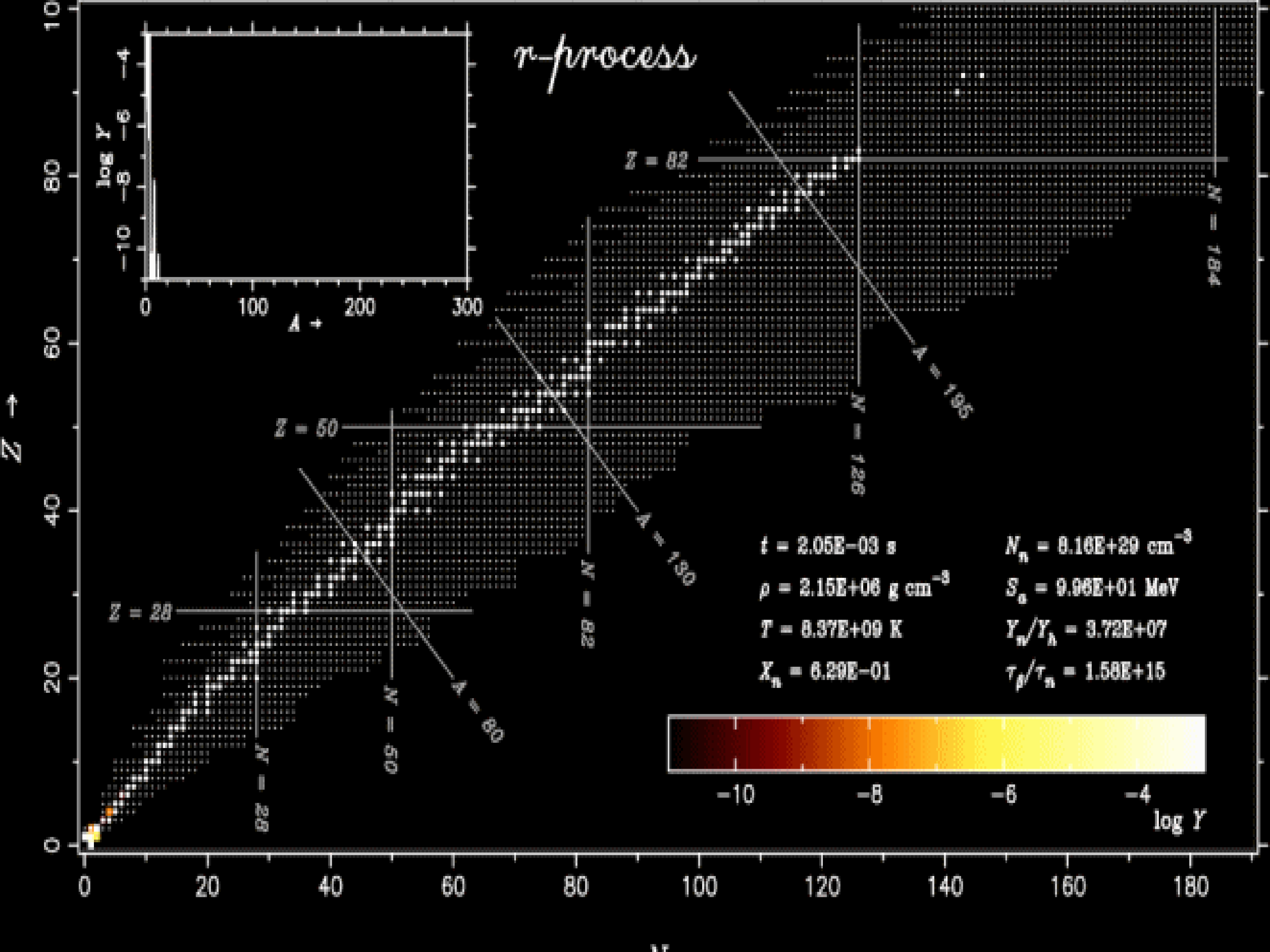
Cowan et al. 2011



Origin of more than 50% of all the elements beyond iron



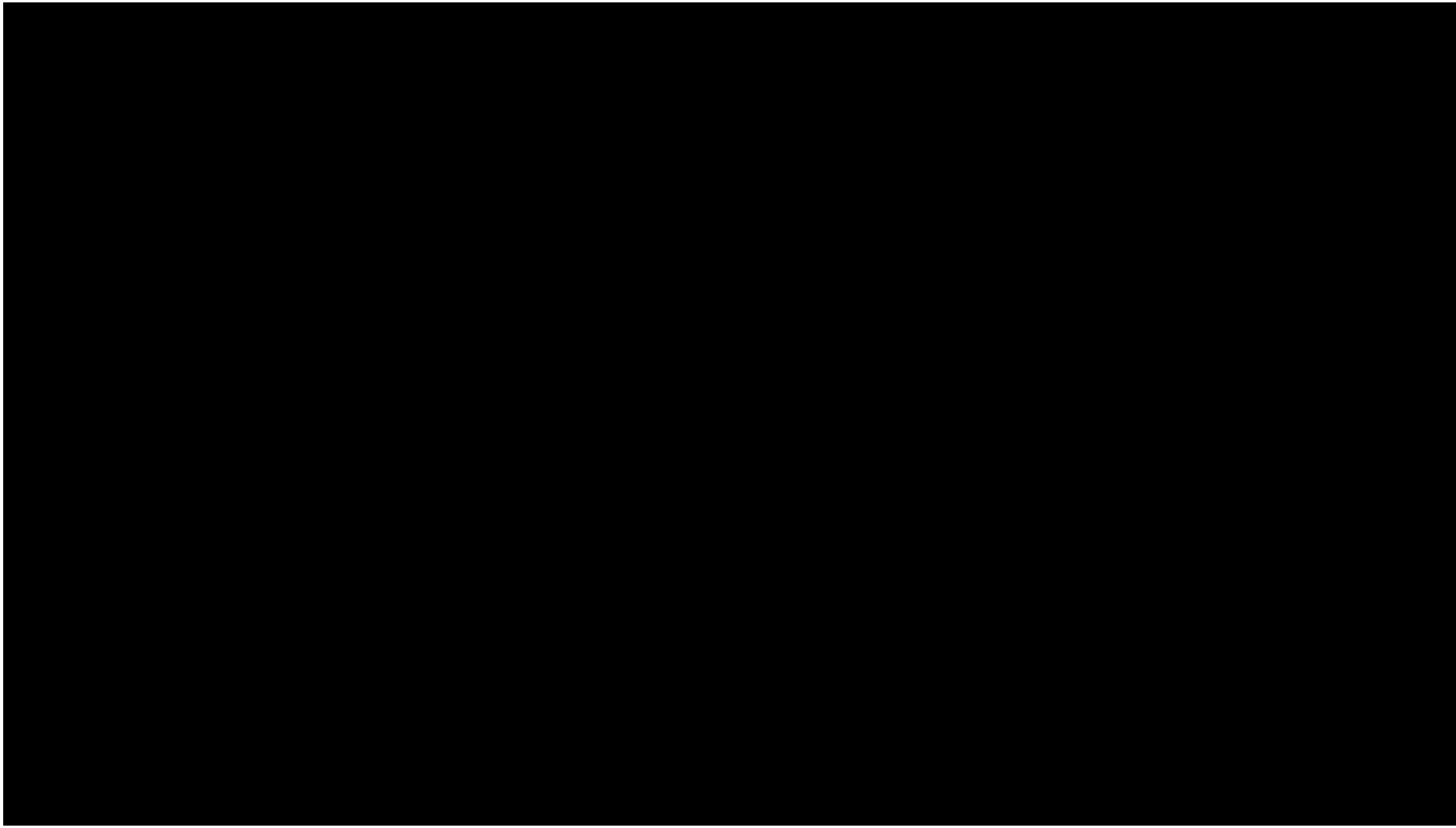
Temperature, density as a function of time, initial compositions, neutrons



r-process
Z = 82
Z = 50
Z = 28
N = 28
N = 50
N = 82
N = 126
N = 184
A = 80
A = 130
A = 195
t = 2.05E-03 s
ρ = 2.15E+06 g cm⁻³
T = 8.37E+09 K
X_n = 6.29E-01
N_n = 8.16E+29 cm⁻³
S_n = 9.96E+01 MeV
Y_n/Y_h = 3.72E+07
τ_β/τ_n = 1.58E+15
log Y
Z →
A →

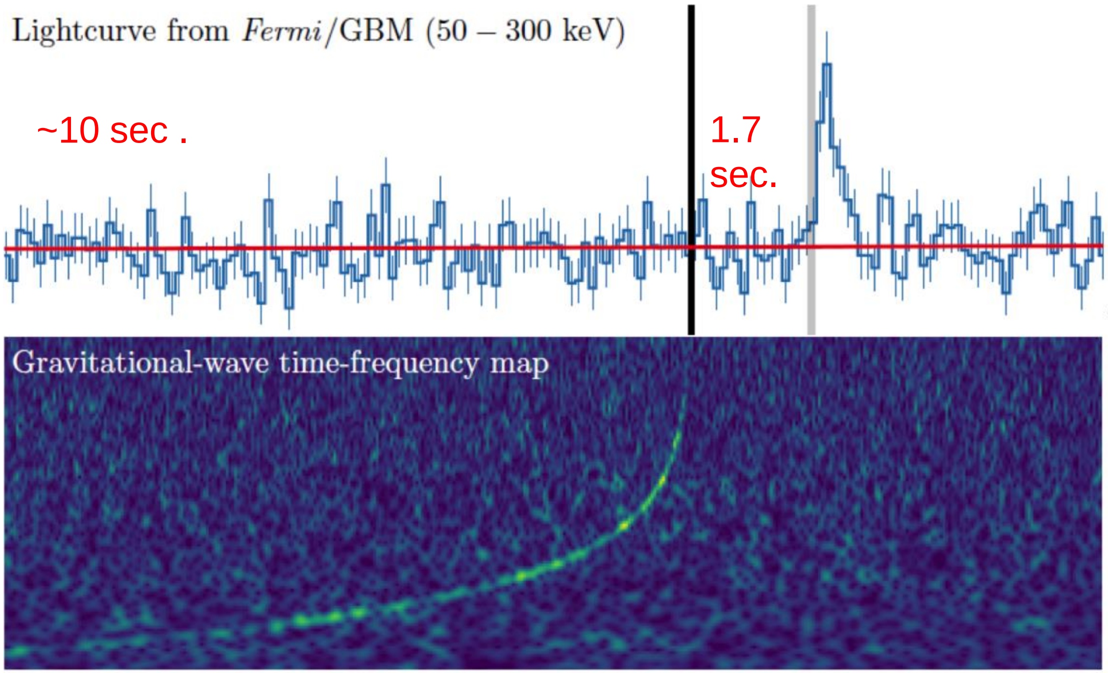
Neutron star – neutron star merger observed on 17 Aug. 2017

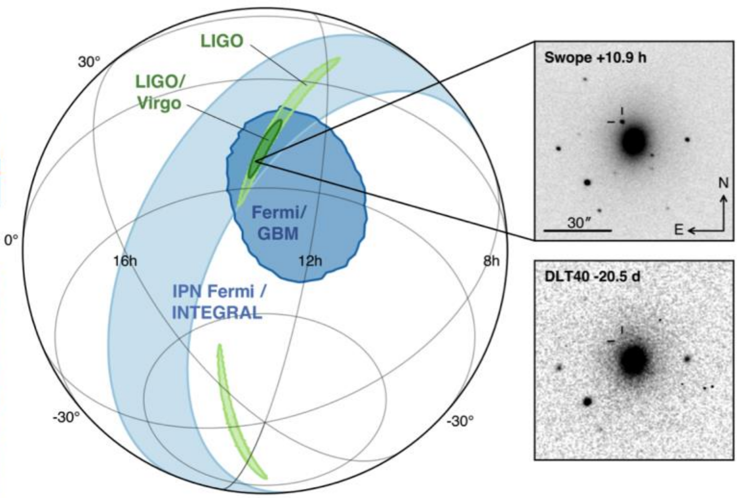
by LIGO and Virgo (gravitational radiation), FERMI (gamma ray telescope) and ~ 70 other electromagnetic observatories.



Neutron star – neutron star merger observed on 17 Aug. 2017 by LIGO and Virgo (gravitational radiation), FERMI (gamma ray telescope) and ~ 70 other electromagnetic observatories.

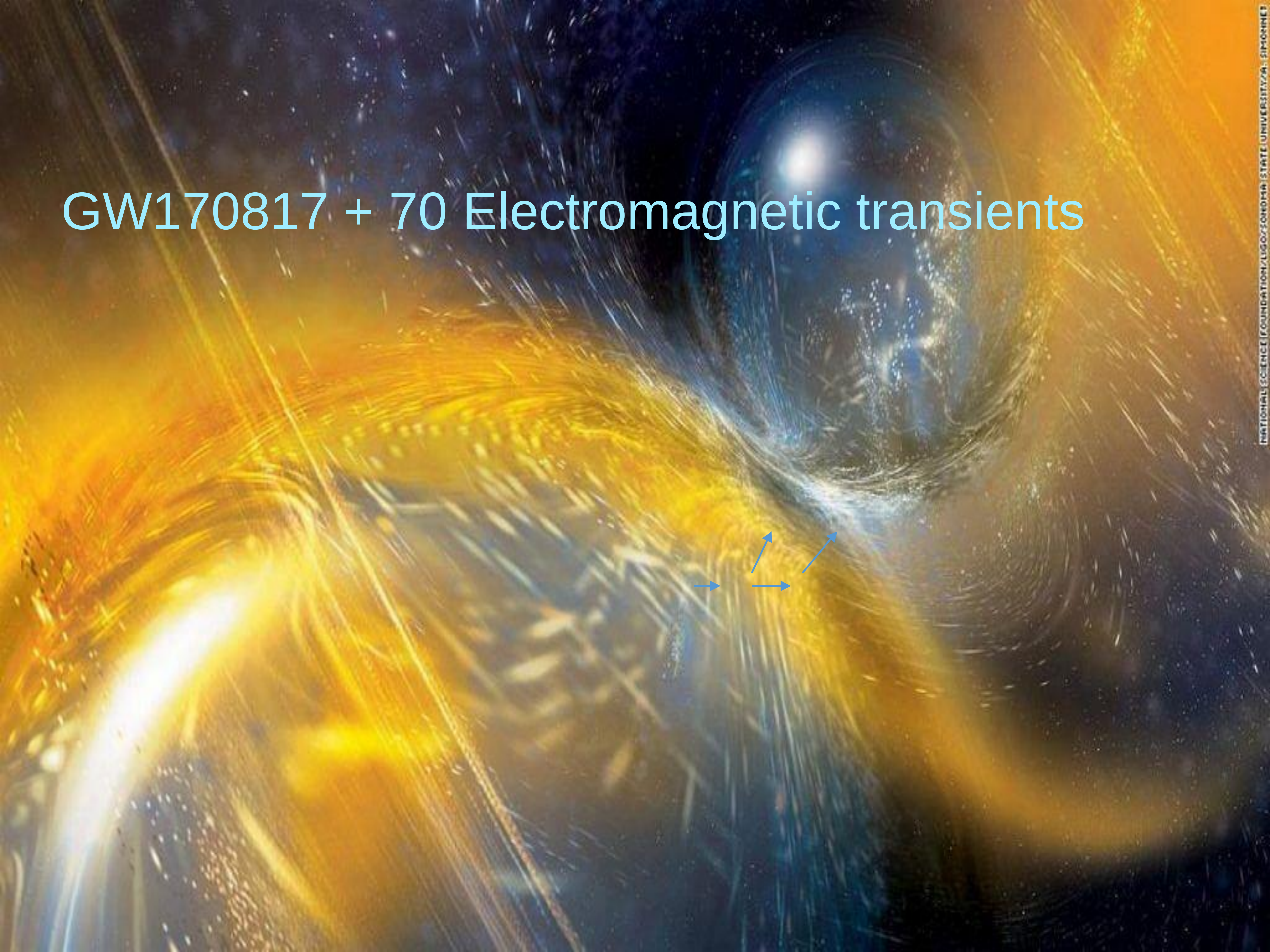
LIGO, Virgo, and partners make first detection of gravitational waves and light from colliding neutron stars



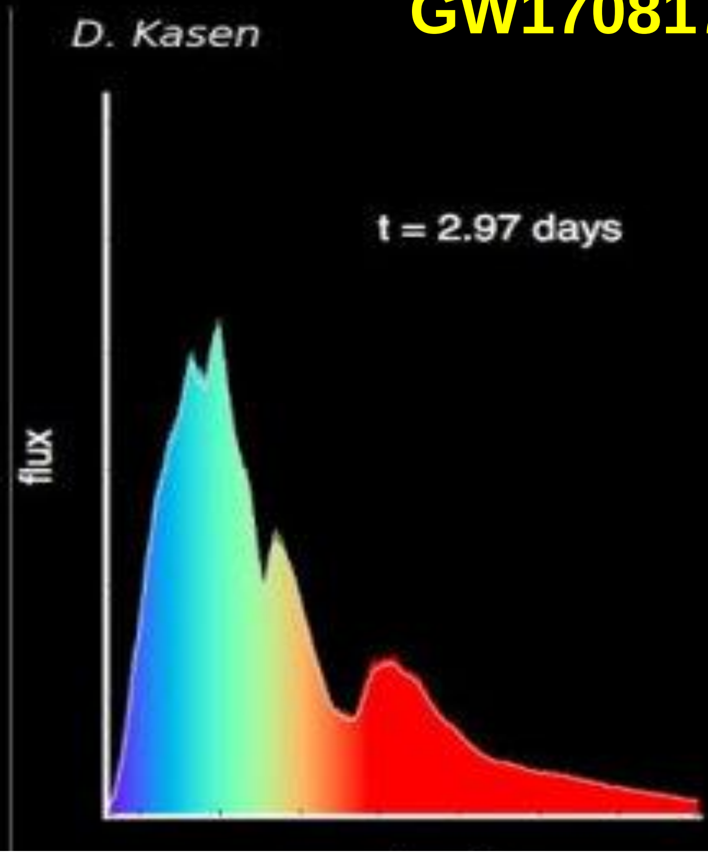


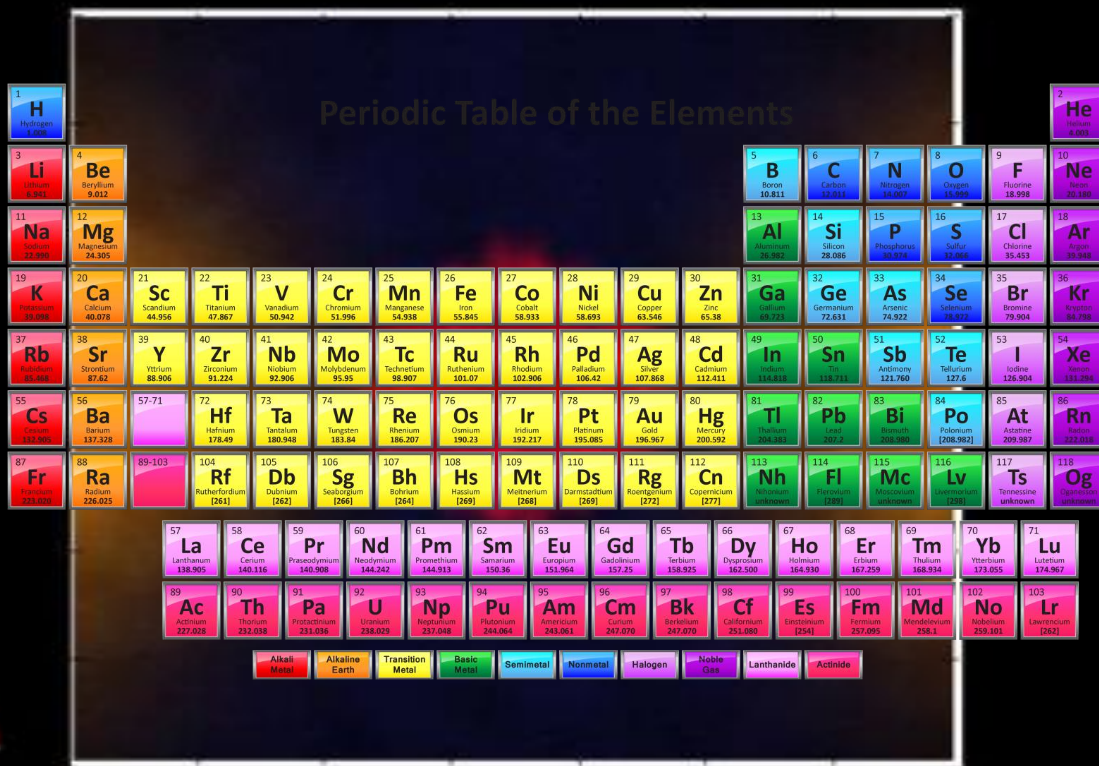
In galaxy NGC 4993

GW170817 + 70 Electromagnetic transients



GW170817 ₮0 Electromagnetic Transients

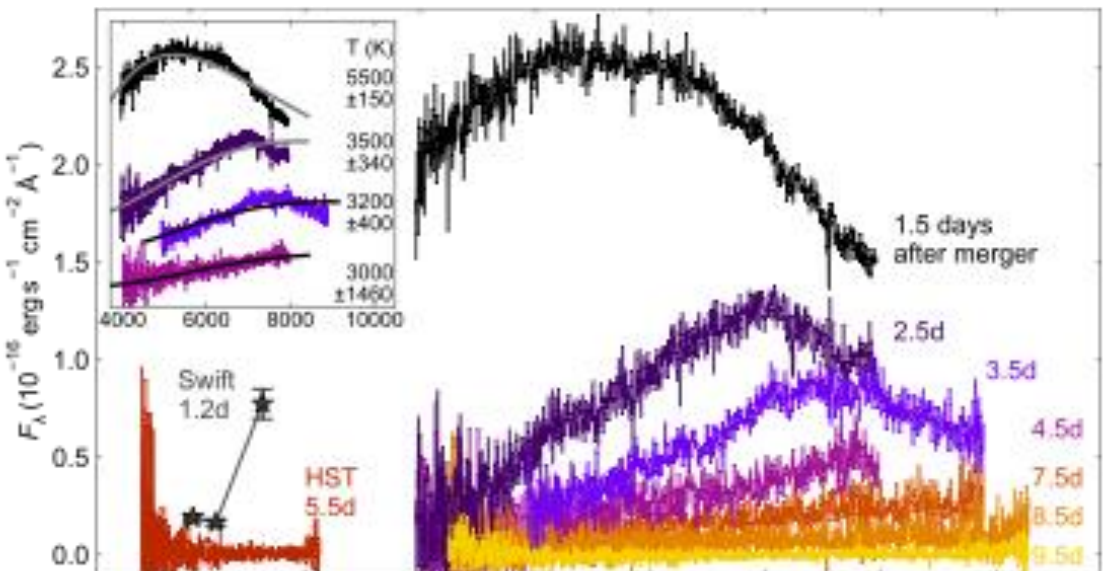




The Astrophysical Journal Letters, 848:L18 (8pp), 2017 October 20

Implications for nuclear physics

LIGO, VIRGO, GAGRA began new observation run on May 24, 2023

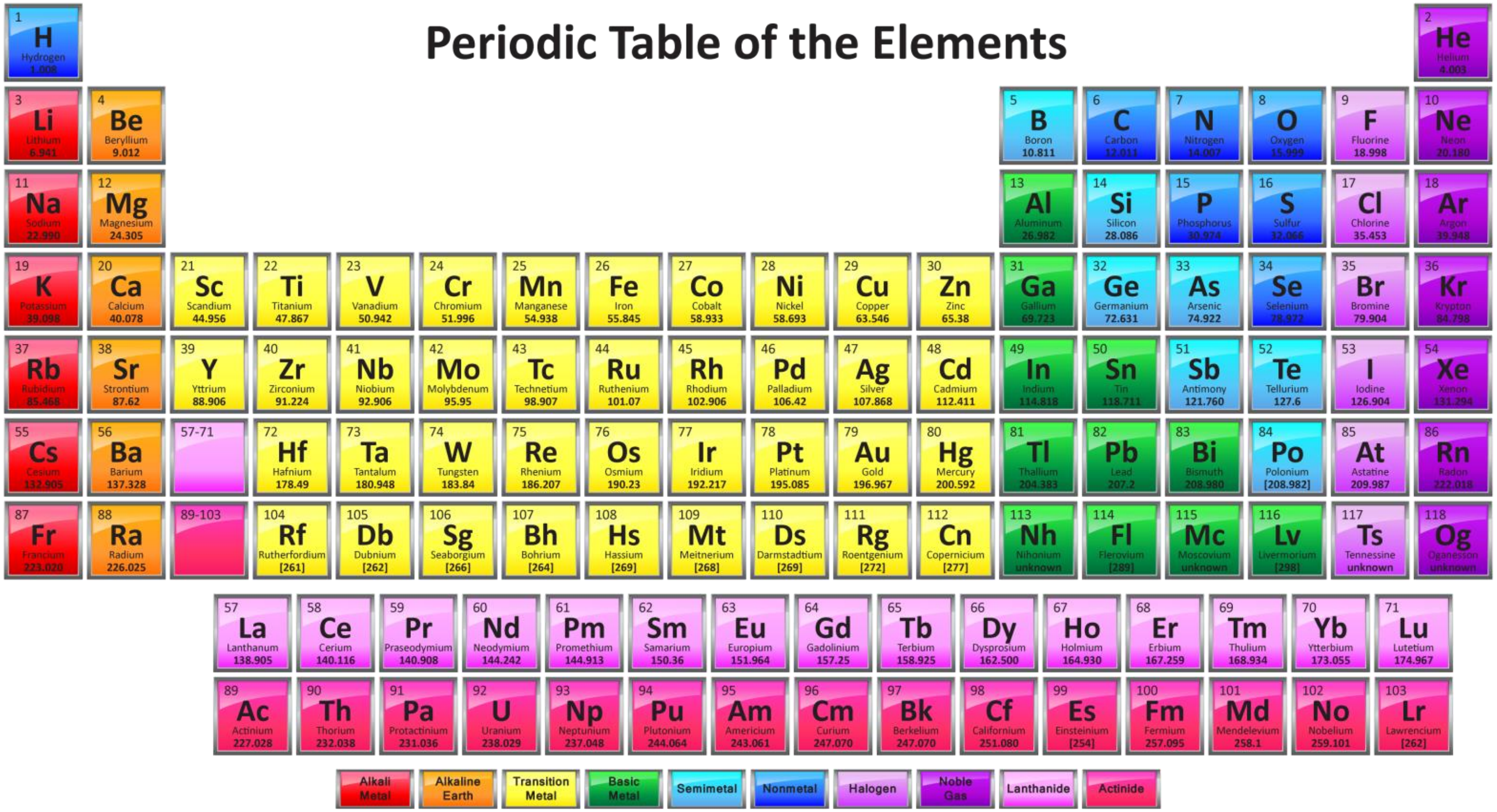


THE ASTROPHYSICAL JOURNAL LETTERS, 848:L18 (8pp), 2017 October 20

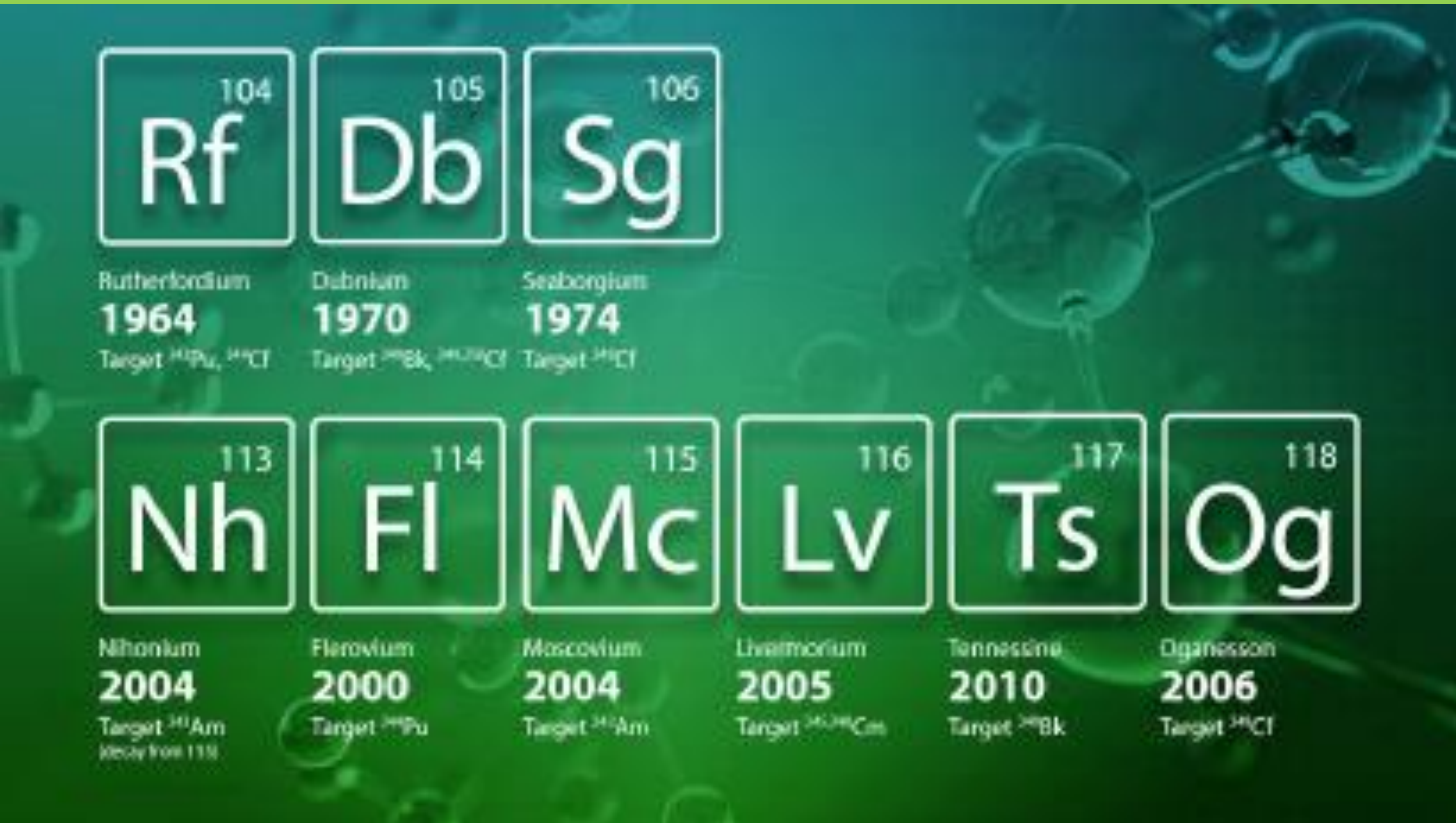
Lu visible signatures go into the IR

James Webb

ինֆրակարմիր

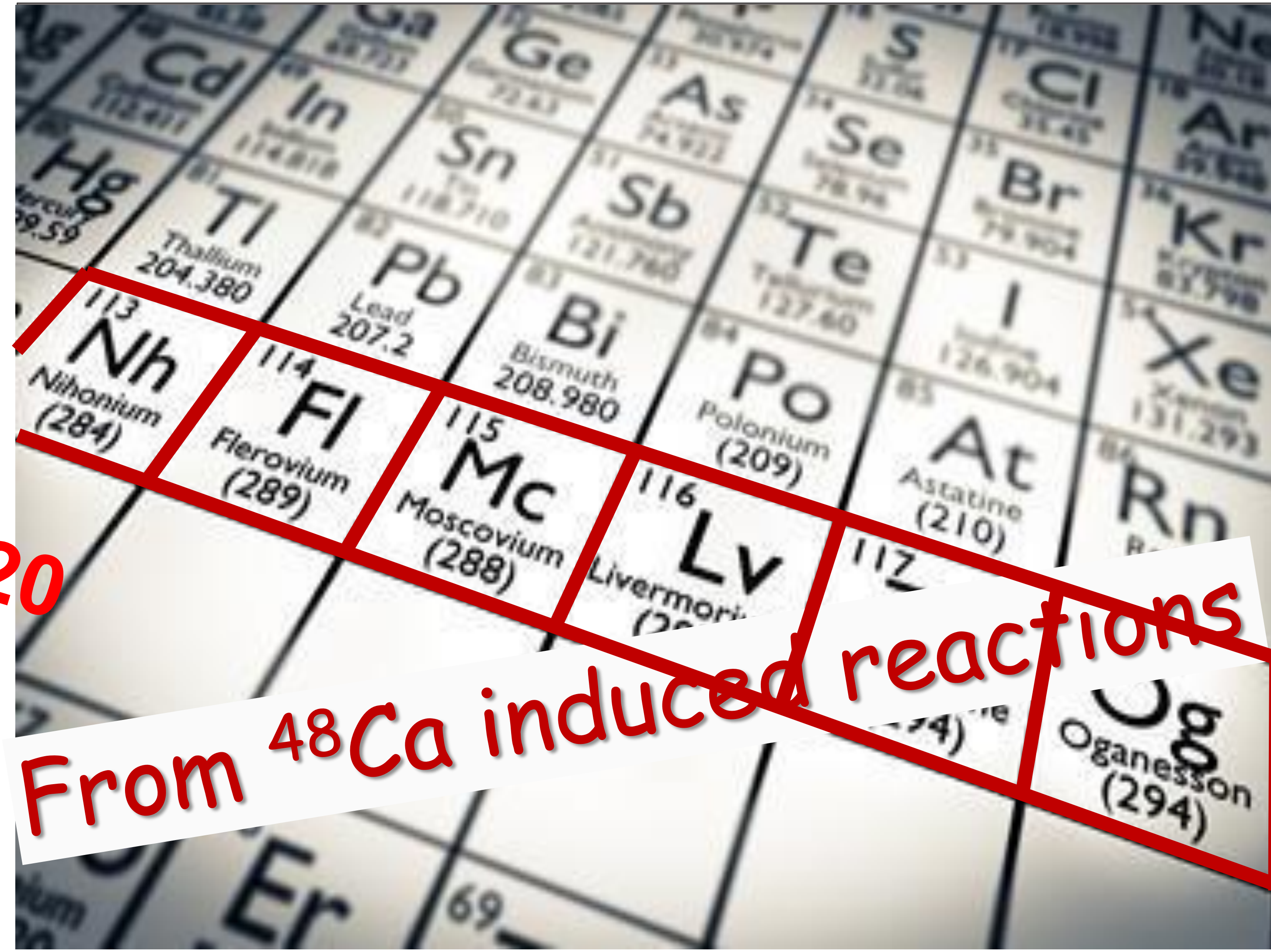


Are there more elements?


104
Rf
105
Db
106
Sg
Rutherfordium
1964
Target Pu, Cf
Dubnium
1970
Target Bk, Cf
Seaborgium
1974
Target Cf
113
Nh
114
Fl
115
Mc
116
Lv
117
Ts
118
Og
Nihonium
2004
Target Am
(decay from 115)
Flerovium
2000
Target Pu
Moscovium
2004
Target Am
Livermorium
2005
Target Cm
Tennessine
2010
Target Bk
Oganesson
2006
Target Cf

Collaboration
LLNL
JINR
ORNL

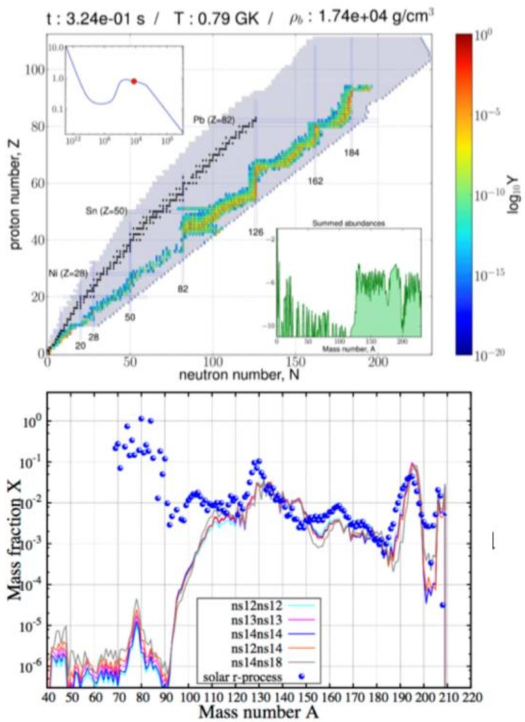
Z=120

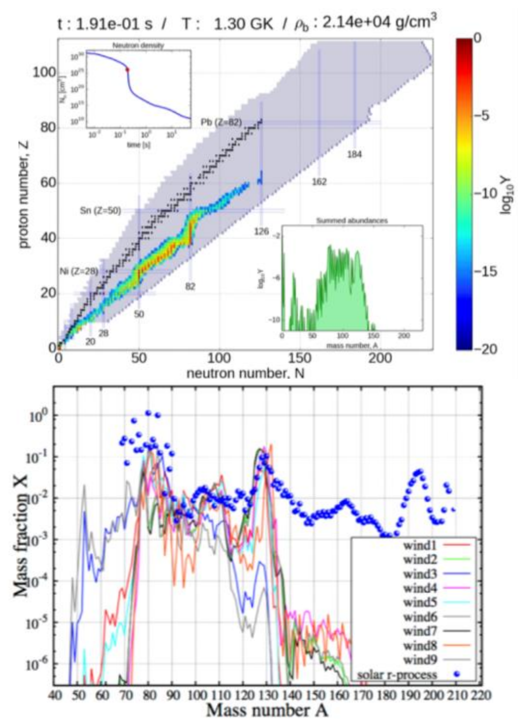


Z=174

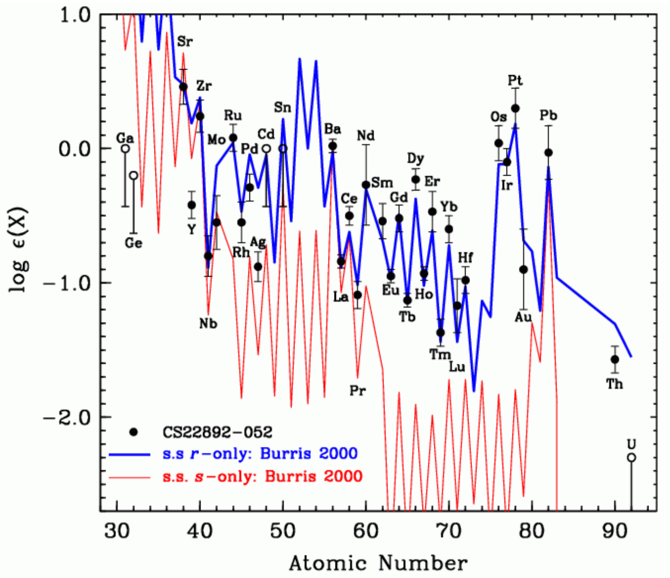
where is the site of the r-process?

Merging neutron stars versus core collapse supernovae, gravitational wave detection identified neutron star mergers as a source of the very heavy elements!

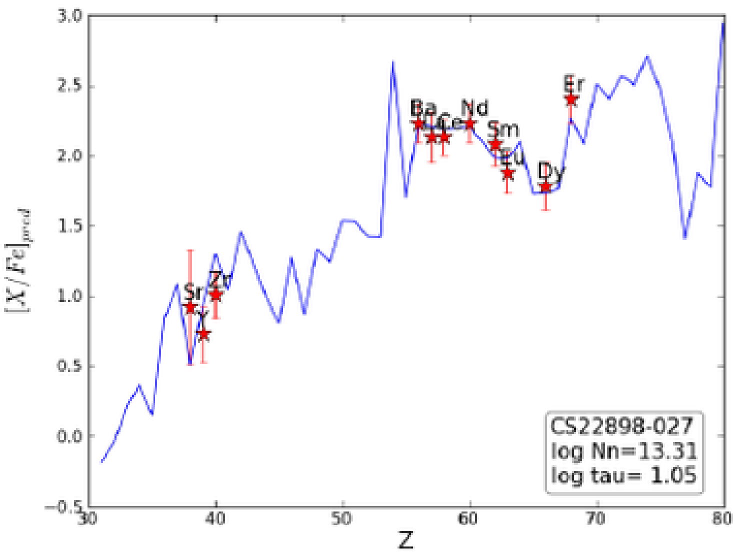




Abundances from other neutron induced nucleosynthesis processes

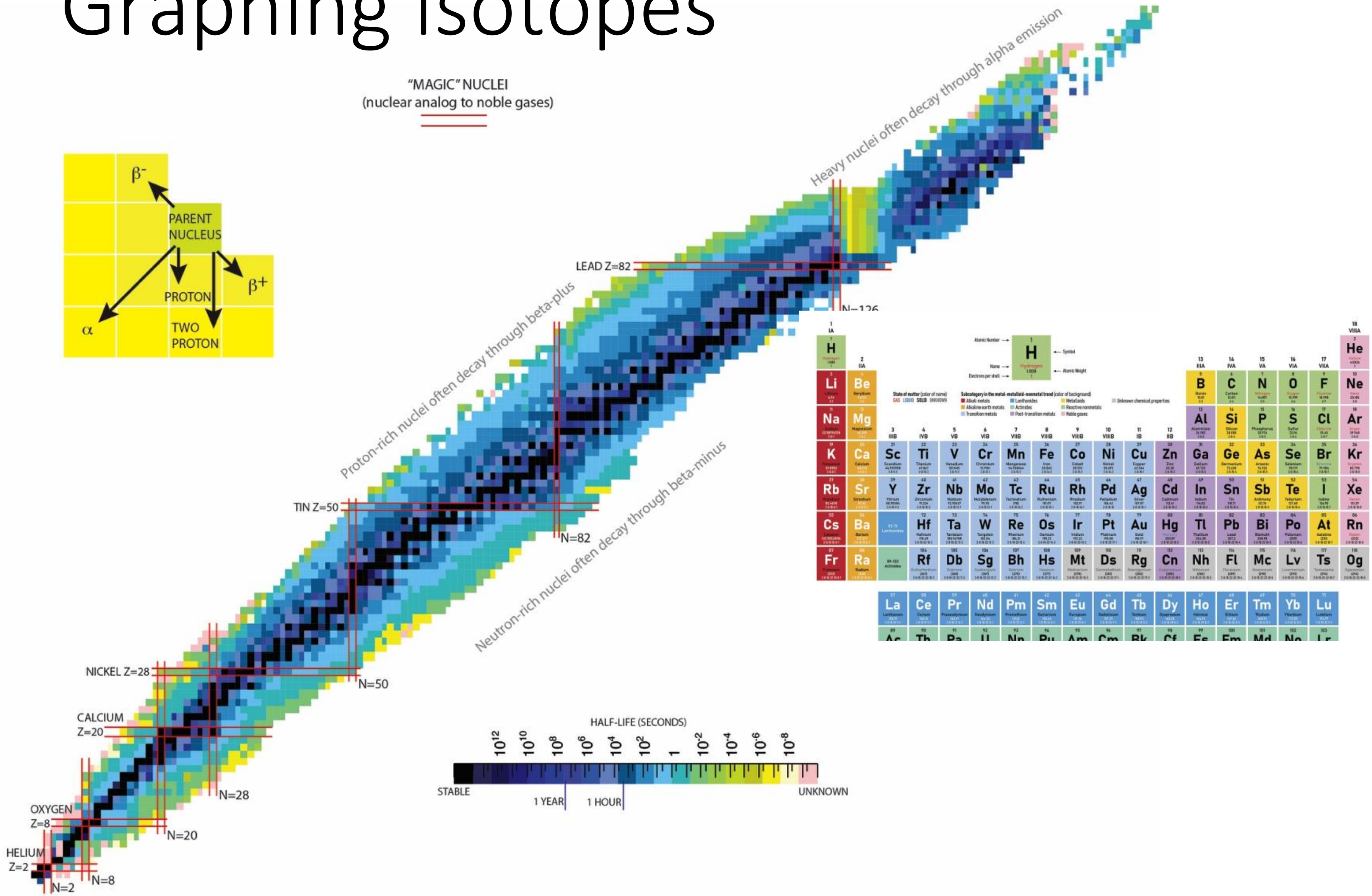


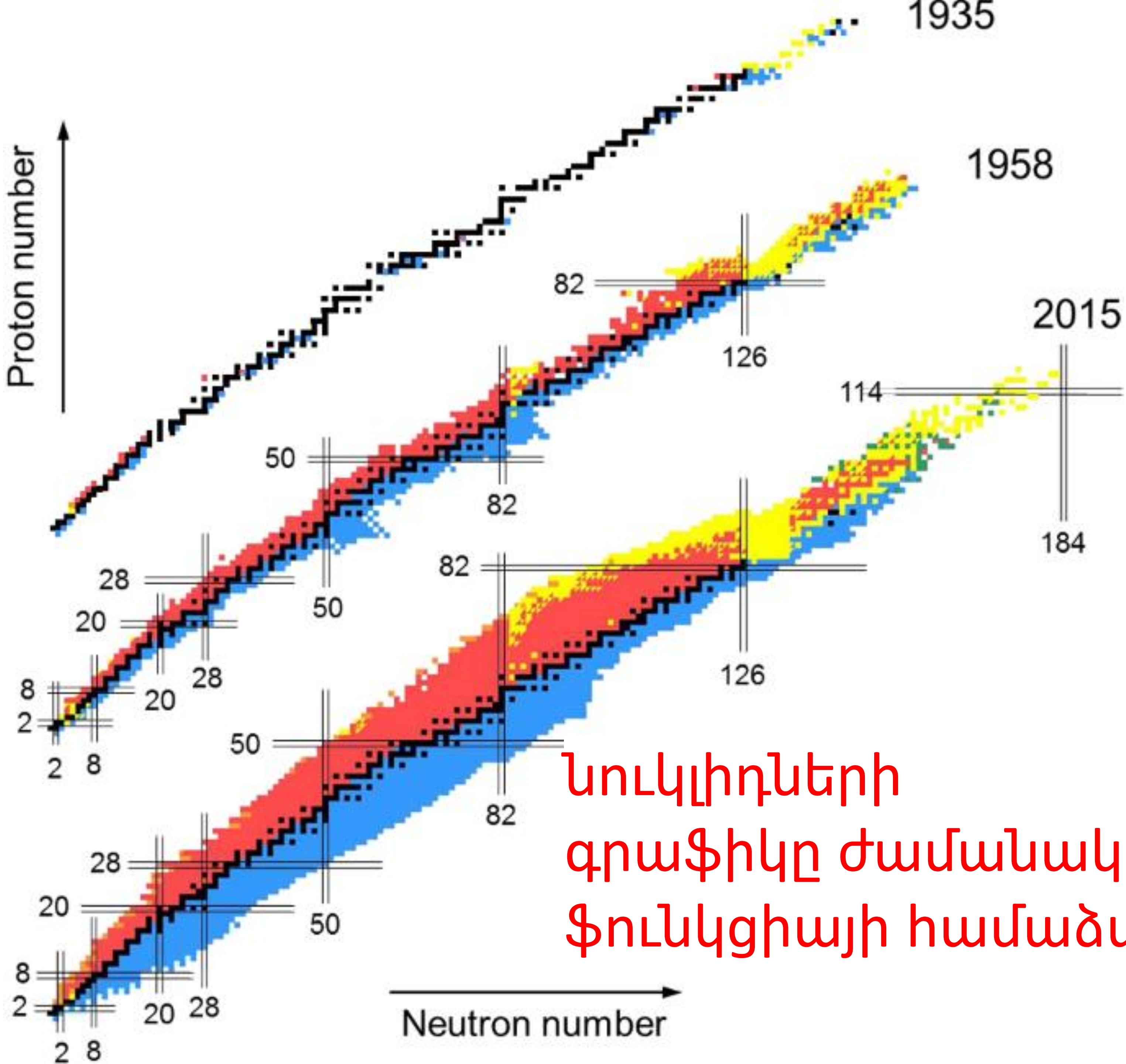
The s-process in comparison to the r-process.The scaling depends on the strength of the s-process neutron source



The i-process in CEMP stars, again the scale depends on the strength of neutron source

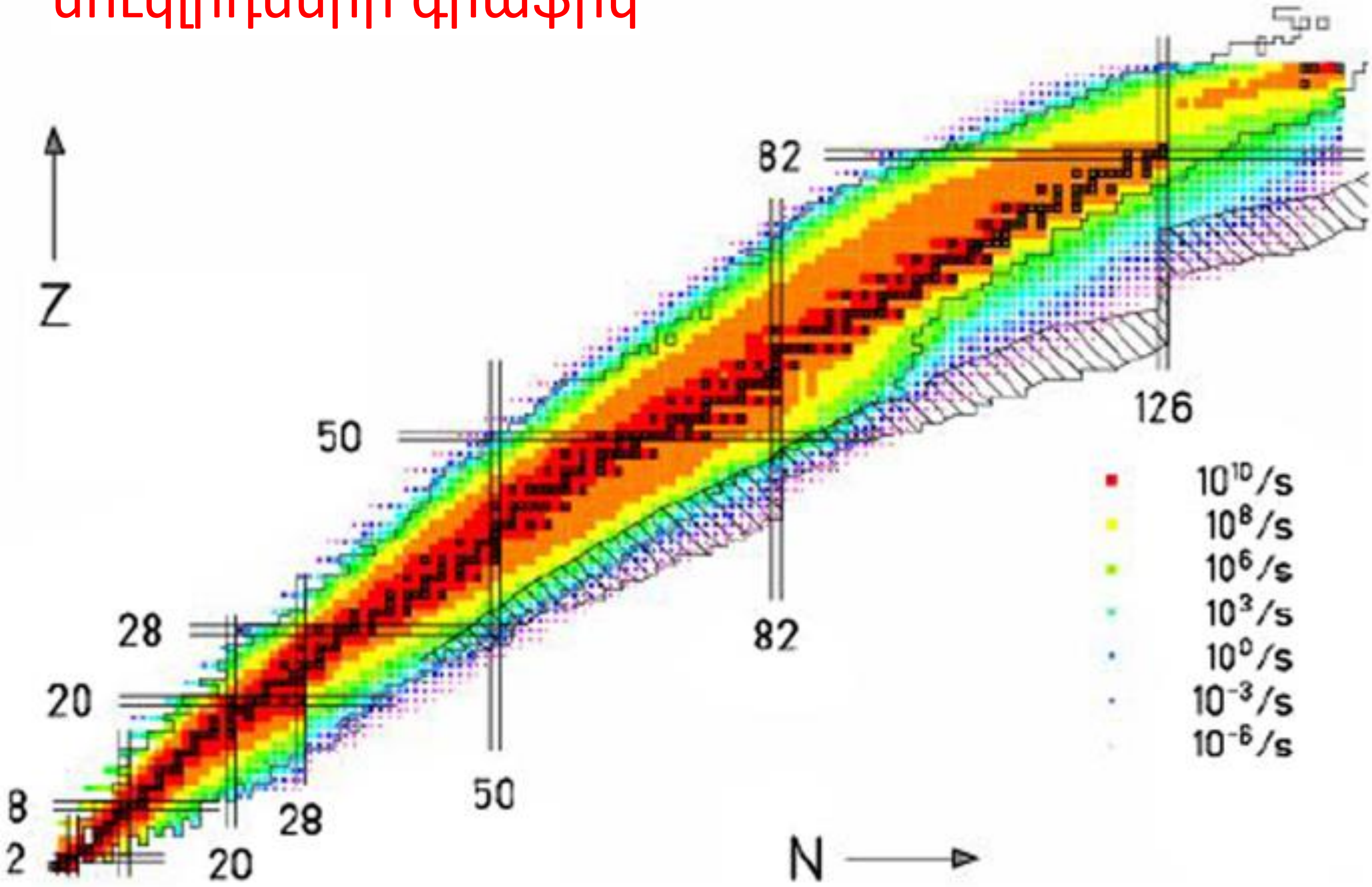
Graphing Isotopes



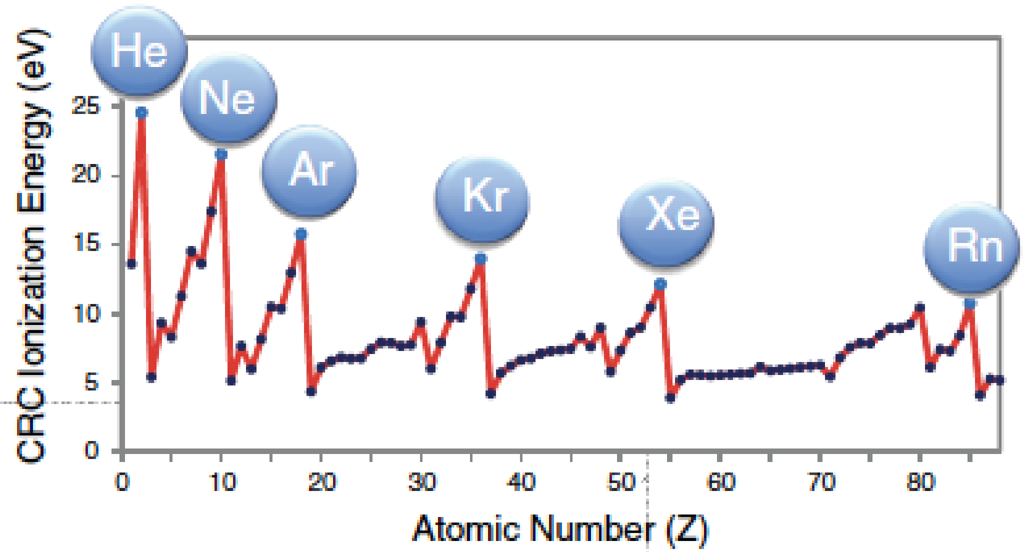


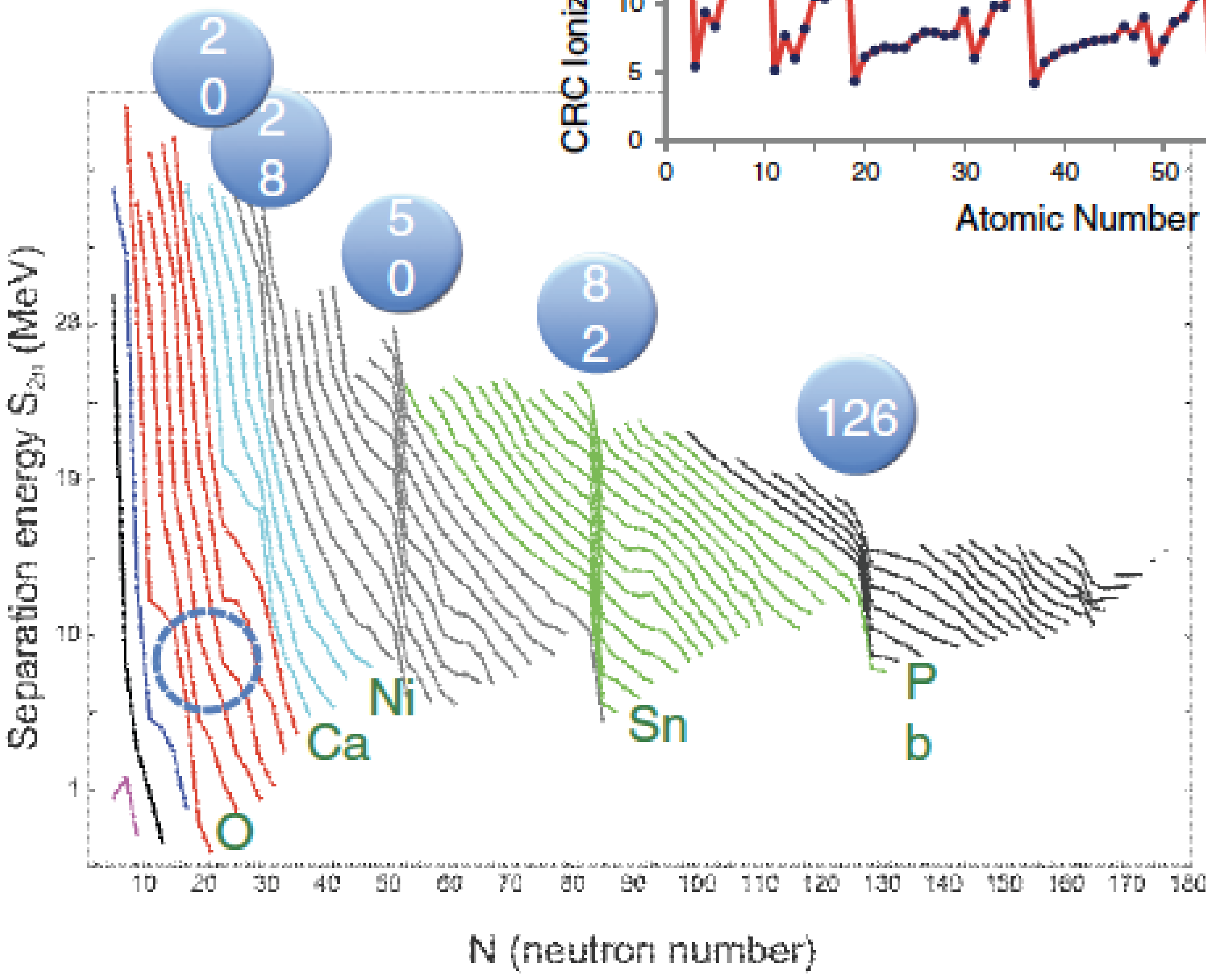
նուկլիդների գրաֆիկը ժամանակի ֆունկցիայի համաձայն

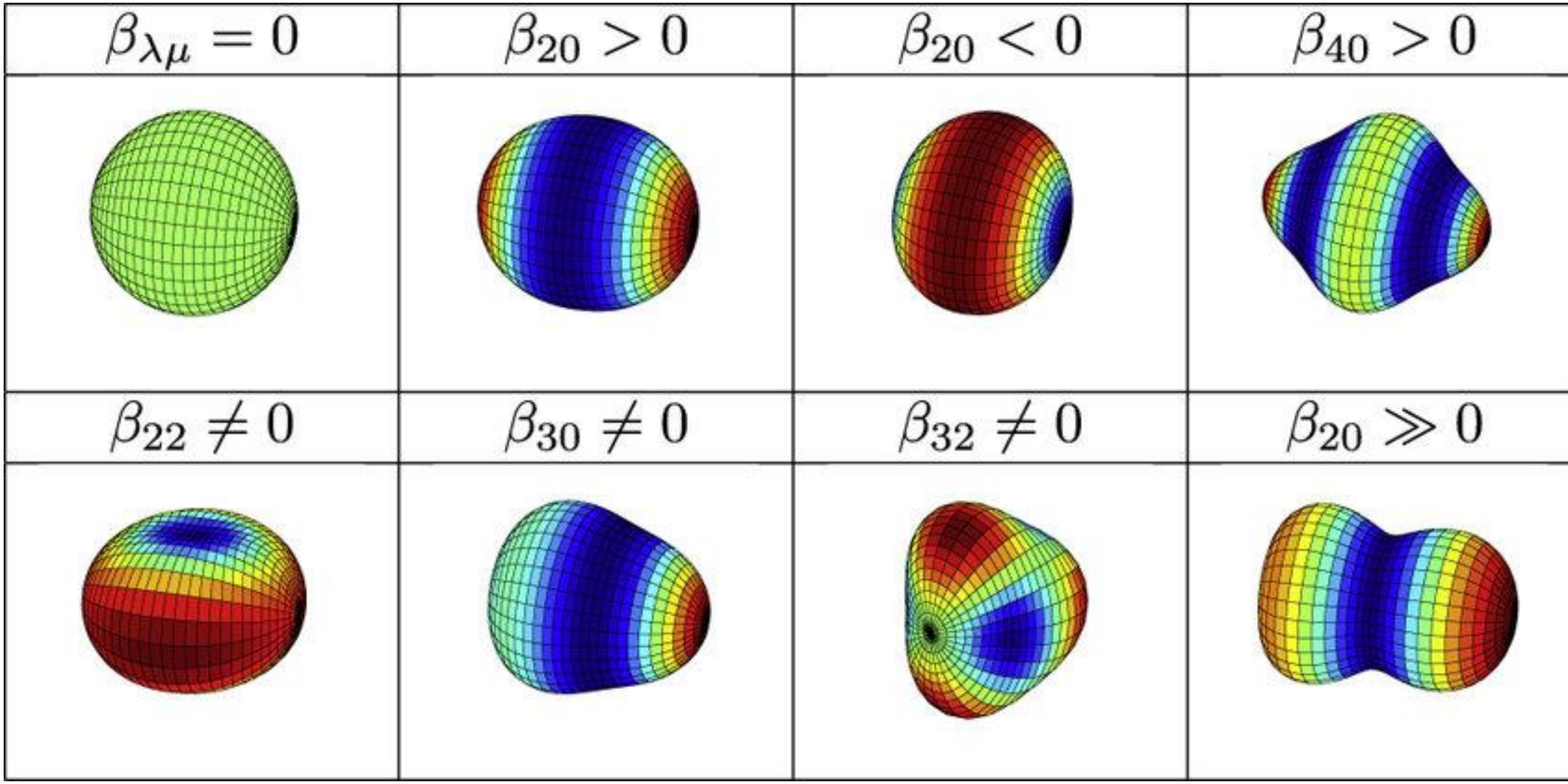
Նուկլիդների գրաֆիկ

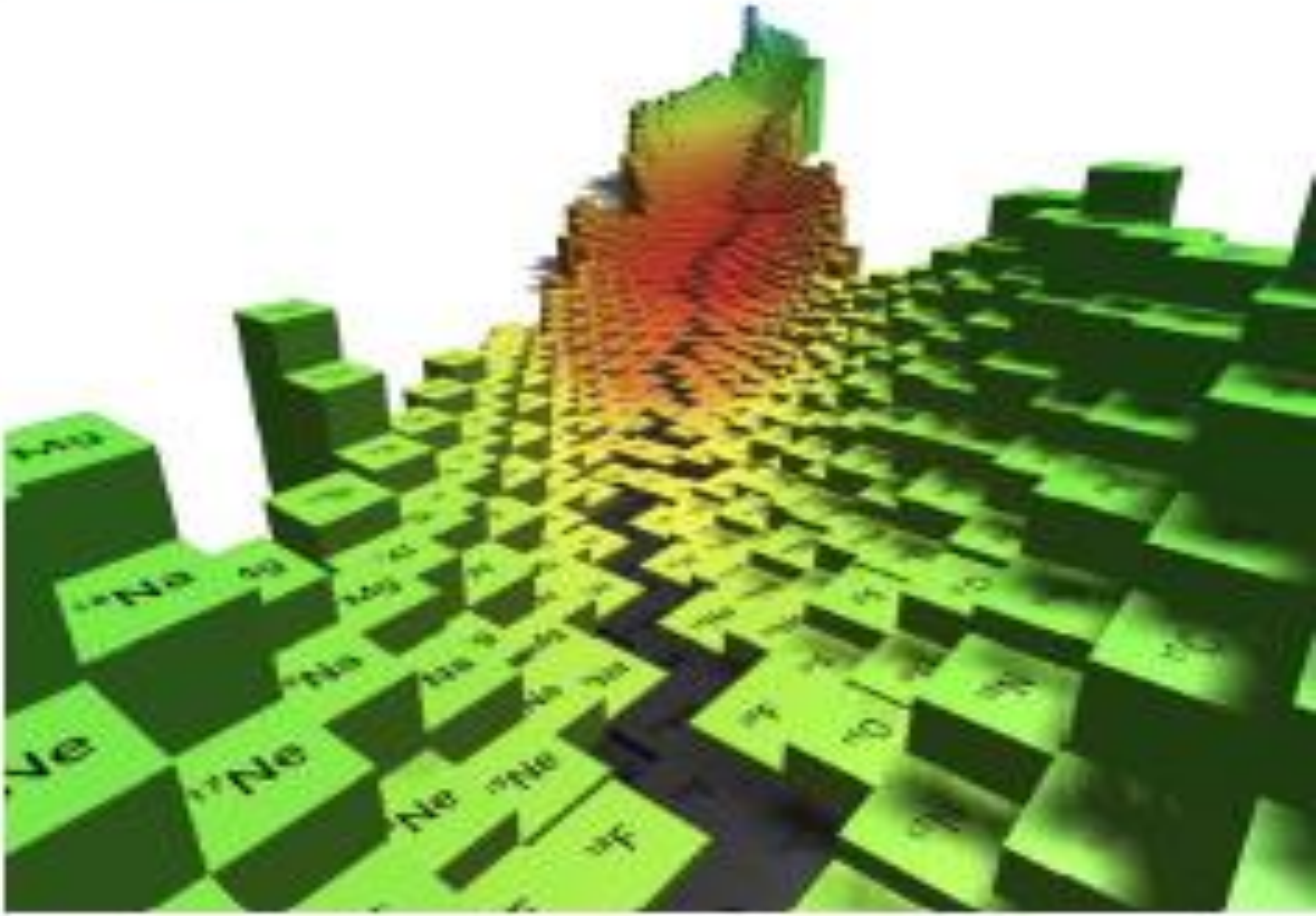


Regularities and periodicities in atoms and nuclei

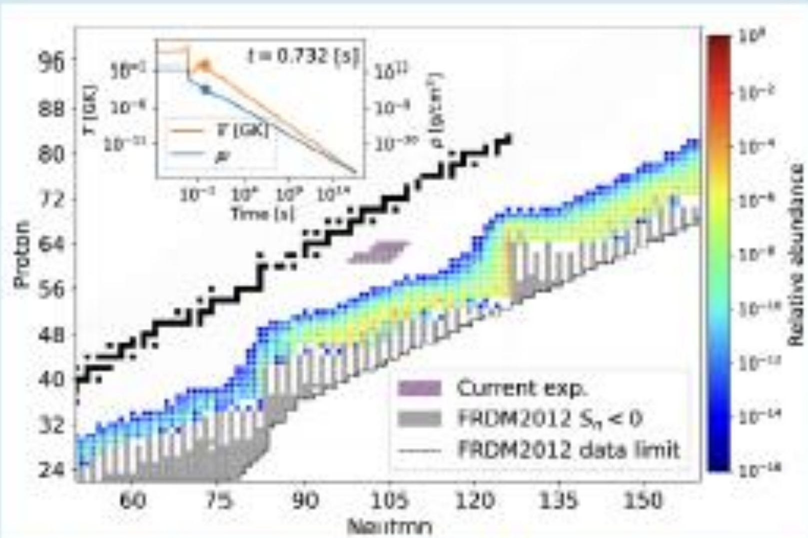





$\beta_{\lambda\mu} = 0$
$\beta_{20} > 0$
$\beta_{20} < 0$
$\beta_{40} > 0$
$\beta_{22} \neq 0$
$\beta_{30} \neq 0$
$\beta_{32} \neq 0$
$\beta_{20} \gg 0$


Mg
Na
Ne

Were the Superheavy elements made in space?

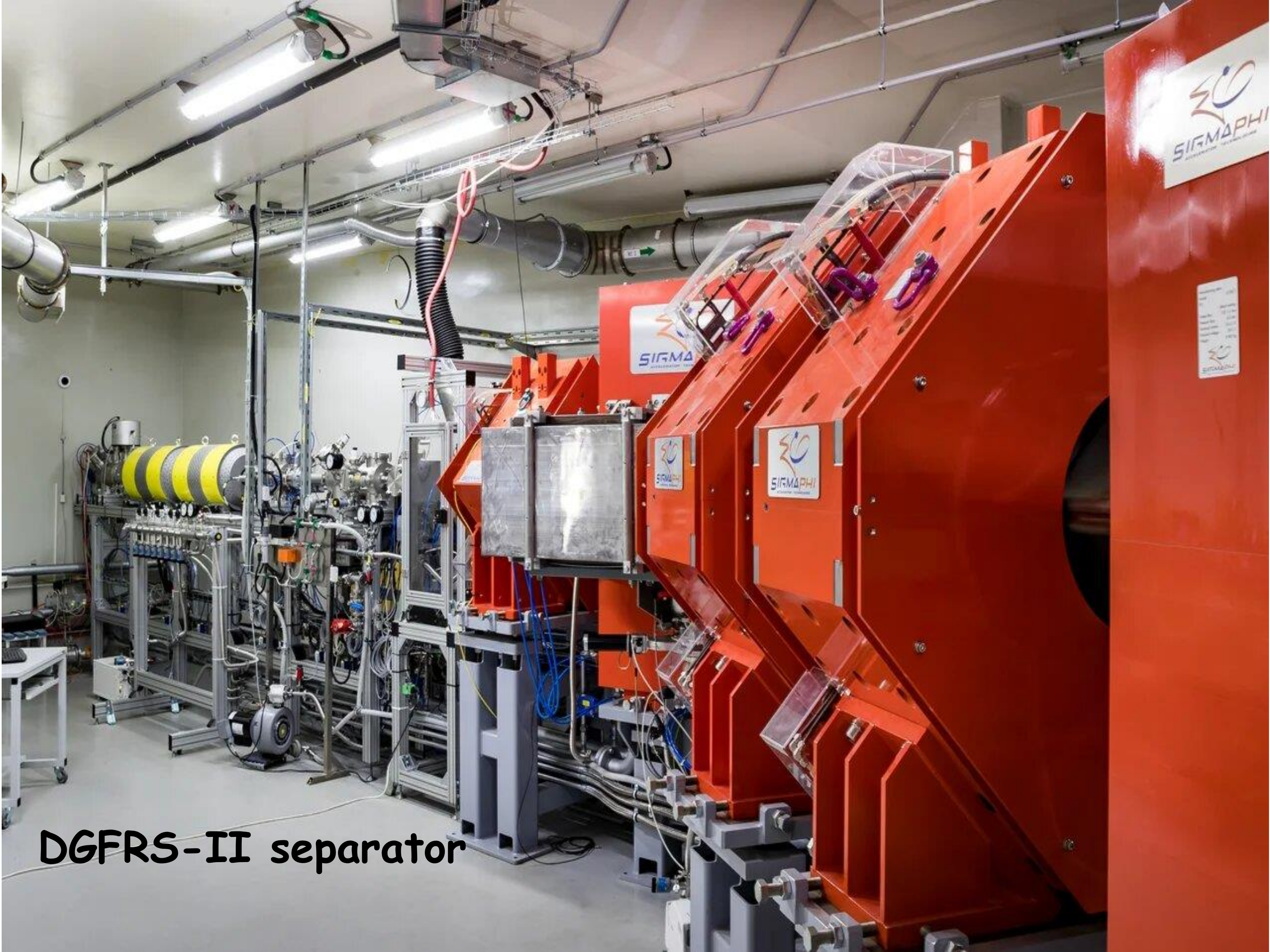


Snapshot of the r-process path in a neutron star merger scenario. Grey boxes indicate nuclei that are unbound. Purple boxes show the isotopes measured in the BRIKEN campaign [S32].

Members of the BRIKEN collaboration [S33].

August 2017, Dubna

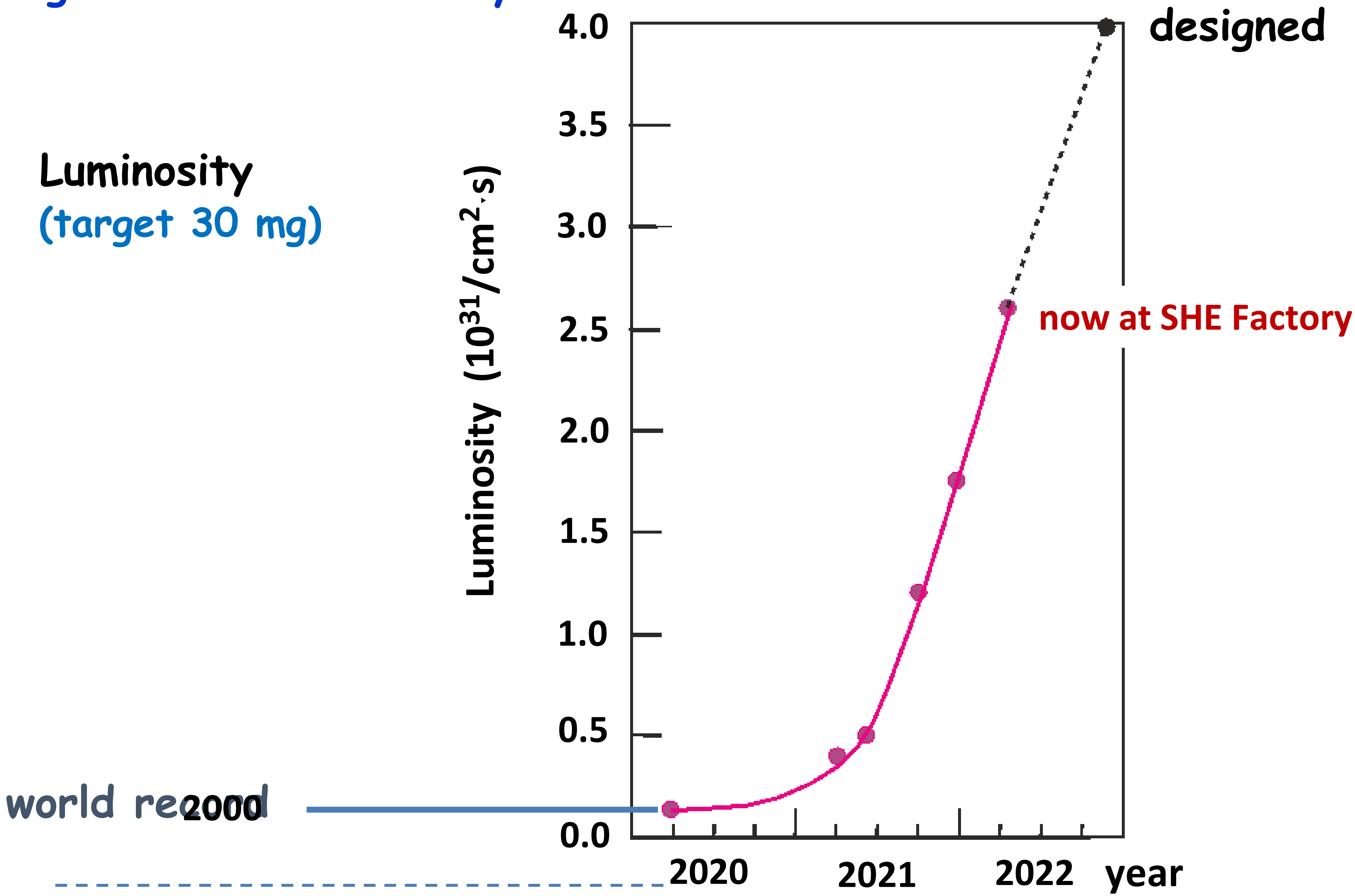

November 2018, Dubna
New cyclotron DC-280

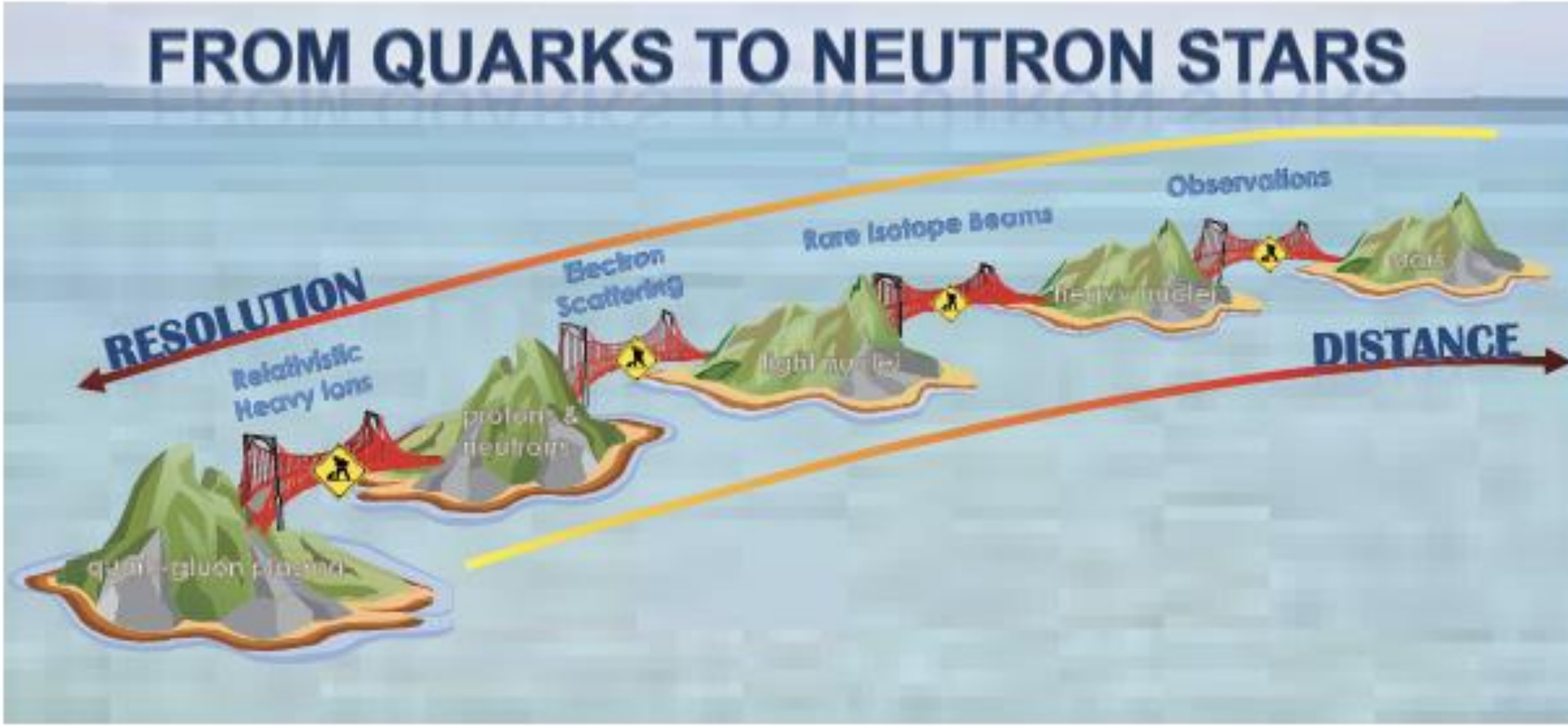


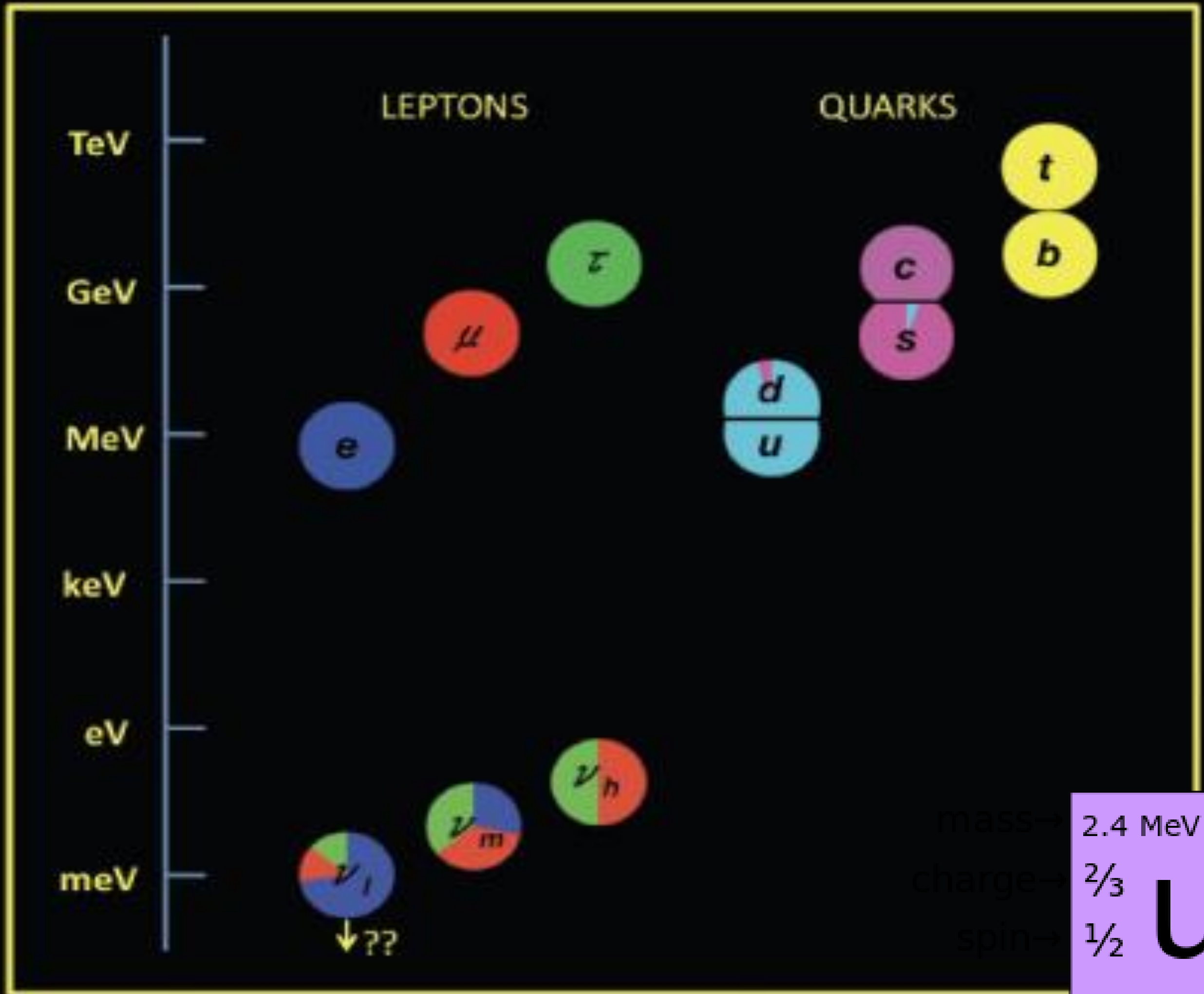
DGFRS-II separator

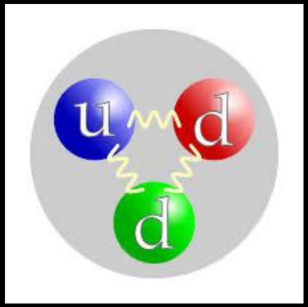
Progress at SHE-Factory

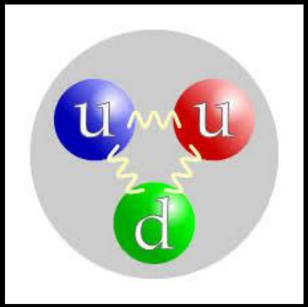
Luminosity
(target 30 mg)

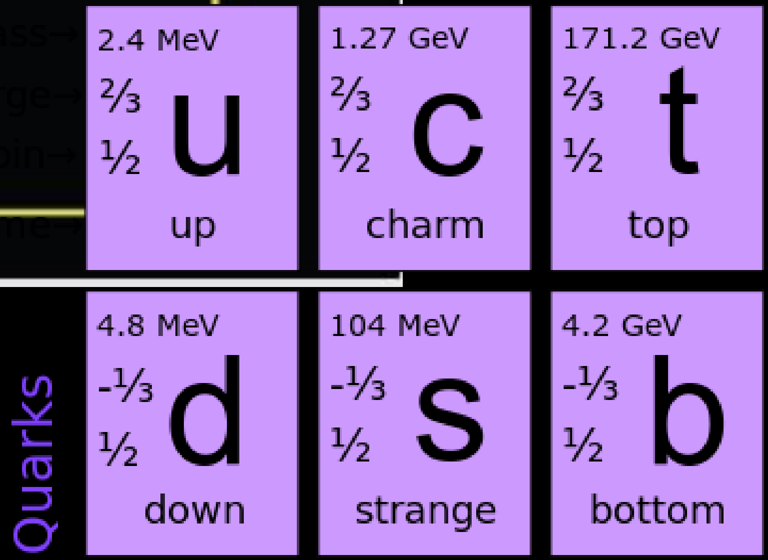


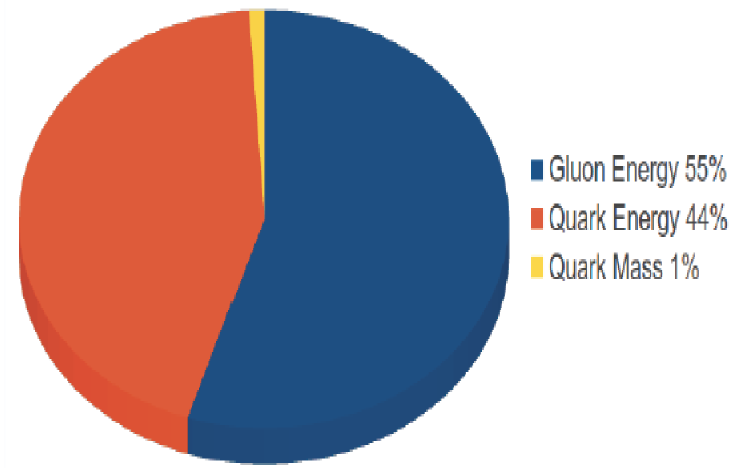

FROM QUARKS TO NEUTRON STARS
RESOLUTION
DISTANCE
Relativistic Heavy Ions
Electron Scattering
Rare Isotope Beams
Observations

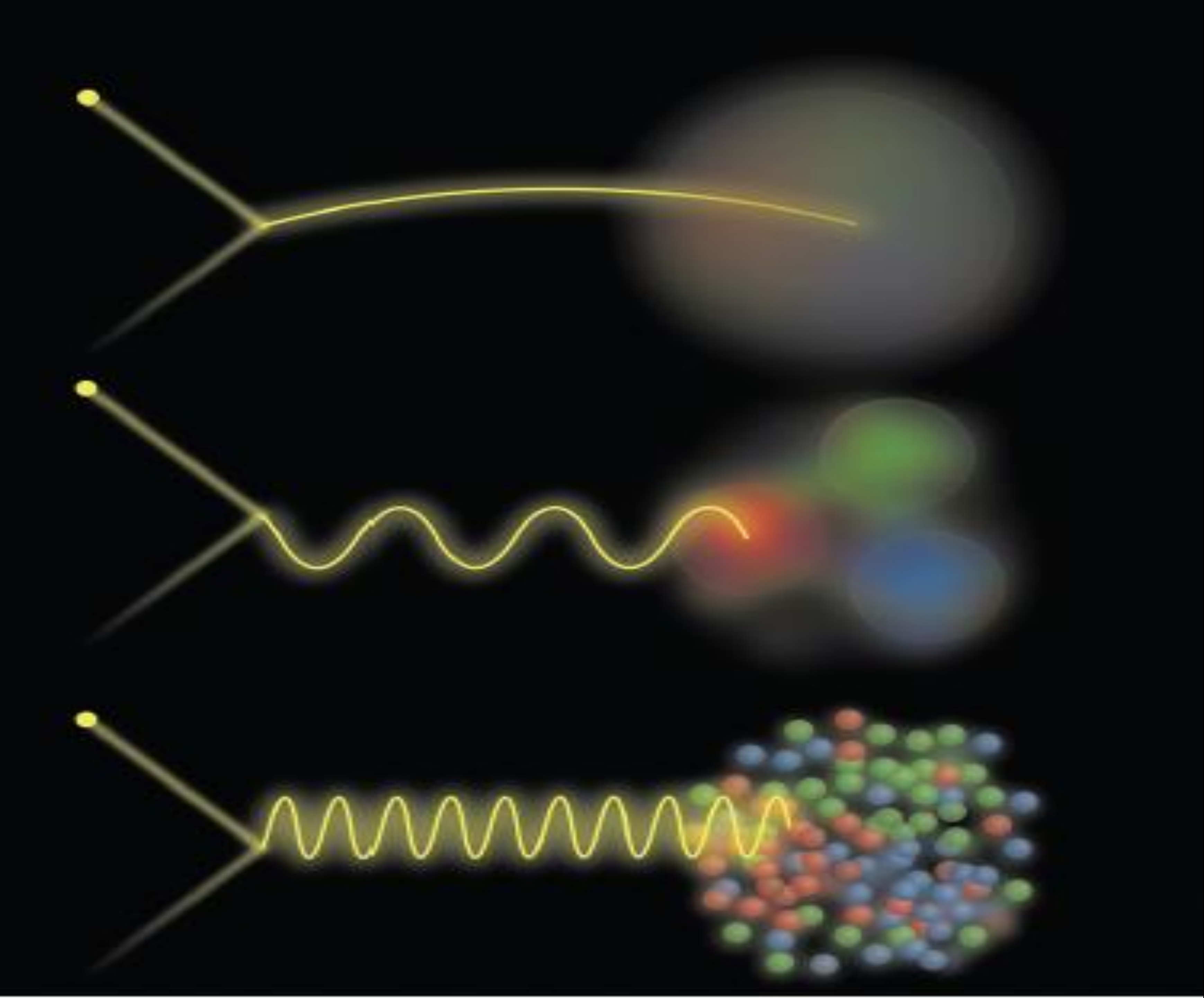

LEPTONS
QUARKS
TeV
GeV
MeV
keV
eV
meV
??

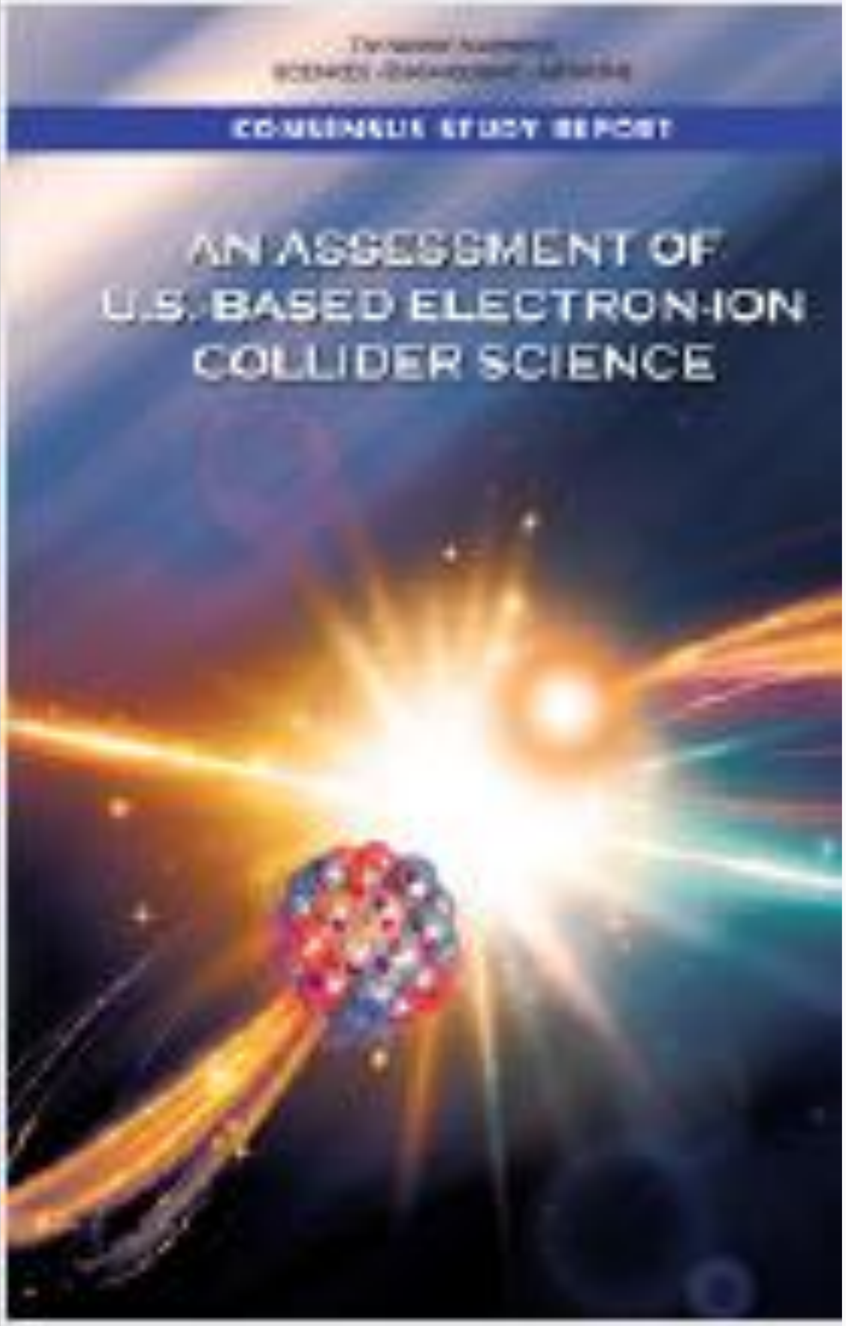

u
d
d


u
u
d

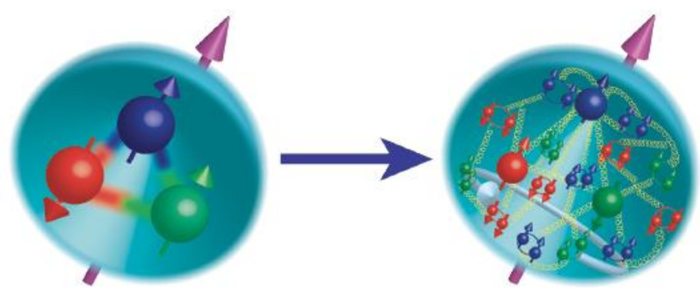

2.4 MeV
⅔
½
u
up
1.27 GeV
⅔
½
c
charm
171.2 GeV
⅔
½
t
top
4.8 MeV
-⅓
½
d
down
104 MeV
-⅓
½
s
strange
4.2 GeV
-⅓
½
b
bottom
Quarks


Gluon Energy 55%
Quark Energy 44%
Quark Mass 1%

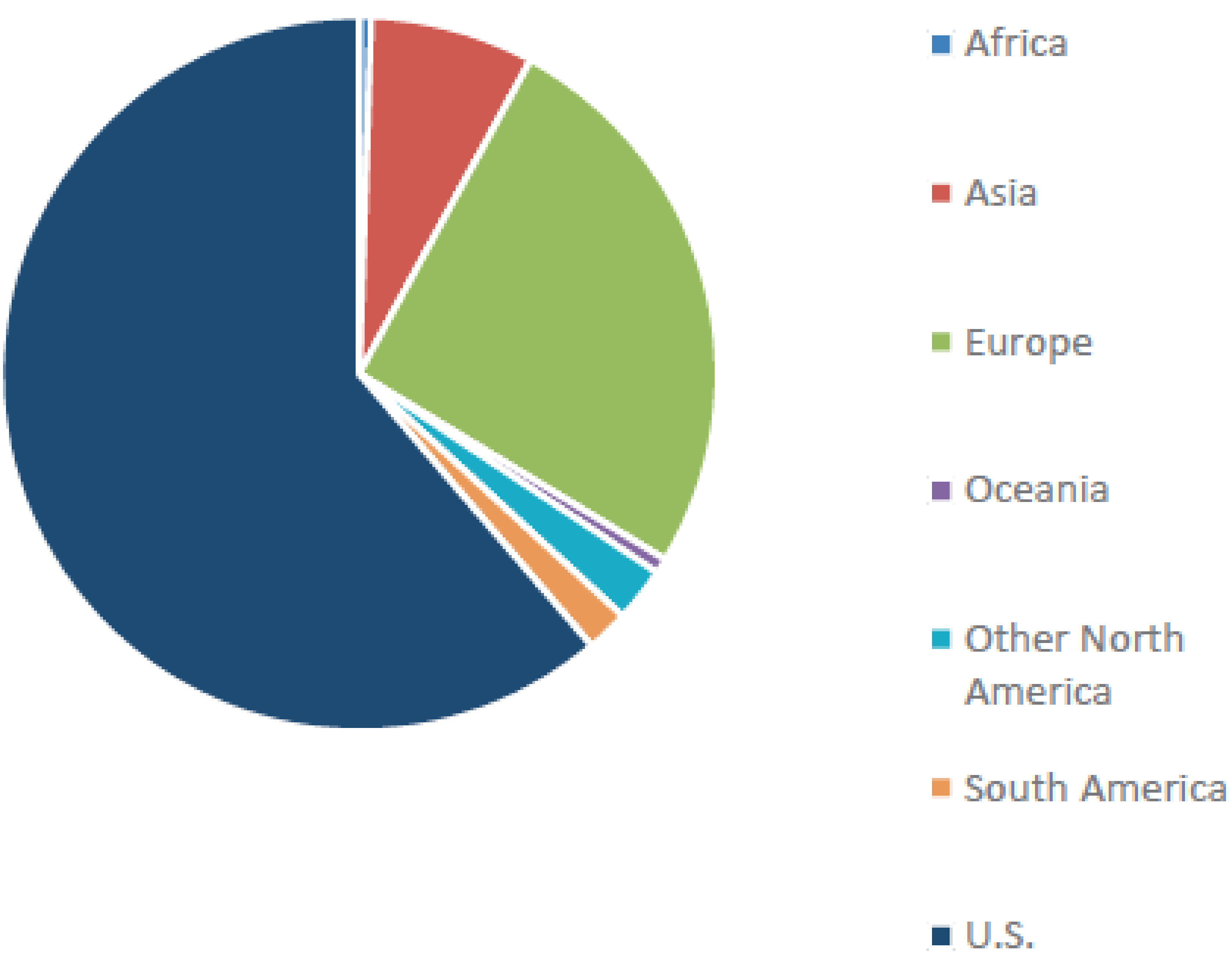


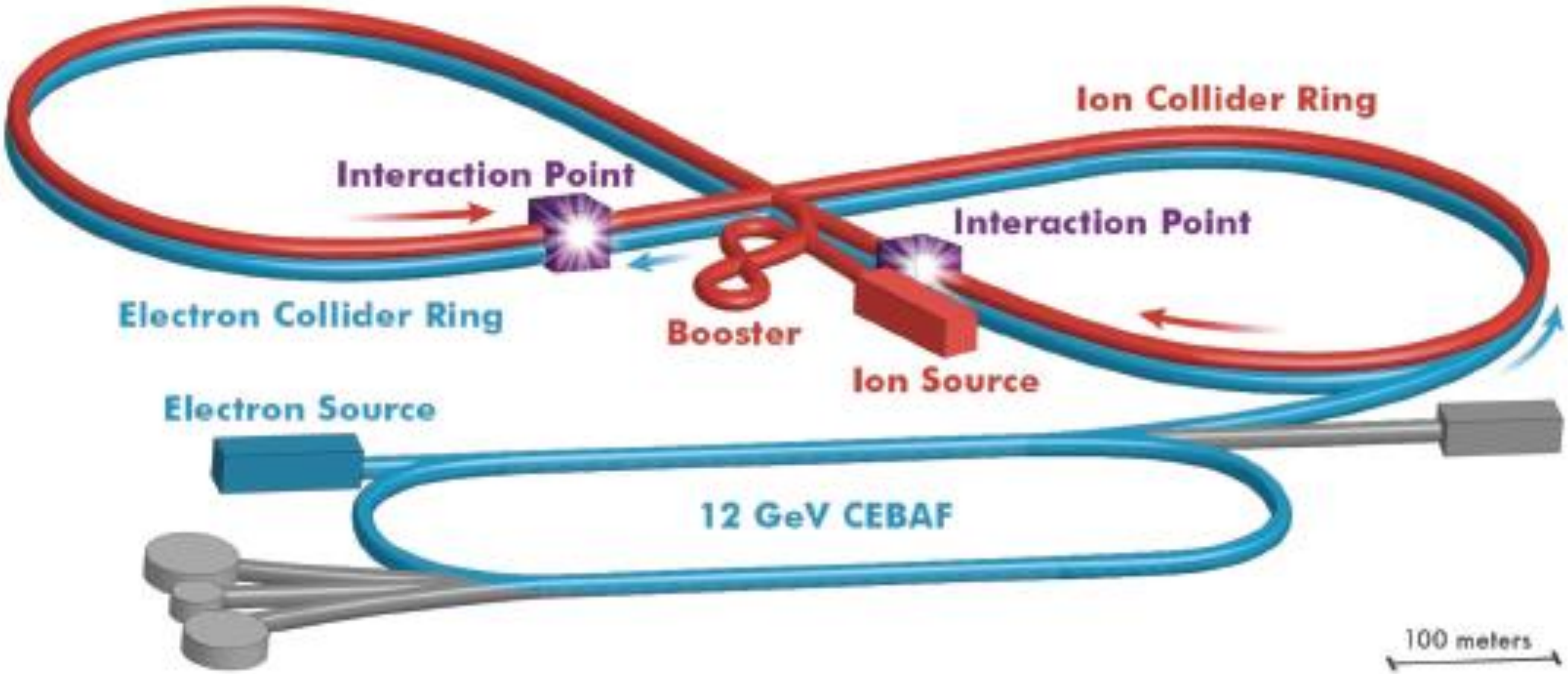


Mass of a proton/neutron?
Spin of the nucleon?
Gluons?

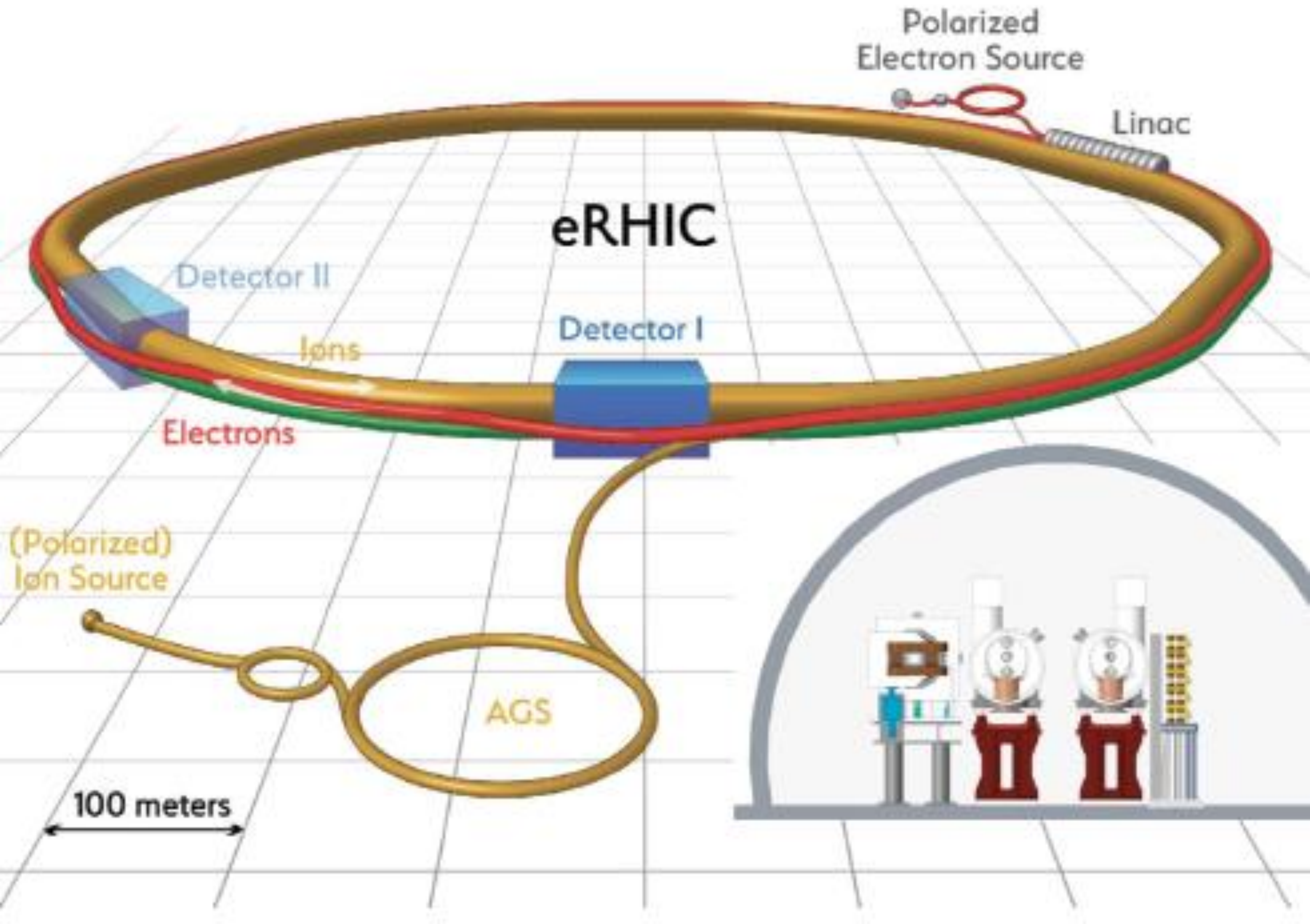


1980’s հիմա


Africa
Asia
Europe
Oceania
Other North America
South America
U.S.

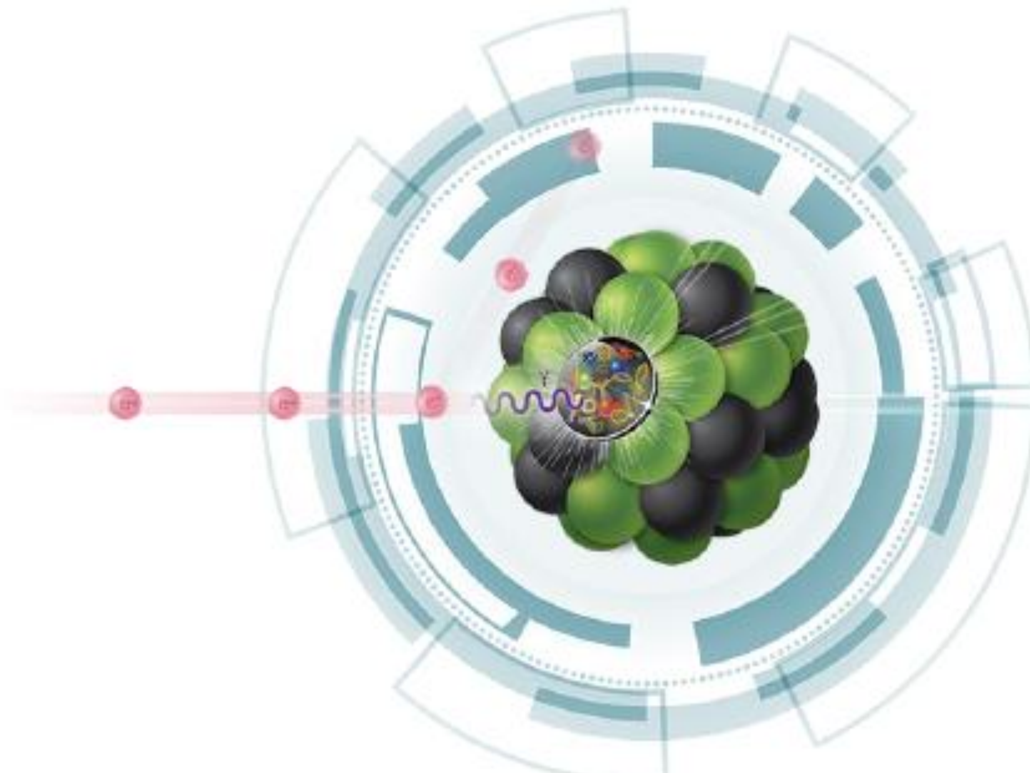


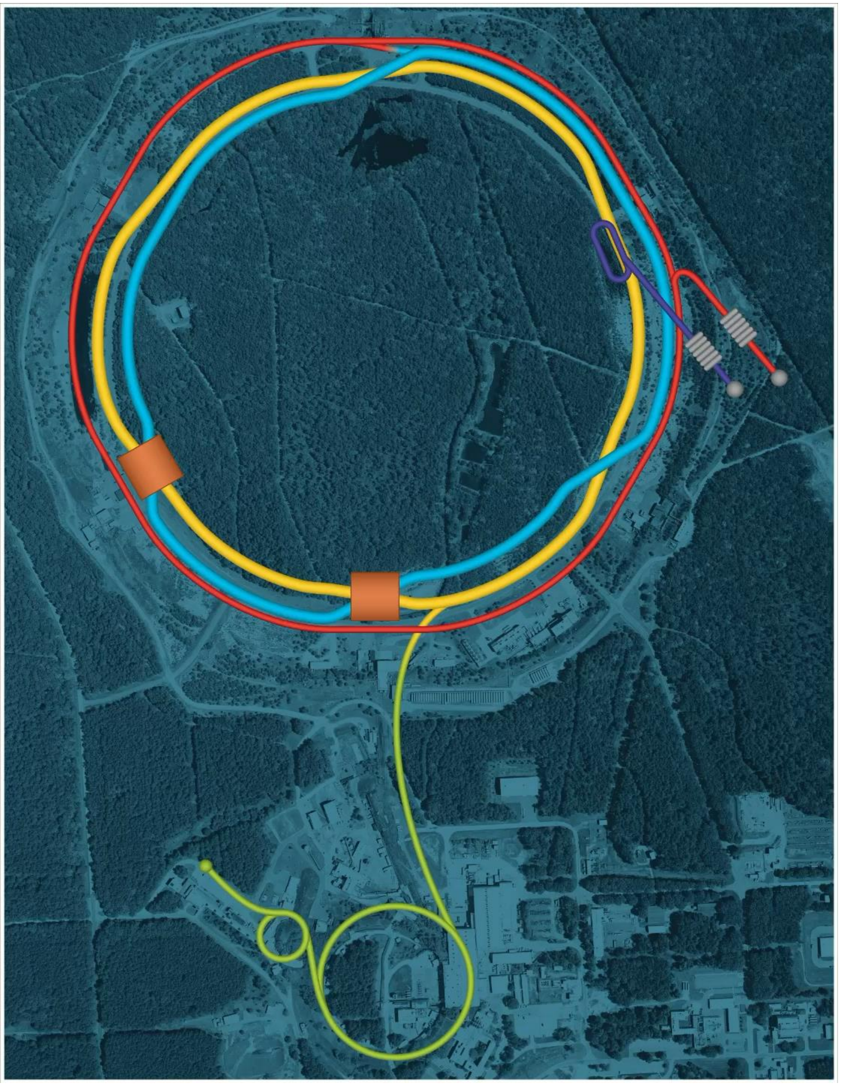
Ion Collider Ring
Interaction Point
Interaction Point
Electron Collider Ring
Booster
Ion Source
Electron Source
12 GeV CEBAF
100 meters


Polarized
Electron Source
Linac
eRHIC
Detector II
Detector I
Ions
Electrons
(Polarized)
Ion Source
AGS
100 meters

The Electron-Ion Collider

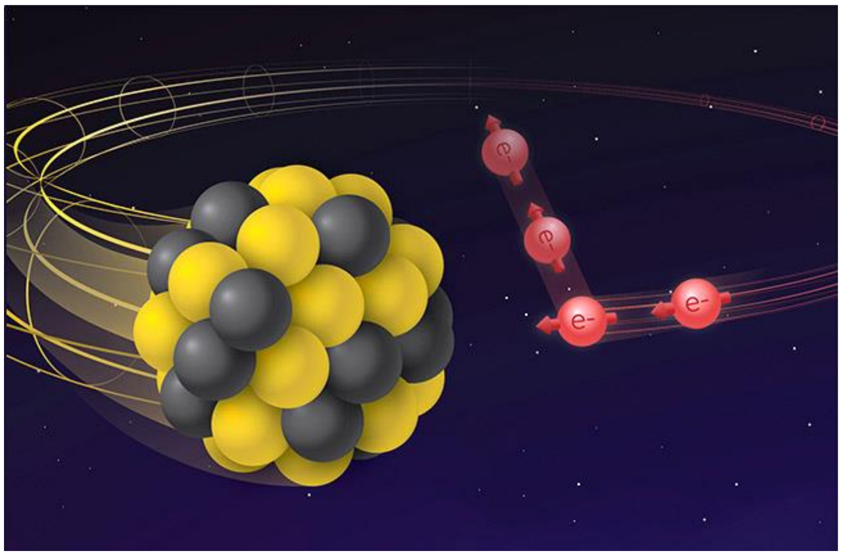
A machine that will unlock the secrets of the strongest force in Nature



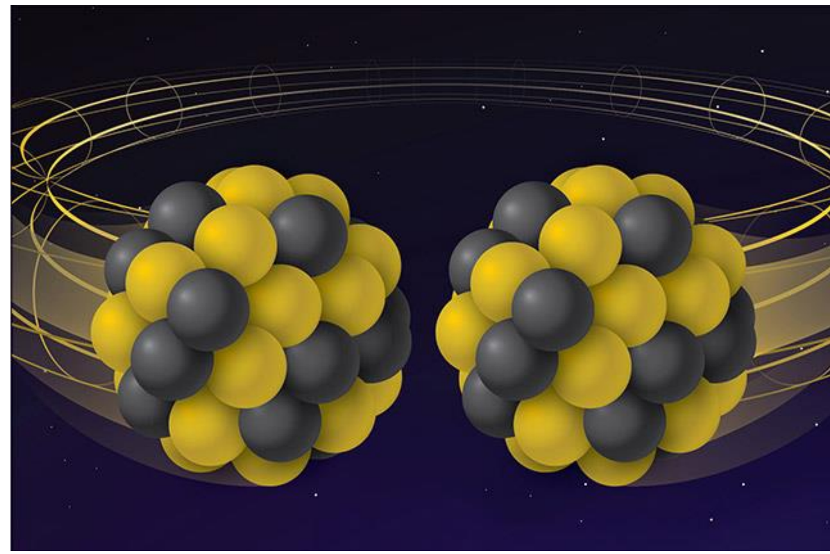


The Electron-Ion Collider (EIC) will be the world's first polarized electron-ion collider, a set of accelerator rings that bring polarized electrons and polarized ions into millions of head-on collisions at nearly the speed of light.

Electron Ion Collider



Relativistic Heavy Ion Collider



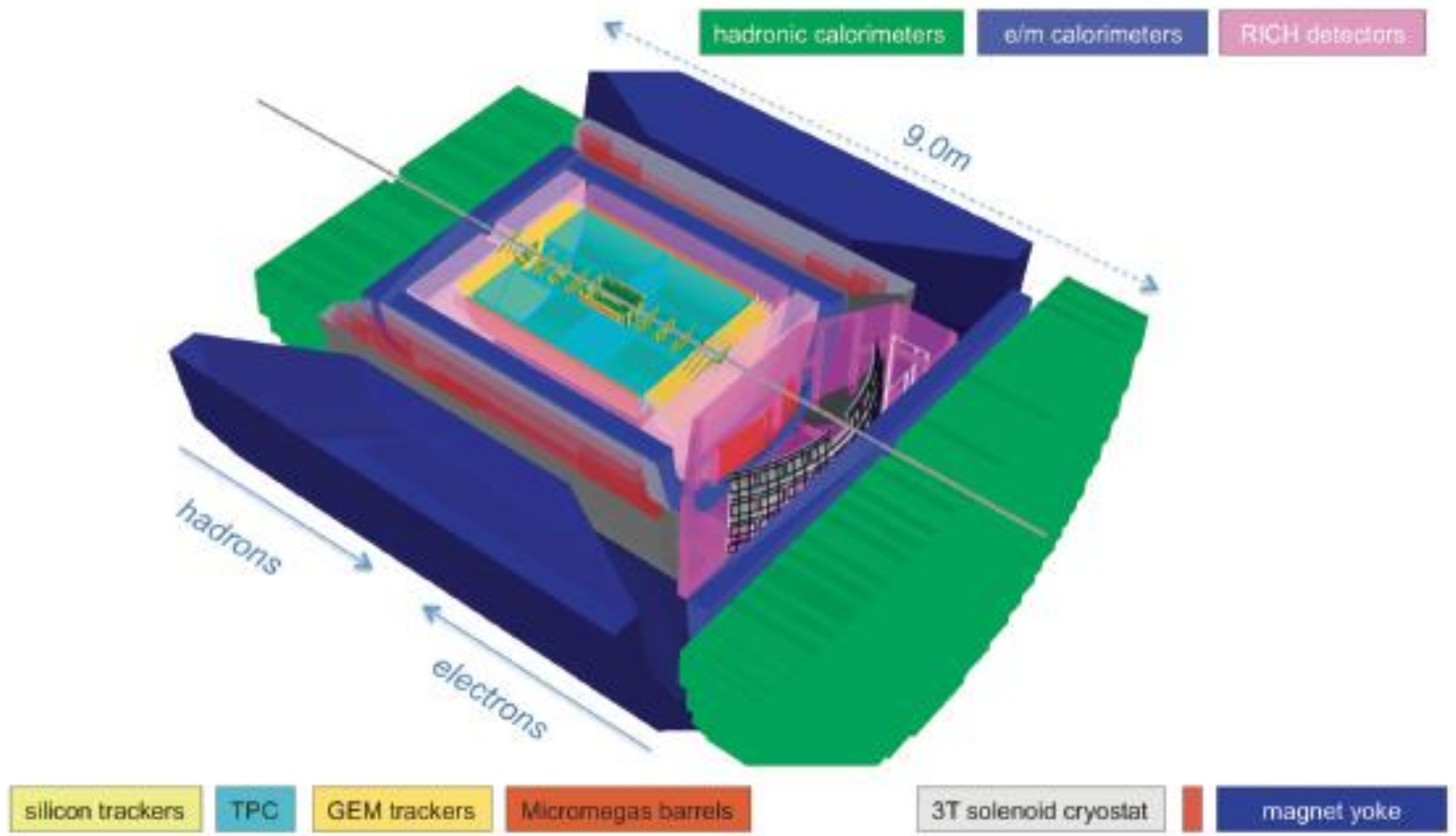

hadronic calorimeters
e/m calorimeters
RICH detectors
9.0m
hadrons
electrons
silicon trackers
TPC
GEM trackers
Micromegas barrels
3T solenoid cryostat
magnet yoke

FIGURE 5.3 View of the COMPASS experiment in a target hall of the Super Proton Synchrotron accelerator at the European Organization for Nuclear Research (CERN). SOURCE: CERN, "View from the Crane of the COMPASS Experiment Facility," © 2011-2018 CERN, http://cds.cern.ch/record/1370231, accessed August 13, 2018.

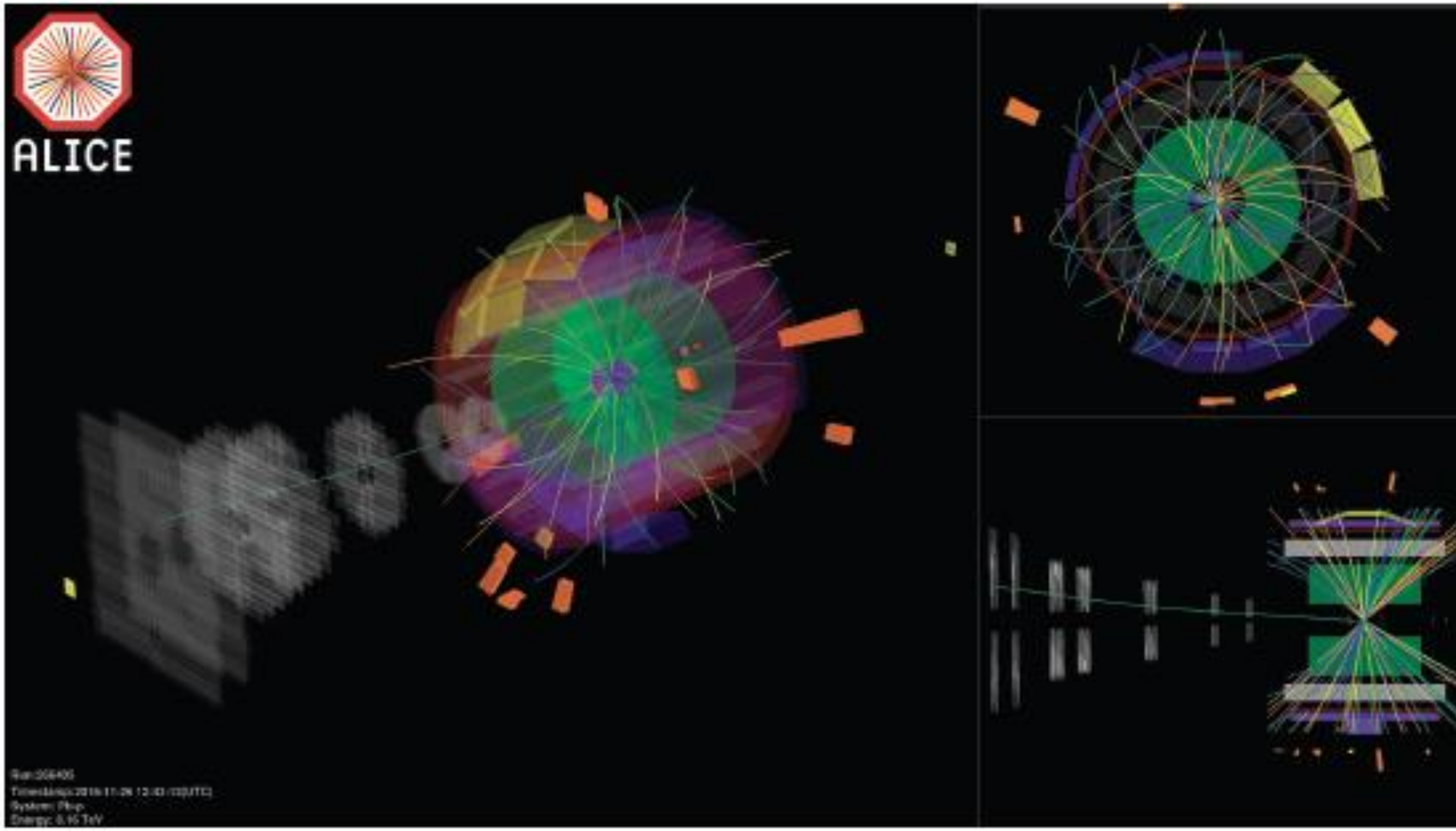


FIGURE 5.5 A collision between a lead nucleus, with a total energy of 533 TeV and a proton of energy 6.5 TeV, yielding an average 8.16 TeV per colliding nucleon pair, recorded in detail by the ALICE detector at the Large Hadron Collider in late 2016. SOURCE: ALICE Experiment, European Organization for Nuclear Research (CERN).

Investments in Science

- https://youtu.be/Xsf_EqGHSDI