

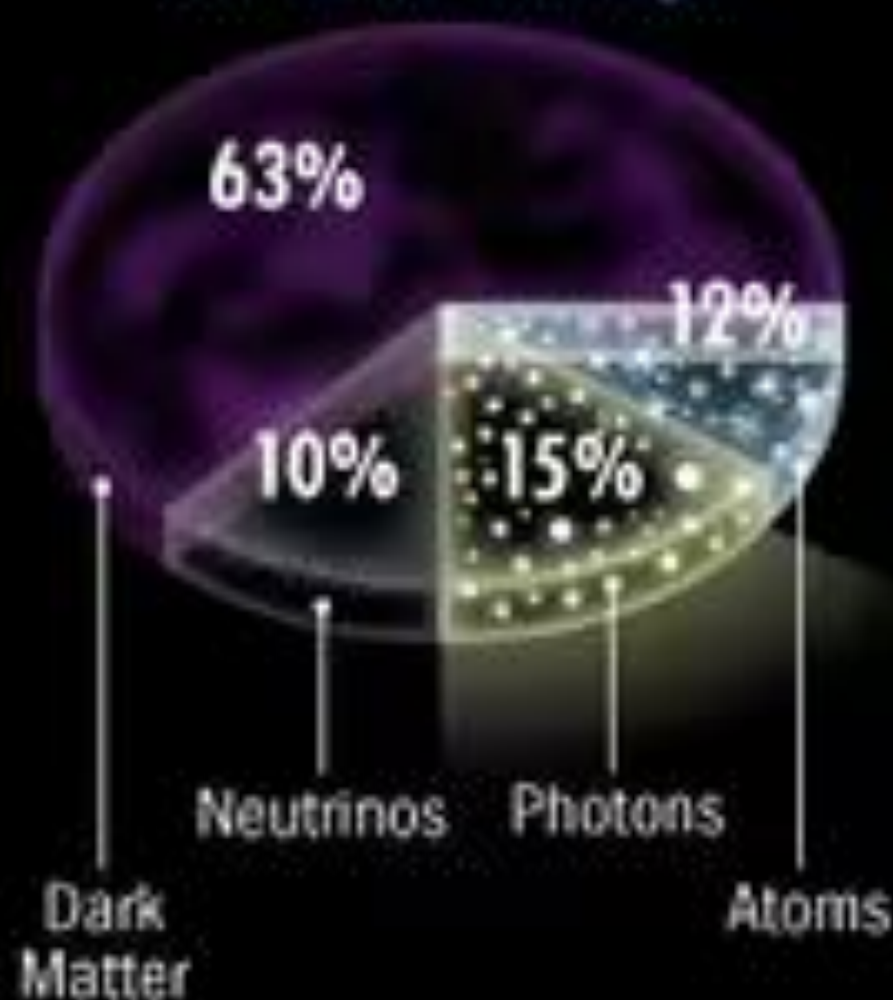
միջուկային ֆիզիկա



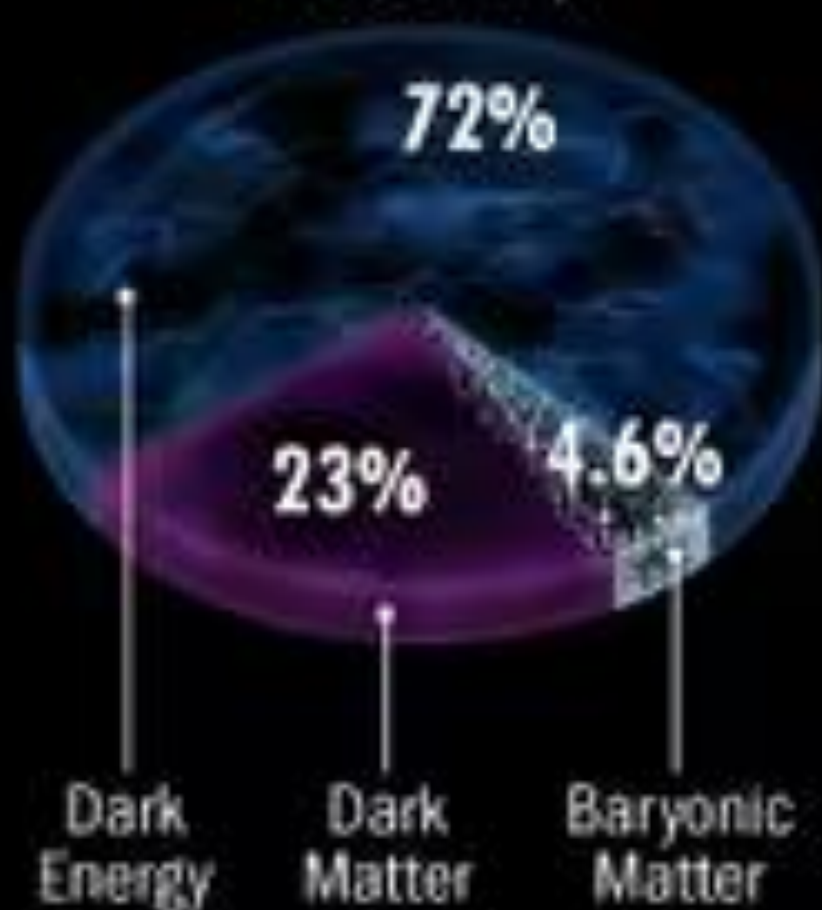
What is the Universe Made of?

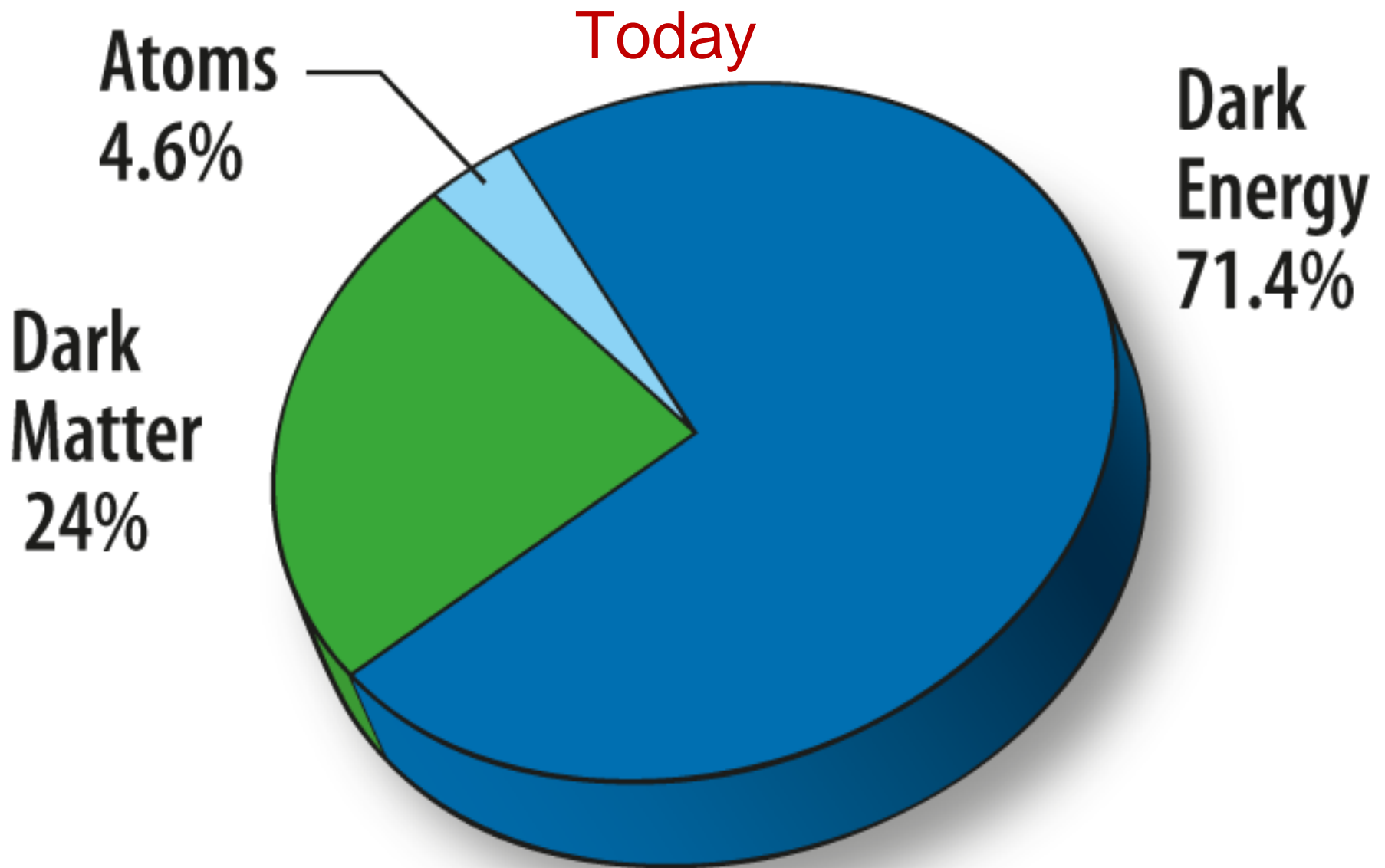
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13.7 Billion Years Ago



Present Day





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....



Atomic Number

6

C

Symbol

Element Name

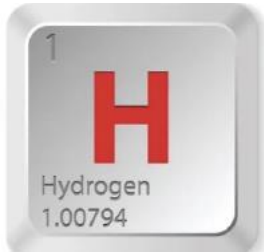
Carbon

12.01

Atomic Mass



Elements and Isotopes



PERIODIC TABLE OF ELEMENTS

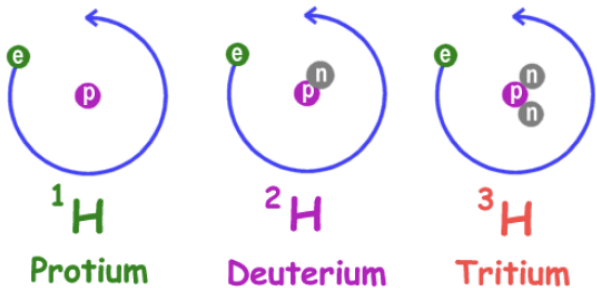
Chemical Group Block

		Atomic Number		17		35.45		Atomic Mass, u																								
		Name		Cl		Chlorine		Halogen		Chemical Group Block																						
2	Li	Be																			He											
3	Na	Mg																			Al	Si	P	S	Cl	Ar						
4	K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr														
5	Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe														
6	Cs	Ba																Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
7	Fr	Ra																Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Cn	Nh	Fl	Mc	Lv	Ts	Og
			La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu															
			Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr															

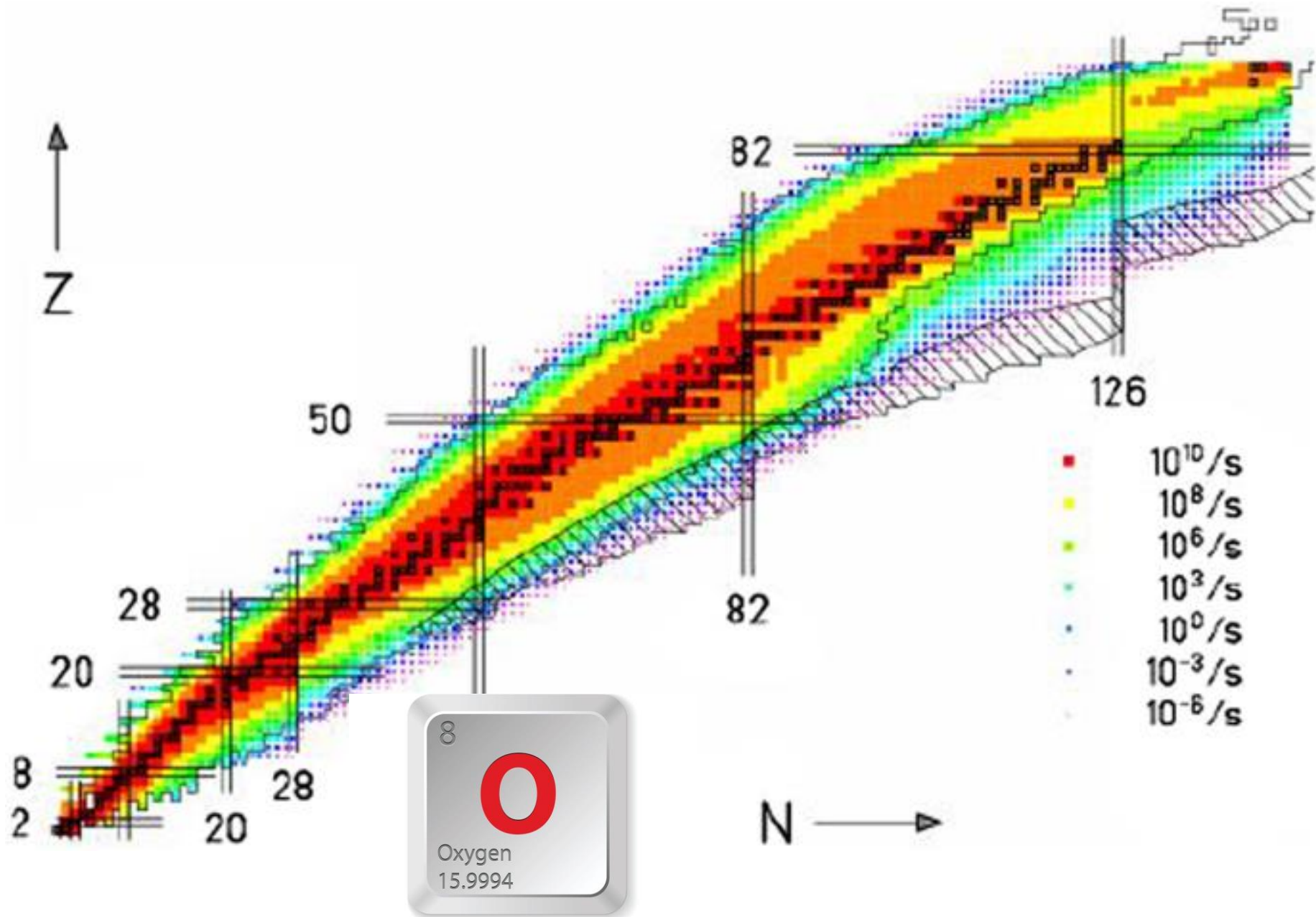
Oxygen



Three Isotopes of Hydrogen

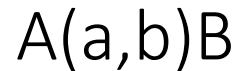
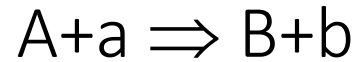
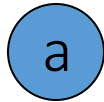


8 protons
 8 neutrons
 8 electrons



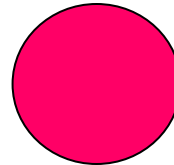
Q value of nuclear reaction process

projectile

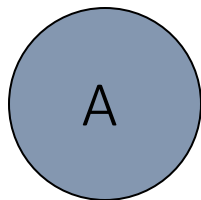


product

b



B



target

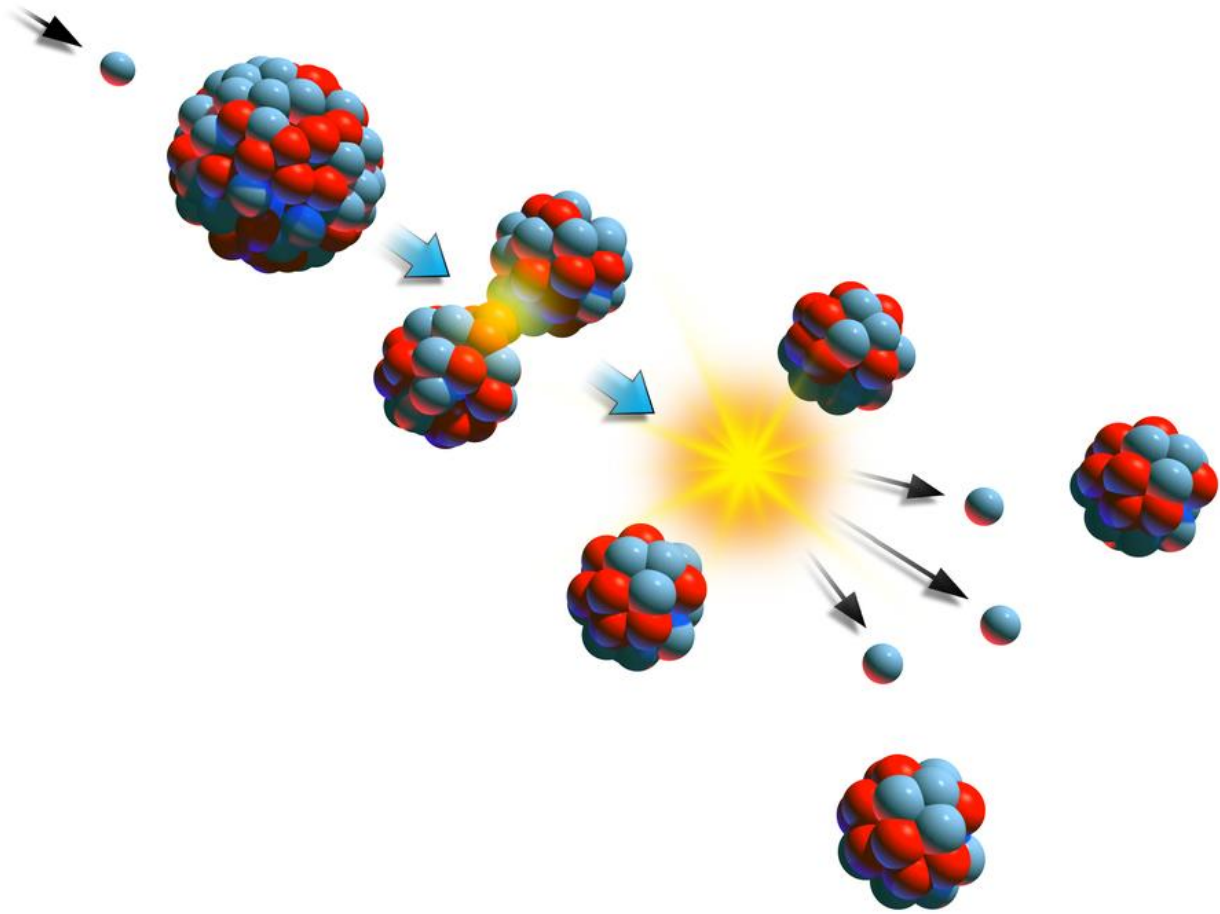
$$Q = (m_B + m_b) \cdot c^2 - (m_A + m_a) \cdot c^2$$

recoil

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

$Q > 0$ exothermic reaction

$Q < 0$ endothermic reaction

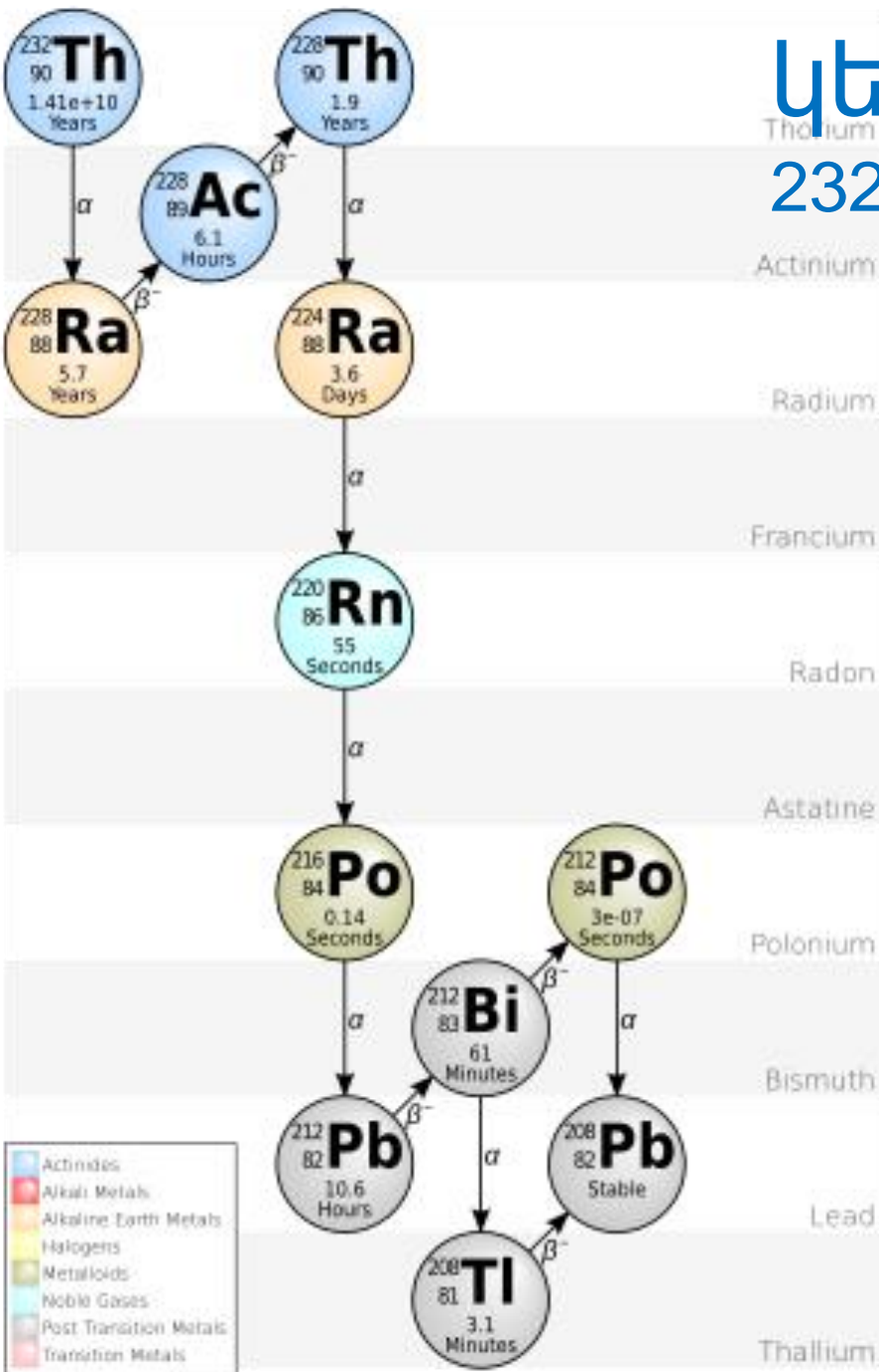


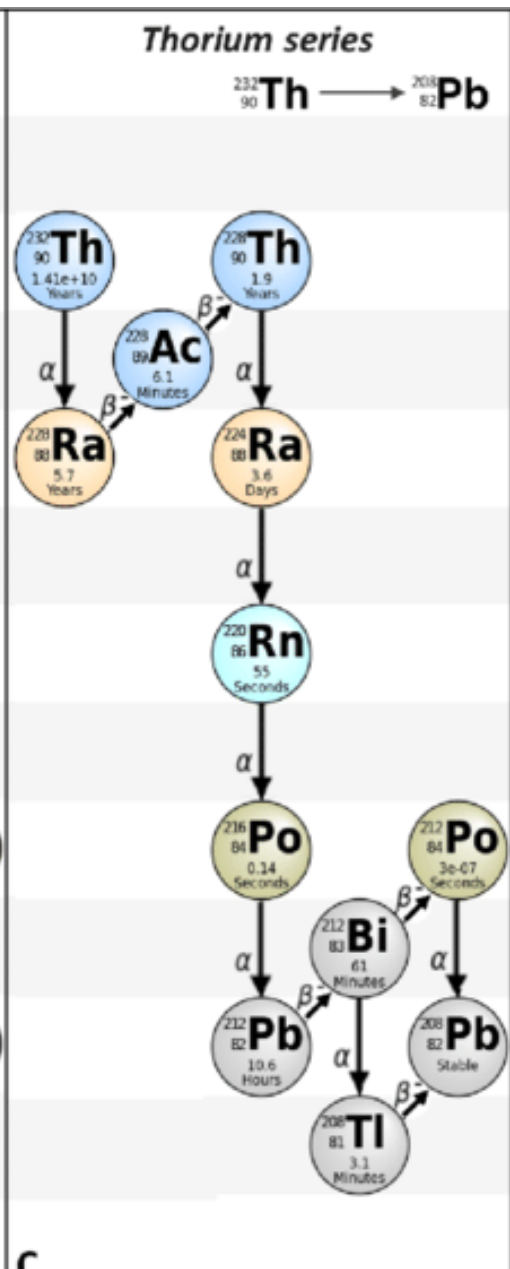
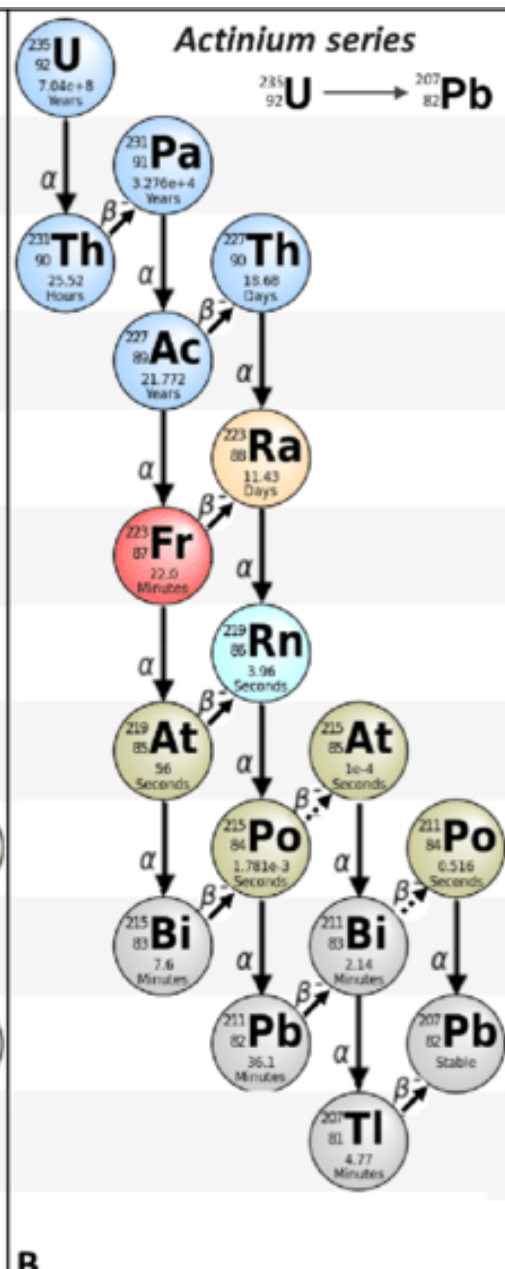
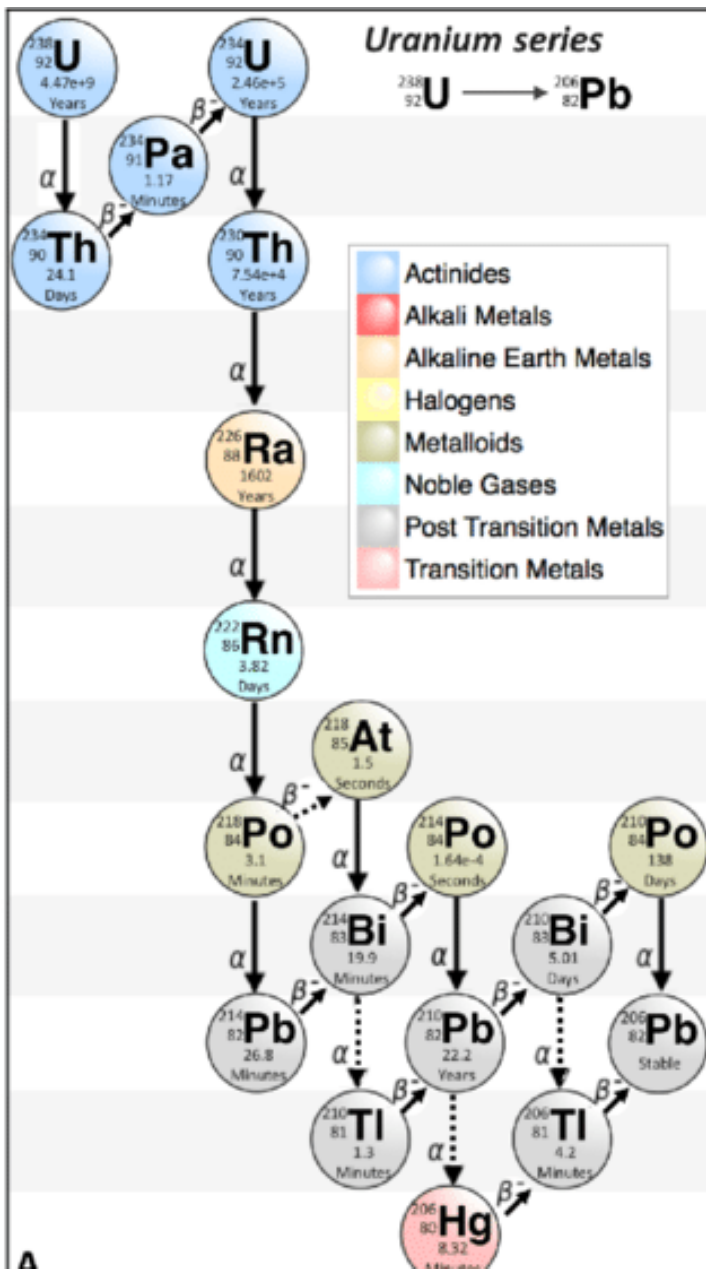
Կես կյանք

$^{232}\text{Th} = 1.4 \times 10^{10}$ տարի

90 պրոտոններ

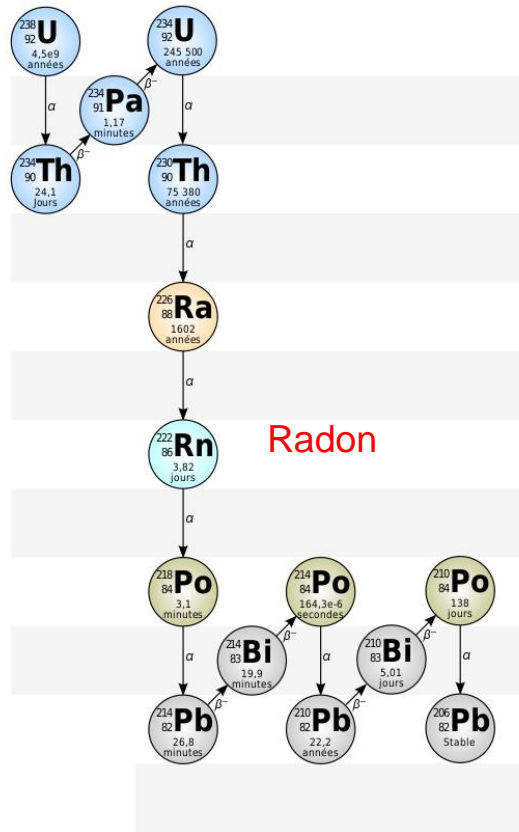
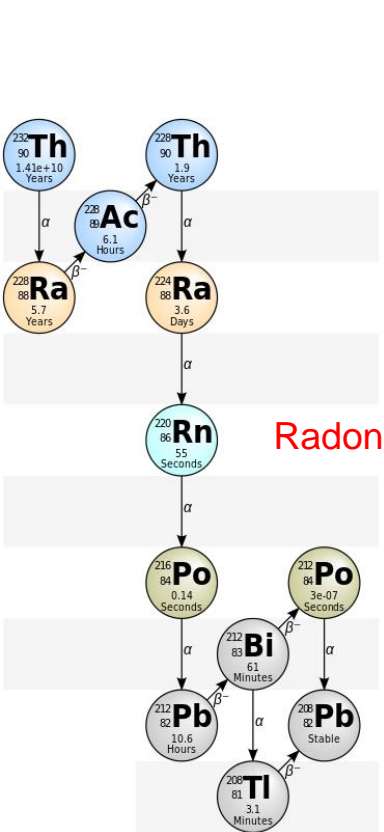
142 նեյտրոններ



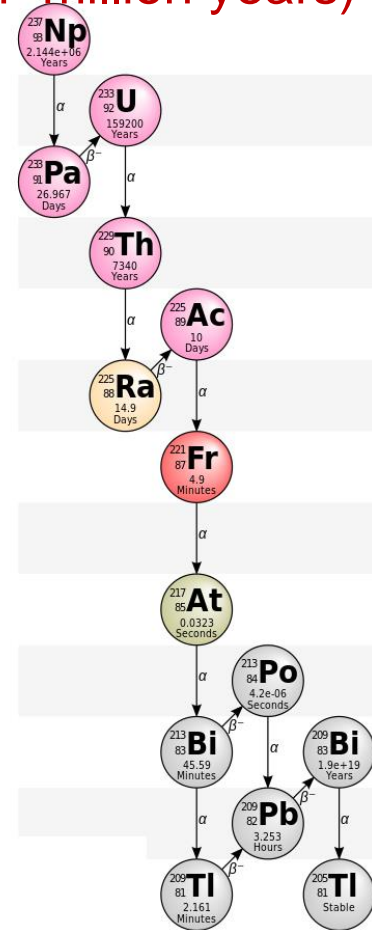


Uranium
Protactinium
Thorium
Actinium
Radium
Francium
Radon
Astatine
Polonium
Bismuth
Lead
Thallium
Mercury

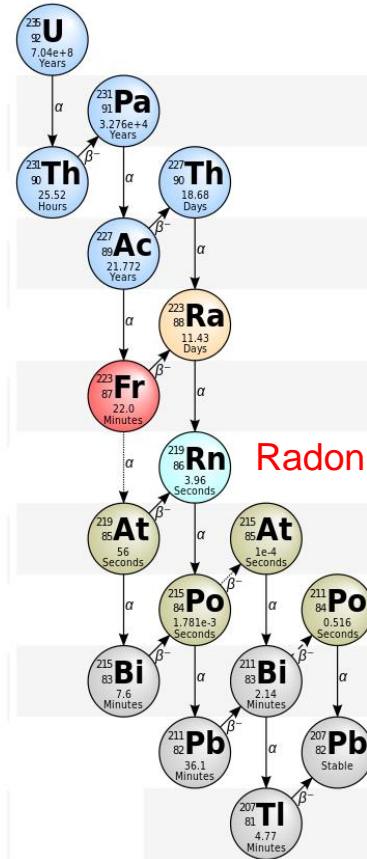
uranium-238
(half-life 4.5 billion years)



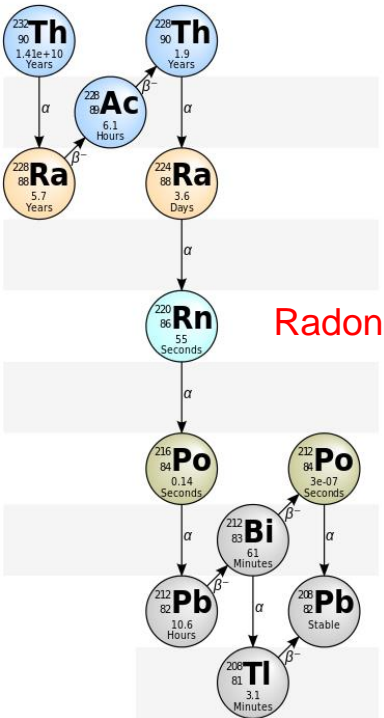
Neptunium-238
(half-life 2.14 million years)



uranium-235
(half-life 700 million years)



thorium-232
(half-life 14 billion 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 ????



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



Dinosaur bone 70 Ma old



Uranium Ore I



Uranium Ore II



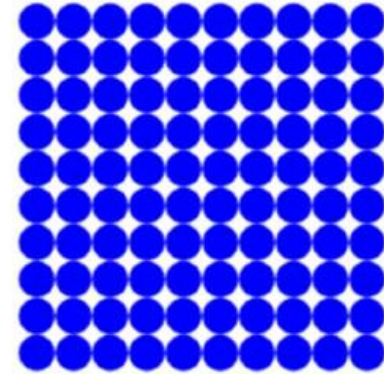
Trinitite from Nuclear Bomb test 1945

Terminology of nuclear decay

radioactive nucleus (parent)



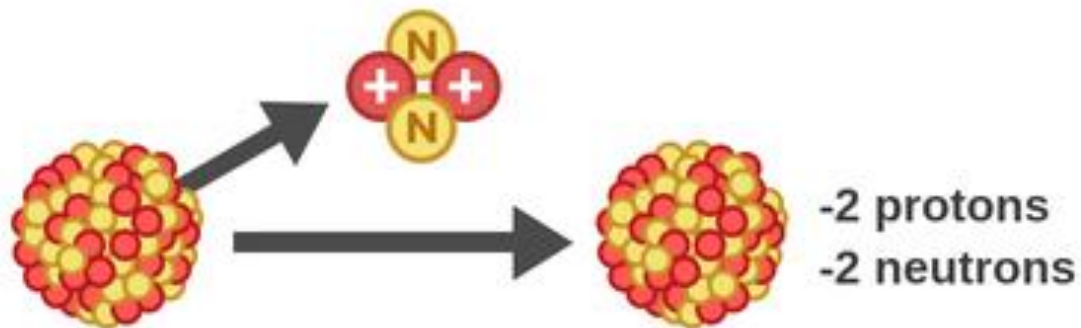
decay product (daughter)



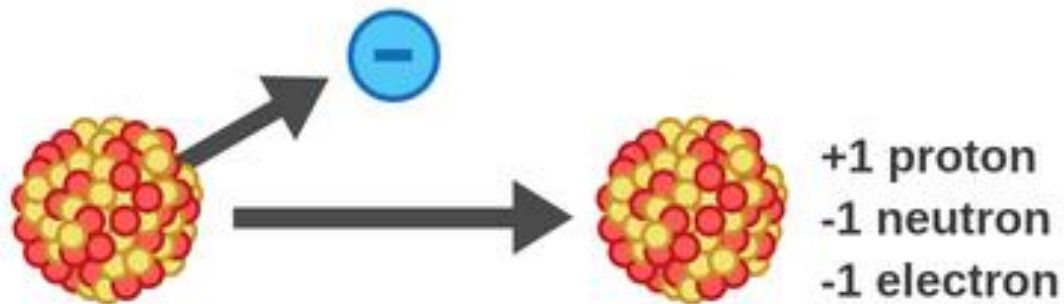
- Activity, $A(t)$: number of decay events per time
- Decay constant, λ : probability of decay
- Half life, $t_{1/2}$: time for the activity to be reduced to 50%
 - Activity corresponds to the number of sand particles dripping through hole
 - Decay constant is associated with the size of the hole



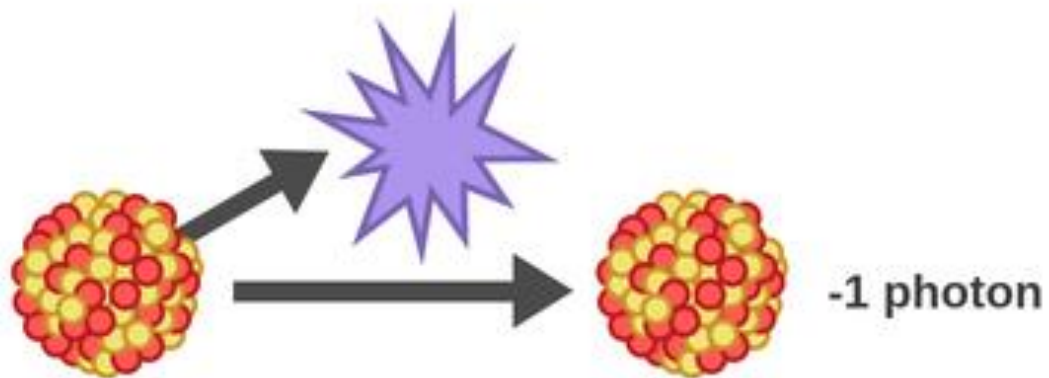
Alpha decay



Beta decay

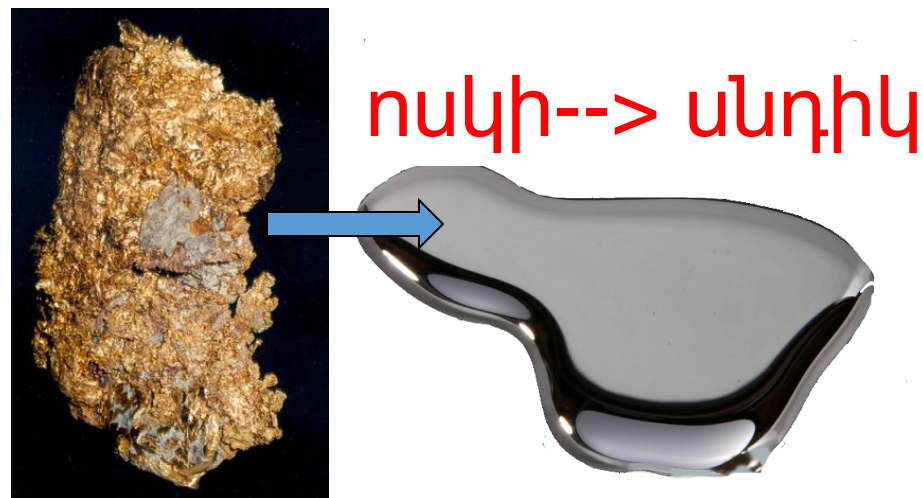


Gamma decay



Changing Z to N or N to Z

Adding a proton (electron)

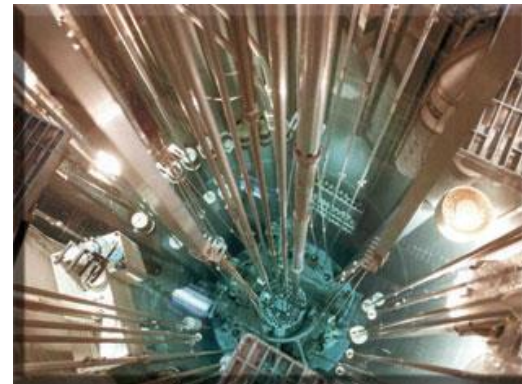


Isotopes of carbon

Carbon-12	Carbon-14
6 protons	6 protons
6 neutrons	8 neutrons

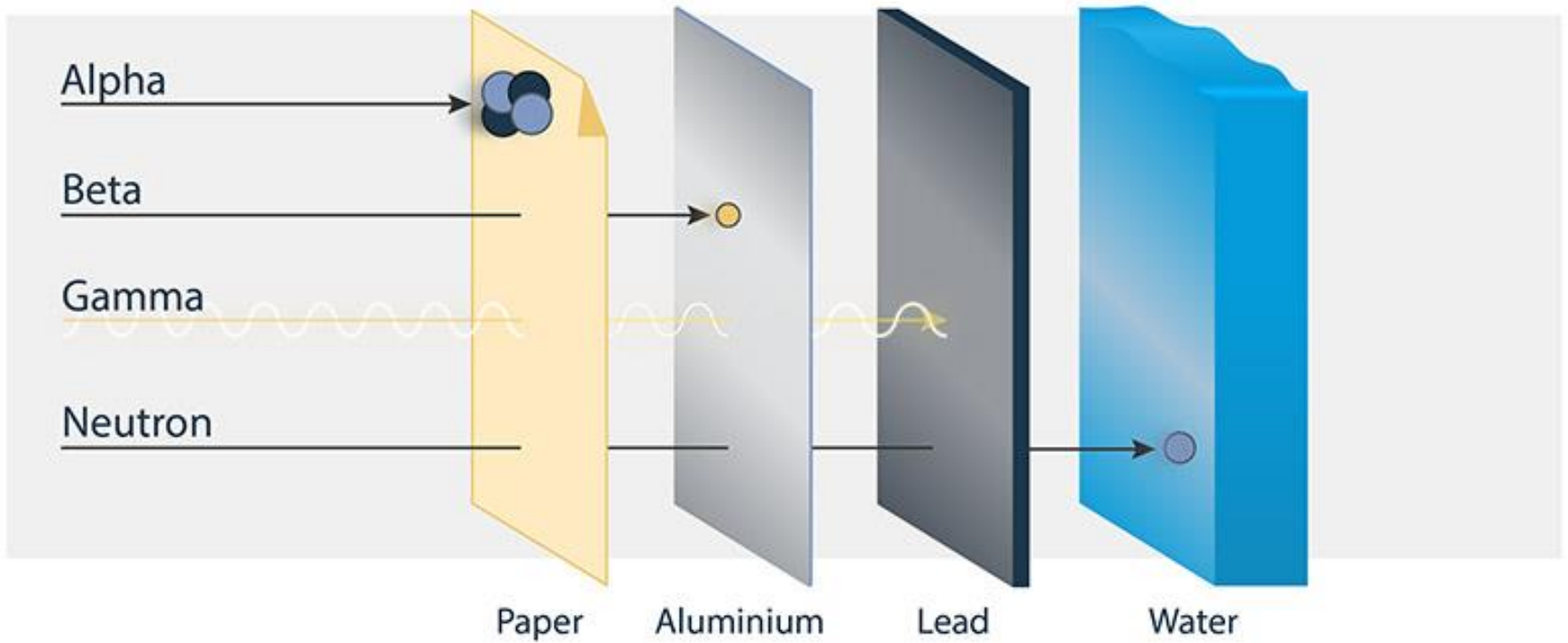
Subtracting or adding neutrons

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



What are the physical laws that govern the decay process?

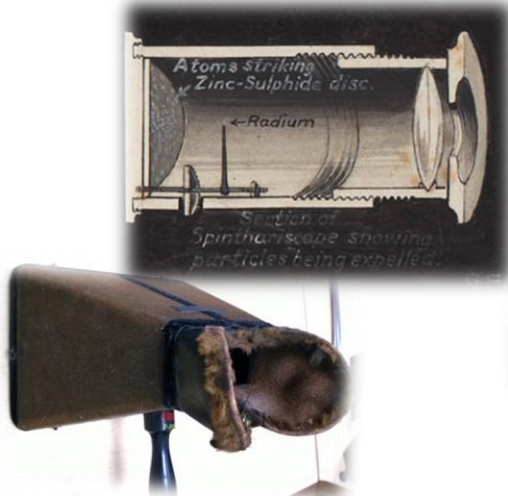
Types of decay



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

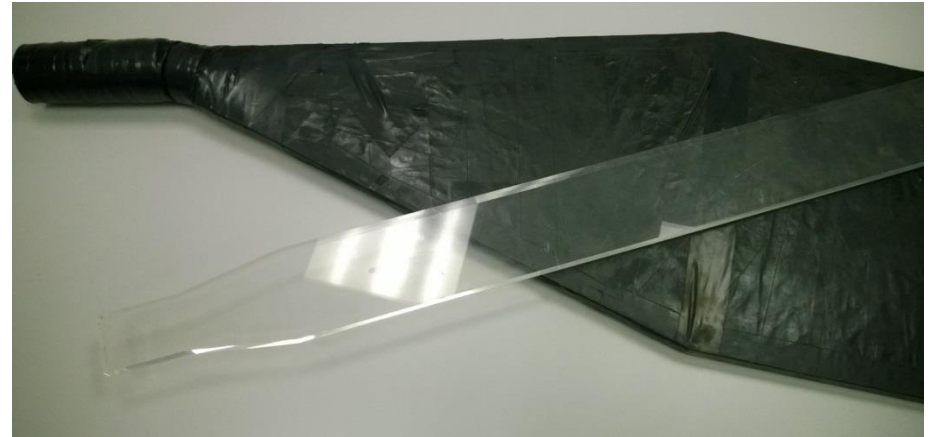


Dosimeters today

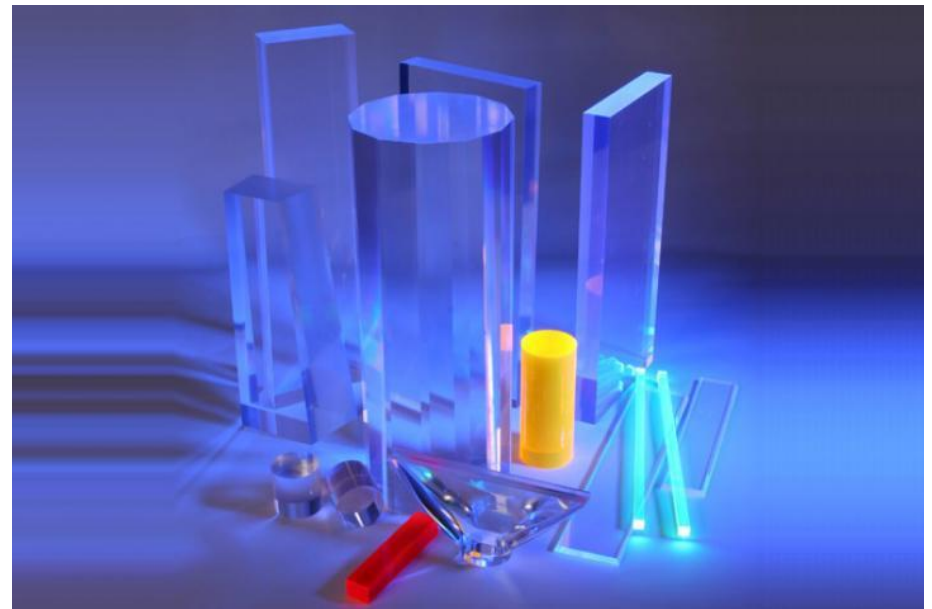


Geiger Counter 2015 version

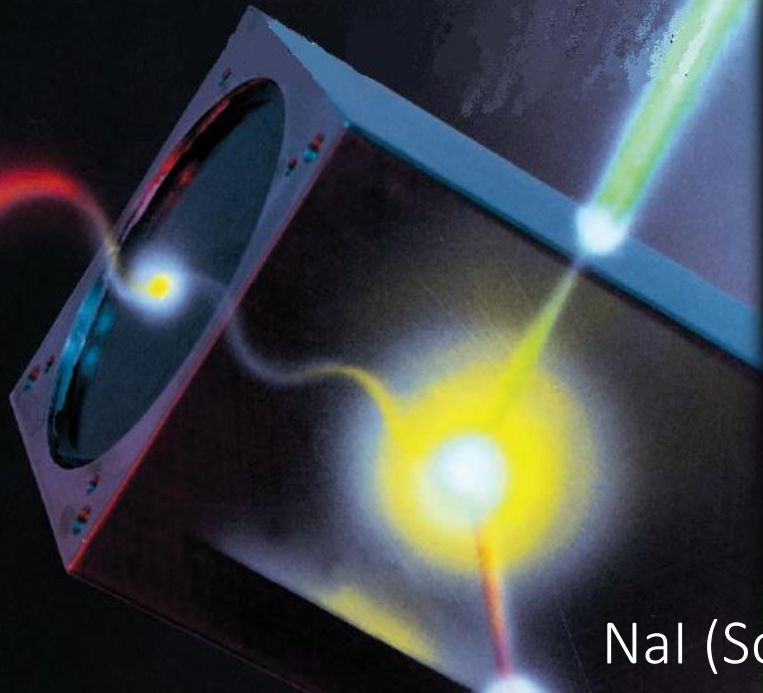
Scintillators



Mostly salt crystal, but increasingly also plastic material that emits light when hit by radiation, ZnS, NaI, CsI, BaF₂, BGO,



Principle of Scintillators



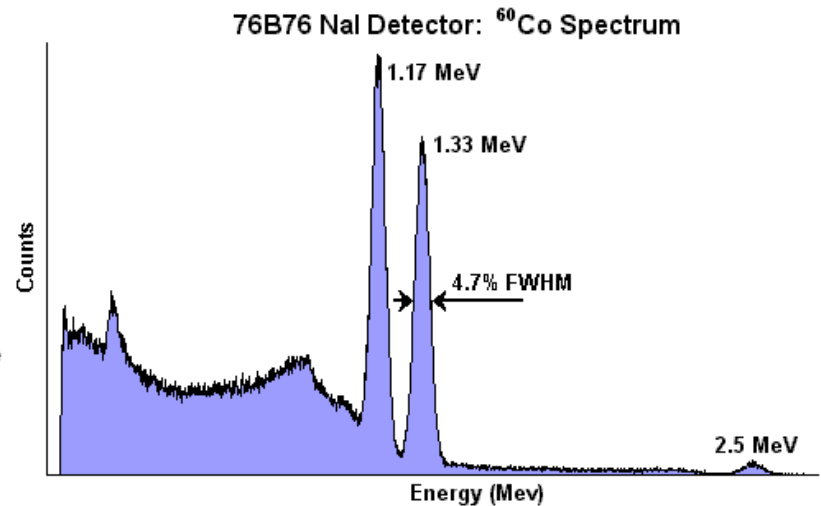
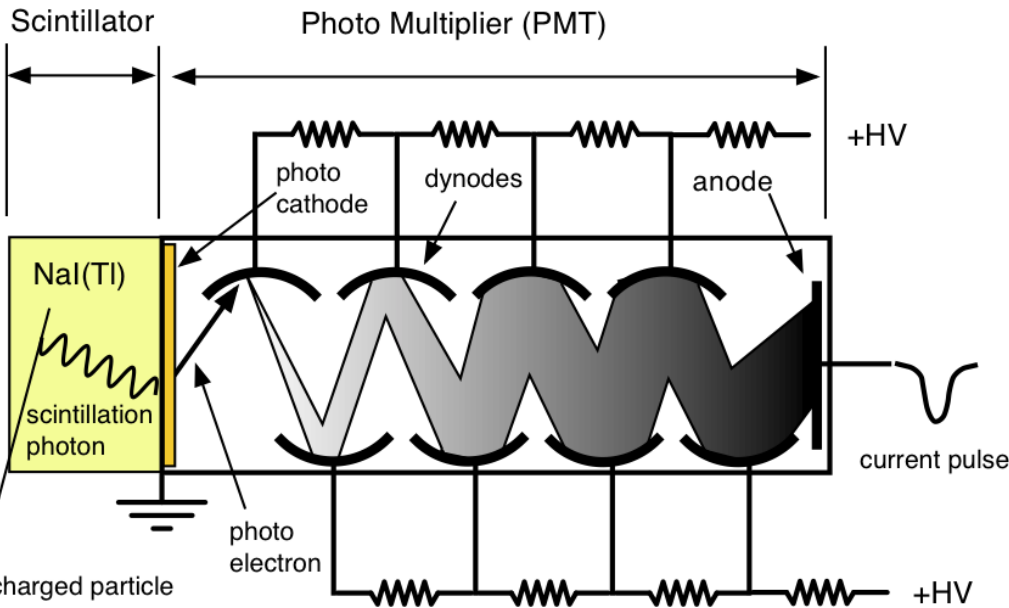
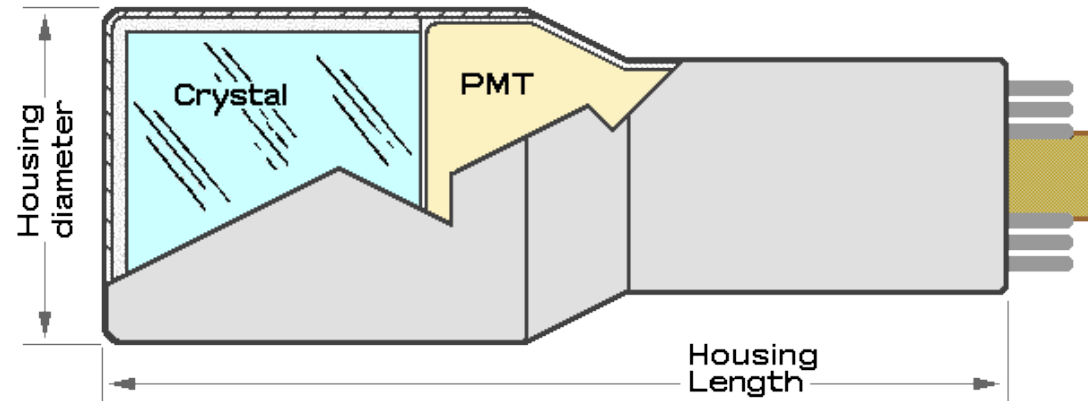
NaI (Sodium Iodide) detector for γ radiation

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)

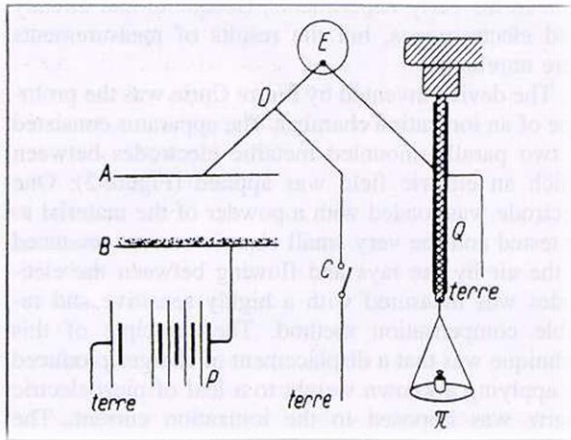
Efficient optical coupling is required between crystal and PMT



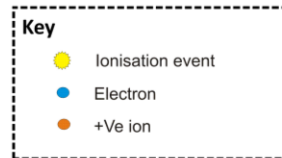
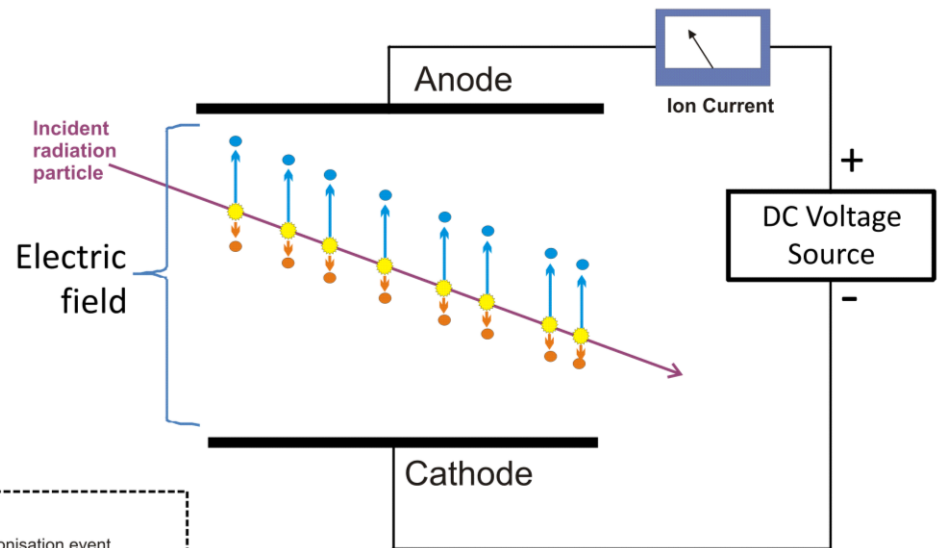
Principle of Ionization chamber

Pierre Curie invented the prototype of an ionization chamber.

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.

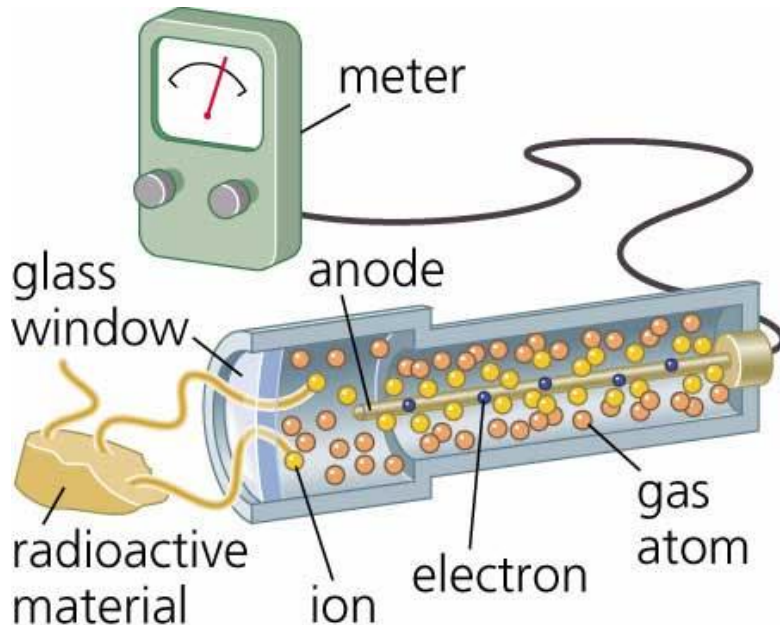


The apparatus consisted of two parallel-mounted metallic electrodes between which an electric field was applied.



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.

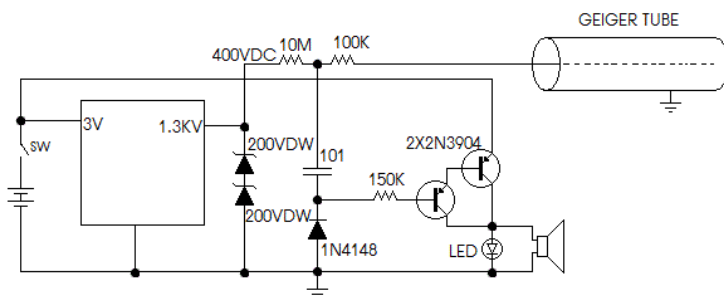
Geiger or Geiger-Müller Counter



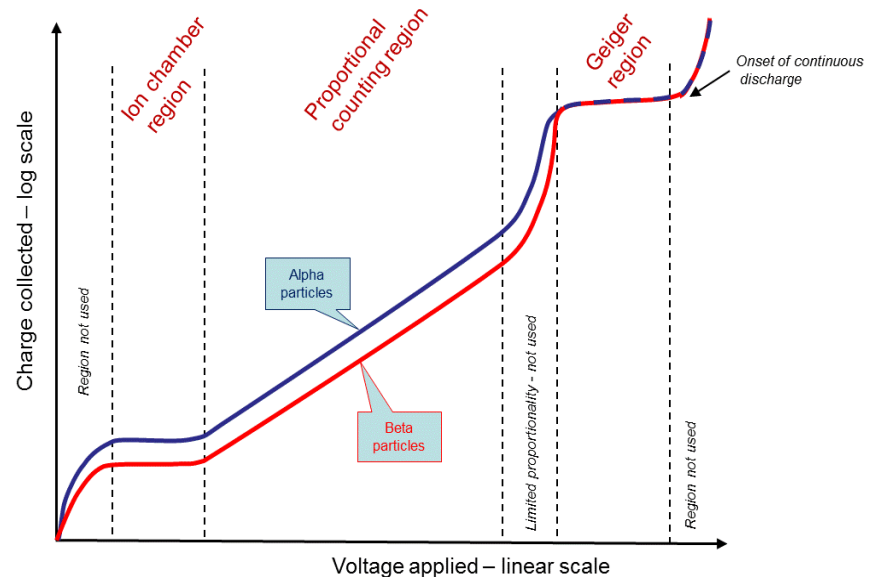
Variation of ionization counter, instead of two parallel plates, cathode (-) and anode (+) the anode is now a central wire in a cylindrical geometry, attracting electrons from the ionized gas and measuring the current proportional to the ionization, which is proportional to the intensity of the radiation.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

SIMPLE GEIGER COUNTER

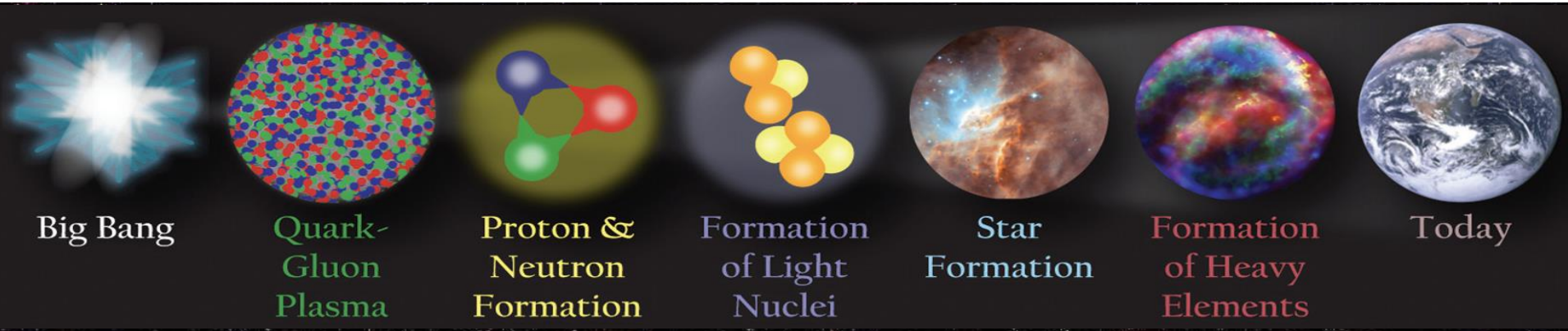
DIGI01 2011.4.9



Variation of ion pair charge with applied voltage

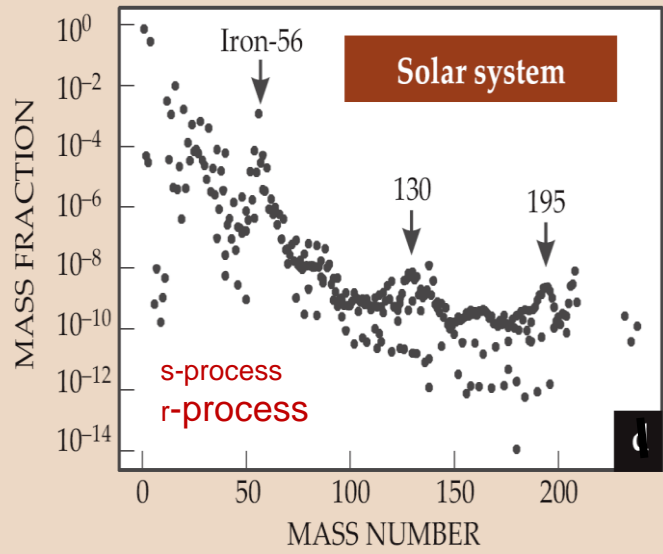
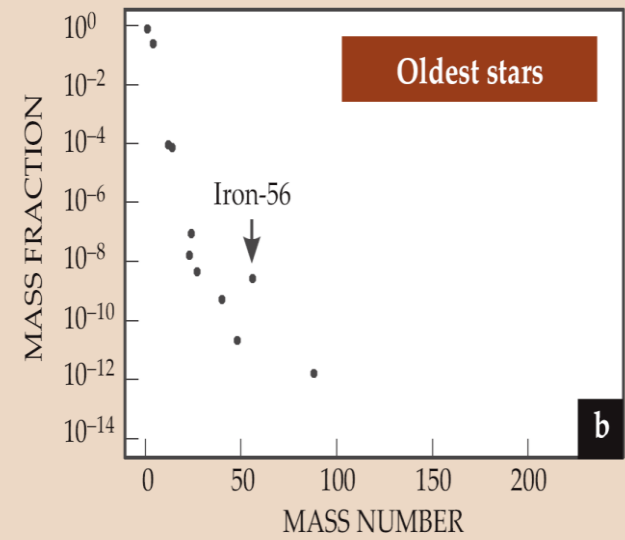
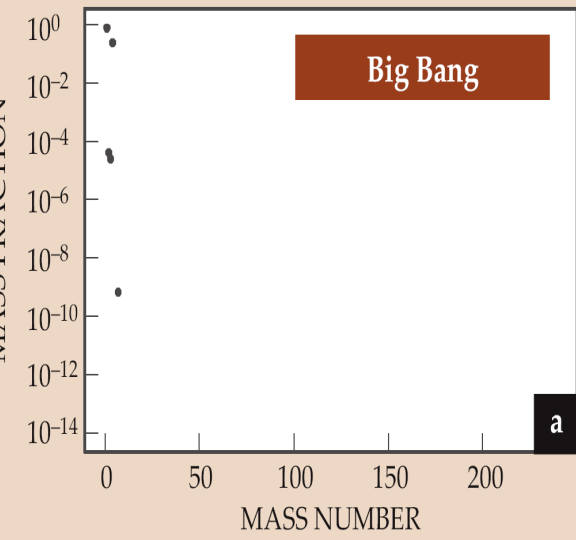


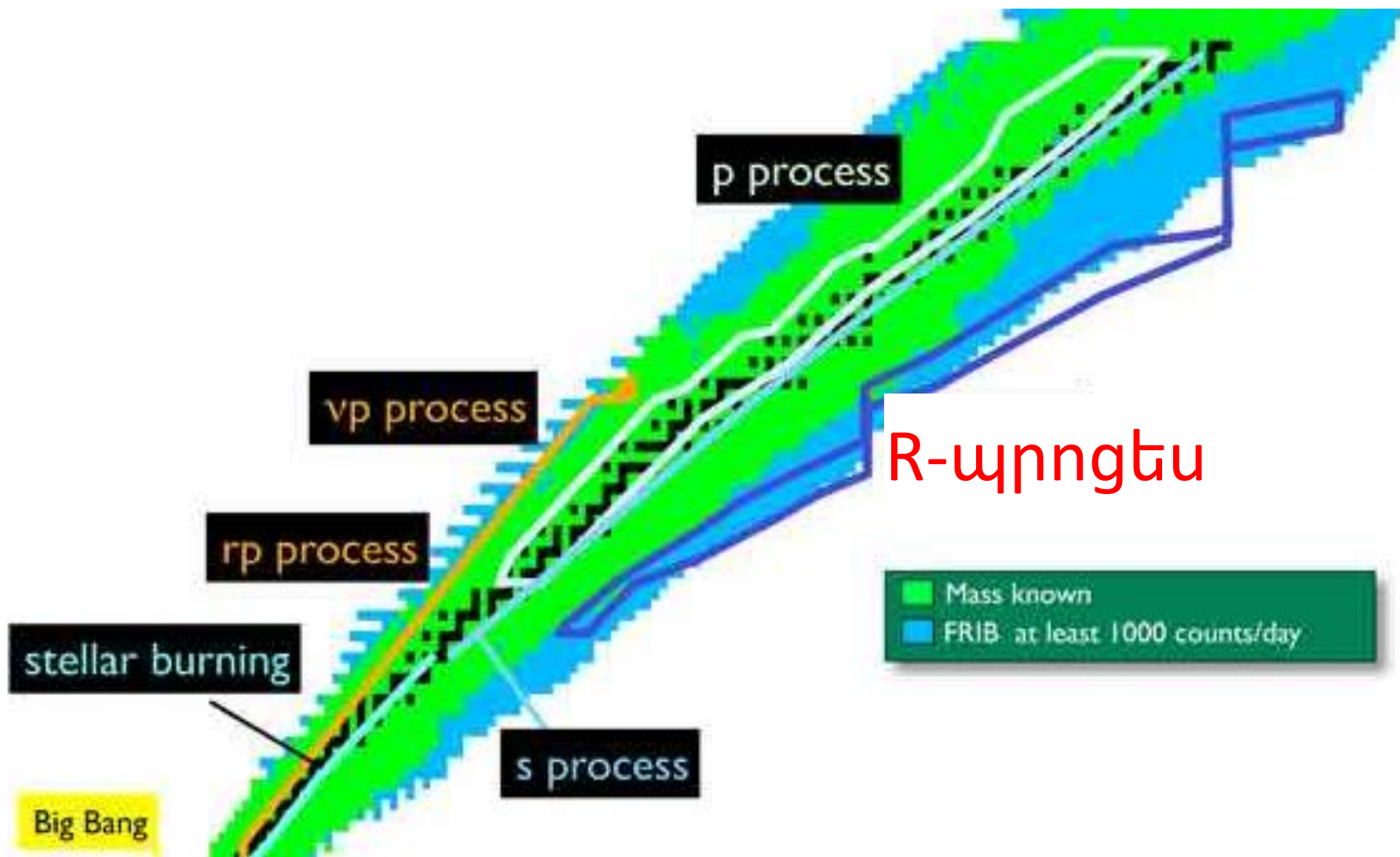
տարրական առատություններ =տիեզերքի պատմություն + միջուկային ֆիզիկա



• How were elements Fe to U made?

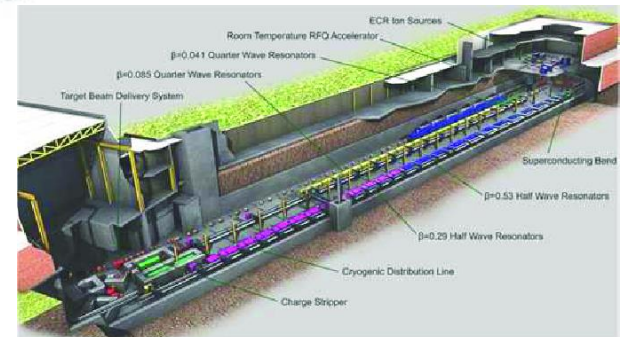
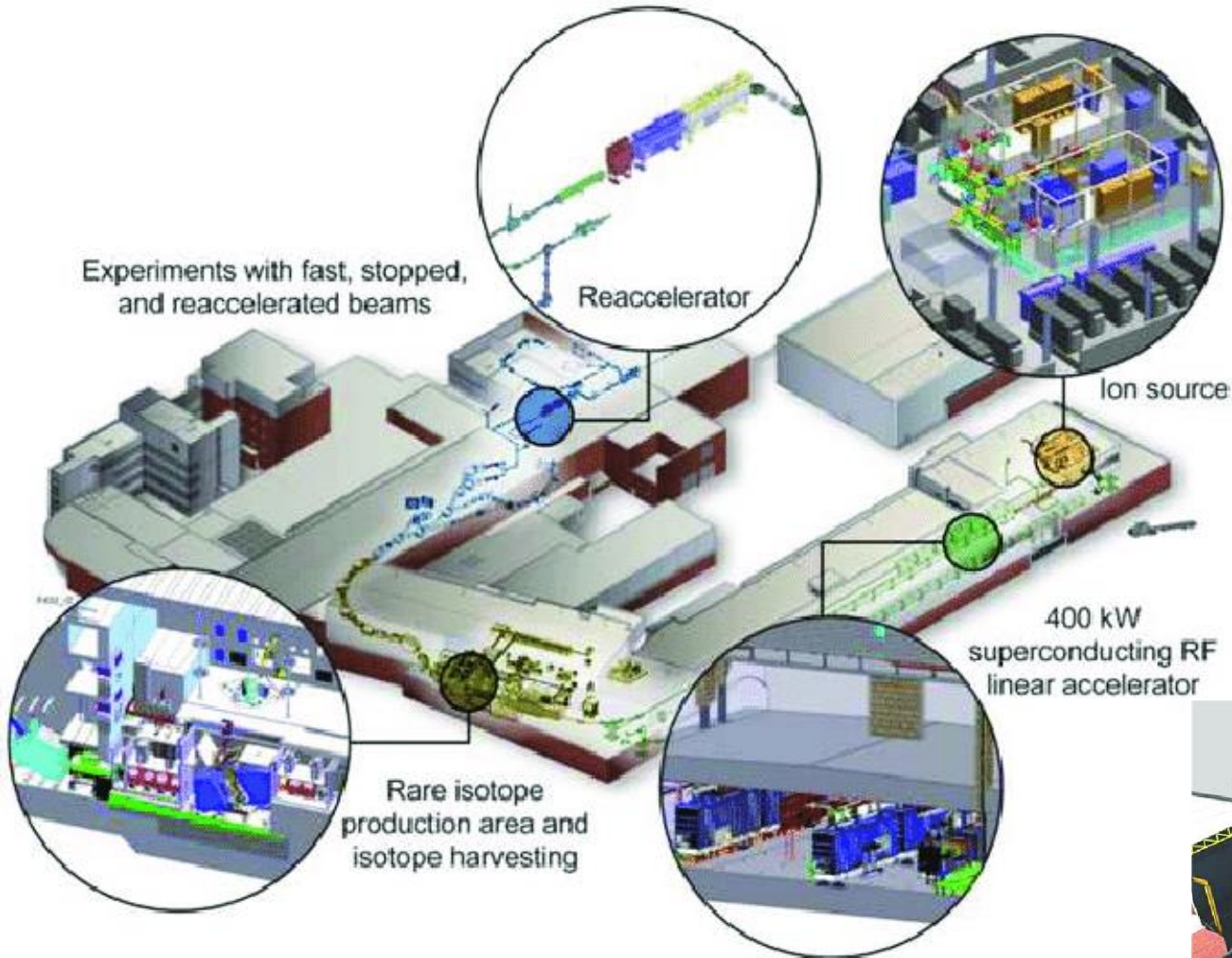
արեգակնային համակարգ





R-պրոցես

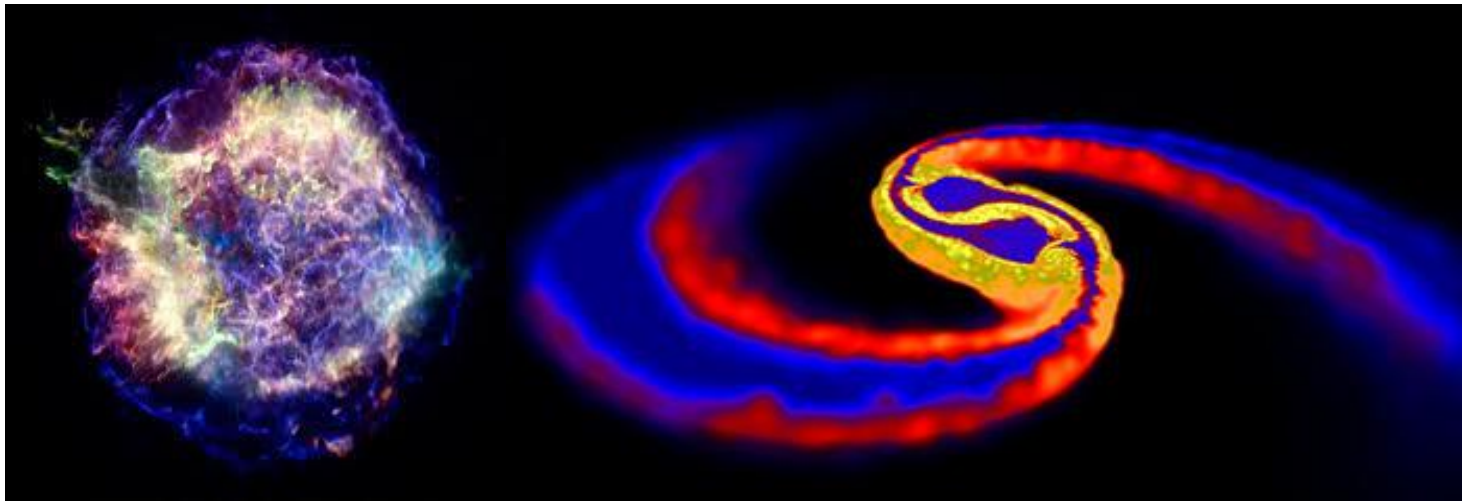
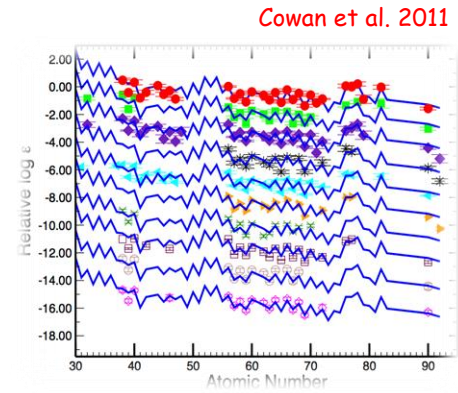




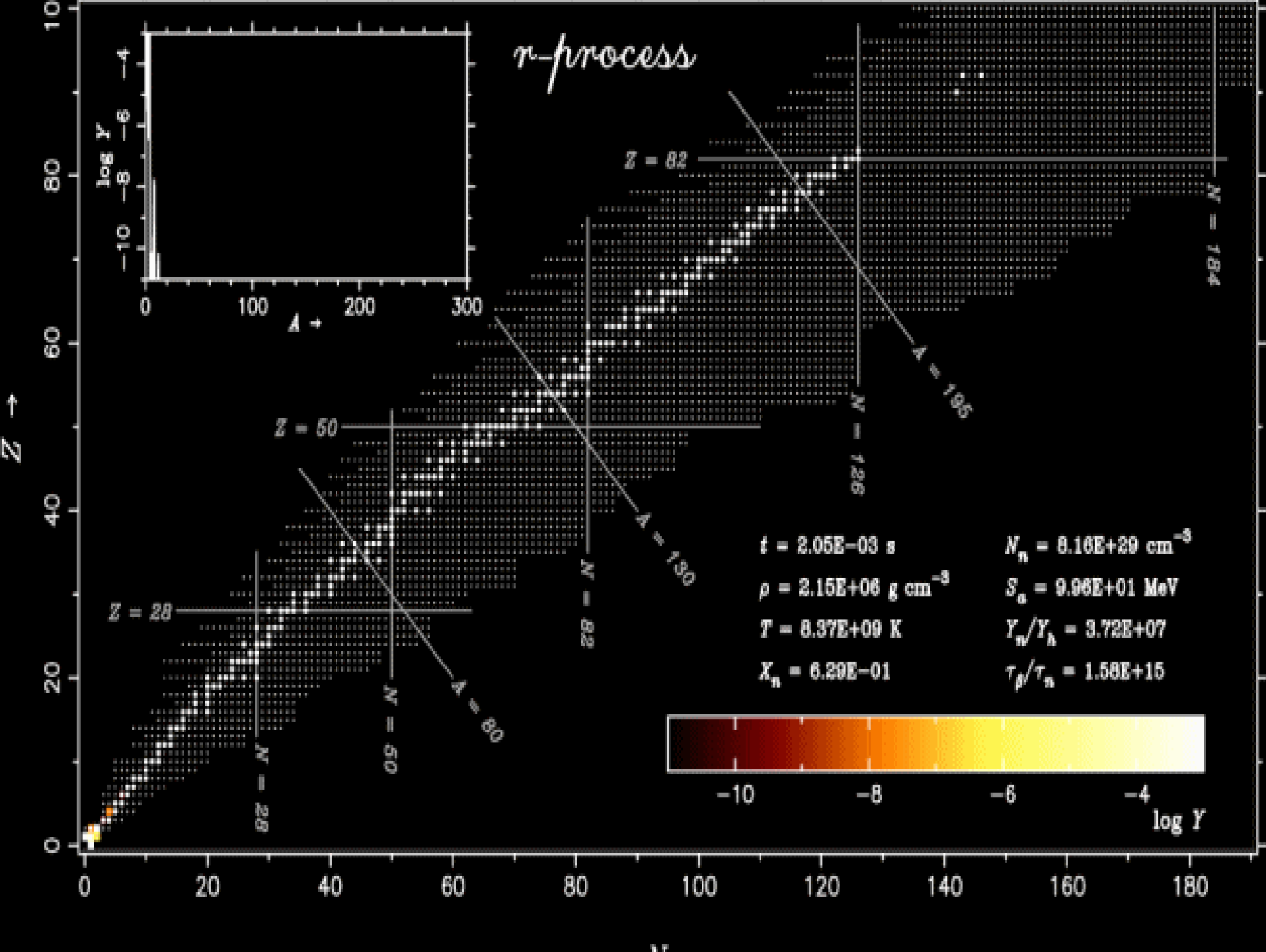
Facility for Rare Isotope Beams: 2022 Michigan State University

R-պրոցես

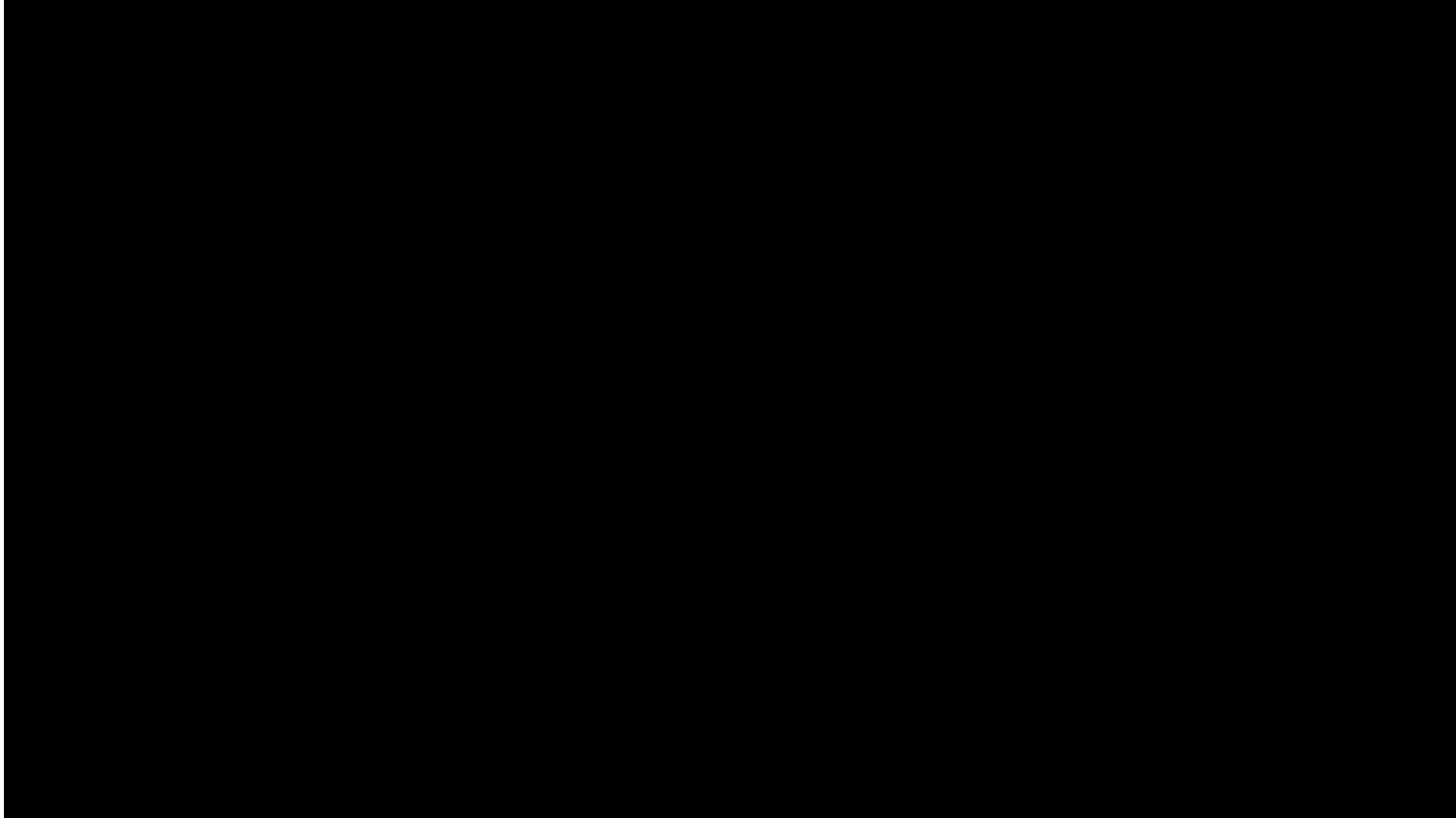
Origin of more than 50% of all the elements beyond iron



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



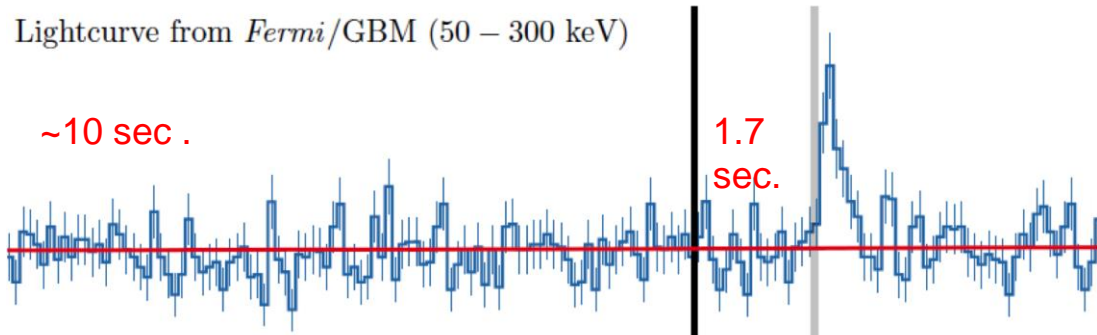
Neutron star – neutron star merger observed on 17 Aug. 2017
by LIGO and Virgo (gravitational radiation), FERMI (gamma ray
telescope) and ~ 70 other electromagnetic observatories.



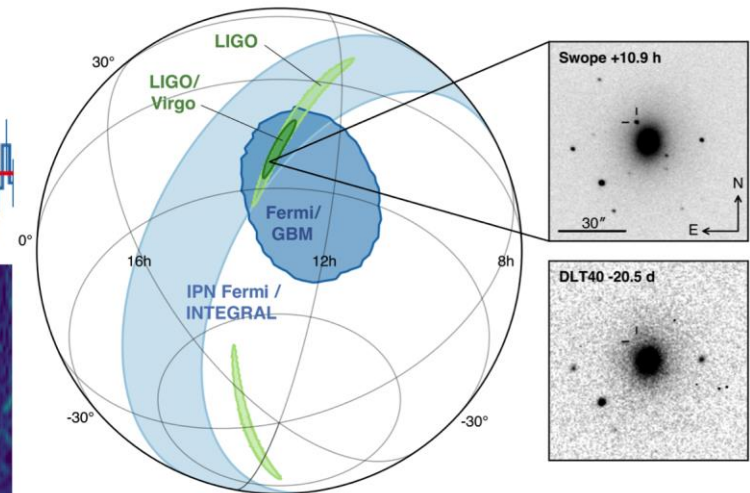
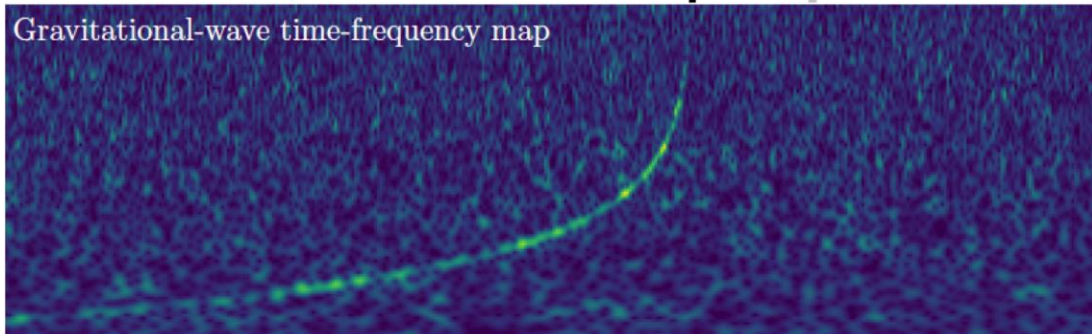
Neutron star – neutron star merger observed on 17 Aug. 2017 by LIGO and Virgo (gravitational radiation), FERMI (gamma ray telescope) and ~ 70 other electromagnetic observatories.

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

Lightcurve from *Fermi*/GBM (50 – 300 keV)



Gravitational-wave time-frequency map



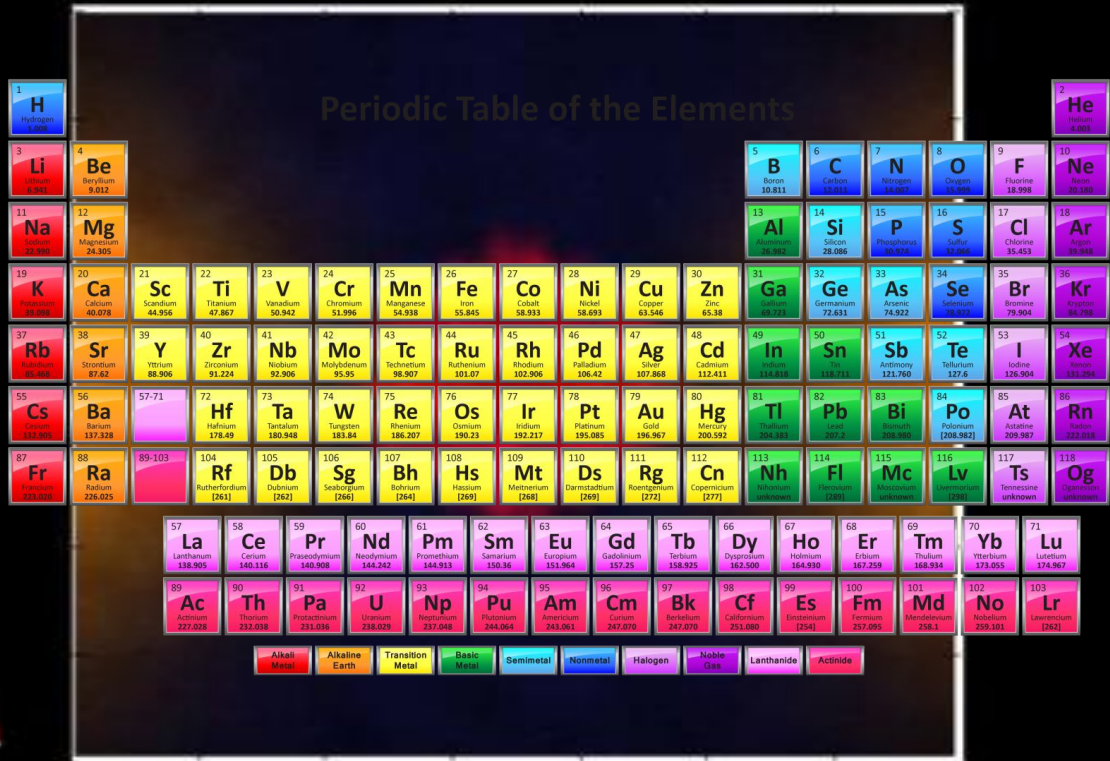
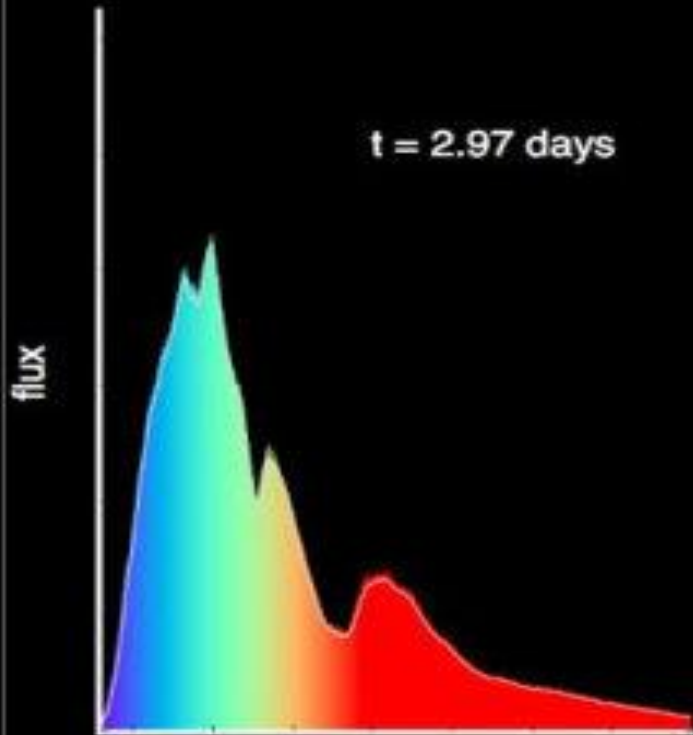
In galaxy NGC 4993

GW170817 + 70 Electromagnetic transients



GW170817 70 Electromagnetic Transients

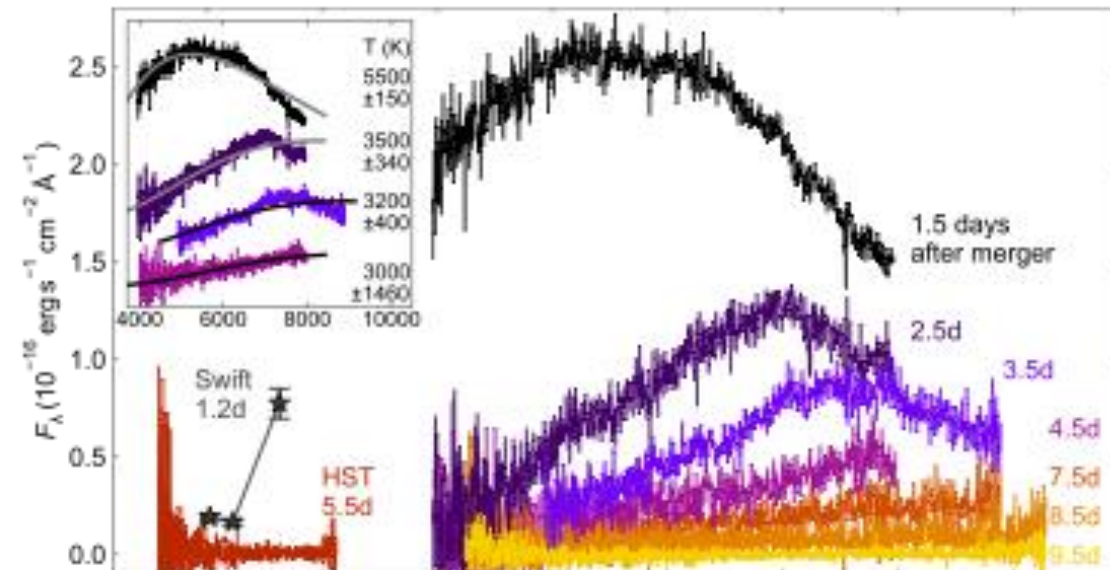
D. Kasen



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

Periodic Table of the Elements

1 H Hydrogen 1.008																	2 He Helium 4.003															
3 Li Lithium 6.941	4 Be Beryllium 9.012											5 B Boron 10.811	6 C Carbon 12.011	7 N Nitrogen 14.007	8 O Oxygen 15.999	9 F Fluorine 18.998	10 Ne Neon 20.180															
11 Na Sodium 22.990	12 Mg Magnesium 24.305											13 Al Aluminum 26.982	14 Si Silicon 28.086	15 P Phosphorus 30.974	16 S Sulfur 32.065	17 Cl Chlorine 35.453	18 Ar Argon 39.948															
19 K Potassium 39.098	20 Ca Calcium 40.078	21 Sc Scandium 44.956	22 Ti Titanium 47.867	23 V Vanadium 50.942	24 Cr Chromium 51.996	25 Mn Manganese 54.938	26 Fe Iron 55.845	27 Co Cobalt 58.933	28 Ni Nickel 58.693	29 Cu Copper 63.546	30 Zn Zinc 65.38	31 Ga Gallium 69.723	32 Ge Germanium 72.631	33 As Arsenic 74.922	34 Se Selenium 78.972	35 Br Bromine 79.904	36 Kr Krypton 83.798															
37 Rb Rubidium 85.468	38 Sr Strontium 87.62	39 Y Yttrium 88.906	40 Zr Zirconium 91.224	41 Nb Niobium 92.906	42 Mo Molybdenum 95.95	43 Tc Technetium 98.907	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.906	46 Pd Palladium 106.42	47 Ag Silver 107.868	48 Cd Cadmium 112.411	49 In Indium 114.818	50 Sn Tin 118.711	51 Sb Antimony 121.760	52 Te Tellurium 127.6	53 I Iodine 126.904	54 Xe Xenon 131.294															
55 Cs Cesium 132.905	56 Ba Barium 137.328	57-71	72 Hf Hafnium 178.49	73 Ta Tantalum 180.948	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.217	78 Pt Platinum 195.085	79 Au Gold 196.967	80 Hg Mercury 200.592	81 Tl Thallium 204.383	82 Pb Lead 207.2	83 Bi Bismuth 208.980	84 Po Polonium [208.982]	85 At Astatine 209.987	86 Rn Radon 222.018															
87 Fr Francium 223.021	88 Ra Radium 226.025	89-103	104 Rf Rutherfordium [261]	105 Db Dubnium [262]	106 Sg Seaborgium [266]	107 Bh Bohrium [264]	108 Hs Hassium [269]	109 Mt Meitnerium [268]	110 Ds Darmstadtium [269]	111 Rg Roentgenium [272]	112 Cn Copernicium [277]	113 Nh Nihonium unknown	114 Fl Flerovium [289]	115 Mc Moscovium unknown	116 Lv Livermorium [292]	117 Ts Tennessine unknown	118 Og Oganesson [289]															
																		57 La Lanthanum 138.905	58 Ce Cerium 140.116	59 Pr Praseodymium 140.908	60 Nd Neodymium 144.242	61 Pm Promethium 144.913	62 Sm Samarium 150.36	63 Eu Europium 151.964	64 Gd Gadolinium 157.25	65 Tb Terbium 158.925	66 Dy Dysprosium 162.500	67 Ho Holmium 164.930	68 Er Erbium 167.259	69 Tm Thulium 168.934	70 Yb Ytterbium 173.055	71 Lu Lutetium 174.967
																		89 Ac Actinium 227.028	90 Th Thorium 232.038	91 Pa Protactinium 231.036	92 U Uranium 238.029	93 Np Neptunium 237.048	94 Pu Plutonium 244.064	95 Am Americium 243.061	96 Cm Curium 247.070	97 Bk Berkelium 247.070	98 Cf Californium 251.080	99 Es Einsteinium [254]	100 Fm Fermium 257.095	101 Md Mendelevium 258.1	102 No Nobelium 259.101	103 Lr Lawrencium [262]
																		Alkali Metal	Alkaline Earth	Transition Metal	Basic Metal	Semimetal	Nonmetal	Halogen	Noble Gas	Lanthanide	Actinide					

Are there more elements?



Rutherfordium

1964

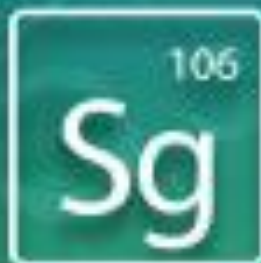
Target ^{249}Pu , ^{249}Cf



Dubnium

1970

Target ^{208}Bk , ^{242}Pu , ^{249}Cf



Seaborgium

1974

Target ^{249}Cf



Nihonium

2004

Target ^{249}Am
Decay from 115



Flerovium

2000

Target ^{249}Pu



Moscovium

2004

Target ^{249}Am



Livermorium

2005

Target ^{248}Pu , ^{249}Cm



Tennesine

2010

Target ^{209}Bk



Oganesson

2006

Target ^{249}Cf

Collaboration
LLNL
JINR
ORNL

113 Nh Nihonium (284)	114 Fl Flerovium (289)	115 Mc Moscovium (288)	116 Lv Livermorium (293)	117 Ts Tennessine (294)	118 Og Oganesson (294)
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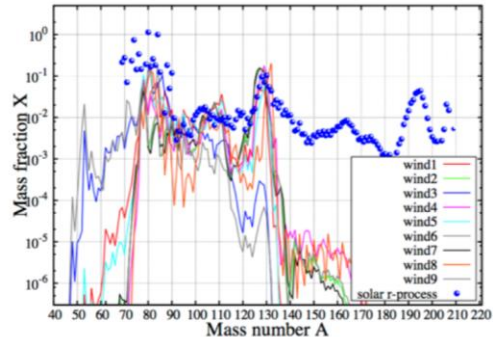
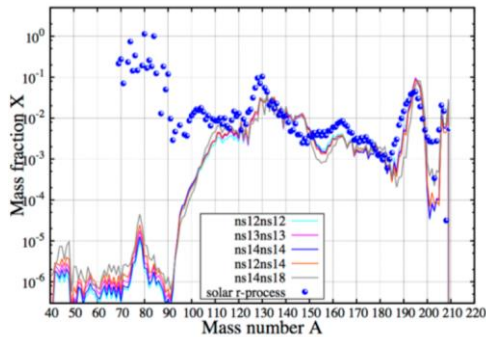
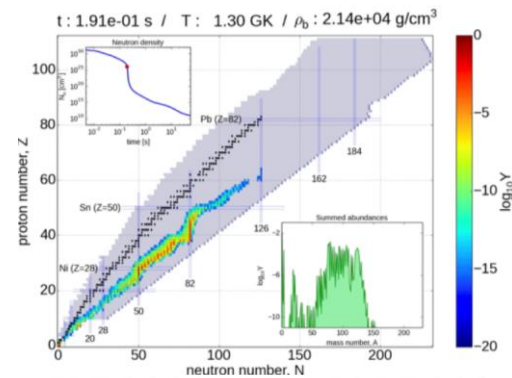
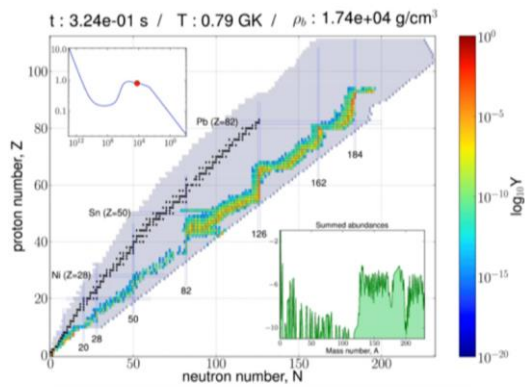
Z=120

From ^{48}Ca induced reactions

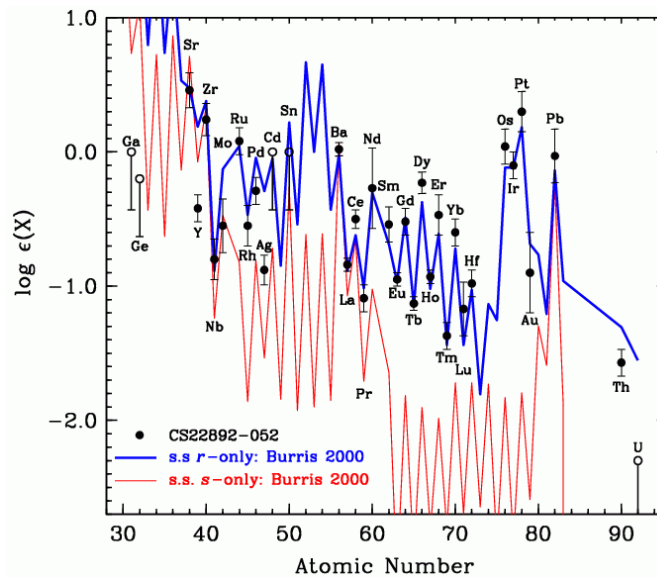
Z=174

where is the site of the r-process?

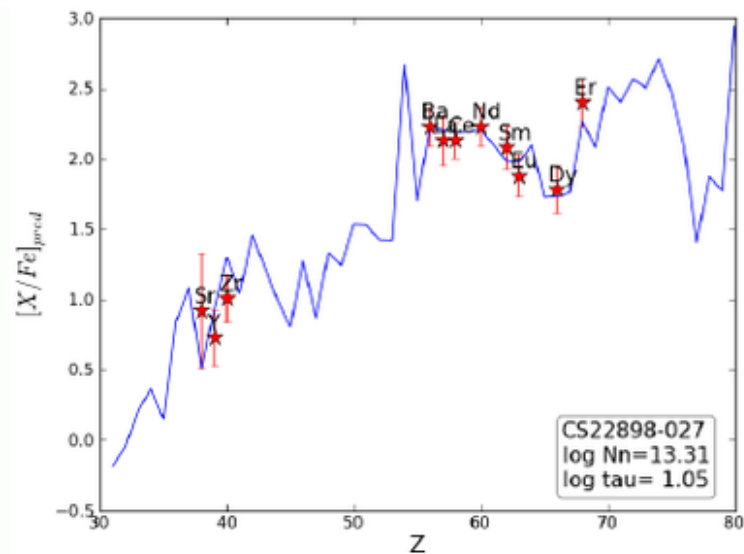
Merging neutron stars versus core collapse supernovae, gravitational wave detection identified neutron star mergers as a source of the very heavy elements!



Abundances from other neutron induced nucleosynthesis processes



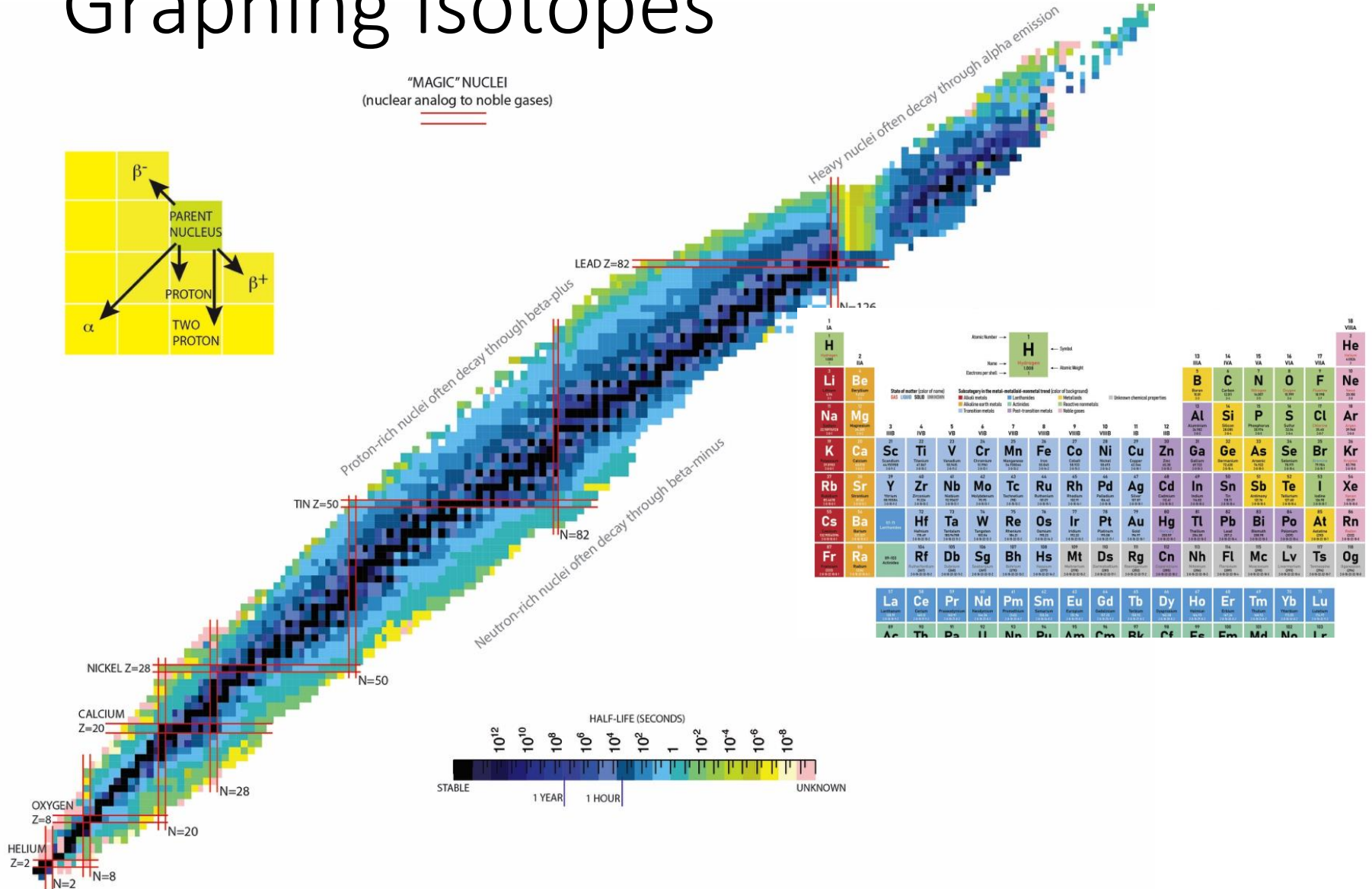
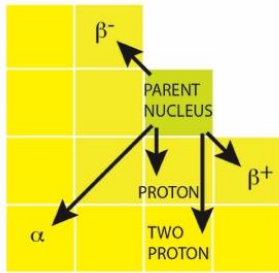
The **s-process** in comparison to the r-process. The scaling depends on the strength of the s-process neutron source



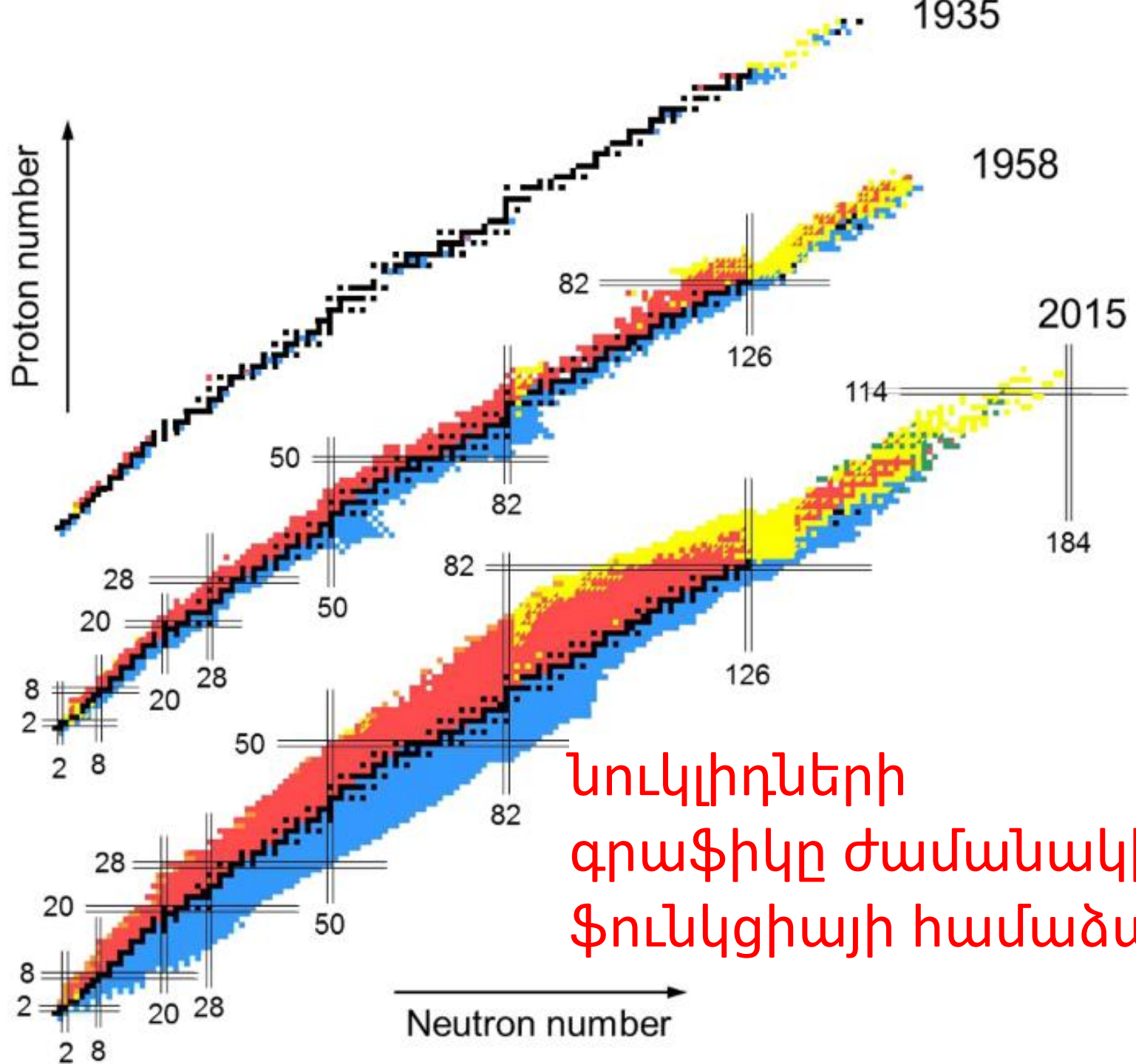
The **i-process** in CEMP stars, again the scale depends on the strength of neutron source

Graphing Isotopes

"MAGIC" NUCLEI
(nuclear analog to noble gases)

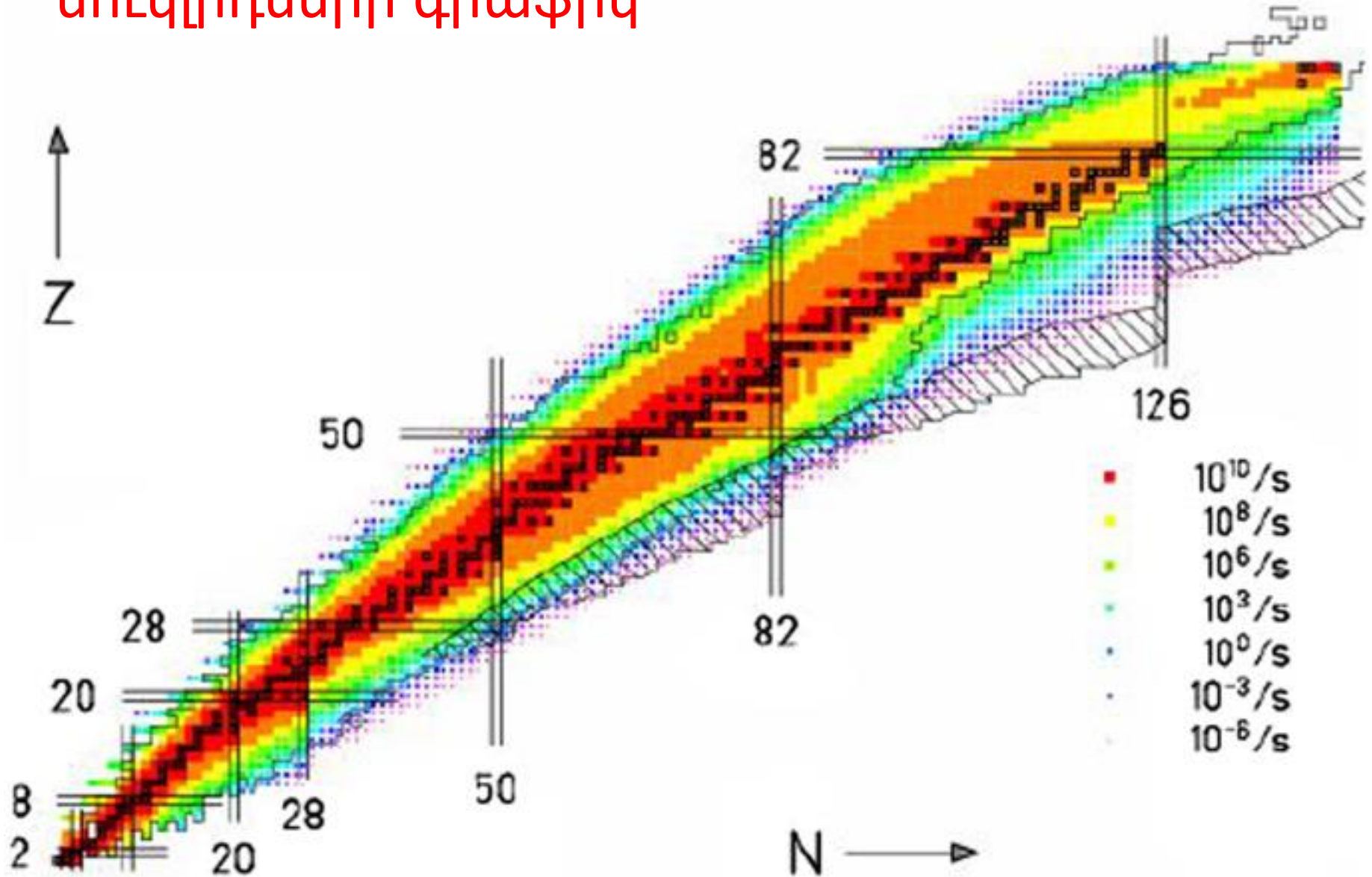


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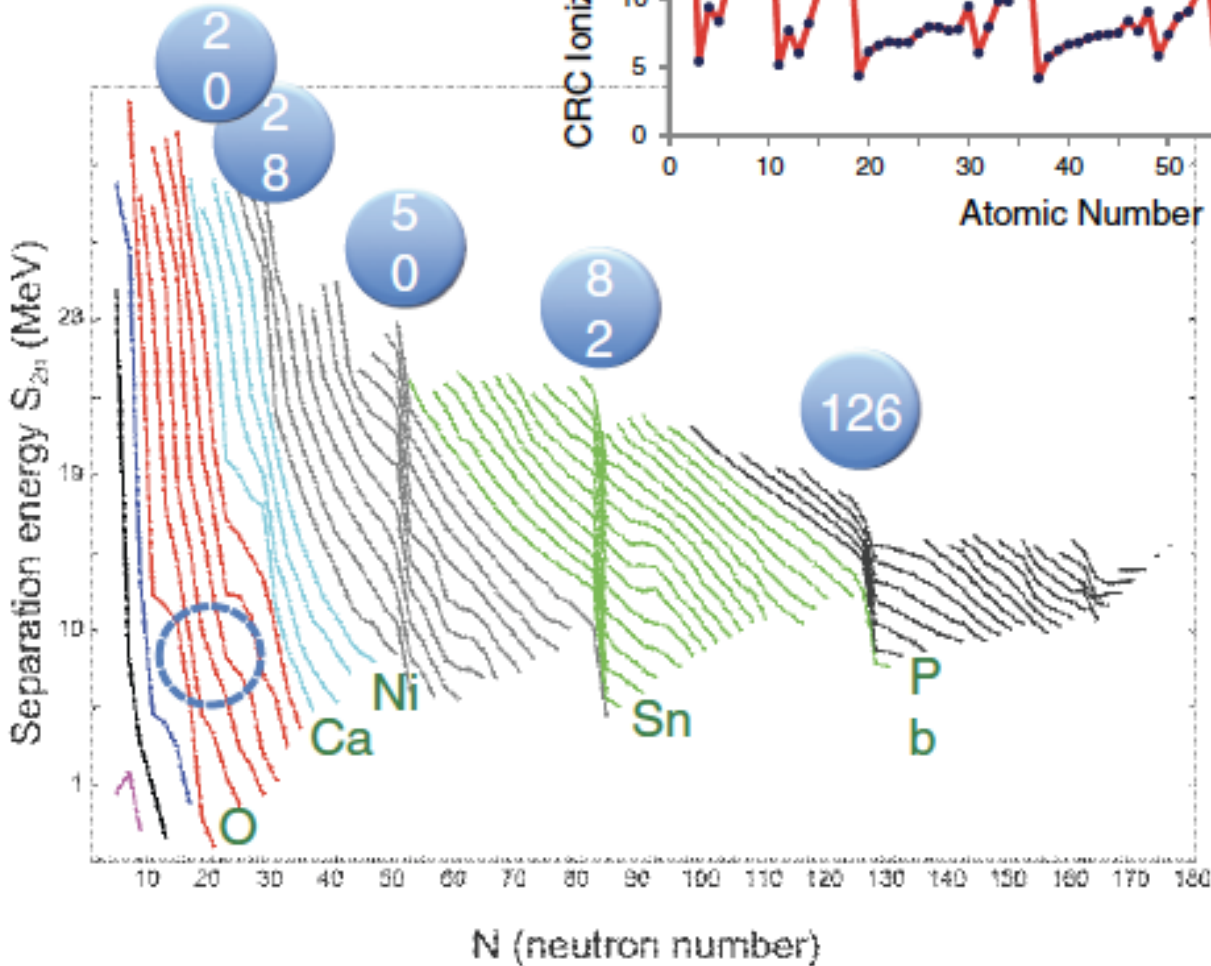
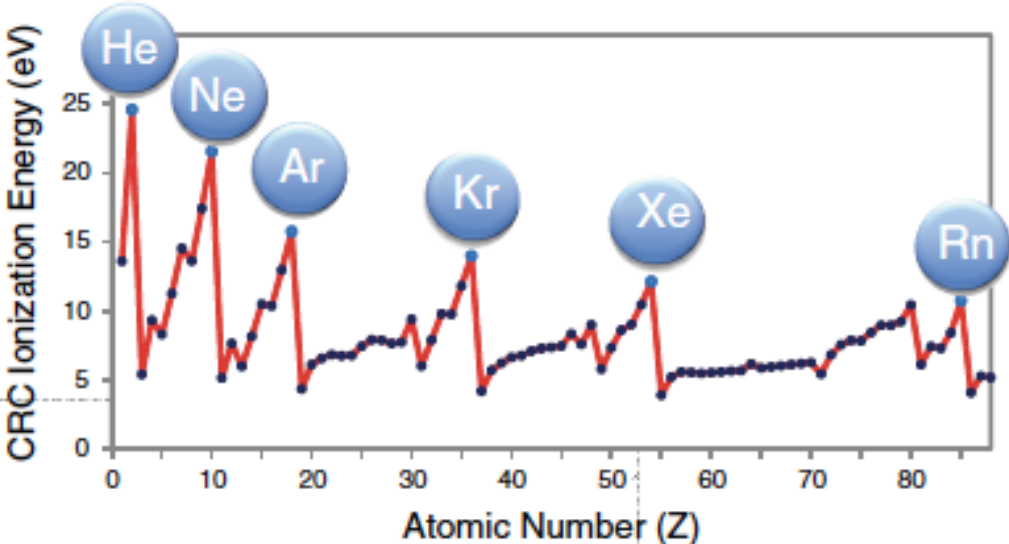


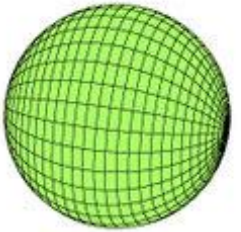
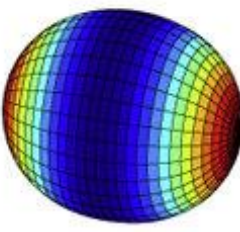
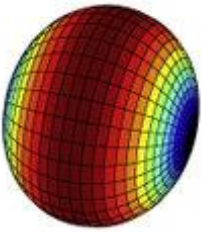
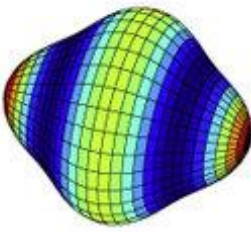
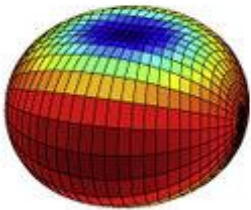
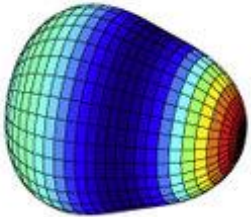
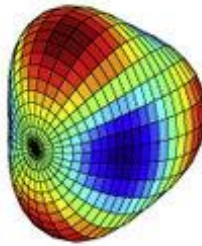
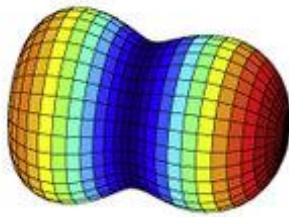
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 գրաֆիկը ժամանակի
 ֆունկցիայի համաձայն

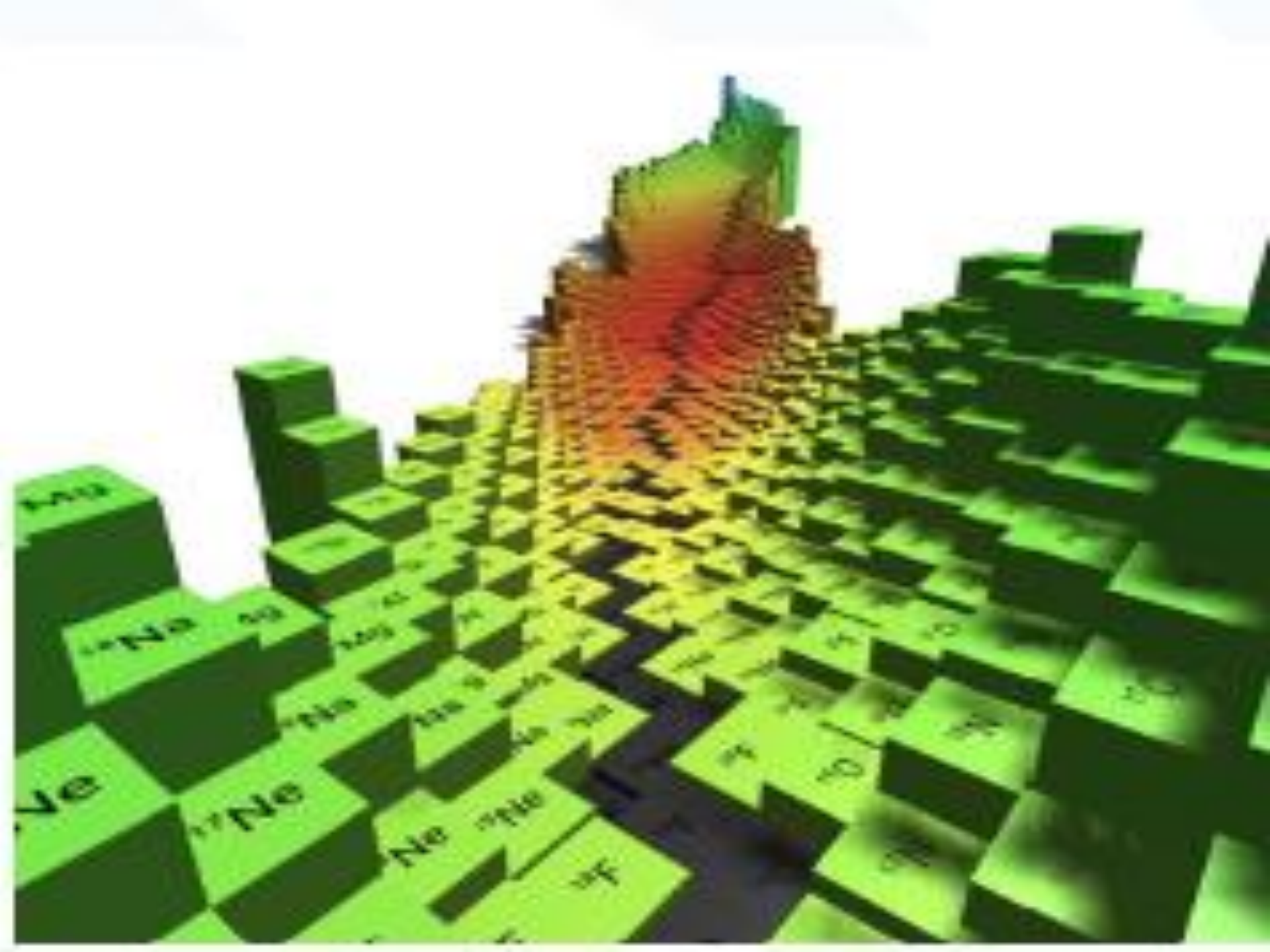
Նուկլիդների գրաֆիկ



Regularities and periodicities in atoms and nuclei

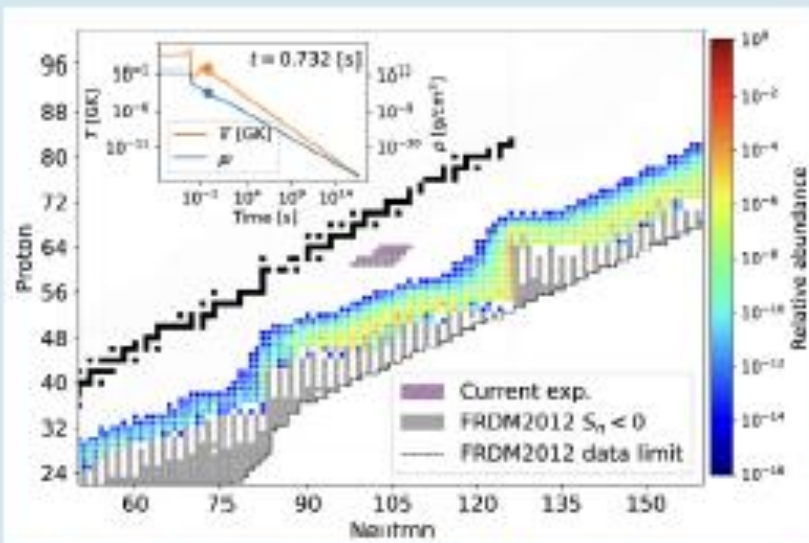


$\beta_{\lambda\mu} = 0$	$\beta_{20} > 0$	$\beta_{20} < 0$	$\beta_{40} > 0$
			
$\beta_{22} \neq 0$	$\beta_{30} \neq 0$	$\beta_{32} \neq 0$	$\beta_{20} \gg 0$
			



**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



SHE-Factory

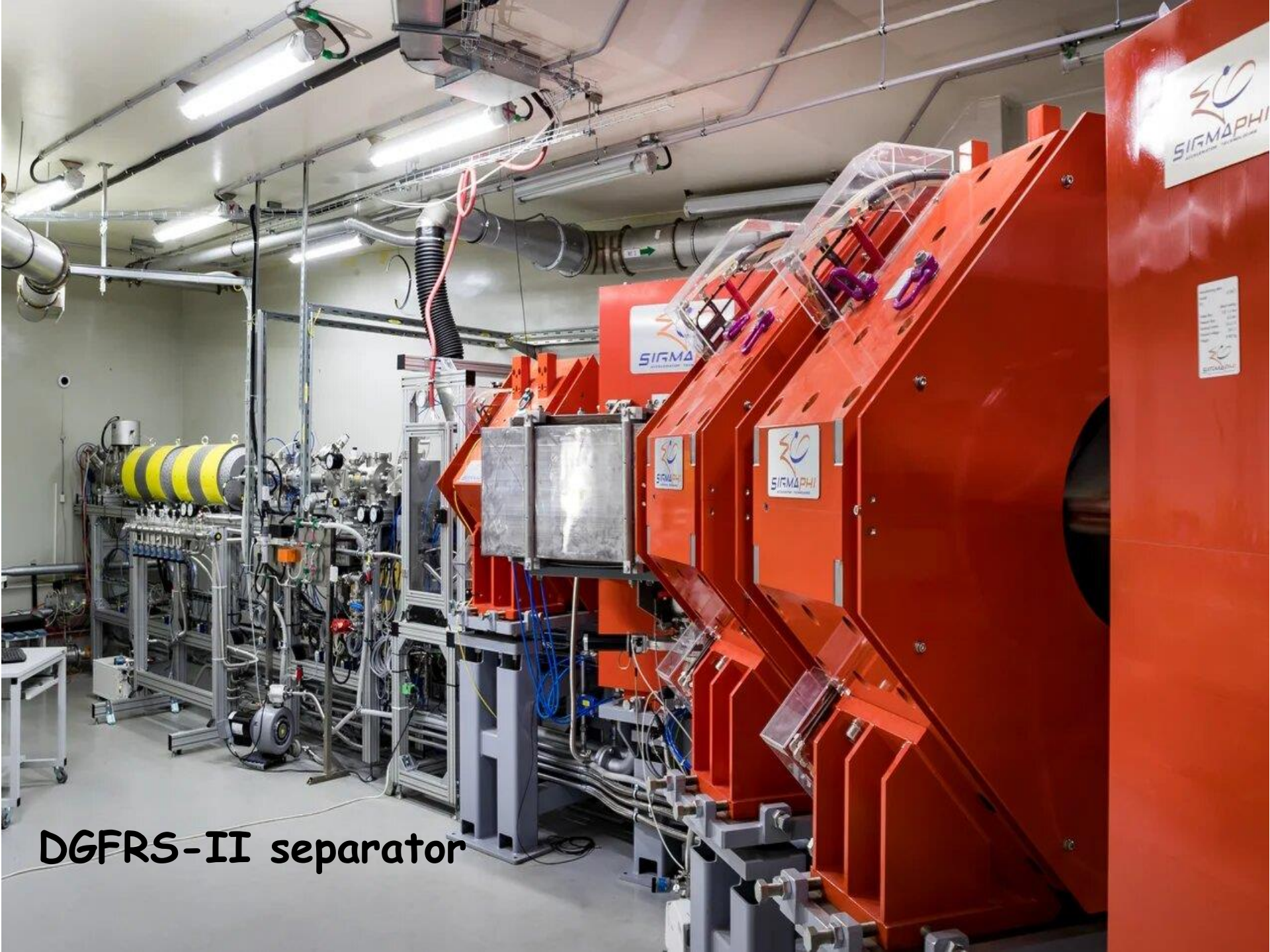
Yuri Oganesian. International Conference "Heaviest Nuclei and Atoms" Apr.25-30, 2023, Yerevan

November 2018, Dubna



New cyclotron DC-280

Yuri Oganessian. International Conference "Heaviest Nuclei and Atoms" Apr.25-30, 2023, Yerevan



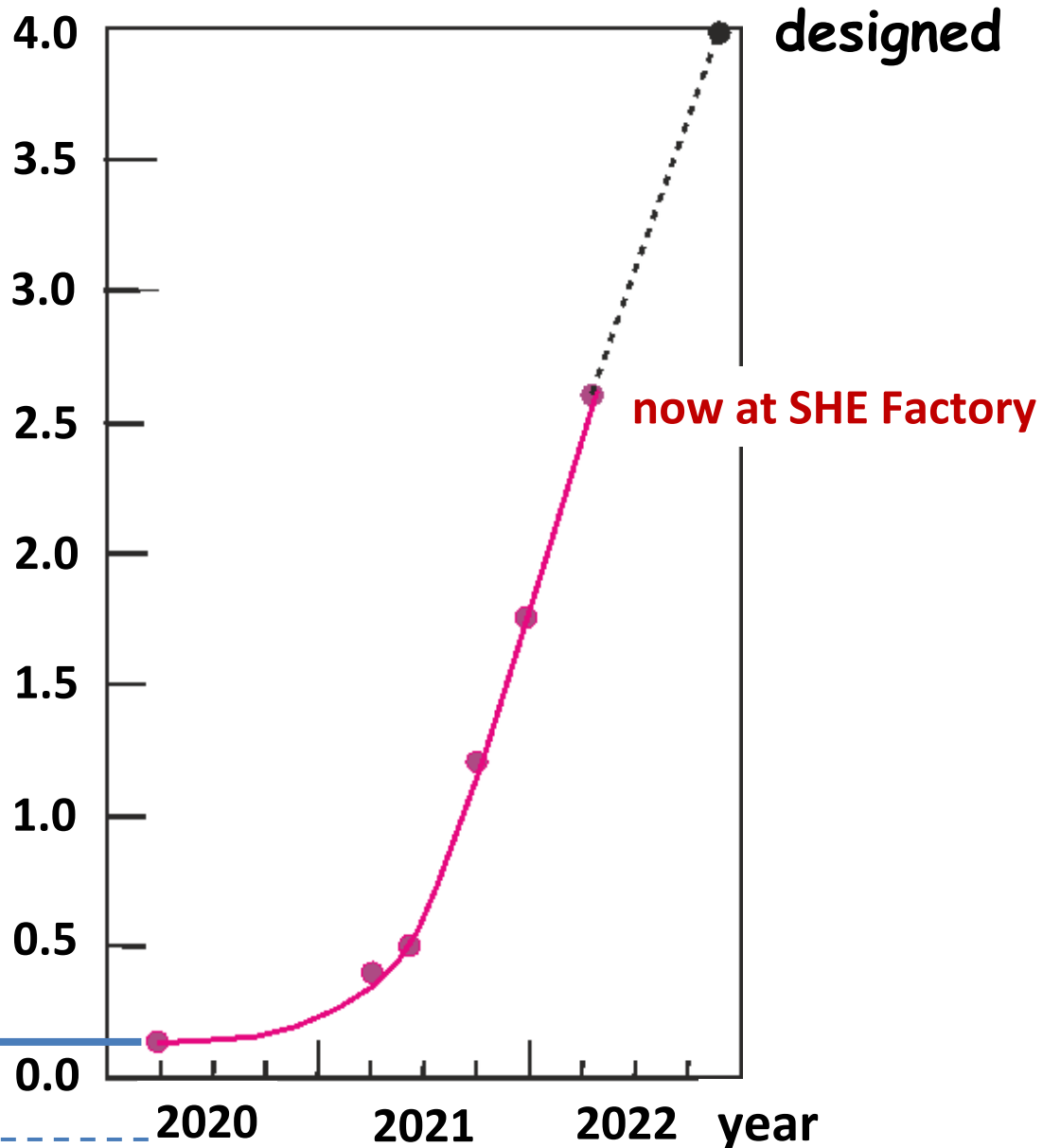
DGFRS-II separator

Progress at SHE-Factory

Luminosity
(target 30 mg)

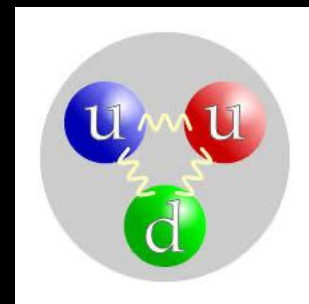
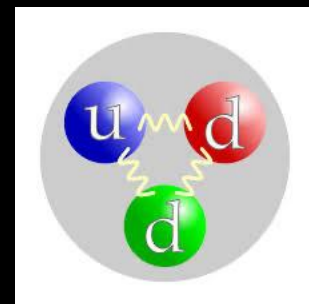
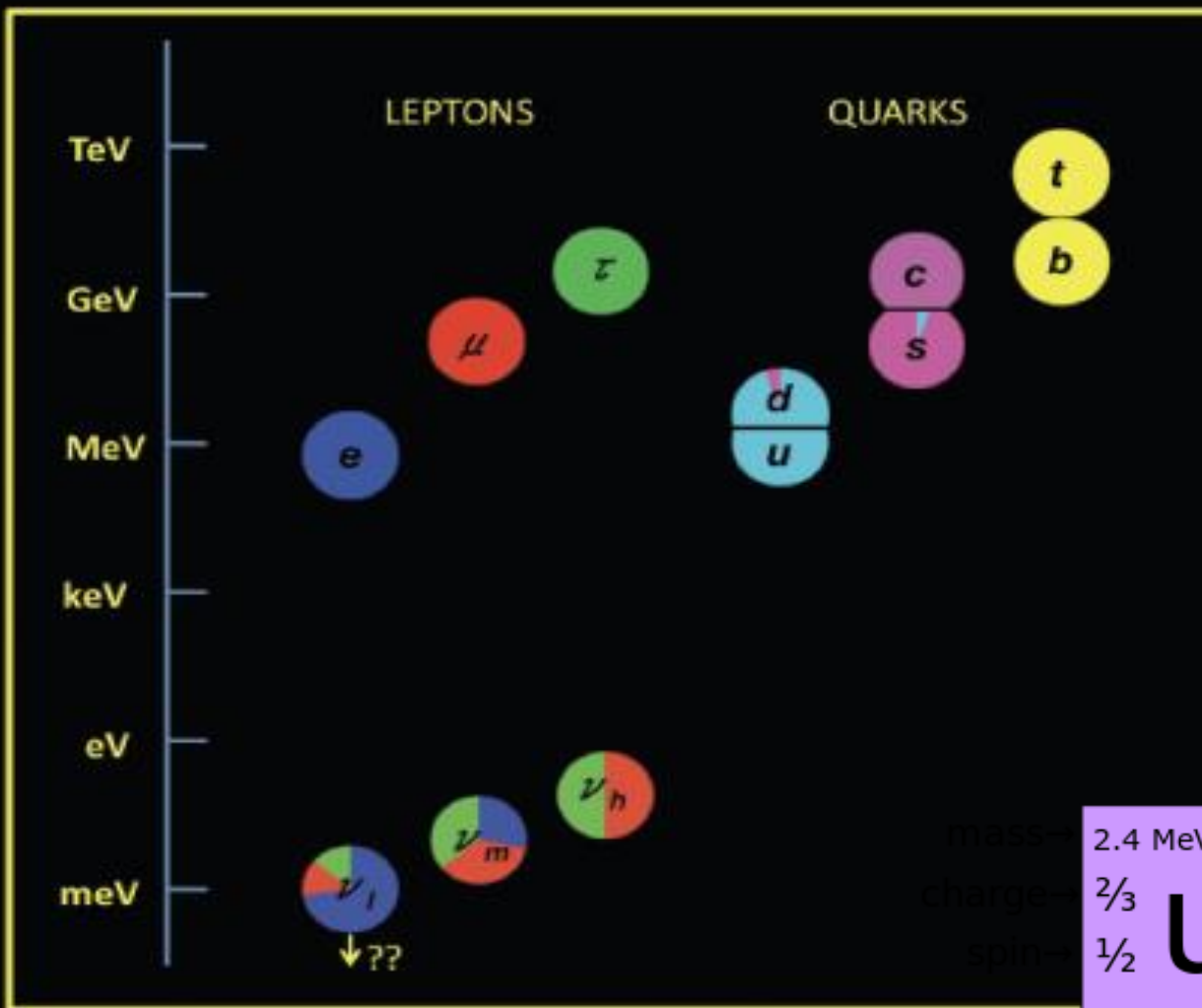
world record

Luminosity ($10^{31}/\text{cm}^2\cdot\text{s}$)



FROM QUARKS TO NEUTRON STARS





mass
charge
spin
name

2.4 MeV
 $\frac{2}{3}$
 $\frac{1}{2}$
u
up

1.27 GeV
 $\frac{2}{3}$
 $\frac{1}{2}$
c
charm

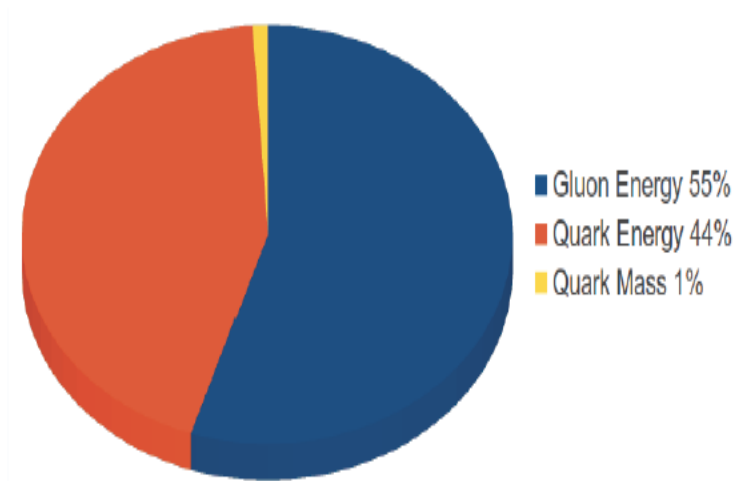
171.2 GeV
 $\frac{2}{3}$
 $\frac{1}{2}$
t
top

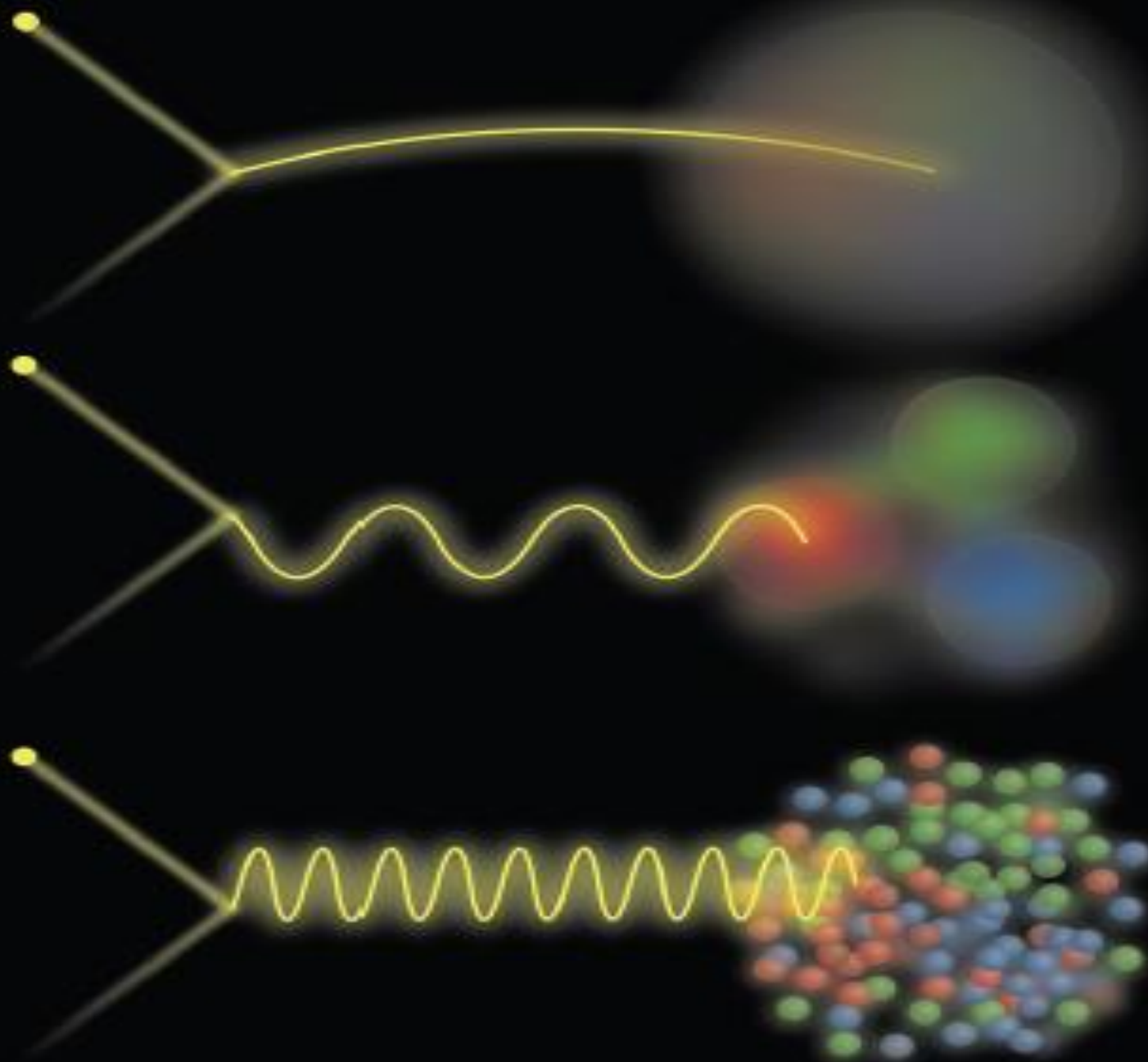
Quarks

4.8 MeV
 $-\frac{1}{3}$
 $\frac{1}{2}$
d
down

104 MeV
 $-\frac{1}{3}$
 $\frac{1}{2}$
s
strange

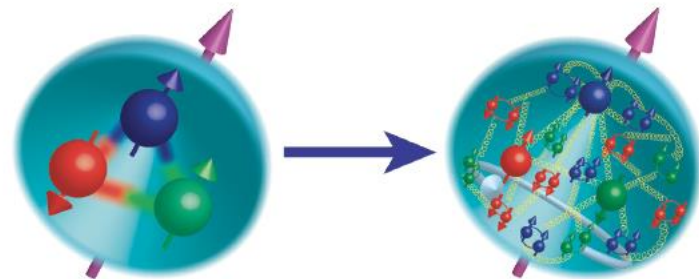
4.2 GeV
 $-\frac{1}{3}$
 $\frac{1}{2}$
b
bottom





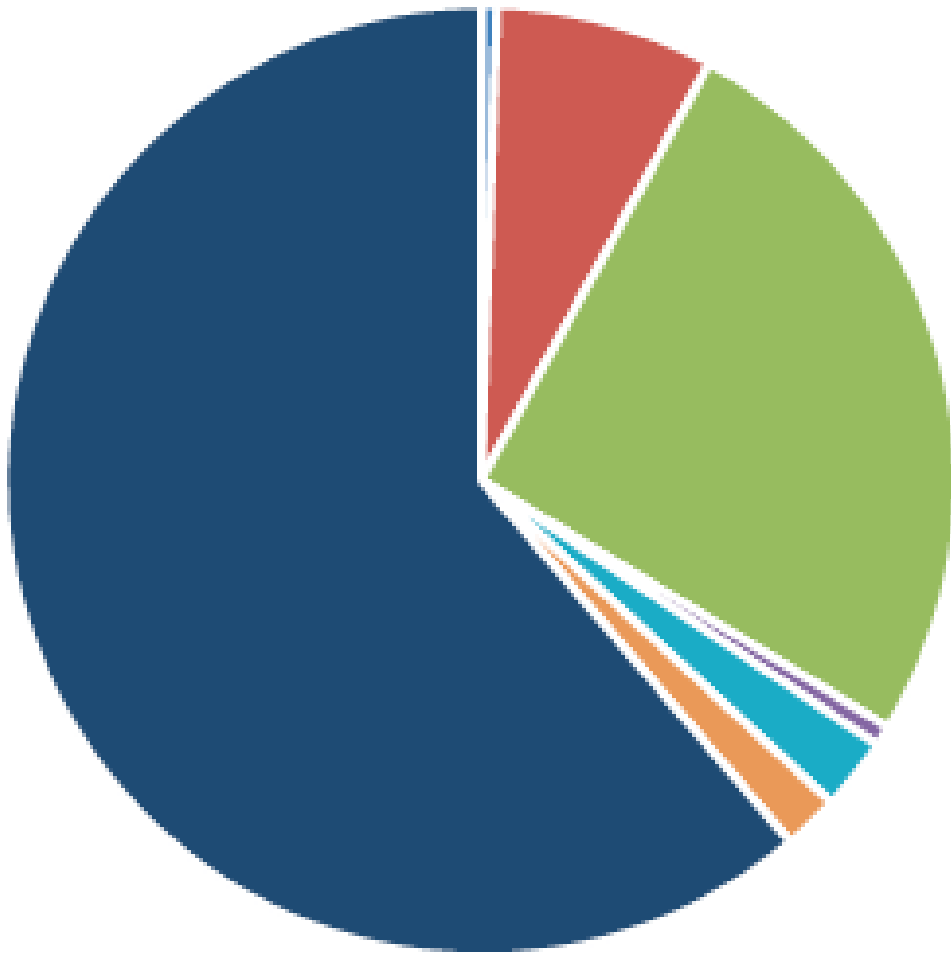
AN ASSESSMENT OF
U.S. BASED ELECTRON-ION
COLLIDER SCIENCE

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



1980's

hħmλ



■ Africa

■ Asia

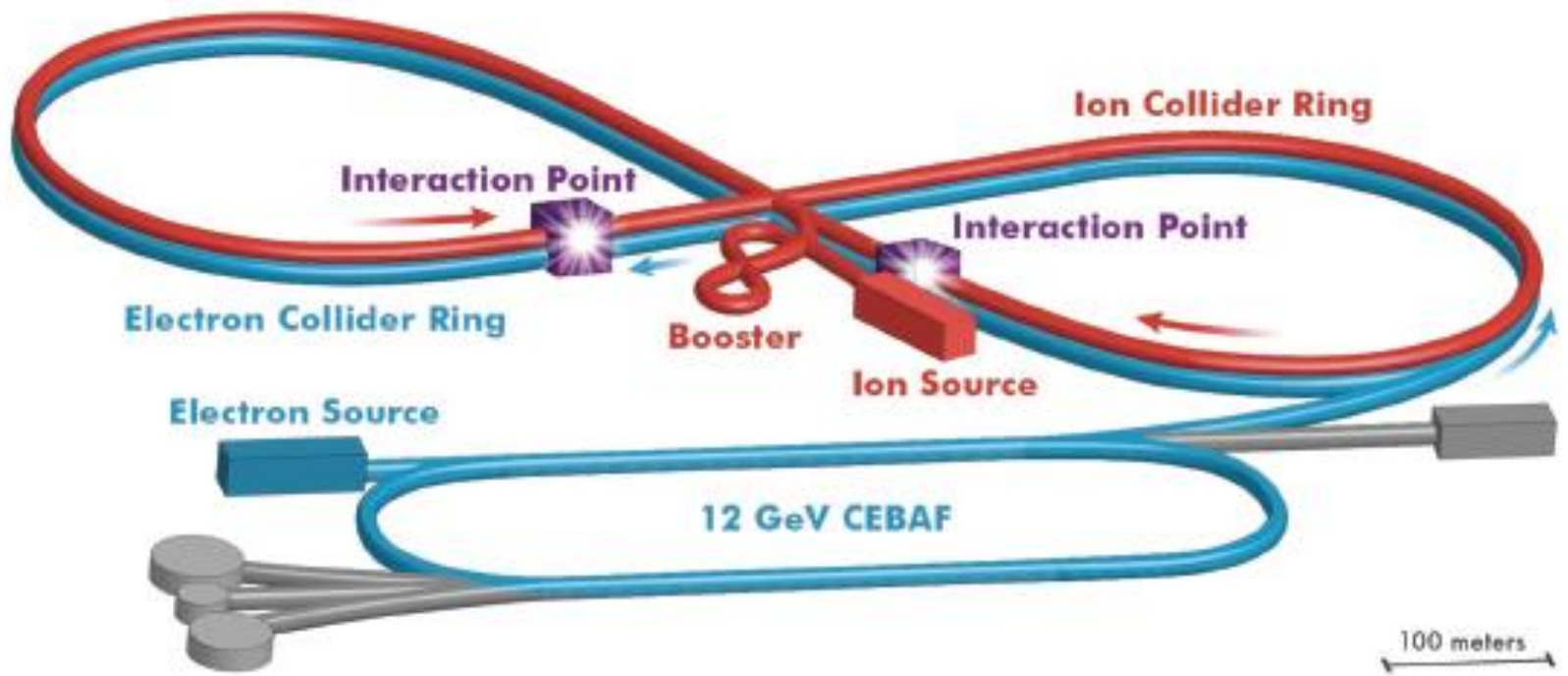
■ Europe

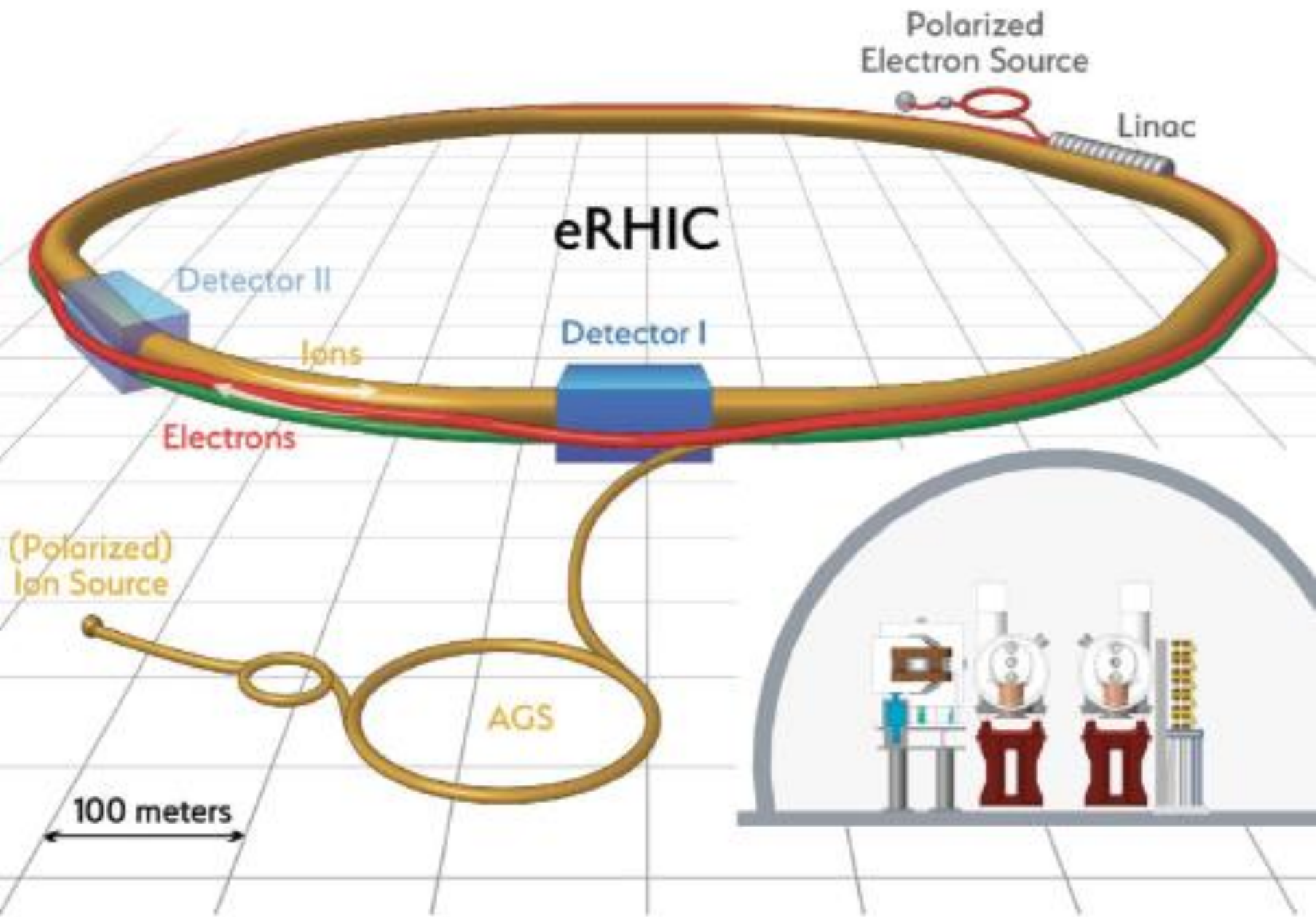
■ Oceania

■ Other North America

■ South America

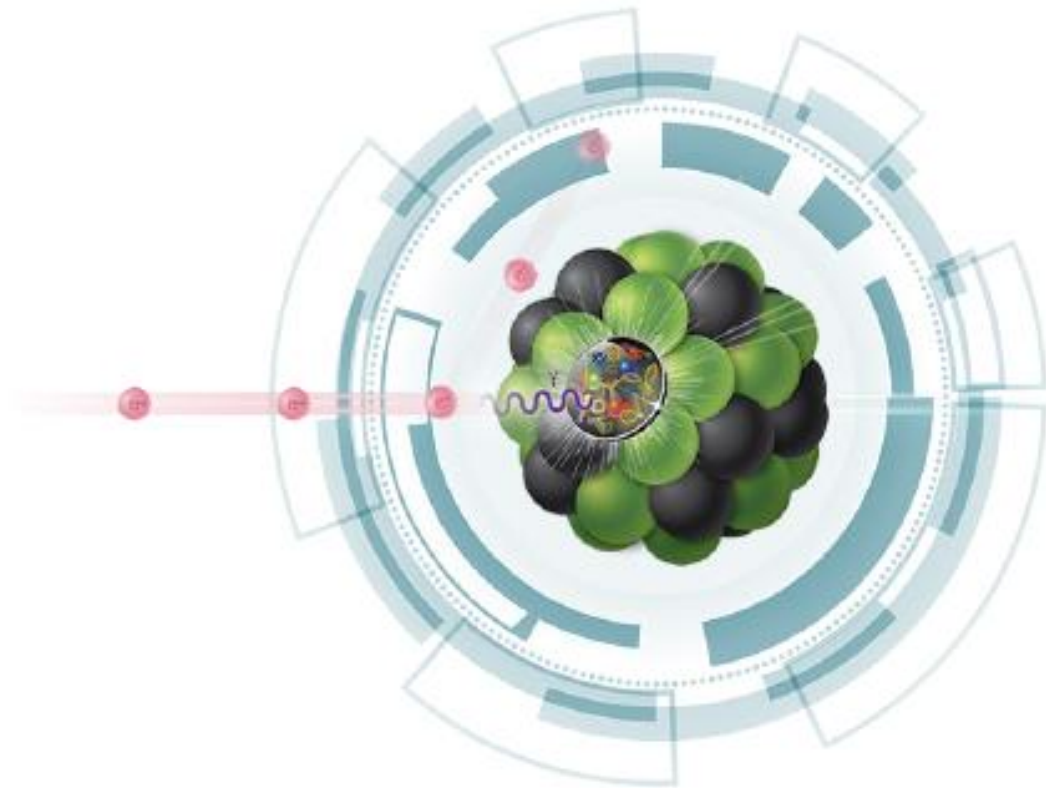
■ U.S.





The Electron-Ion Collider

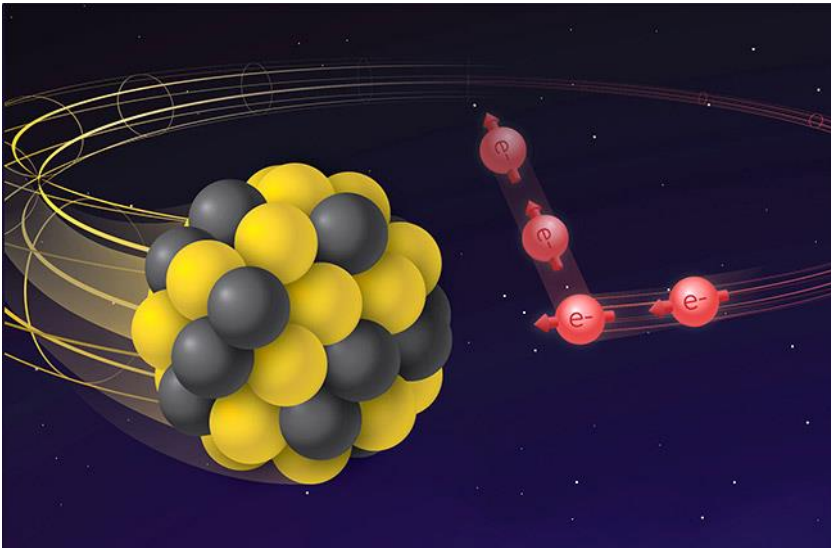
A machine that will unlock the secrets of the strongest force in Nature



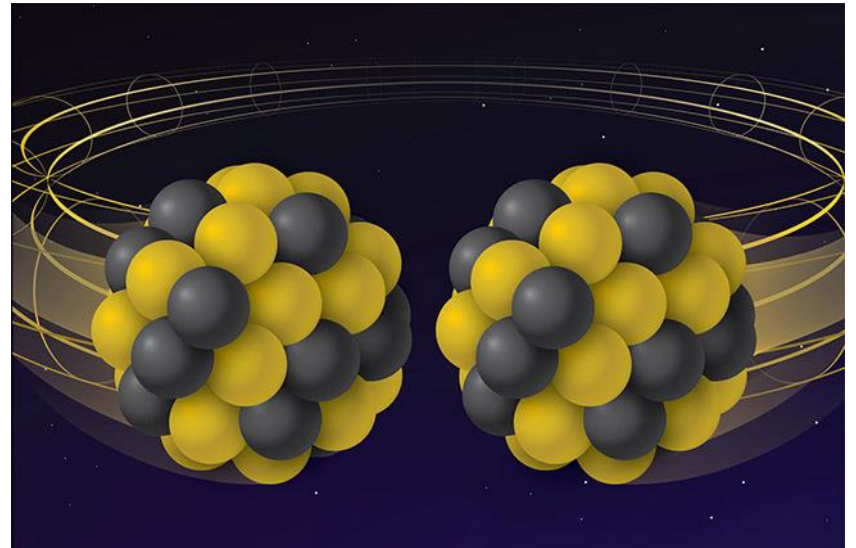


The Electron-Ion Collider (EIC) will be the world's first polarized electron-ion collider, a set of accelerator rings that bring polarized electrons and polarized ions into millions of head-on collisions at nearly the speed of light.

Electron Ion Collider



Relativistic Heavy Ion Collider



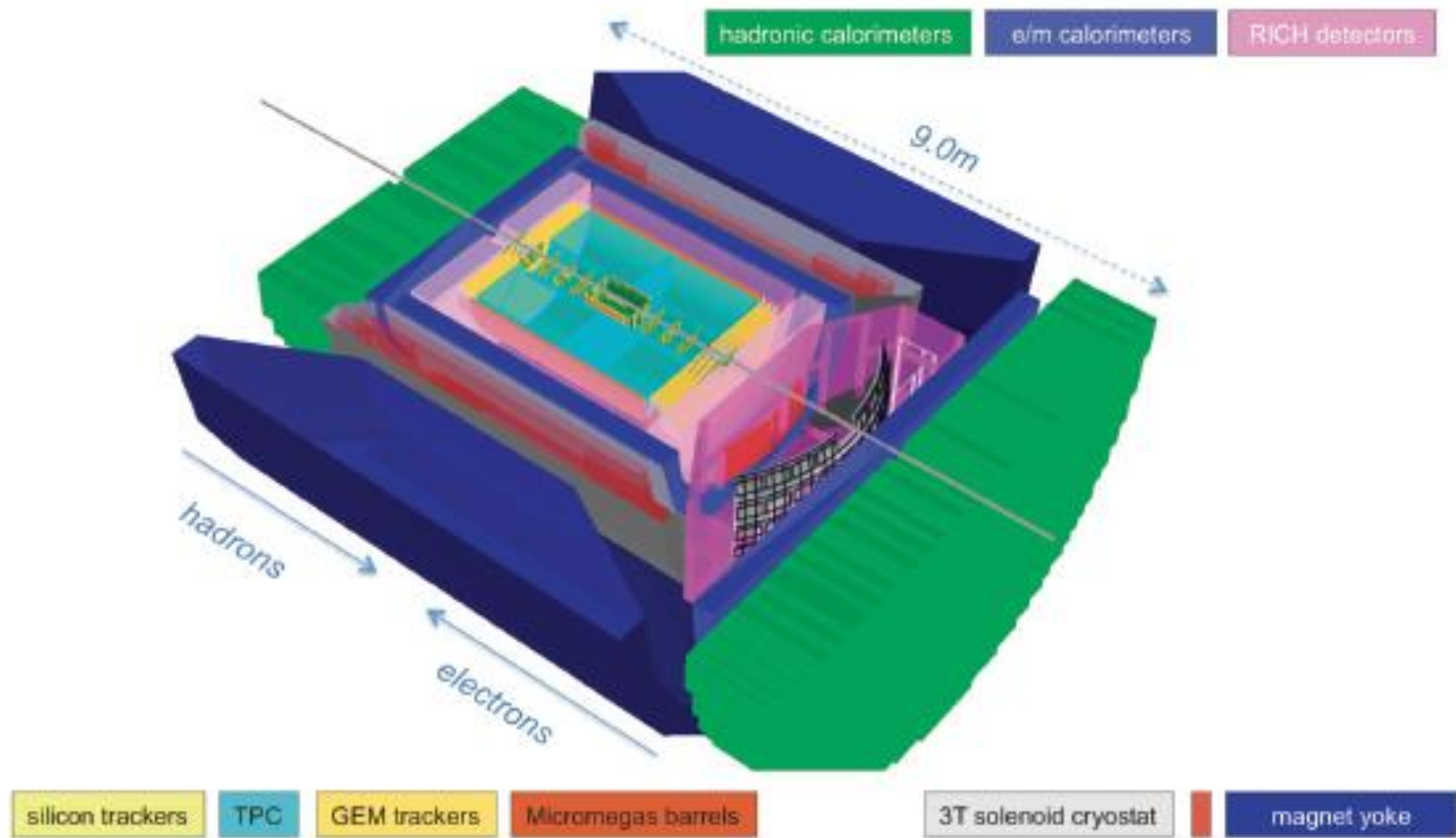






FIGURE 5.3 View of the COMPASS experiment in a target hall of the Super Proton Synchrotron accelerator at the European Organization for Nuclear Research (CERN). SOURCE: CERN, "View from the Crane of the COMPASS Experiment Facility," © 2011-2018 CERN, <http://cds.cern.ch/record/1370231>, accessed August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

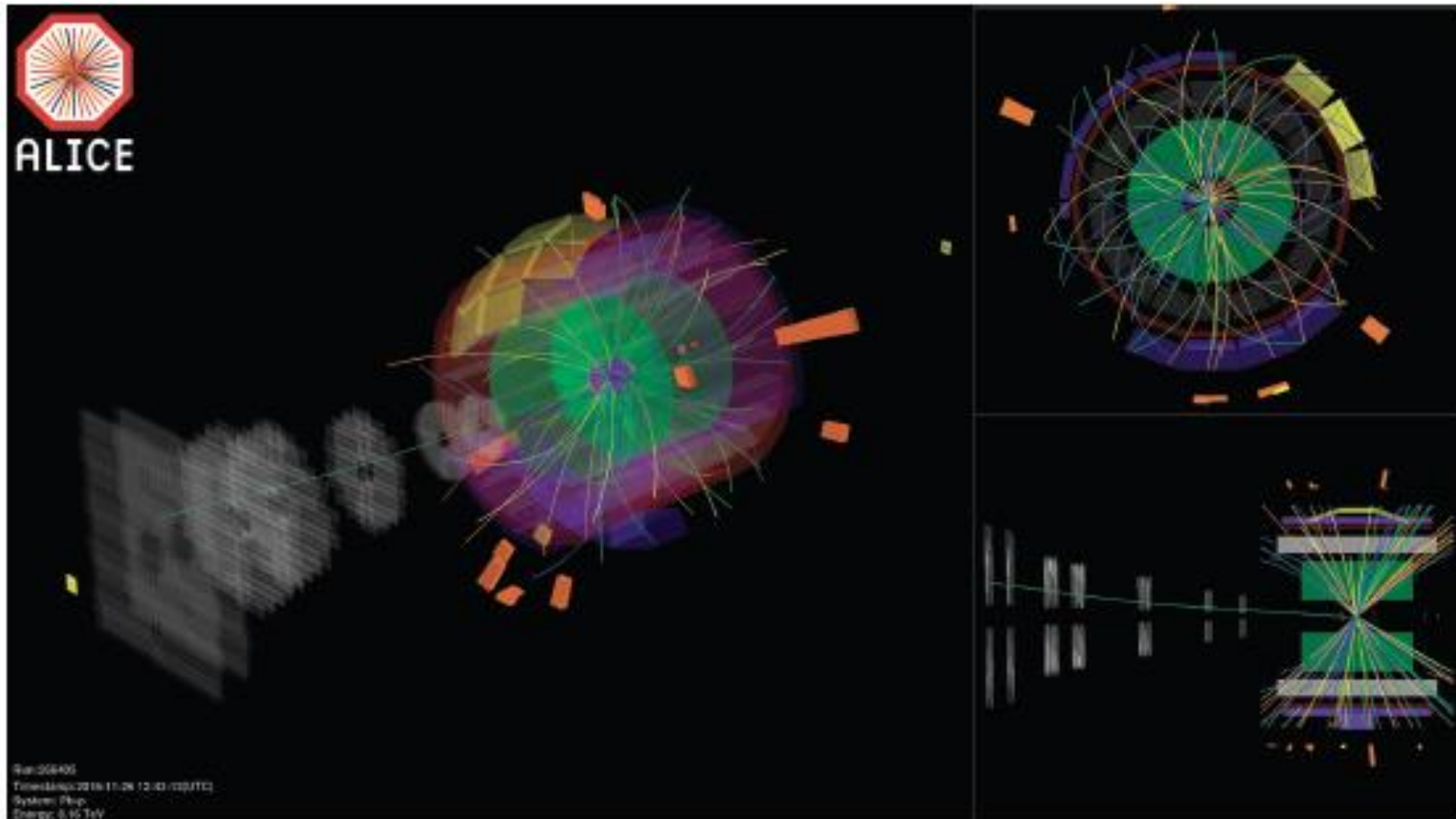


FIGURE 5.5 A collision between a lead nucleus, with a total energy of 533 TeV and a proton of energy 6.5 TeV, yielding an average 8.16 TeV per colliding nucleon pair, recorded in detail by the ALICE detector at the Large Hadron Collider in late 2016. SOURCE: ALICE Experiment, European Organization for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

A NEW ERA OF DISCOVERY

THE 2023 LONG RANGE PLAN FOR NUCLEAR SCIENCE

2023 | VERSION 1.2



Investments in Science



- https://youtu.be/Xsf_EqGHSDI