James Webb Telescope
December 2023

Անի Աբրահամյան

Ֆիզիկայի պրոֆեսոր
Քիմիայի և կենսաքիմիայի զուգահեռ պրոֆեսոր
Նոտր Դամի համալսարան

Ես շատ ուրախ եմ ձեզ հետ հանդիպելու համար...դուք երիտասարդ մտքերի կերտողն եք Հայաստանի ապագայի համար:

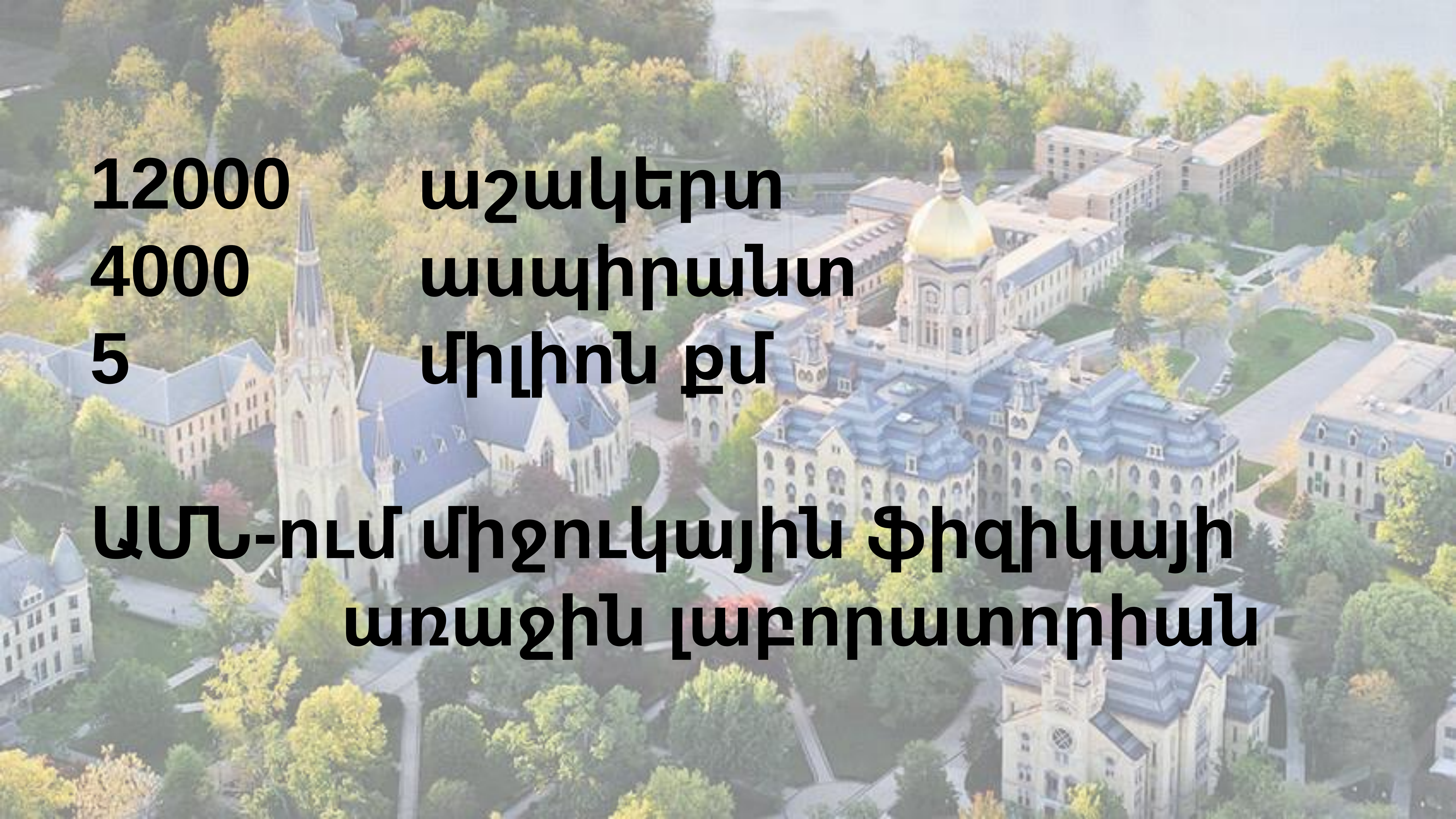
Հայաստանում իմ փորձառությունն ինձ ցույց տվեց, որ հայ ուսանողները շատ են հետաքրքրված Ֆիզիկայով: Ոչ ԱՄՆ-ի ուսանողների նման: Տարբերությունը Հայաստանի լավ ուսուցիչներն են:

Ո՞վ է Անի Աբրահամյանը

Միջուկային ֆիզիկա

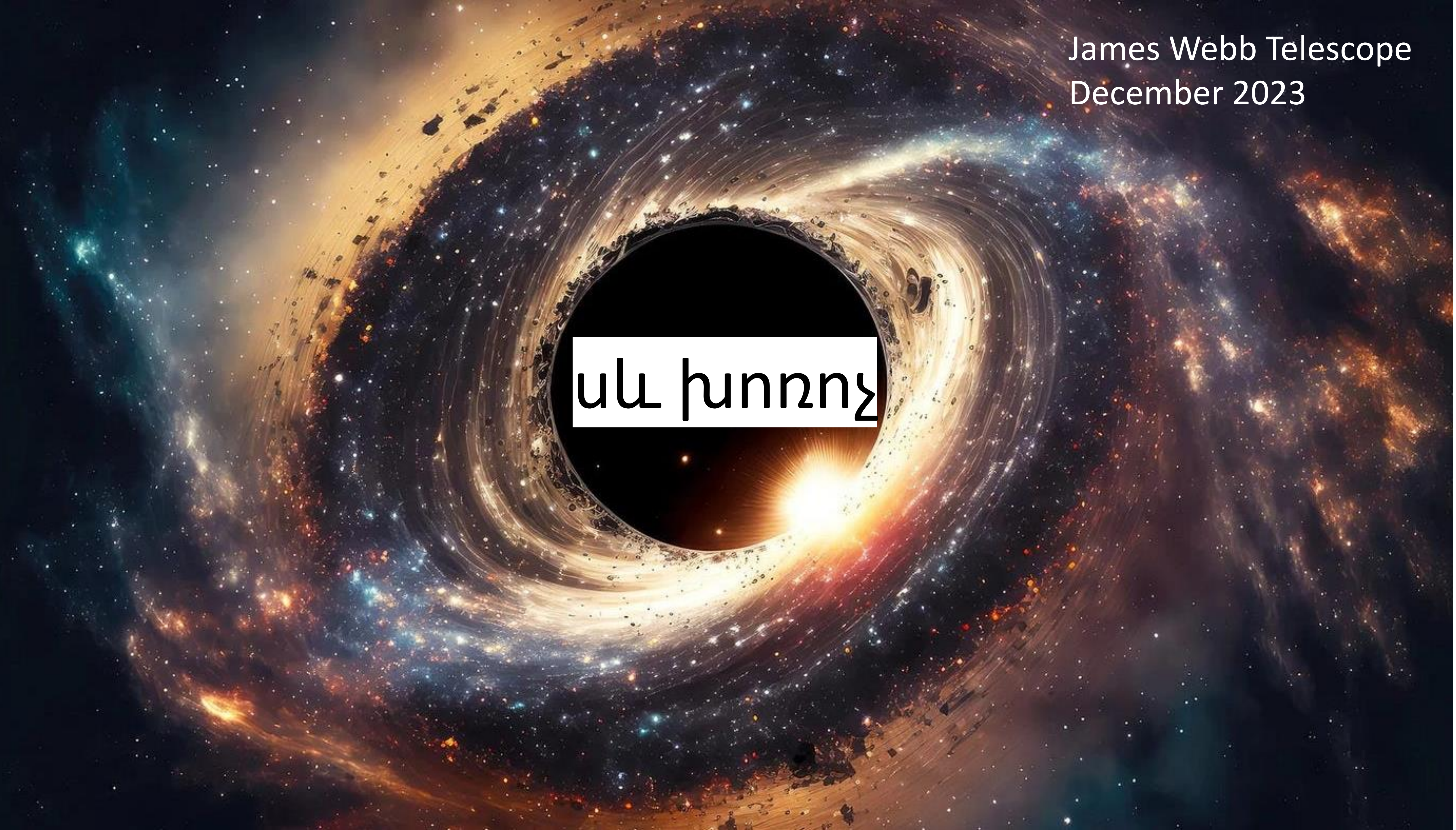
Որտե՞ղ է գտնվում Նոտր Դամի համալսարանը։

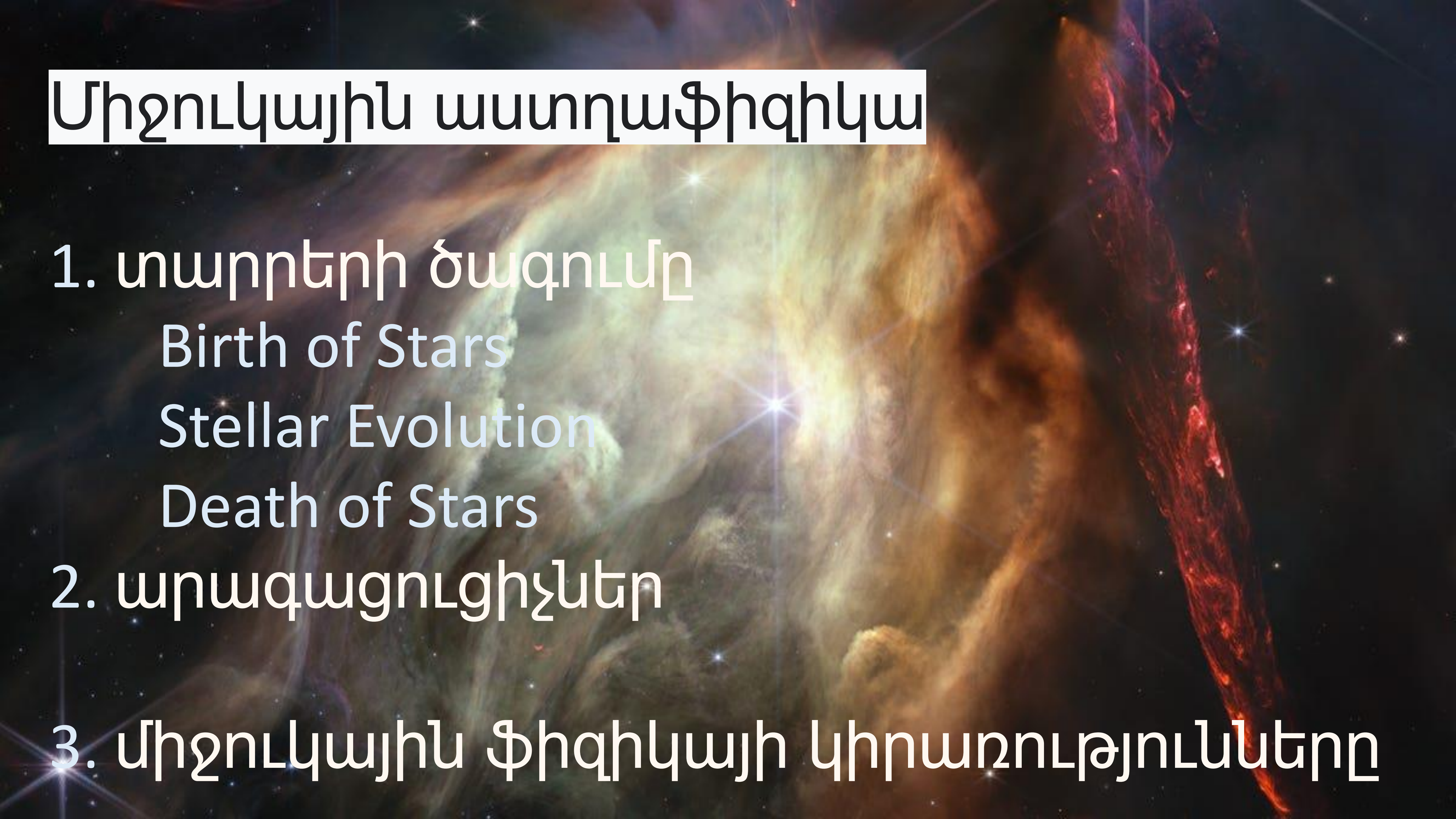

United States
CANADA
WASHINGTON
Olympia
MONTANA
Helena
NORTH DAKOTA
Bismarck
MINNESOTA
St Paul
OREGON
Salem
IDAHO
Boise
WYOMING
Cheyenne
SOUTH DAKOTA
Pierre
WISCONSIN
Madison
MICHIGAN
Lansing
Lake Superior
Lake Michigan
NEW YORK
Albany
MAINE
Augusta
Montpelier
Concord
VERMONT
NEW HAMPSHIRE
MASSACHUSETTS
Boston
Providence
RHODE ISLAND
Hartford
CONNECTICUT
NEVADA
Carson City
CALIFORNIA
Sacramento
Los Angeles
UTAH
Salt Lake City
COLORADO
Denver
NEBRASKA
Lincoln
IOWA
Des Moines
Chicago
ILLINOIS
Springfield
INDIANA
OHIO
Columbus
PENNSYLVANIA
Harrisburg
Trenton
NEW JERSEY
Dover
DELAWARE
Annapolis
Washington
DC
MARYLAND
WEST VIRGINIA
Charleston
VIRGINIA
Richmond
KANSAS
Topeka
MISSOURI
Jefferson City
KENTUCKY
Frankfort
TENNESSEE
Nashville
NORTH CAROLINA
Raleigh
ARIZONA
Phoenix
NEW MEXICO
Santa Fe
OKLAHOMA
Oklahoma City
ARKANSAS
Little Rock
SOUTH CAROLINA
Columbia
GEORGIA
Atlanta
ALABAMA
Montgomery
MISSISSIPPI
Jackson
LOUISIANA
Baton Rouge
TEXAS
Austin
Tallahassee
FLORIDA
PACIFIC OCEAN
ATLANTIC OCEAN
HAWAII
Honolulu
ARCTIC OCEAN
RUSSIA
ALASKA
100 mi



12000 աշակերտ
4000 ասպիրանտ
5 միլիոն քմ

ԱՄՆ-ում միջուկային Ֆիզիկայի առաջին լաբորատորիան


James Webb Telescope
December 2023
սև խոռոչ



Միջուկային աստղաֆիզիկա

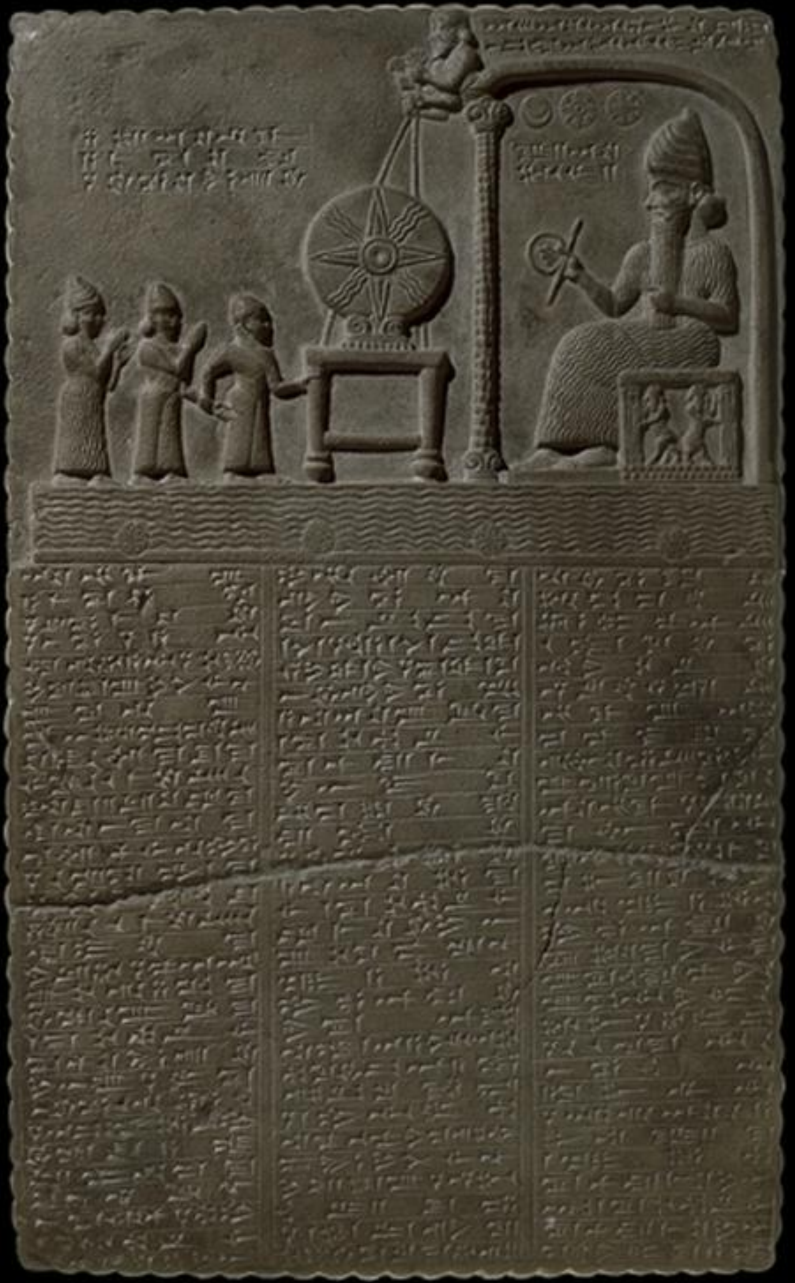
1. տարրերի ծագումը
    - Birth of Stars
    - Stellar Evolution
    - Death of Stars
2. արագացուցիչներ

3. միջուկային ֆիզիկայի կիրառությունները

Միջուկային աստղաֆիզիկա

What is the origin of Nuclear Astrophysics?

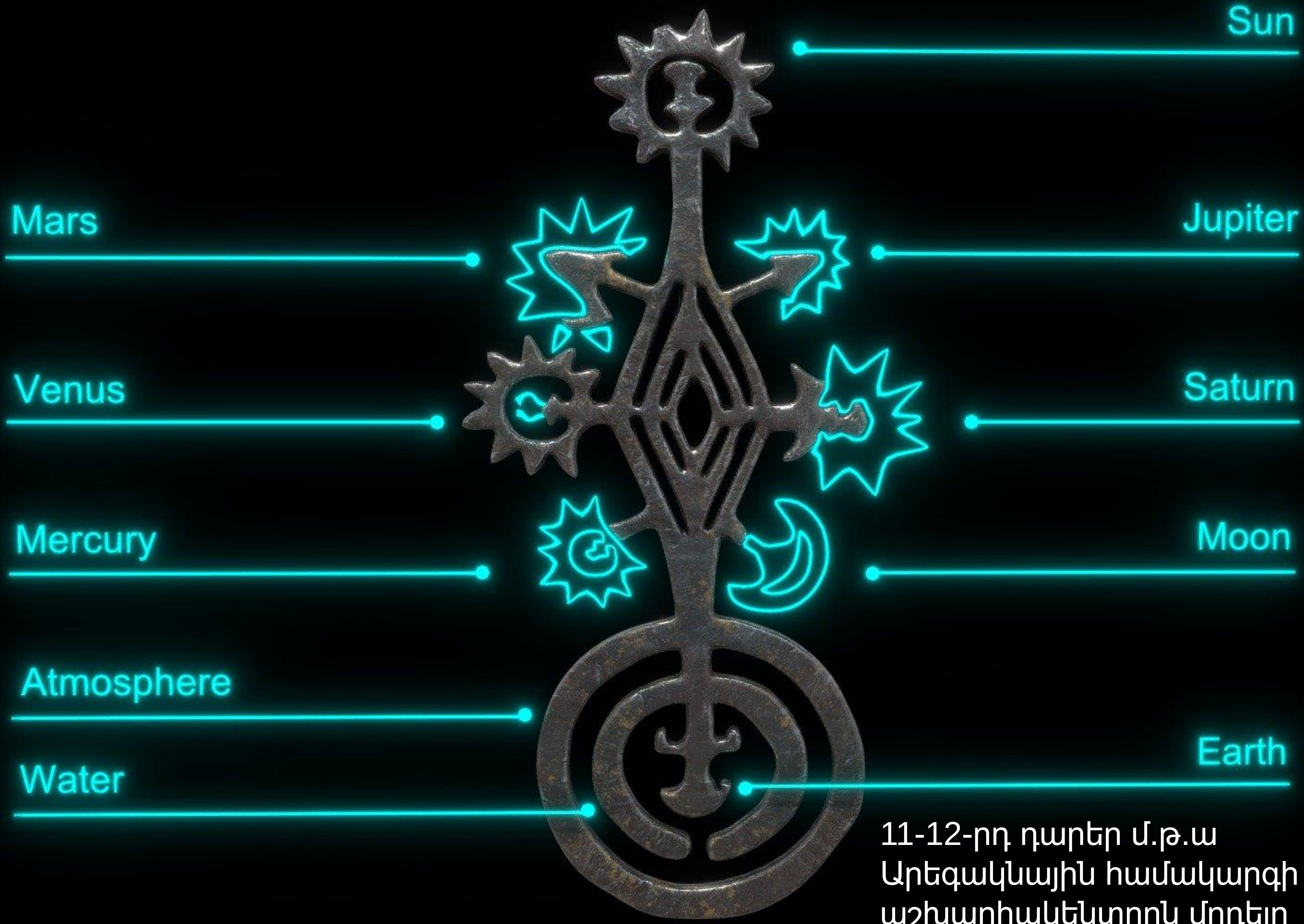
Միջուկային ֆիզիկա
Աստղաֆիզիկա
Աստղագիտություն



Astronomy

Babylonian stone tablet of Shamash, the Sun-god, dated early 9th century BC. From Sippar, southern Iraq.

The first documented records of systematic astronomical observations date back to the Assyro-Babylonians around 1000 BCE in Mesopotamia.

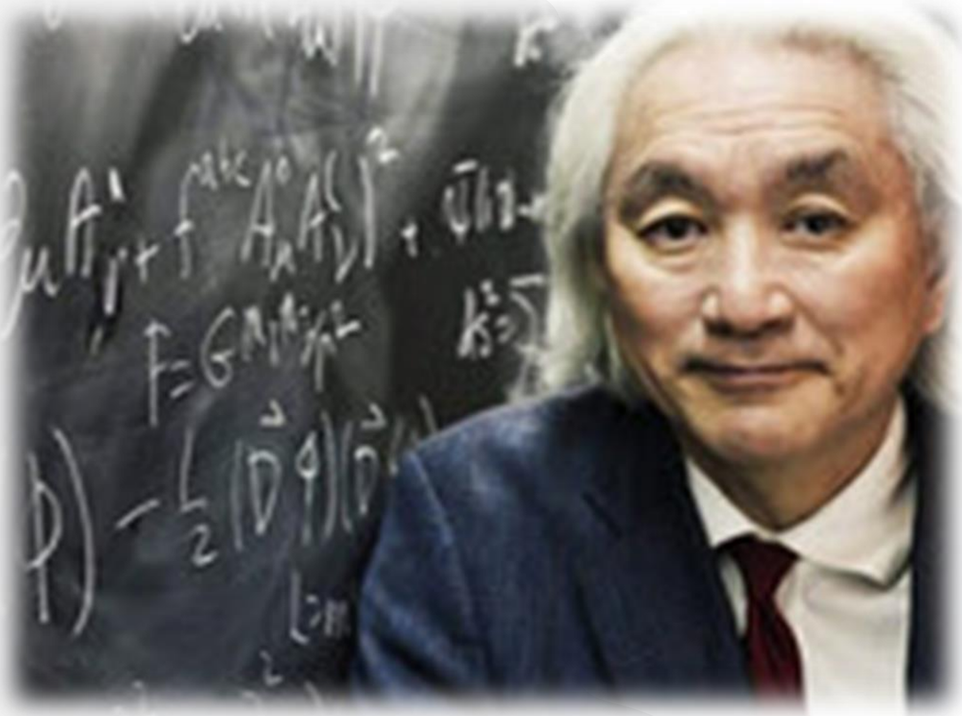


11-12-րդ դարեր մ.թ.ա
Արեգակնային համակարգի ամենահին աշխարհակենտրոն մոդելը

January 19, 1798- September 5, 1857

On the subject of stars, all investigations which are not ultimately reducible to simple visual observations are... necessarily denied to us.. We shall never be able by any means to study their chemical composition.

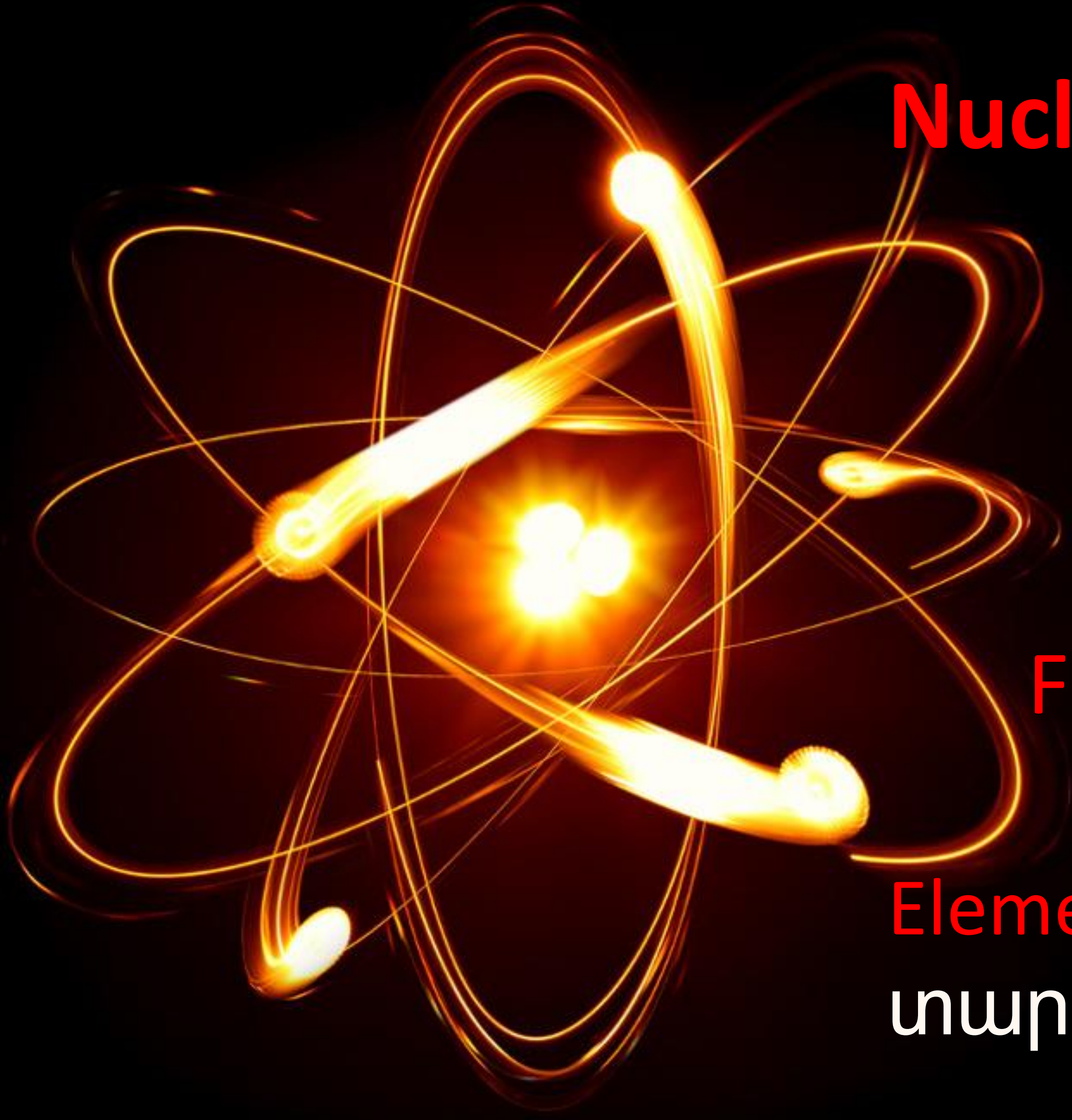
- Auguste Comte -



“A hundred years ago, Auguste Comte, … a great philosopher, said that humans will never be able to visit the stars, that we will never know what stars are made out of, that that's the one thing that science will never ever understand, because they're so far away. And then, just a few years later, scientists took starlight, ran it through a prism, looked at the rainbow coming from the starlight, and said: "Hydrogen!" Just a few years after this very rational, very reasonable, very scientific prediction was made, that we'll never know what stars are made of.”

- Michio Kaku

Thousands upon thousands of stars illuminate this breathtaking image of star cluster Liller 1, imaged with Hubble's Wide Field Camera 3. This stellar system, located 30,000 light-years from Earth, formed stars over 11 billion years….



Nuclear Physics Discoveries

Radioactivity:

Reaction Rates:
ռեակցիայի տեմպերը

Fission: տրոհում

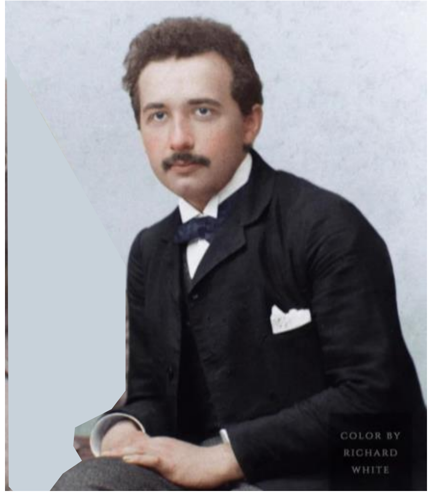
Elemental Abundances:
տարրական առատություններ

The Scientific Basis – Two Formulas

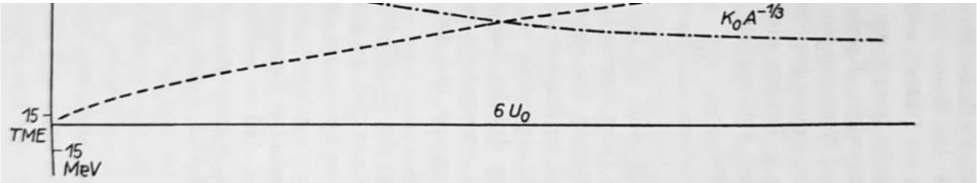
for the energy generation in bomb and stars

$$E = m \cdot c^2$$

Albert Einstein 1904



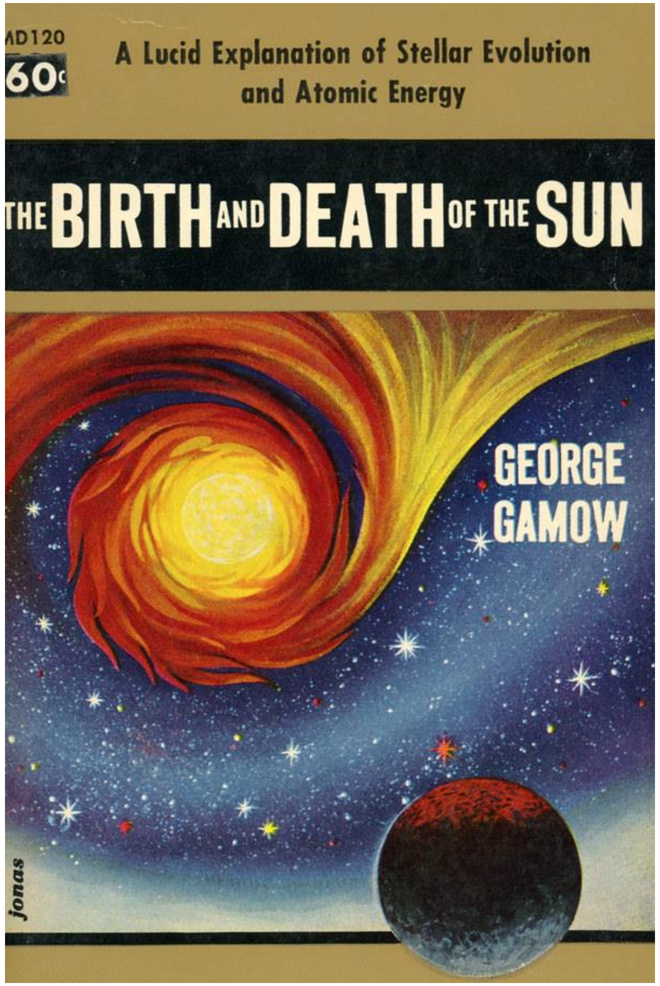
$$E_b^{even-odd} \approx \underbrace{(15.75 MeV)A}_{\text{Volume term}} - \underbrace{(17.8 MeV)A^{2/3}}_{\text{Surface term}} - \underbrace{\frac{(0.711 MeV)Z^2}{A^{1/3}}}_{\text{Coulomb term}} - \underbrace{\frac{(23.7 MeV)(A-2Z)^2}{A}}_{\text{Pauli term}}$$



Weizsäcker 1934

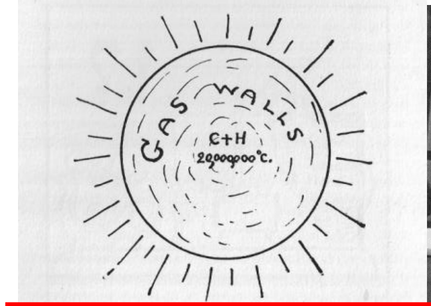
Mass Formula

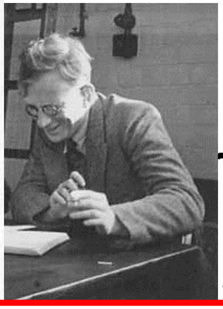
The energy source of the Sun and other stars



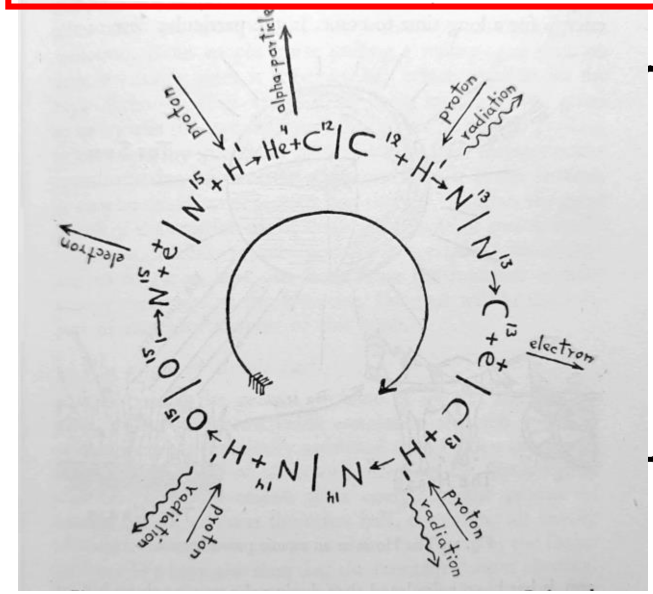
Stars are driven by the release of nuclear energy

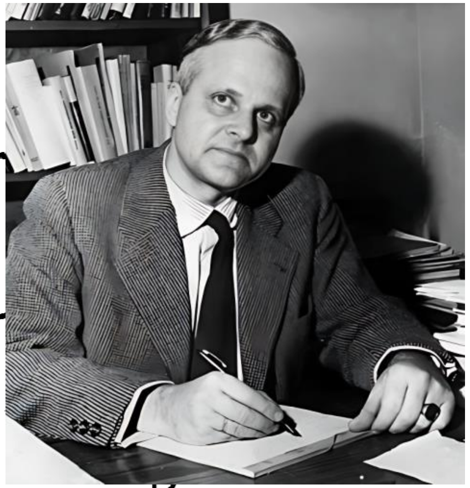
G. Gamow and E. Teller, “The Rate of Selective Thermonuclear Reactions,” *Phys. Rev.* 53 (1938): 608-609.





1) Durch Herrn Gamow habe ich erfahren, daß Bethe neuerdings denselben Zyklus quantitativ untersucht hat.



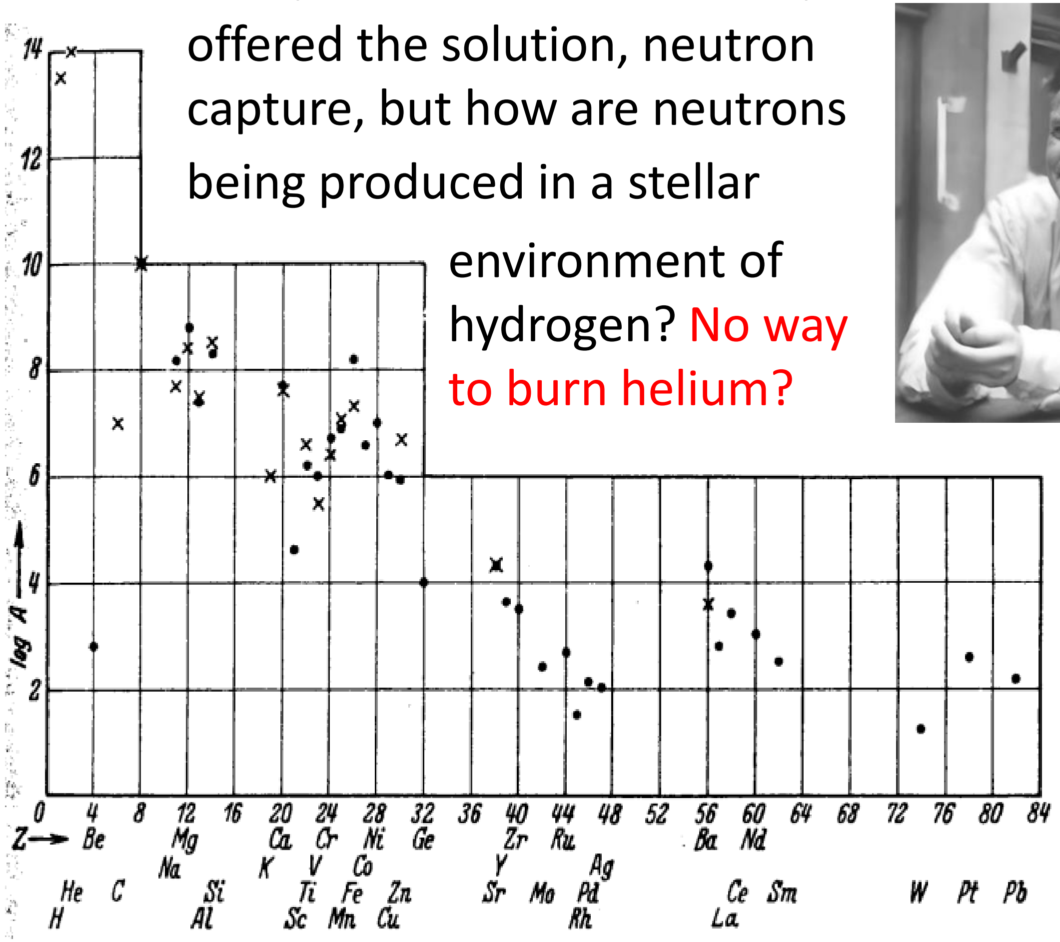


Two seminal papers in 1938 discussed the energy generation in the sun and the origin of the elements in our universe!

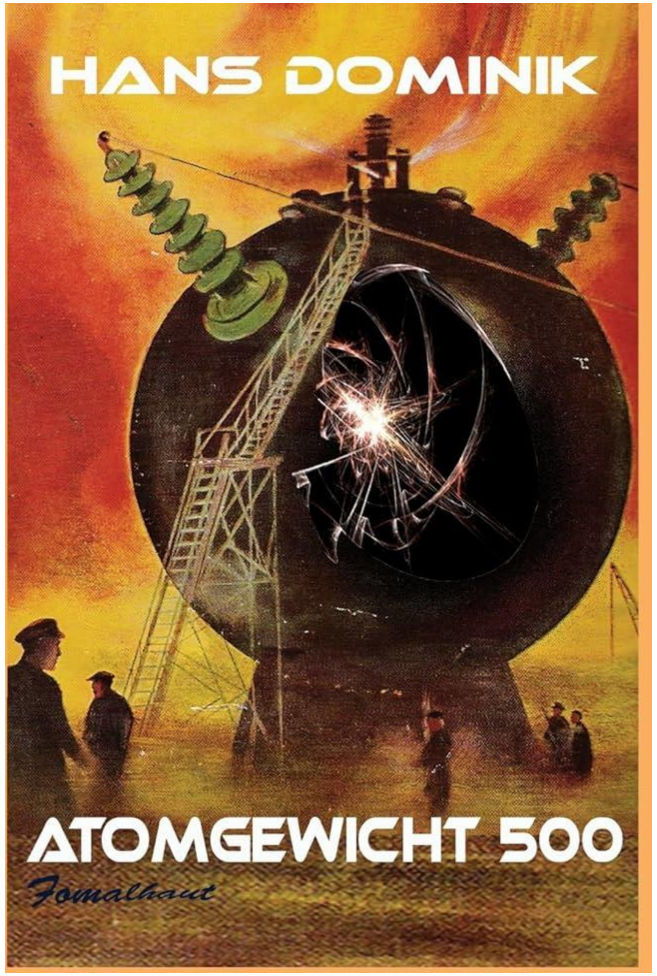
Neutrons for superheavy element production

Observation of heavy elements in 1920-1930
How are heavy elements been produced???

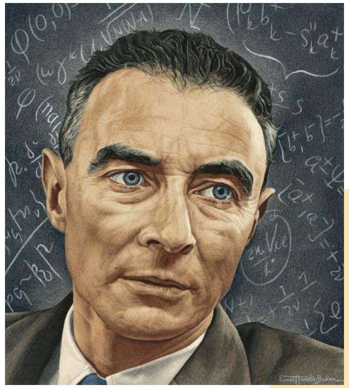
The discovery of the neutron in 1932 by James Chadwick offered the solution, neutron capture, but how are neutrons being produced in a stellar environment of hydrogen? No way to burn helium?



Continuous neutron capture would lead to the formation of ever heavier elements, a source of energy through radioactive decay!

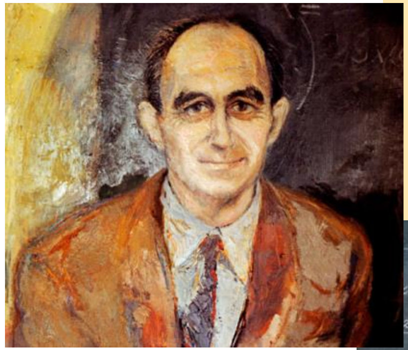


Leaders of the Manhattan Project: USA

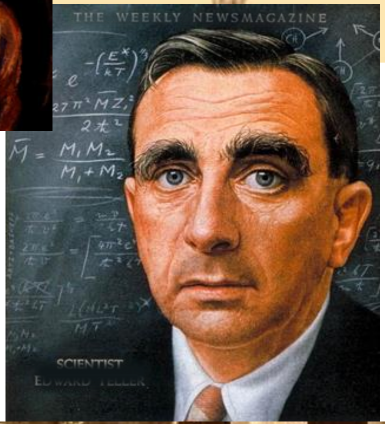


J. Robert Oppenheimer: theoretical physicist in Berkeley and Caltech, focusing on the study of quantum physics and the structure of neutron stars and black holes!

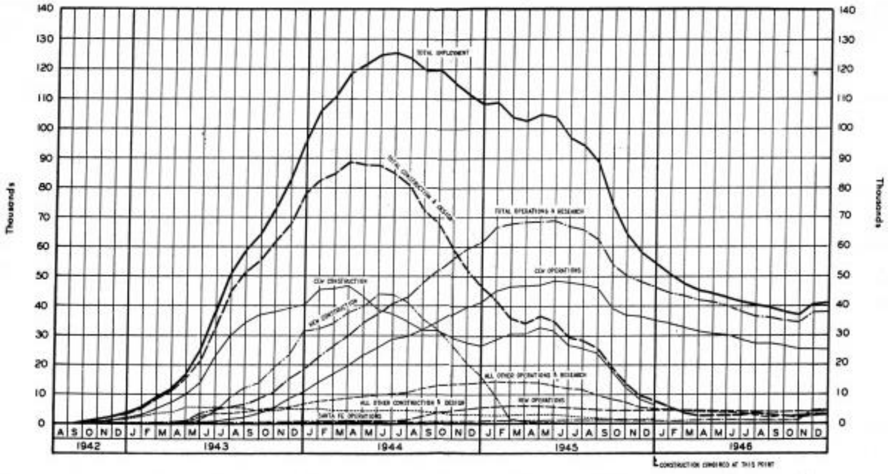
Hans A. Bethe: Trained in Germany by Sommerfeld, he quickly emerged as a rising star in nuclear physics at Cornell, interest in light ion fusion processes in stars!



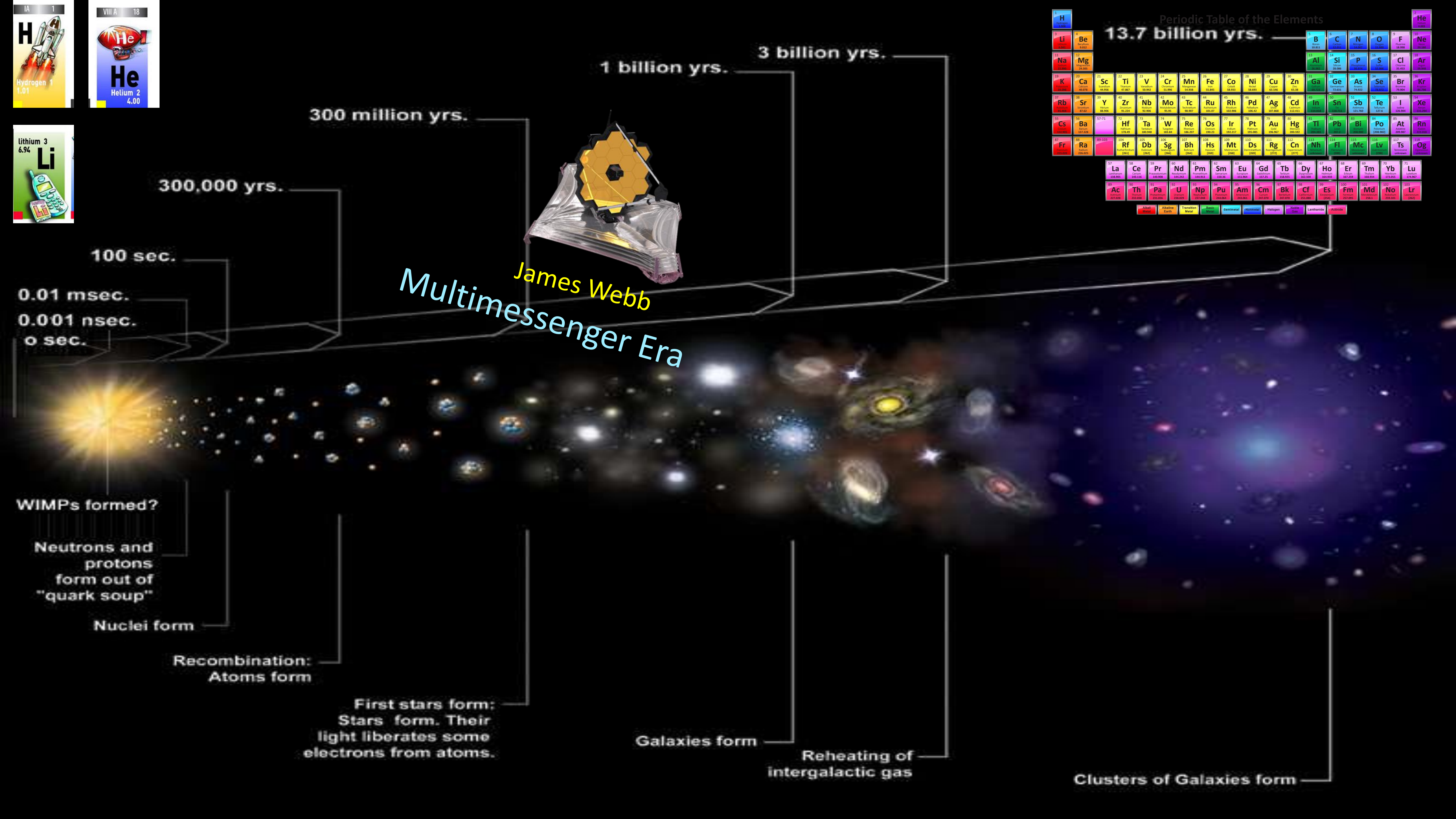
Enrico Fermi: an Italian physicist, wo used the opportunity of his Nobel prize in 1936 to leave Fascist Italy for the United States. He was essential for the understanding of neutrons and their role in fission.

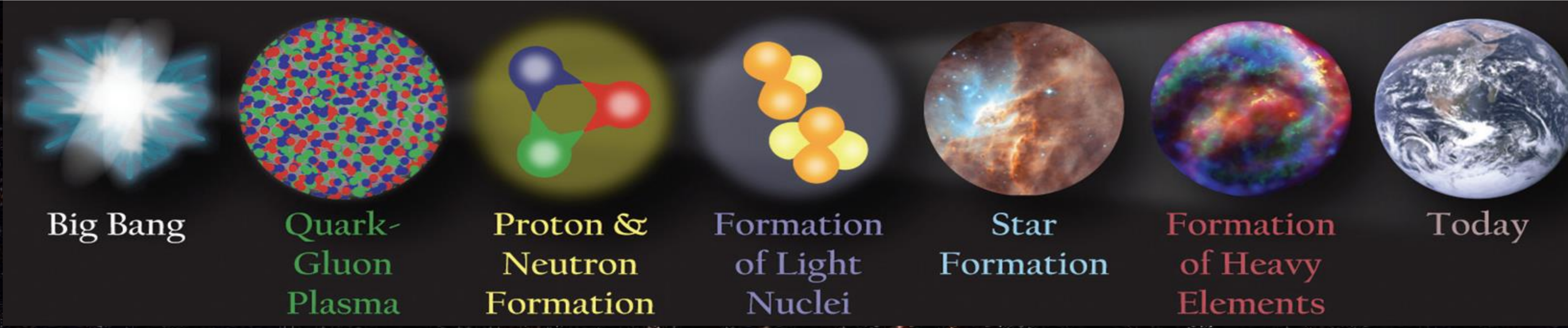


Edward Teller: Hungarian firebrand, worked with Heisenberg in Germany before emigrating to the United States in 1933. At George Washington University he became an expert in light ion fusion reactions and a vehement spokesperson for the hydrogen bomb.



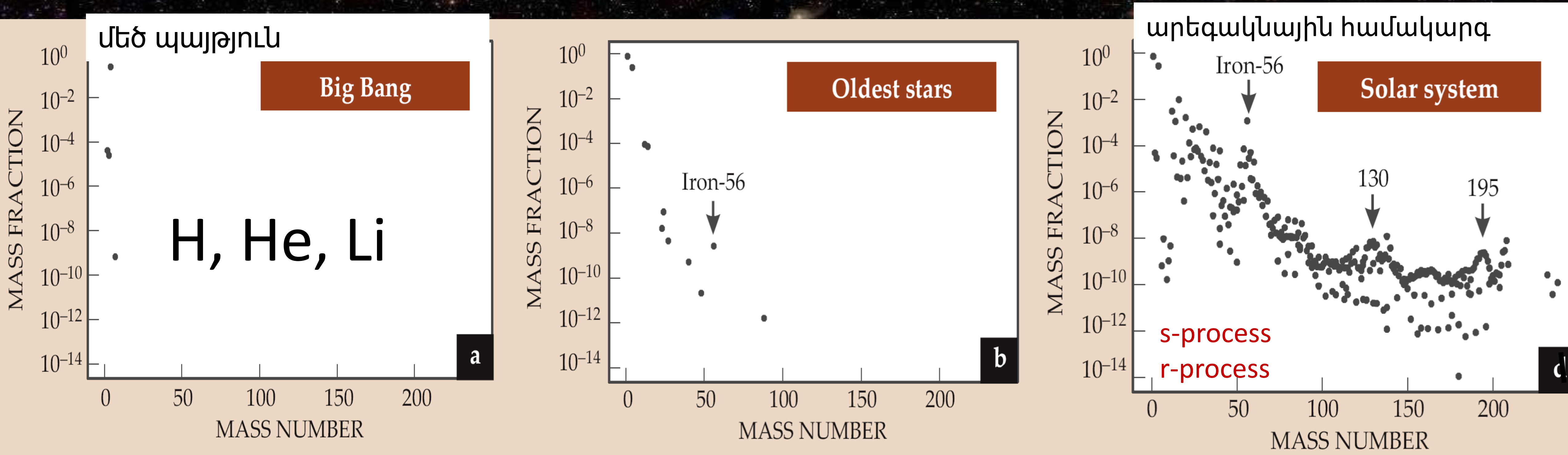
Plus more than 125,000 scientists, technicians, administrators, military people involved in the project!


IA 1
H
Hydrogen 1
1.01
VIII A 18
He
He
Helium 2
4.00
lithium 3
6.94
Li
Periodic Table of the Elements
13.7 billion yrs.
3 billion yrs.
1 billion yrs.
300 million yrs.
300,000 yrs.
100 sec.
0.01 msec.
0.001 nsec.
o sec.
James Webb
Multimessenger Era
WIMPs formed?
Neutrons and
protons
form out of
"quark soup"
Nuclei form
Recombination:
Atoms form
First stars form:
Stars form. Their
light liberates some
electrons from atoms.
Galaxies form
Reheating of
intergalactic gas
Clusters of Galaxies form

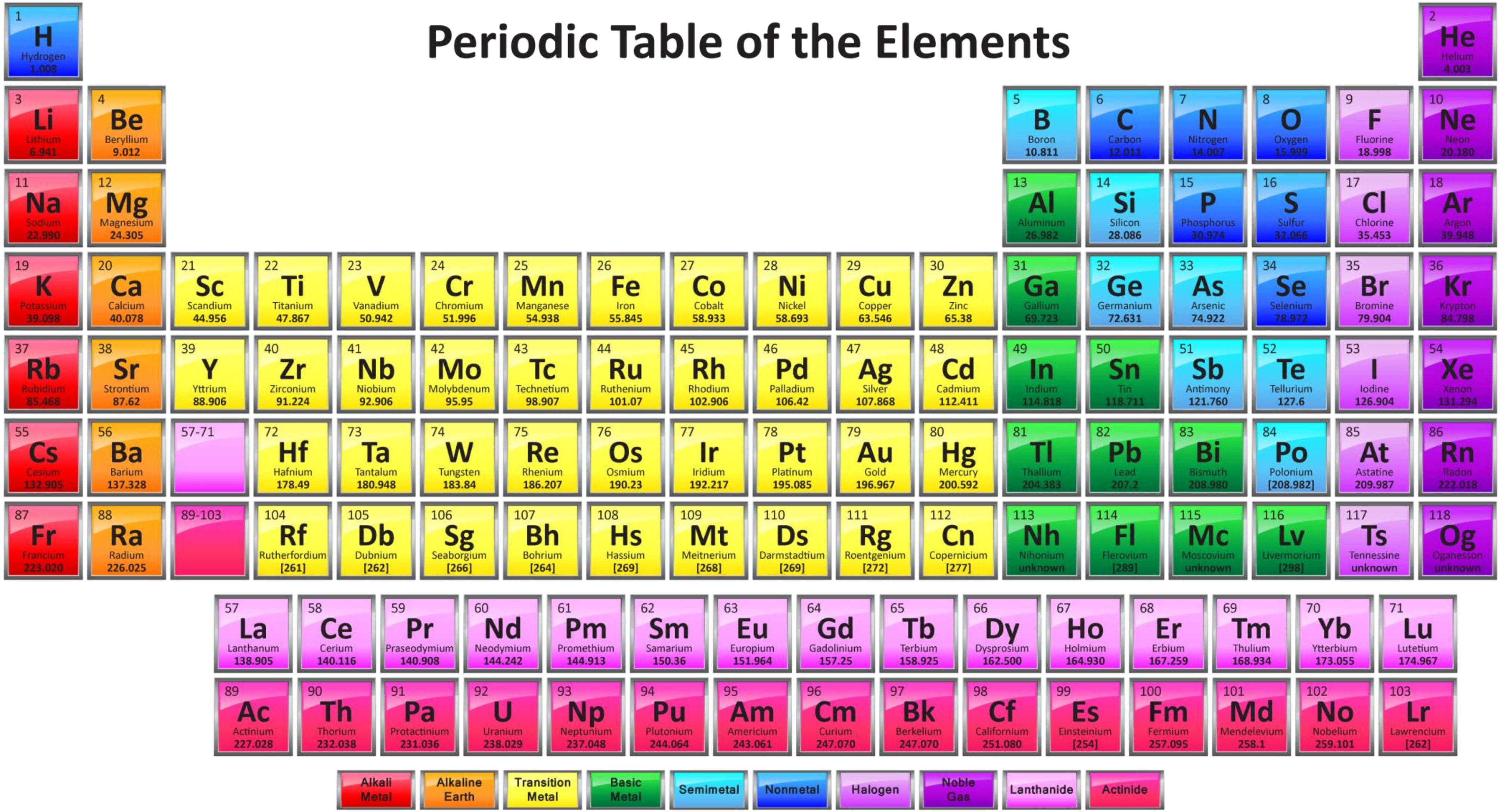


- How were elements Fe to U made?

Wiescher
Schatz

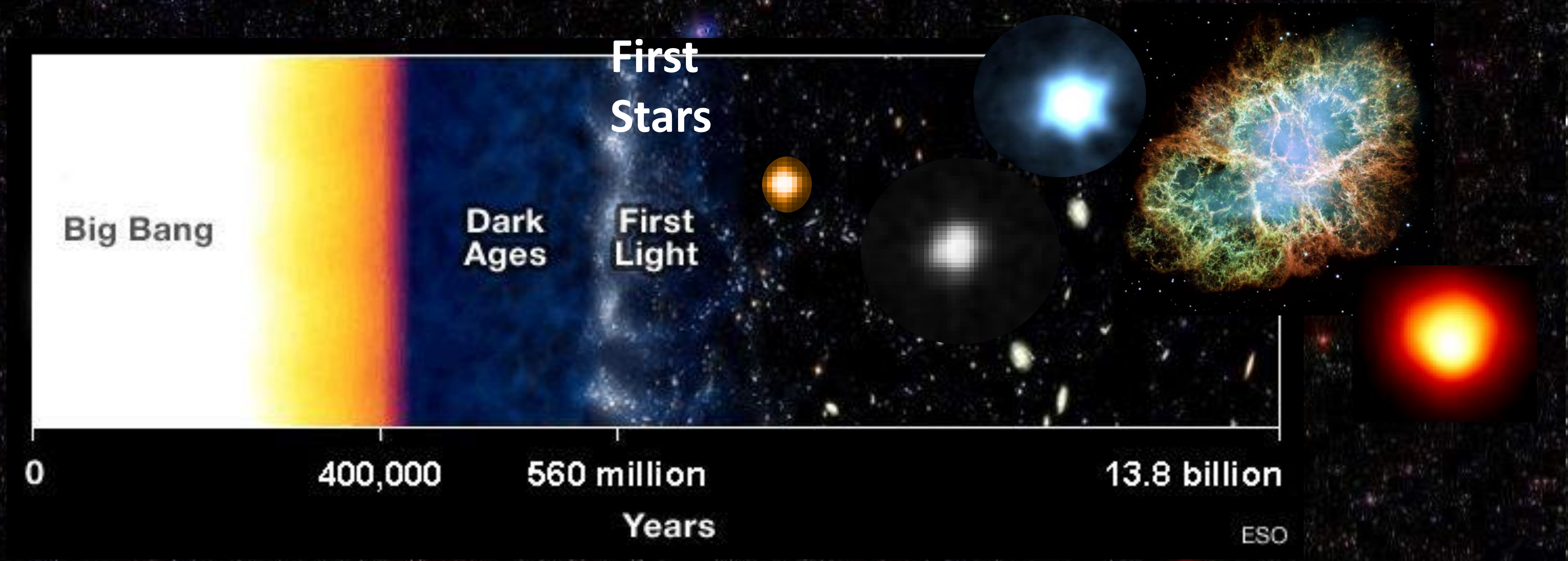


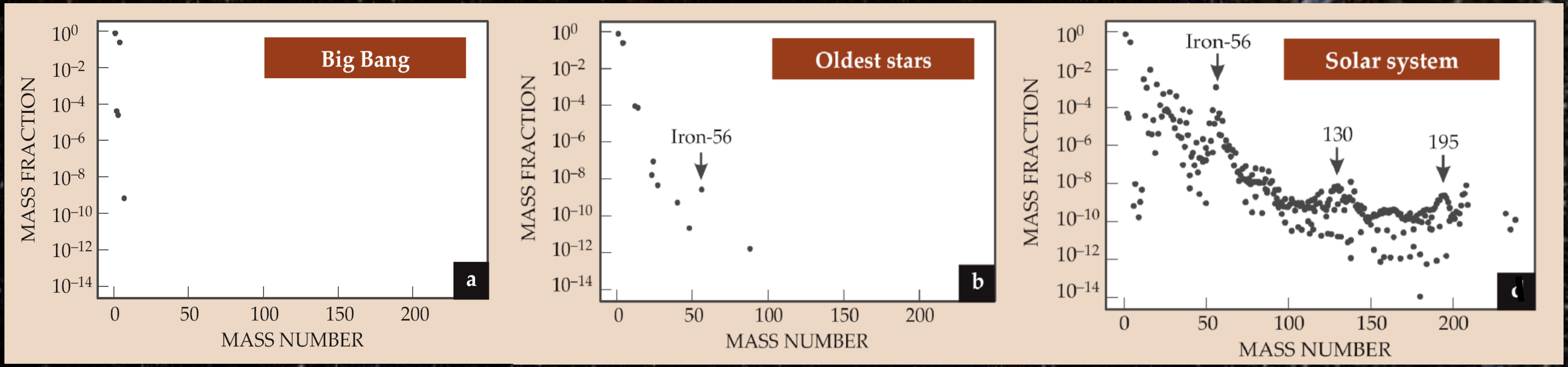
Մենդելեևի տարրերի աղյուսակ



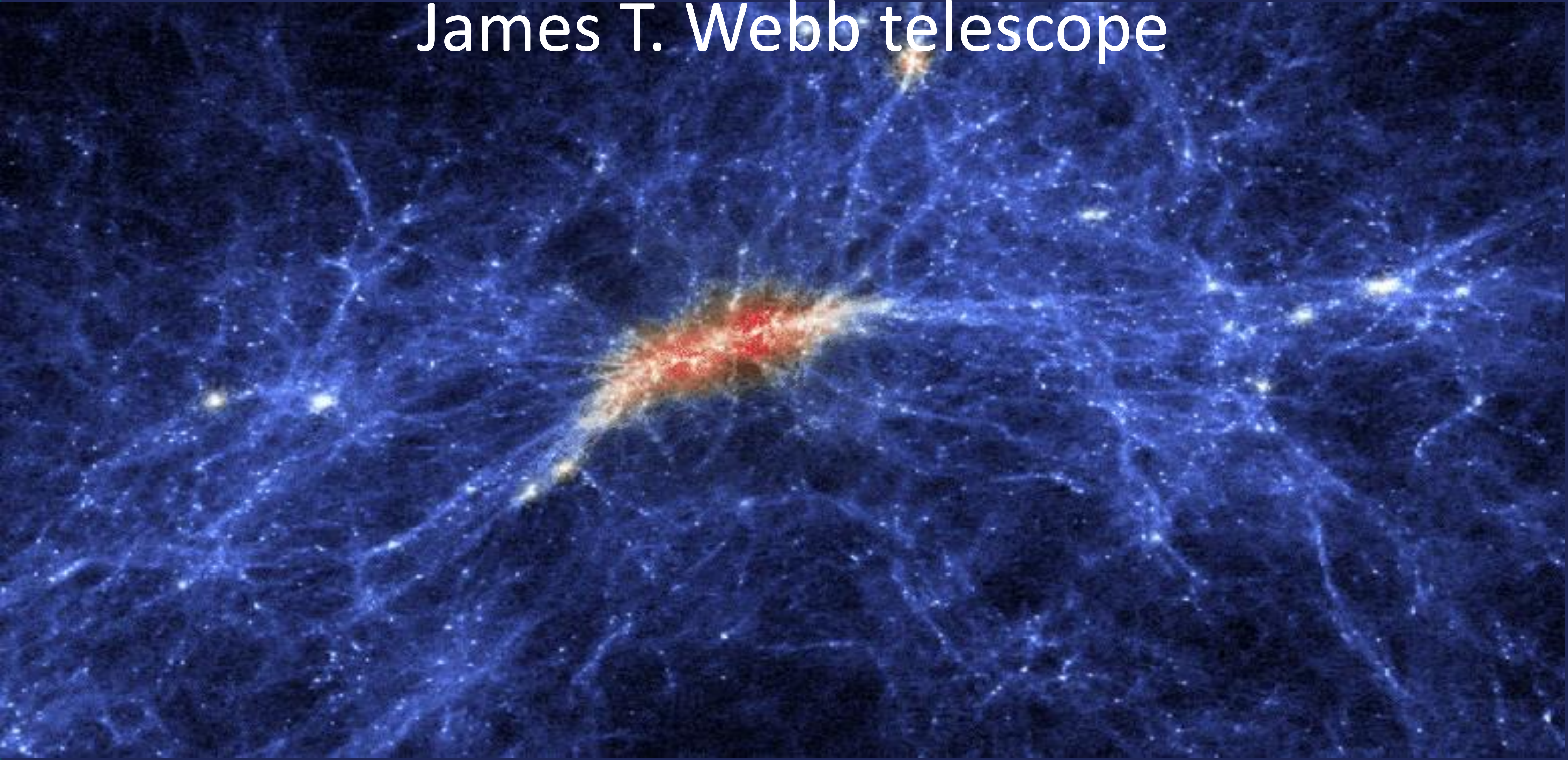
Are there more elements?

Galactic Chemical Evolution

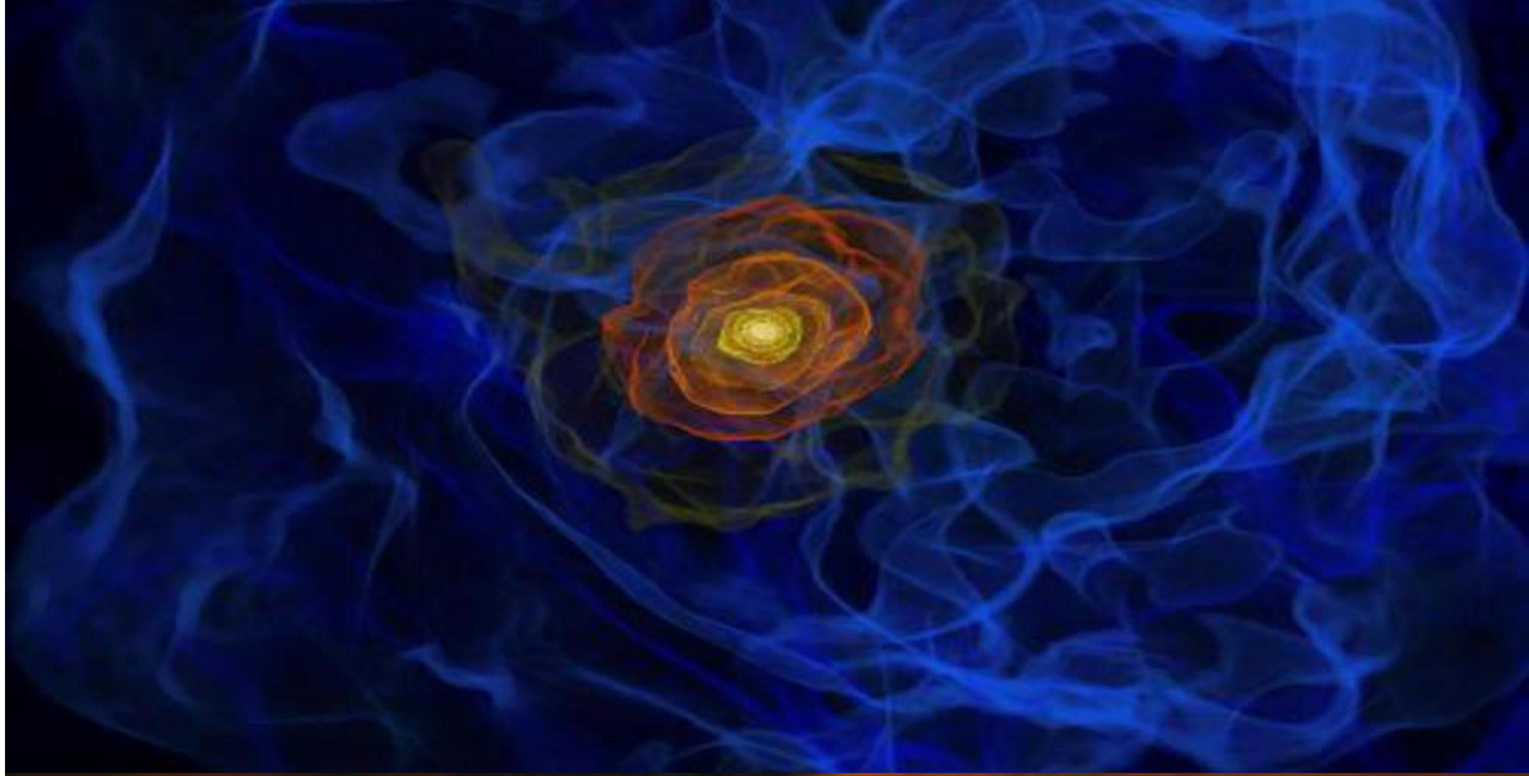


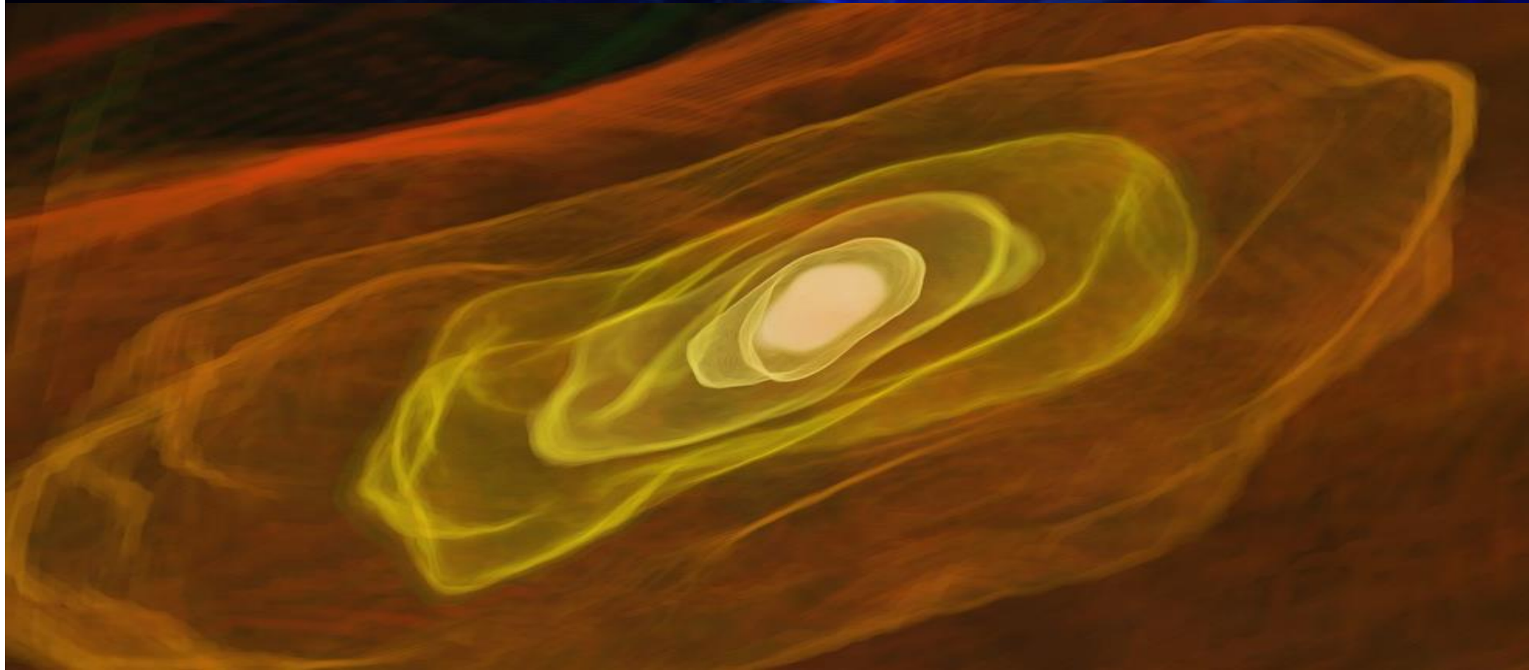


The view towards the early stars and galaxies in the Universe with the James T. Webb telescope



First Star formation from inhomogeneities in the mass distribution of the early universe





The Mass Distribution of First Stars

SUN

MASS: 1.989×10^{30} kilograms
RADIUS: 696,000 kilometers
LUMINOSITY: 3.85×10^{23} kilowatts
SURFACE TEMPERATURE: 5,780 kelvins
LIFETIME: 10 billion years

FIRST STARS

MASS: 100 to 1,000 solar masses
RADIUS: 4 to 14 solar radii
LUMINOSITY: 1 million to 30 million solar units
SURFACE TEMPERATURE: 100,000 to 110,000 kelvins
LIFETIME: 3 million years

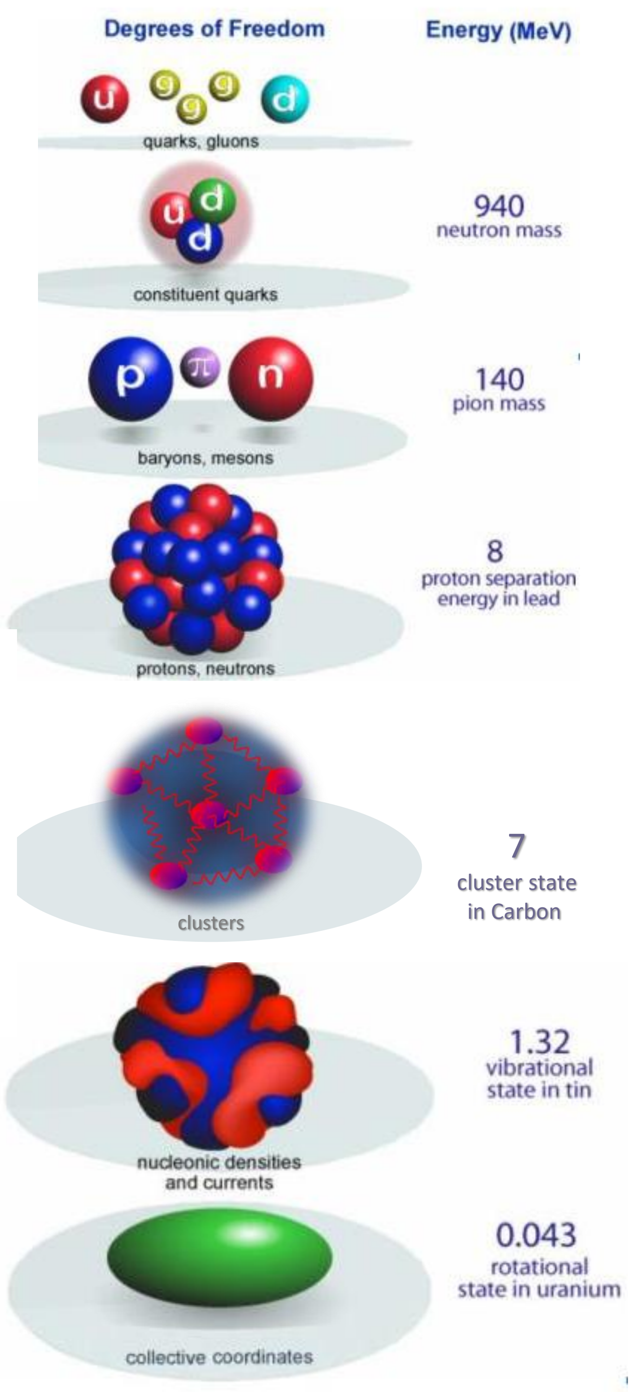
James Webb observation:

Methuselah is located in the constellation Libra, close to the Milky Way galaxy's Ophiuchus border, and around 190 light-years away from the Earth.

14.5 +/-0.8 Billion years old

Բարձր էներգիայի մասնիկների ֆիզիկա

Միջուկային ֆիզիկա



Single particle configurations

Cluster – molecular configurations

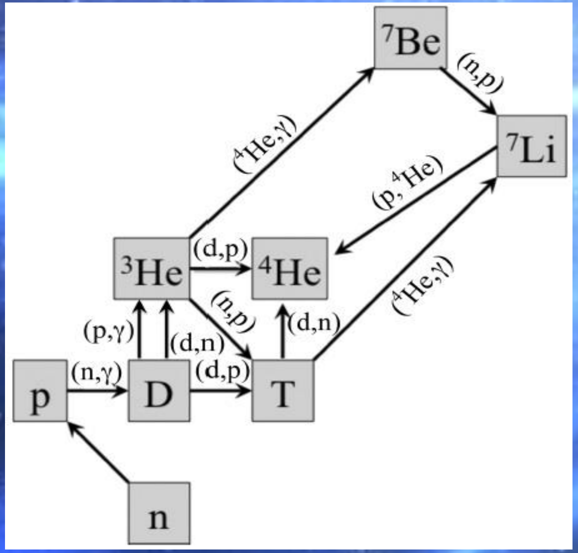
Nuclear Structure

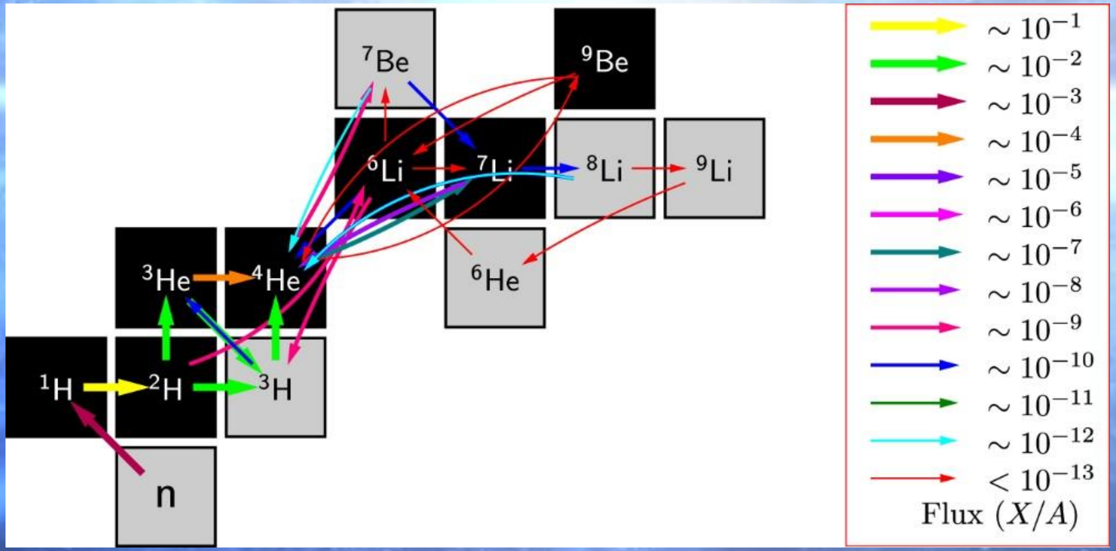
Collective vibrational configurations

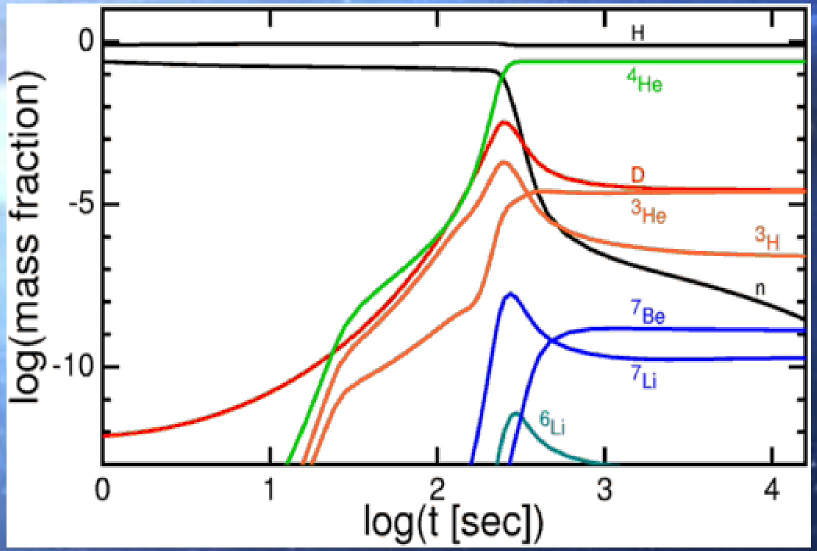
Collective rotational configurations

Big Bang Nucleosynthesis

The origin of the primordial elements: H, He, Li

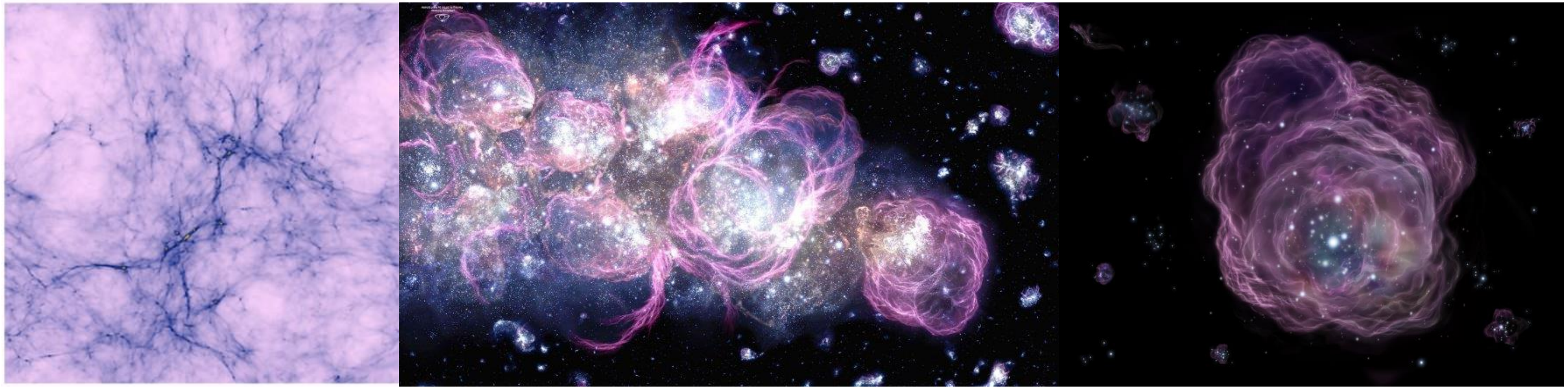






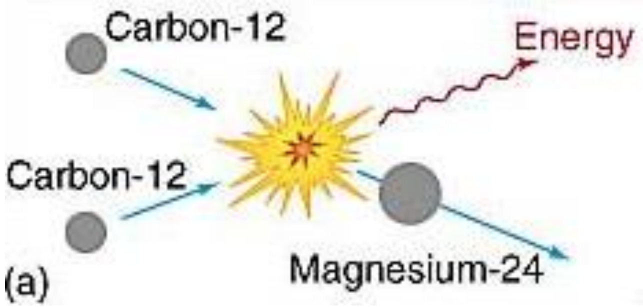
The mass A=5 gap prohibits the production of substantial amounts of lithium and beryllium.
The mass A=8 gap prohibits the production of heavier elements such as boron, carbon, and beyond!

Fusion Reactions in Stars



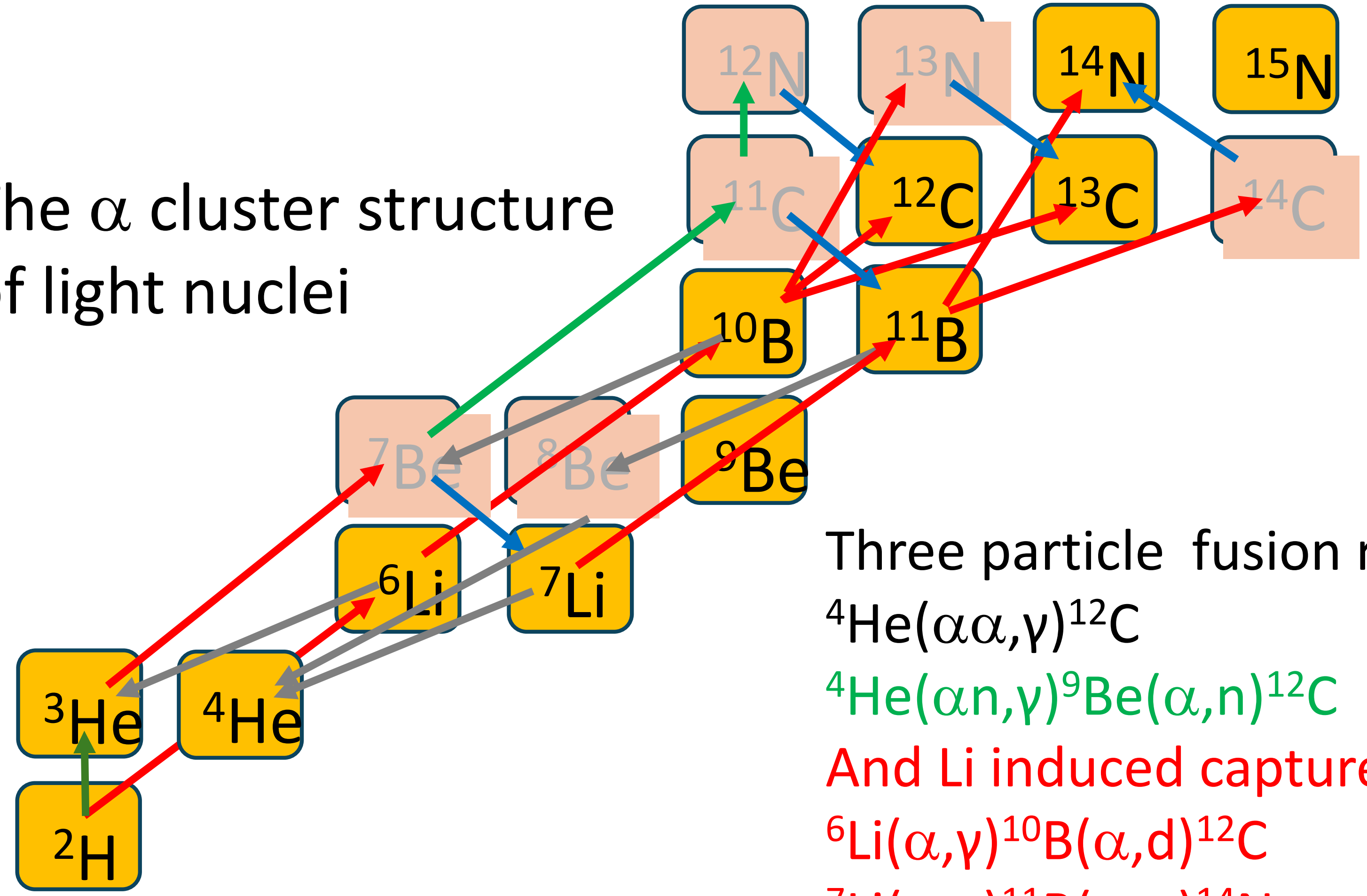
- First stars: fusion for mid-mass elements

- Late stars: post-red-giant stellar evolution, carbon and oxygen burning
- Ignition of type Ia supernovae
- Ignition of superbursts



The stepping stones for bridging the gap

The α cluster structure of light nuclei



Three particle fusion reactions:

$^{4}He(\alpha\alpha,\gamma)^{12}C$

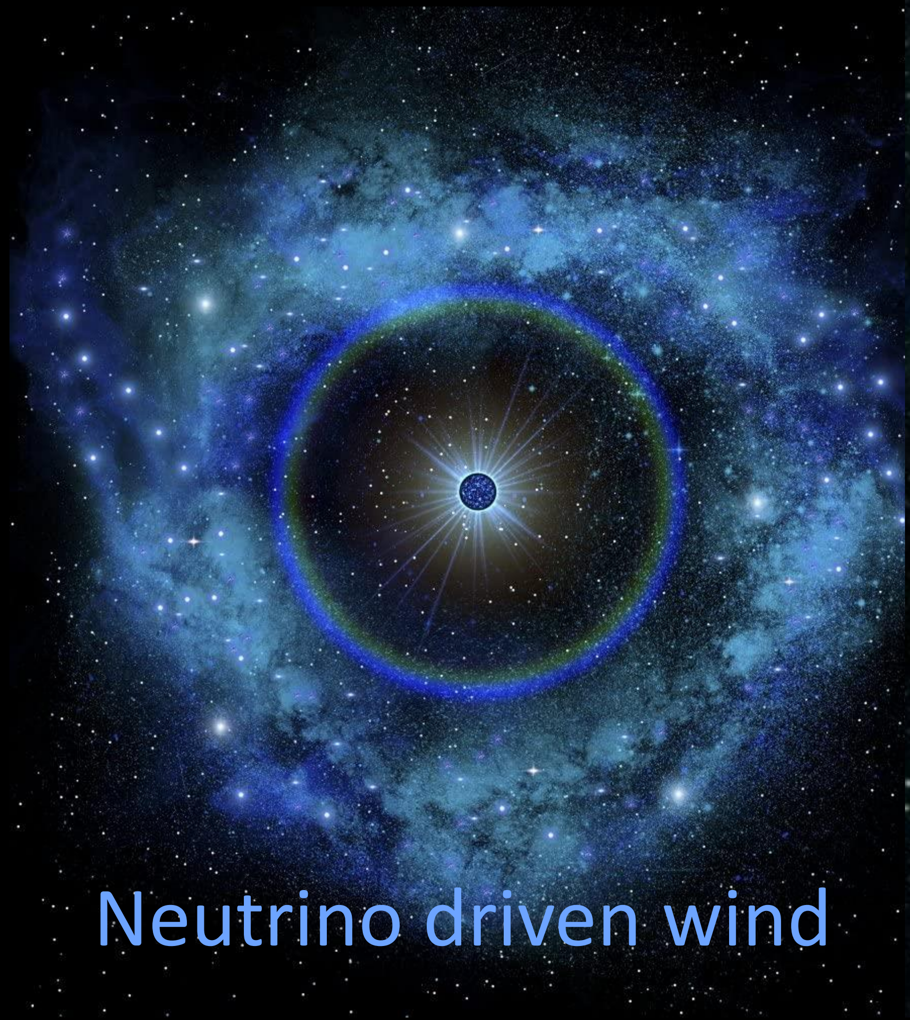
$^{4}He(\alpha n,\gamma)^{9}Be(\alpha,n)^{12}C$

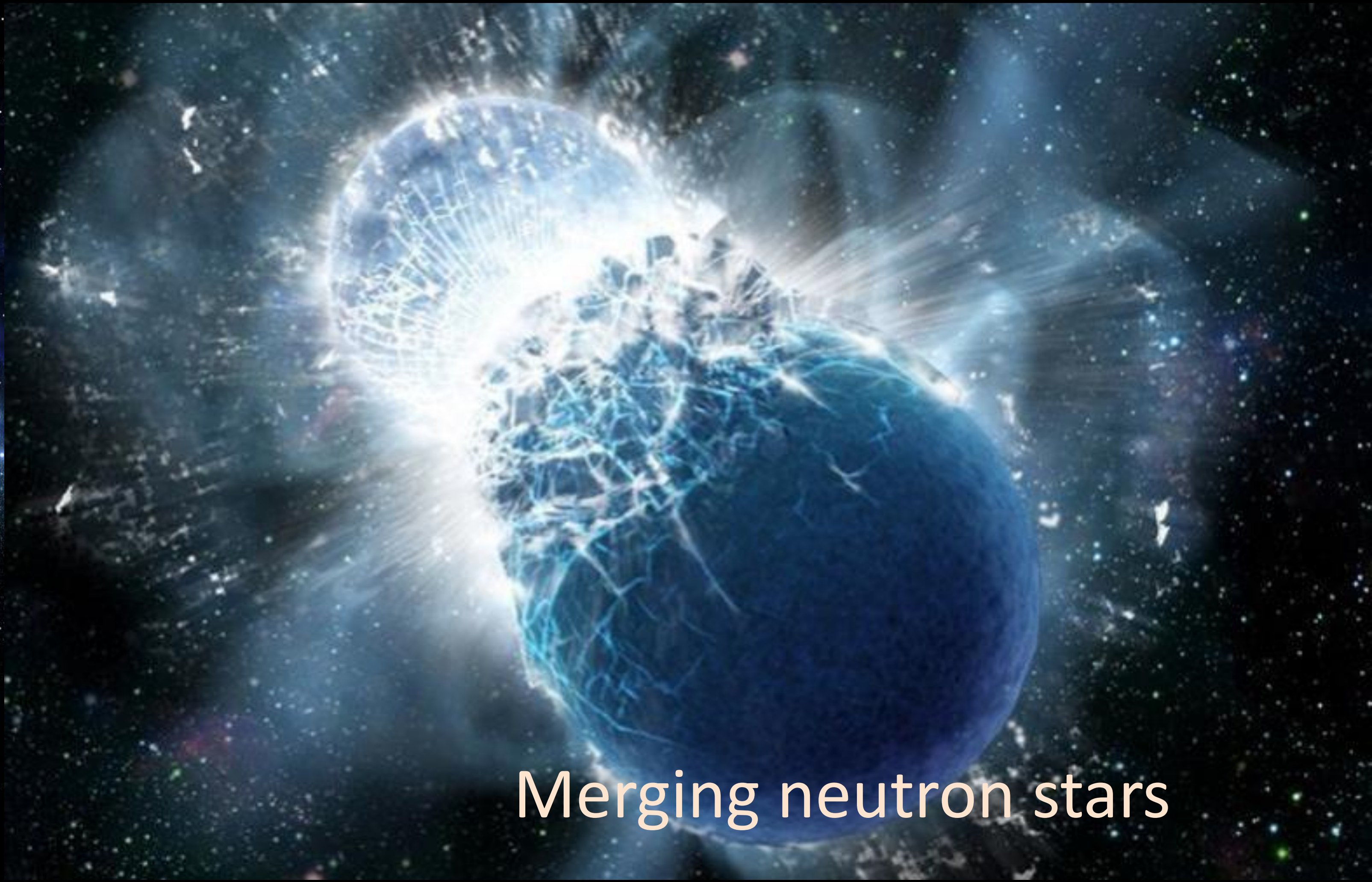
And Li induced capture processes:

$^{6}Li(\alpha,\gamma)^{10}B(\alpha,d)^{12}C$ deuteron cycle

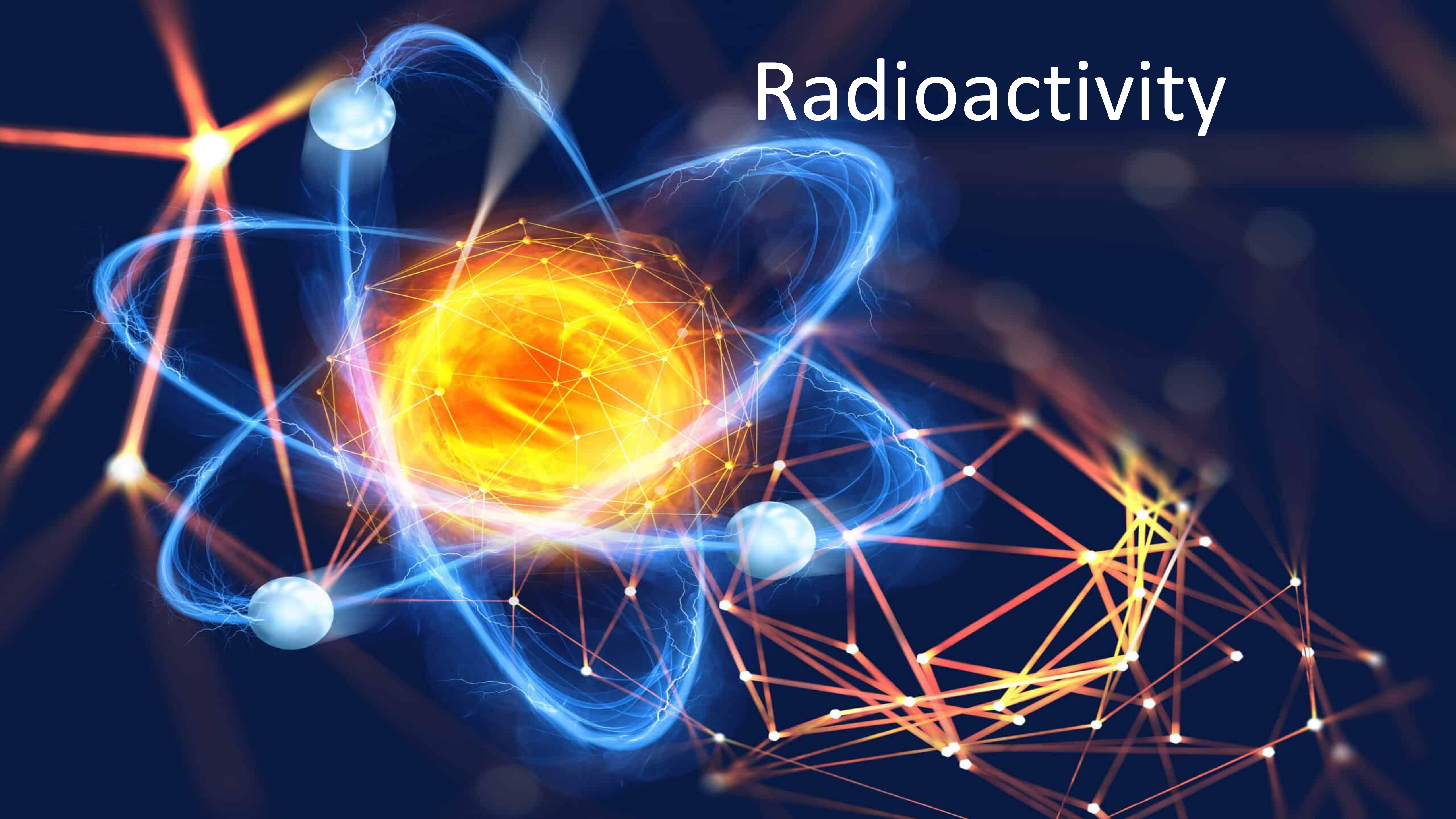
$^{7}Li(\alpha,\gamma)^{11}B(\alpha,n)^{14}N$ neutron source

Dissociation of elements at high temperature and density conditions?





Radioactivity



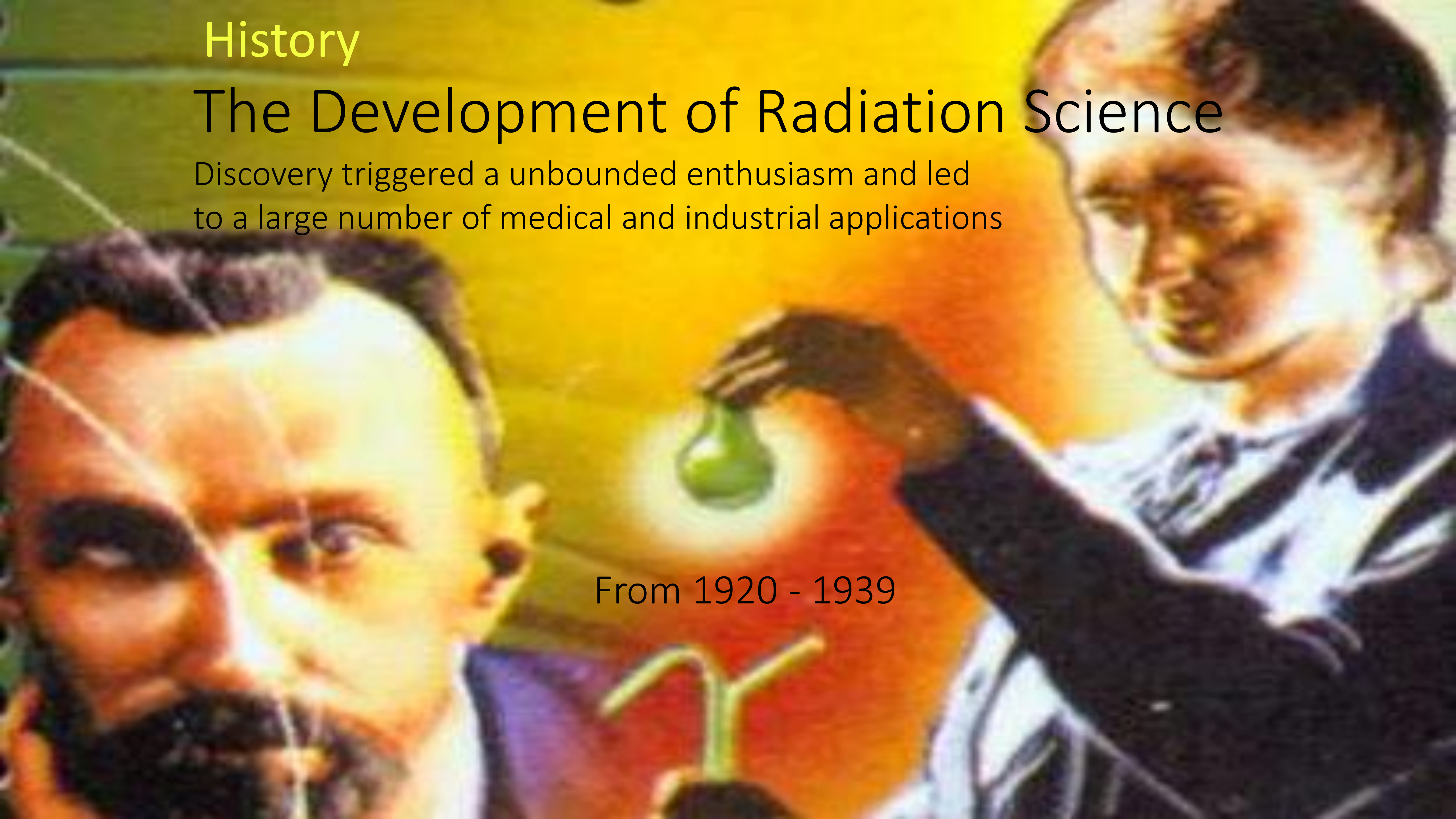
A more multi-facetted picture of Radioactivity

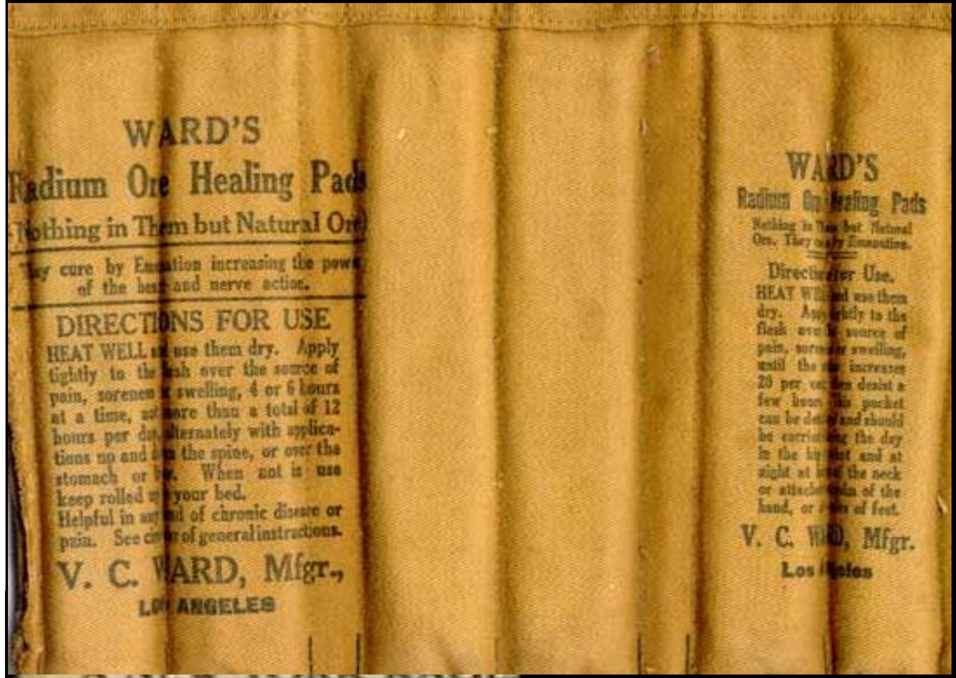
History

The Development of Radiation Science

Discovery triggered a unbounded enthusiasm and led to a large number of medical and industrial applications

From 1920 - 1939





Applications for Radioactivity

Applications

Popular products included radioactive tooth paste for cleaner teeth and better digestion, face cream to lighten the skin; radioactive hair tonic, suppositories, and radium-laced chocolate bars marketed in Germany as a "rejuvenator." In the U.S, hundreds of thousands of people began drinking bottled water laced with radium, as a general elixir known popularly as "liquid sunshine." As recently as 1952 LIFE magazine wrote about the beneficial effects of inhaling radioactive radon gas in deep mines. As late as 1953, a company in Denver was promoting a radium-based contraceptive jelly. Albert Geyser made a fortune in 1920 selling x-ray machines as hair removal systems. ”X-Ray treatment is save, harmless and effective, and in this he was brilliantly successful. The Tricho System of Treatment is the result. This dries up the hair roots in a manner similar to that of gradually getting bald, instead of attempting their sudden and violent destruction.”

Radione tablets for Energy

Radon water: Radon half life = 3.82 days

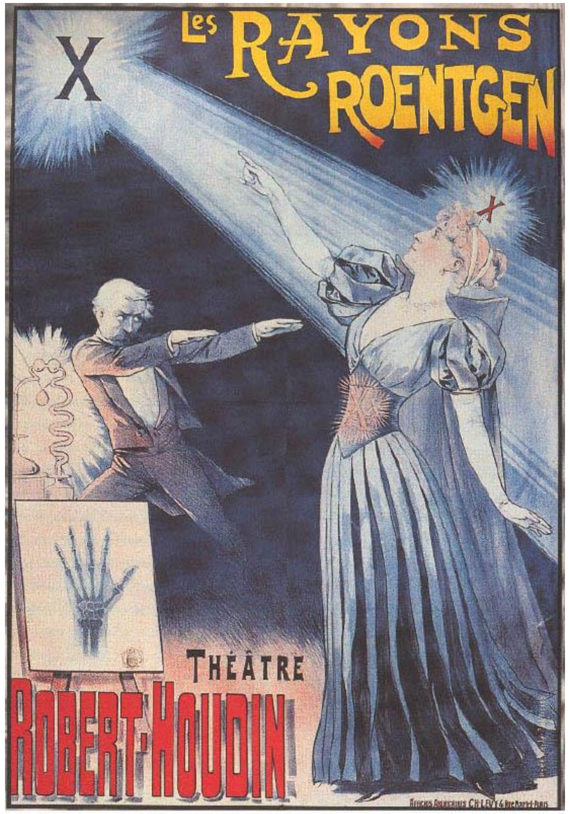
A century ago radioactivity was new, exciting and good for you–at least if you believed the people selling
radium pendants for rheumatism,
all-natural radon water for vigor,
uranium blankets for arthritis and
thorium-laced medicine for digestion
(you don’t even want to know about the radioactive suppositories).

Radon Spas

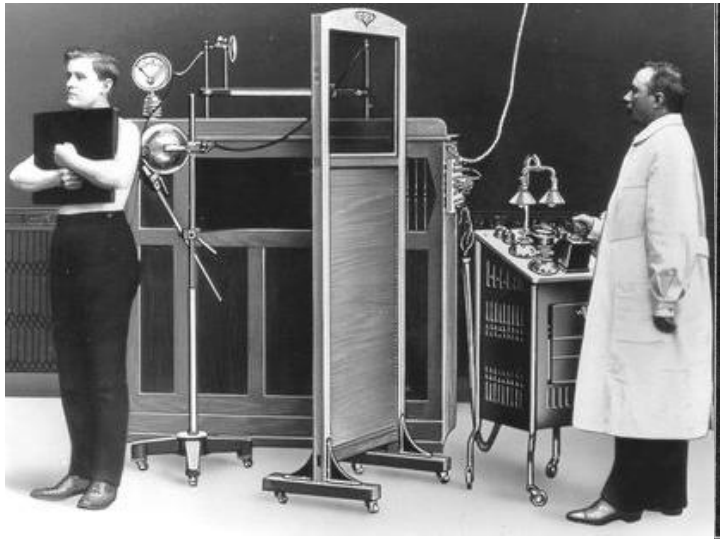
Radon bath and therapy in St. Joachimsthal in Bohemia, now Czech Republic

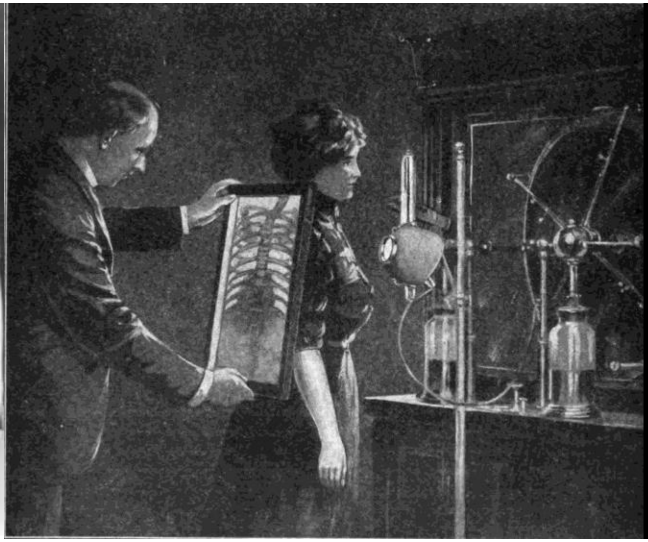
Medical Science

- X-rays offered opportunity for new diagnostics
- Radioactivity offered opportunity for treatment.
- Big business in radiation



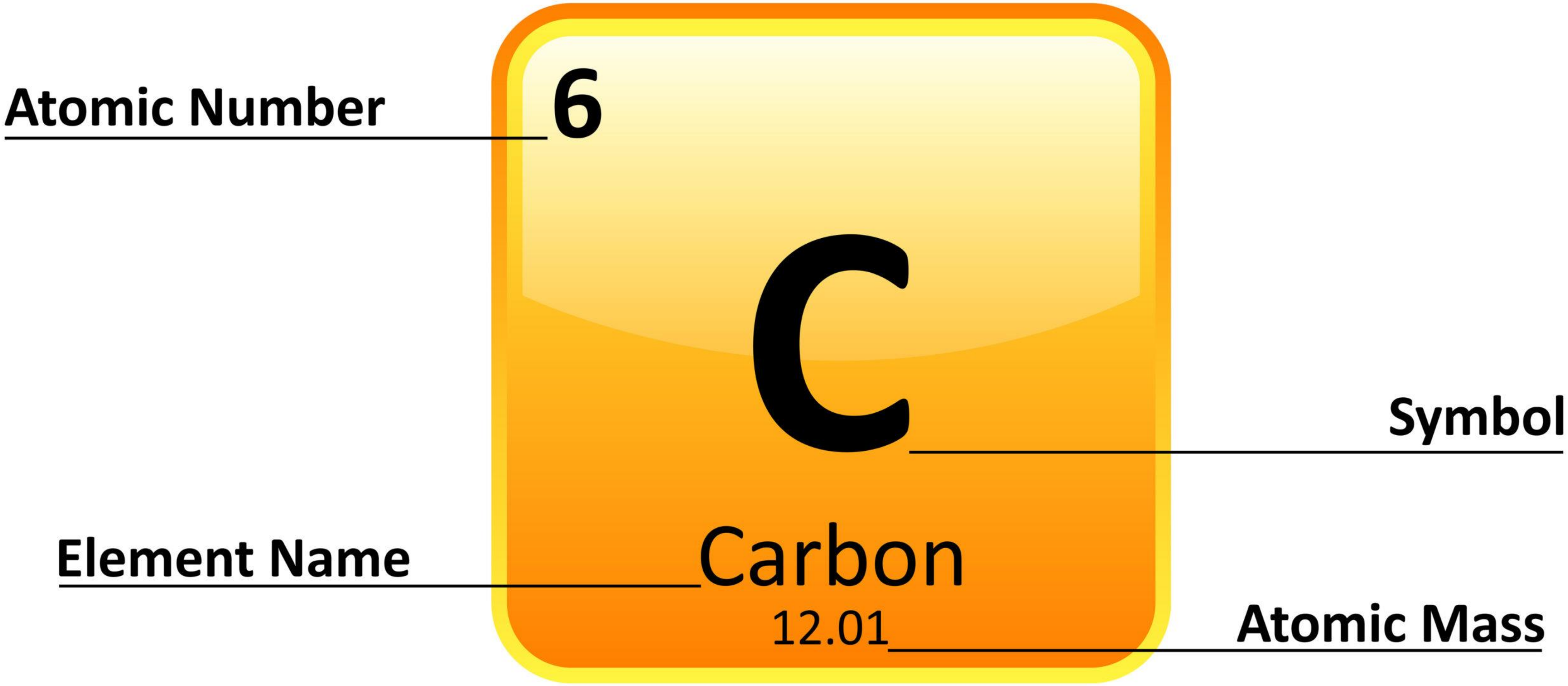
Affiche de spectacle au Théâtre Robert-Houdin
(source : revue *Contrastes* de Guerbet, 1995)





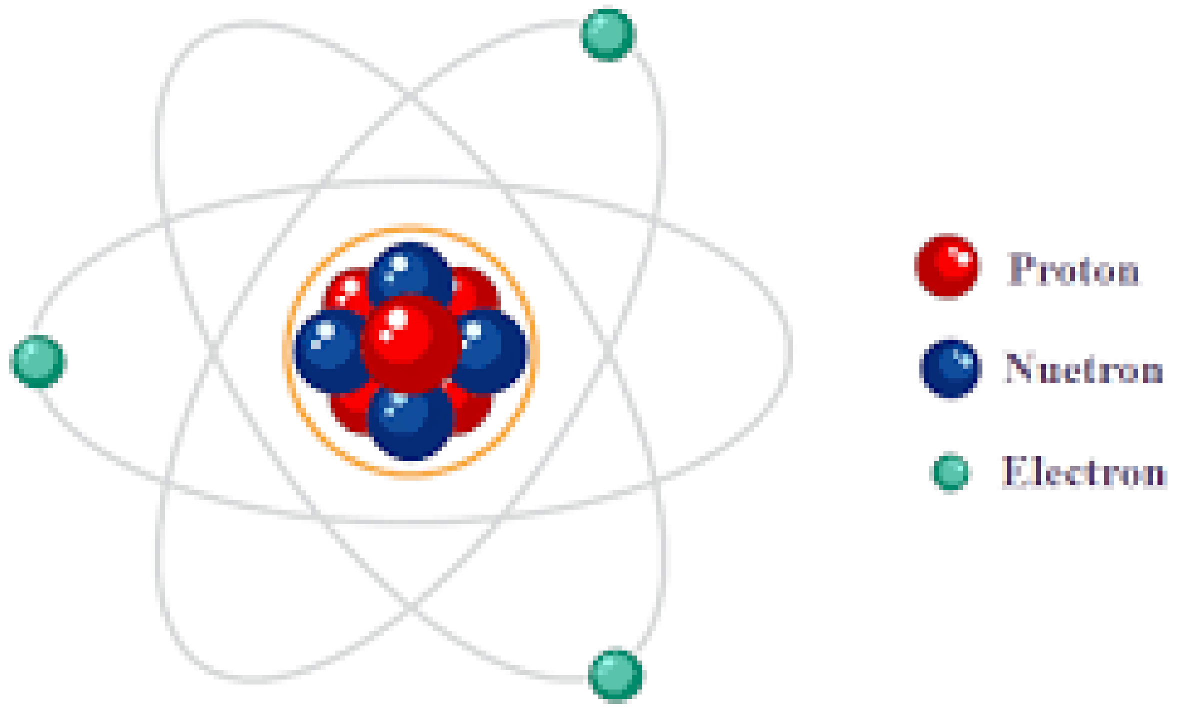
Objects of Intrigue: Look Radiant in Radium


1
H
Hydrogen
1.0079
3
Li
Lithium
6.941
4
Be
Beryllium

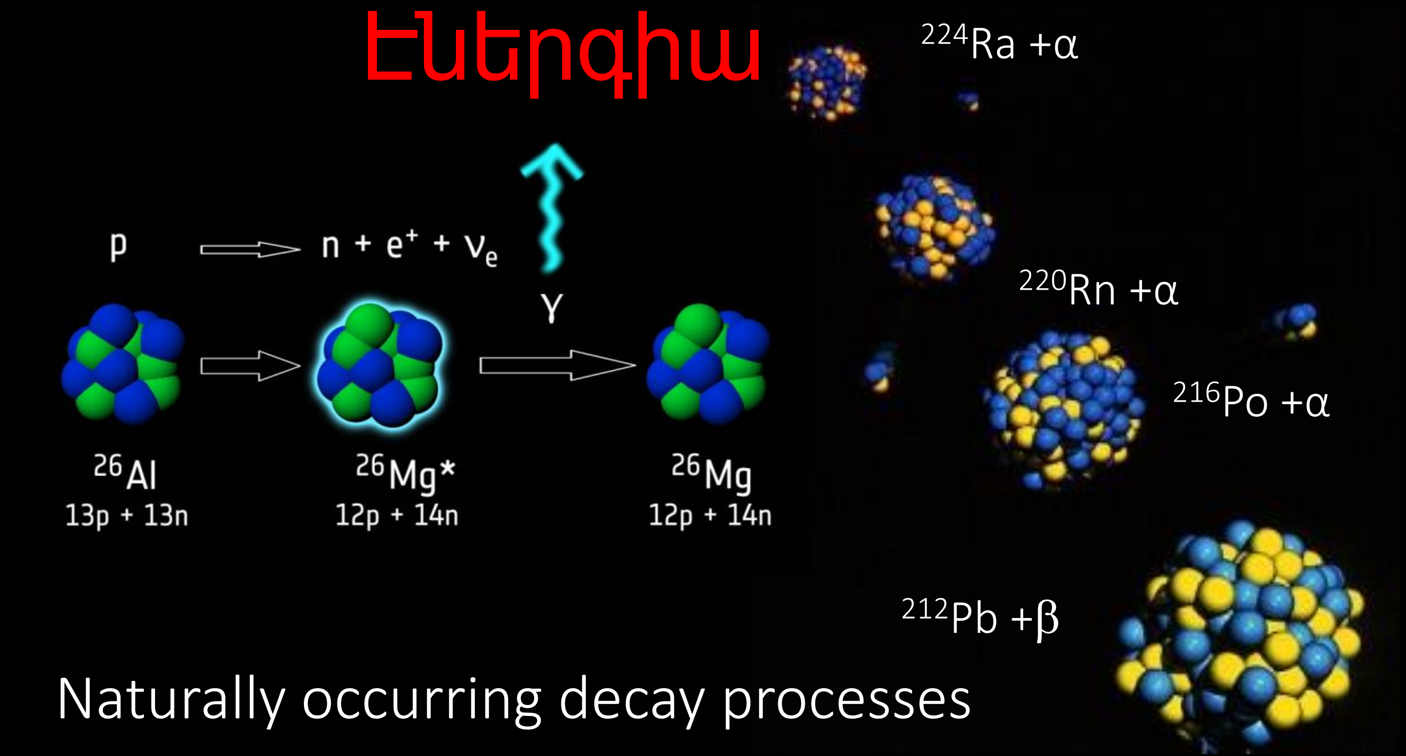

Atomic Number
6
C
Symbol
Element Name
Carbon
12.01
Atomic Mass


Ce
Th
Pa
U
Am
Cm
Es
Fm

Structure of Atom



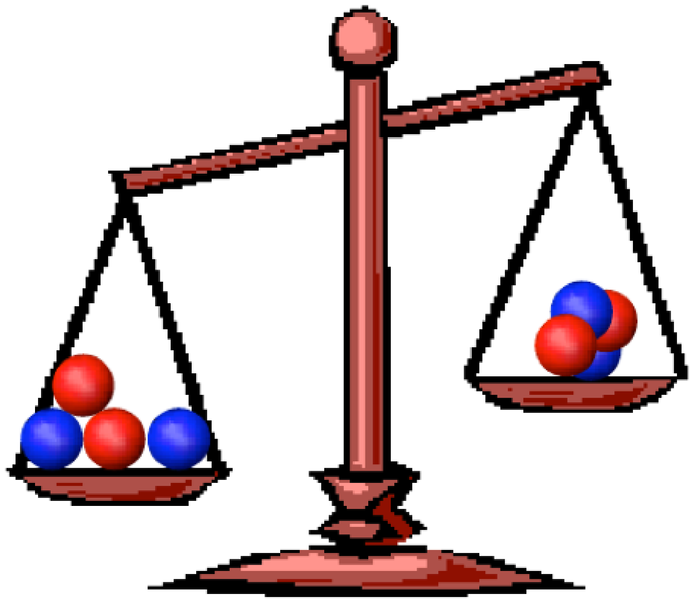
Radioactivity is associated with Nuclear Transmutation



Naturally occurring decay processes

Nuclear binding energy

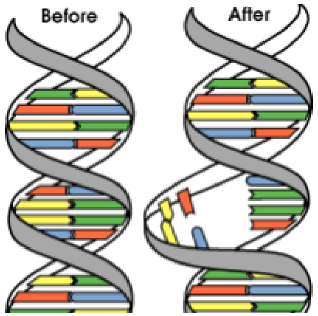
Nuclei weigh less than the sum of the masses of their protons and neutrons



Energy and mass are related

$$(2m_p + 2m_n) > m(^4He)$$

$$BE = (2m_p + 2m_n) - m(^4He)$$



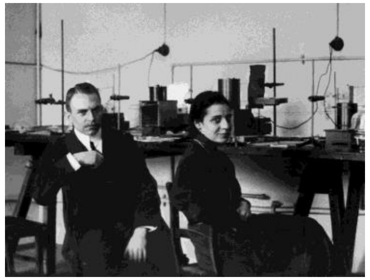
Consequences?

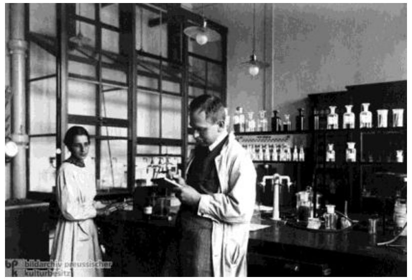
- Mutation
  Evolution
  Death
- Cancer
- Death

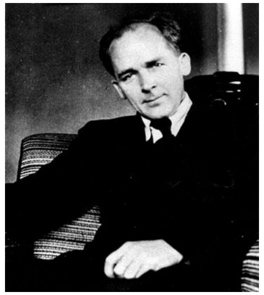
pends on radiation dose (radiation sickness)
pends on radiation damage
pends on enzyme repair mechanisms
pends on natural selection (survivability)

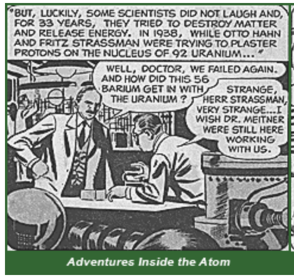
Alexander Litvinenko, 1962-2006

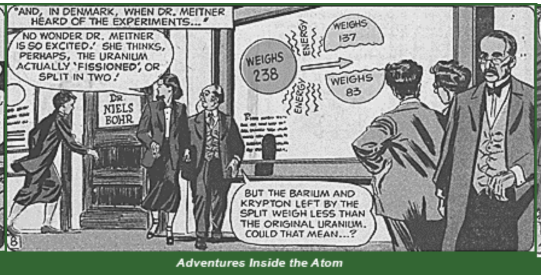
Nuclear Fission

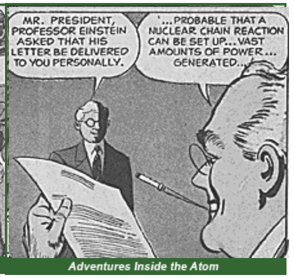




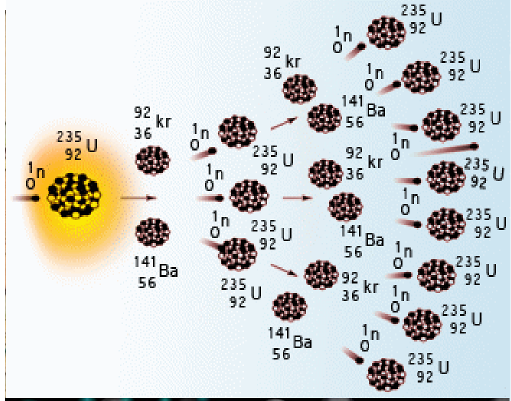


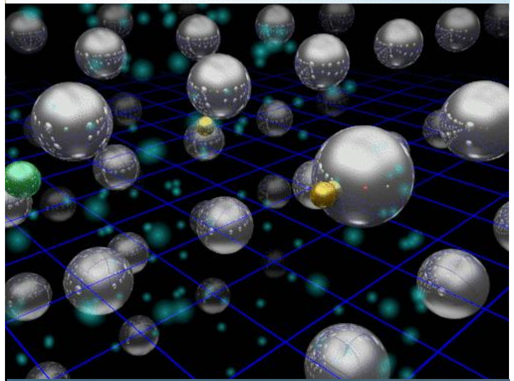




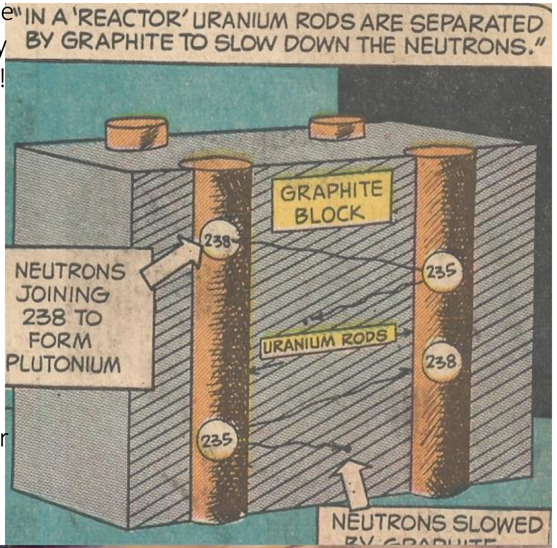


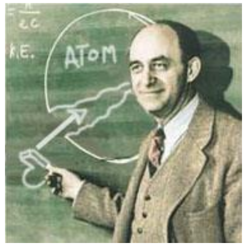
Chain Reactions



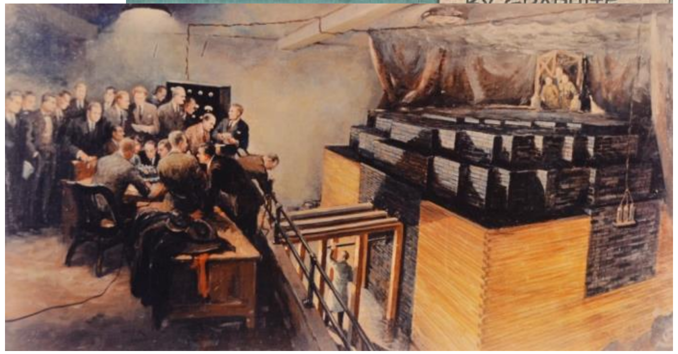


Slow neutrons are more likely to be captured by ^{235}U and induce fission!

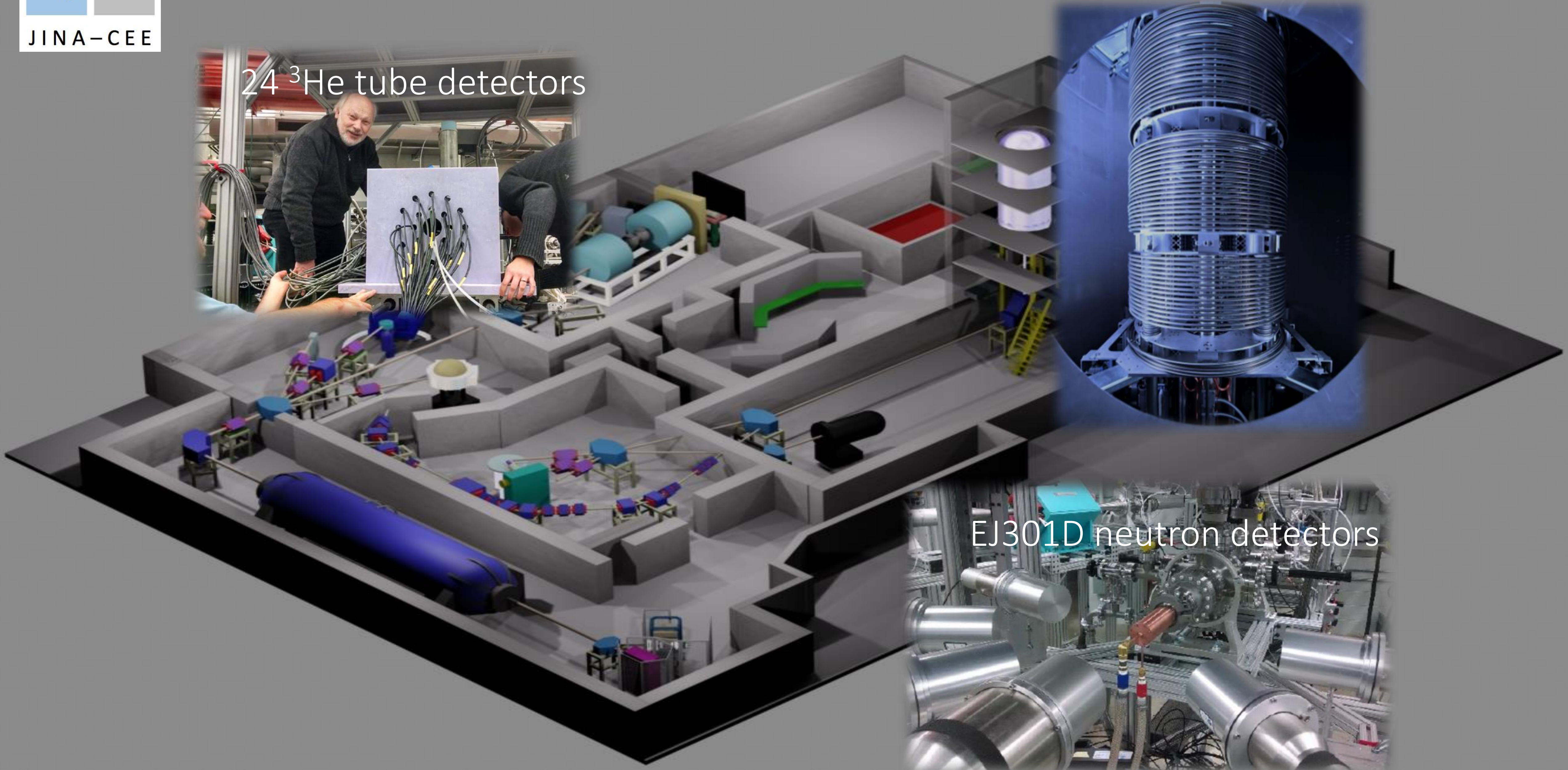


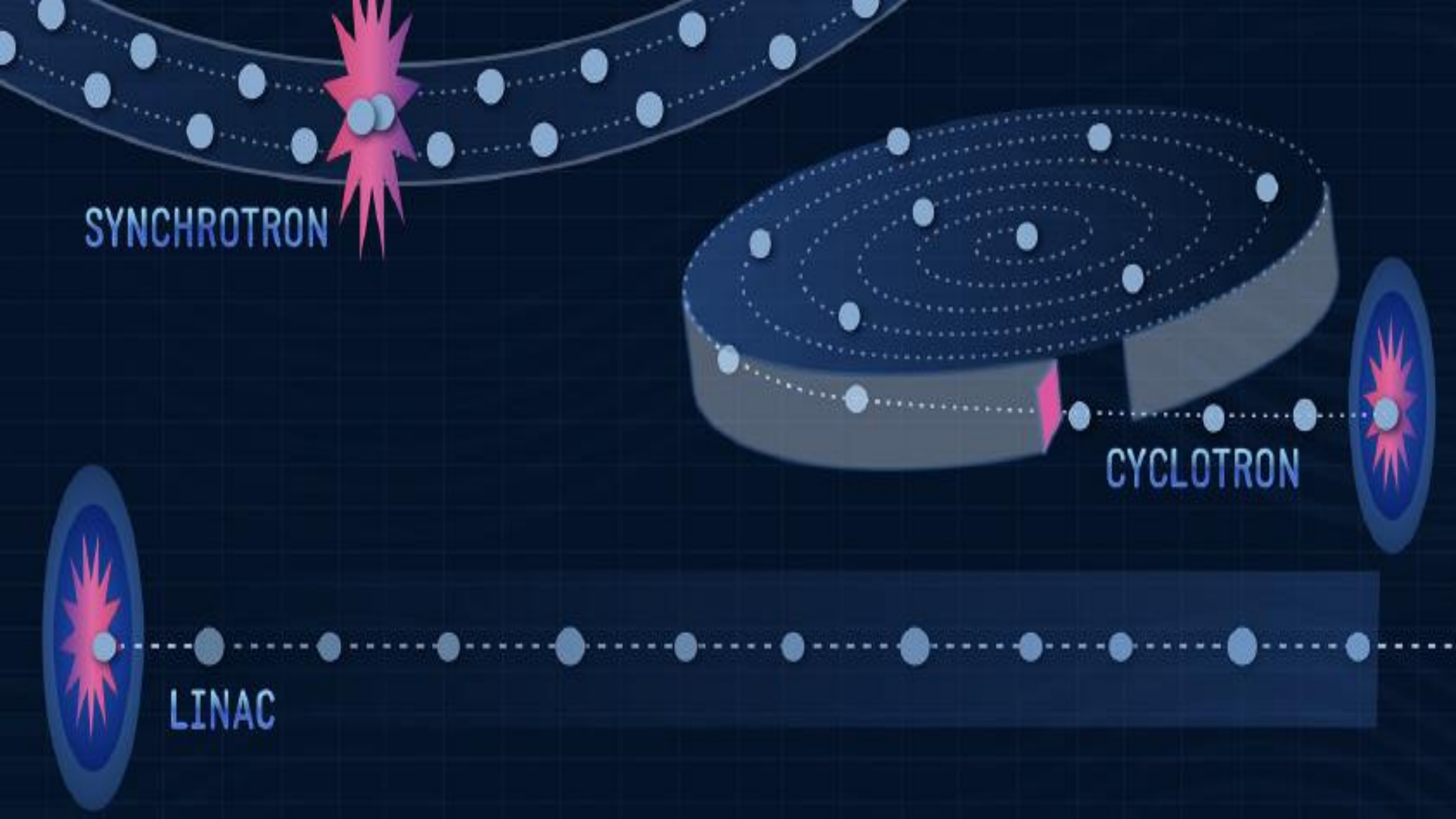


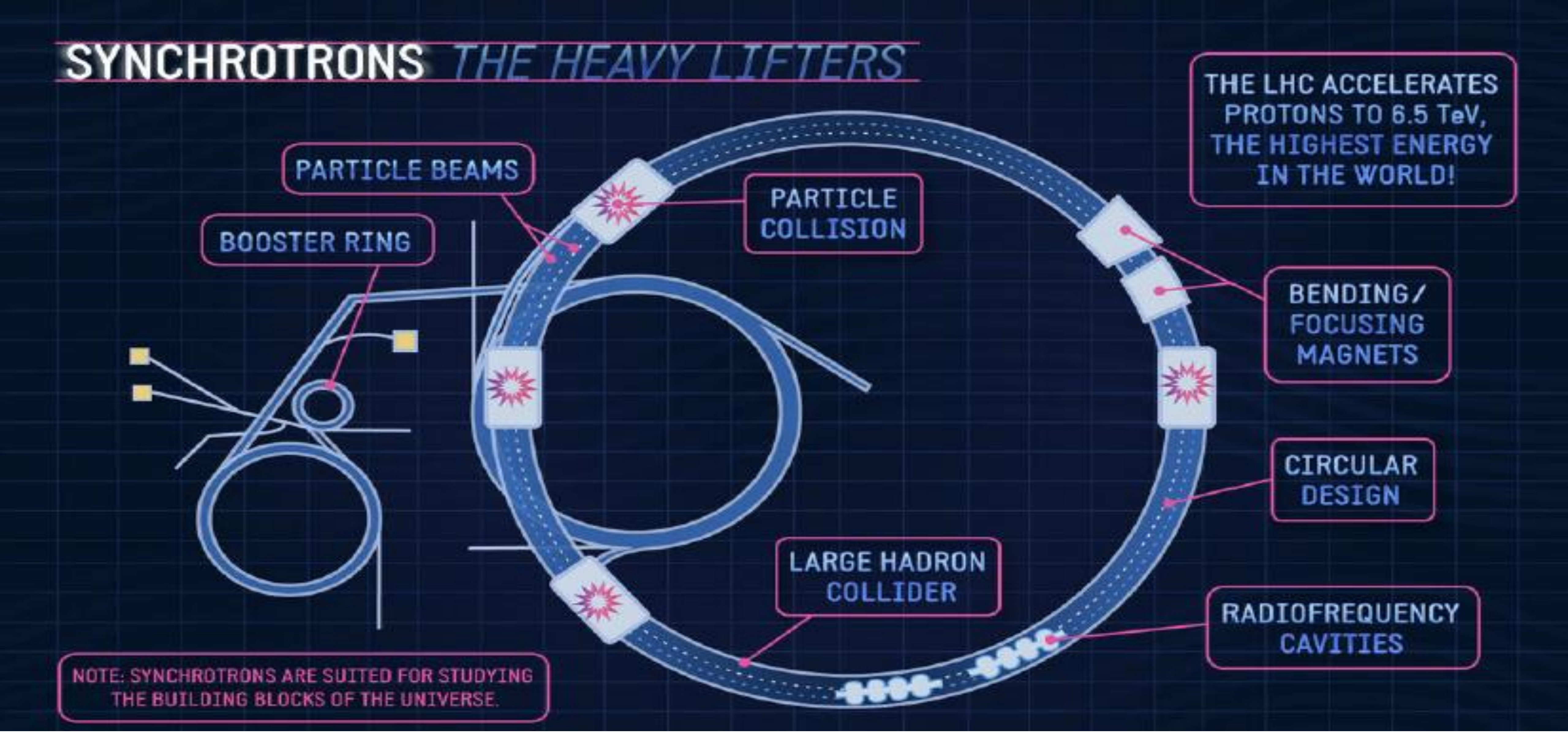
The first nuclear reactor developed by Enrico Fermi in Chicago in 1942.



Experimental facilities at Notre Dame




SYNCHROTRON
CYCLOTRON
LINAC

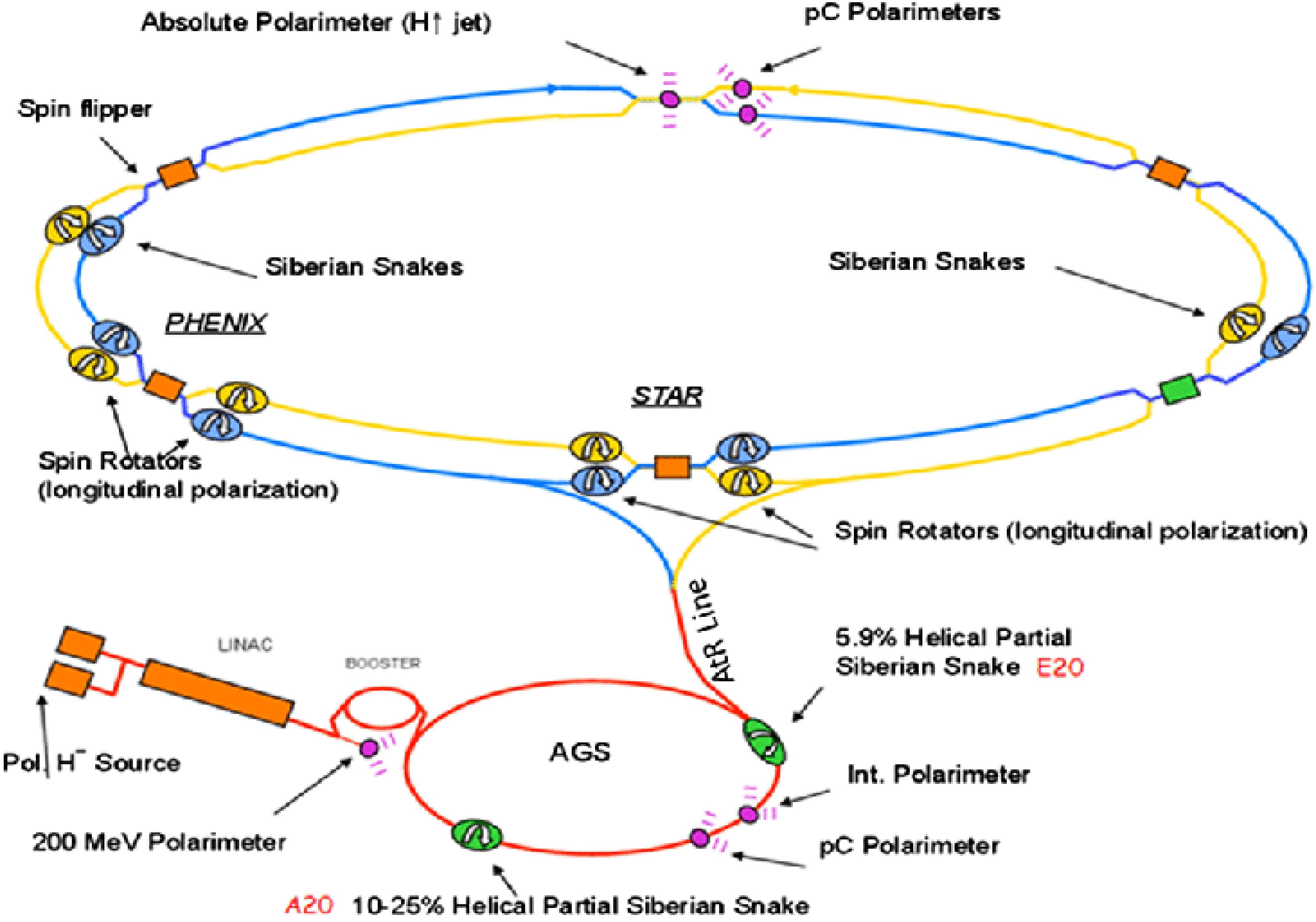


Particles accelerated in a closed loop in vacuum: LHC, 14 million times in 20 minutes

Mainly protons but can accelerate everything up to Pb.

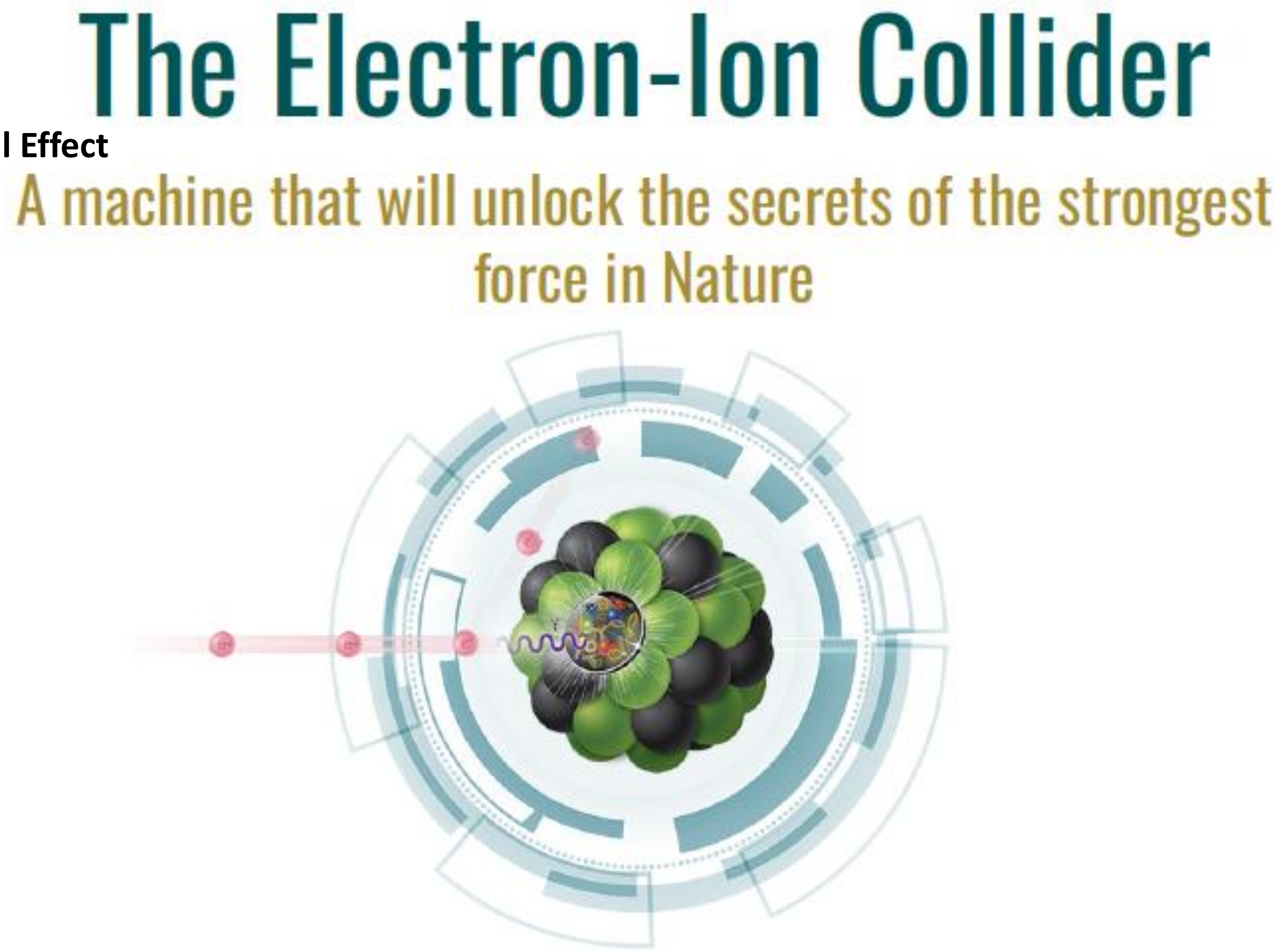
ARUS in YerPhi


RHIC
HENIX
STAR
NSRL
EBIS
BOOSTER
AGS


Absolute Polarimeter (H↑ jet)
pC Polarimeters
Spin flipper
Siberian Snakes
Siberian Snakes
PHENIX
STAR
Spin Rotators
(longitudinal polarization)
Spin Rotators (longitudinal polarization)
AtR Line
5.9% Helical Partial
Siberian Snake E20
LINAC
BOOSTER
AGS
Pol. H⁻ Source
Int. Polarimeter
200 MeV Polarimeter
pC Polarimeter
A20 10-25% Helical Partial Siberian Snake

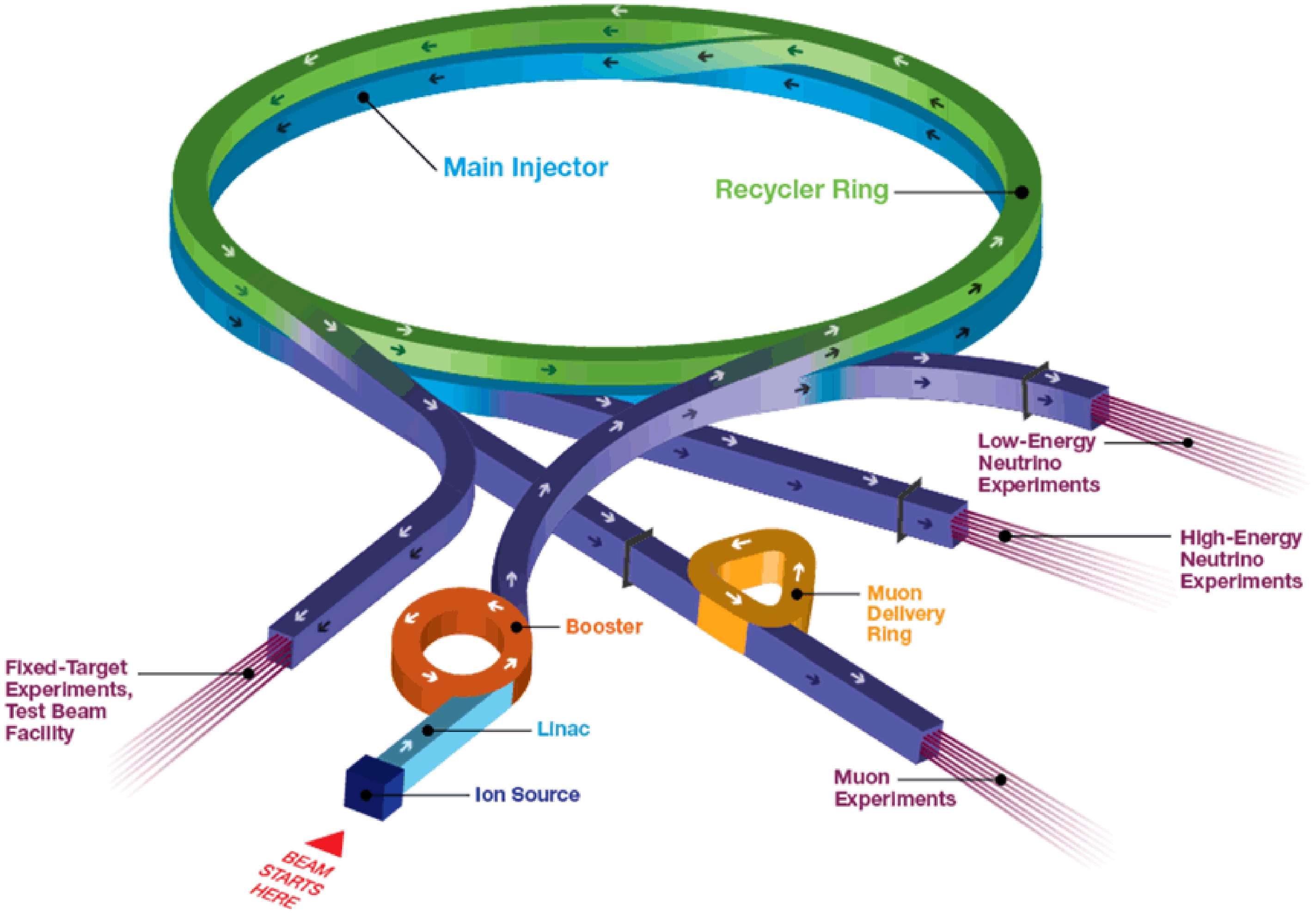
2.1 Association Agreements with Legal Effect

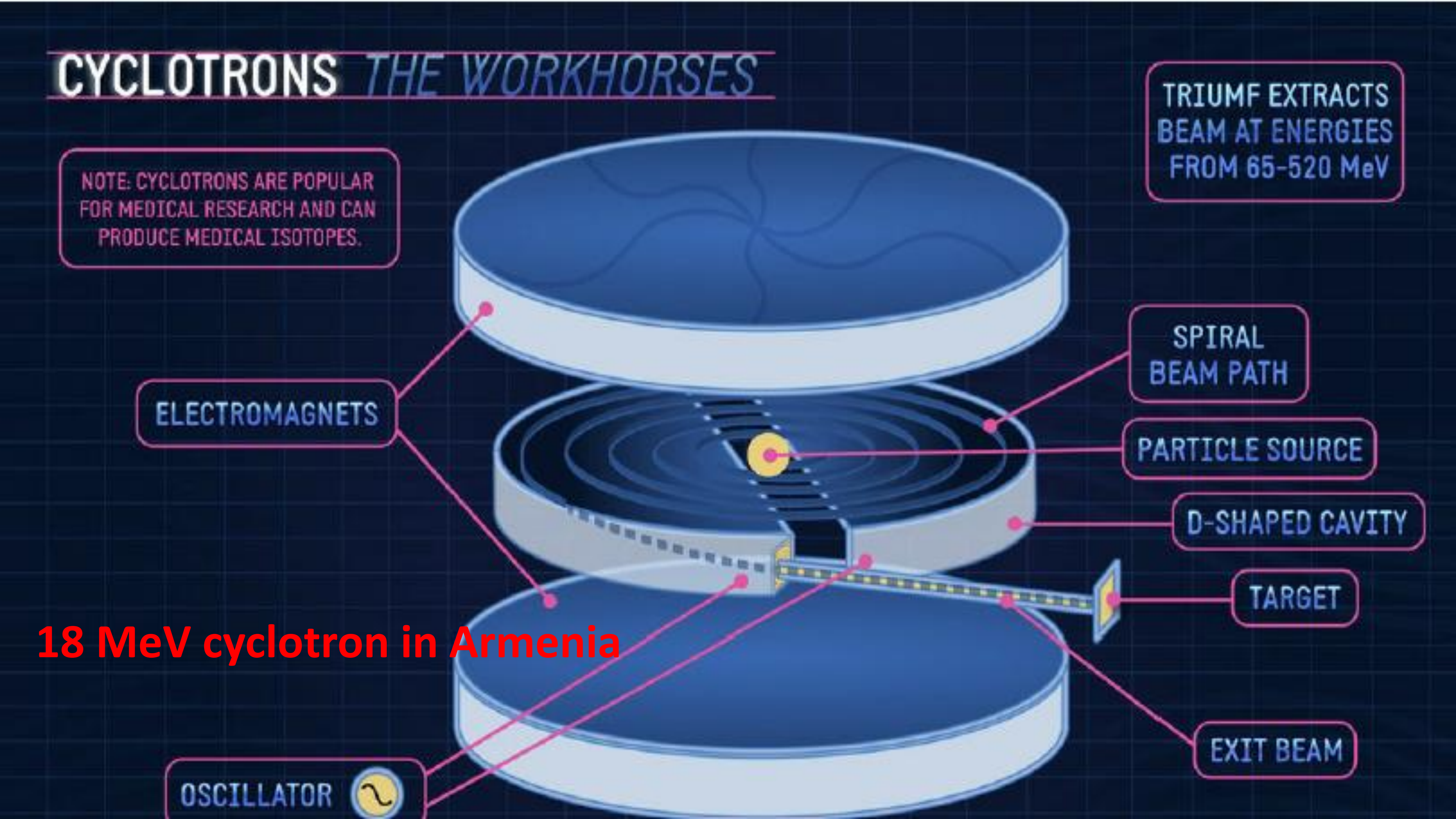
1.Albania
2.Armenia
3.Bosnia and Herzegovina
4.Faroe Islands
5.Georgia
6.Iceland
7.Israel
8.Kosovo
9.Moldova
10.Montenegro
11.North Macedonia
12.Norway
13.Serbia
14.Tunisia
15.Turkey
16.Ukraine



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.

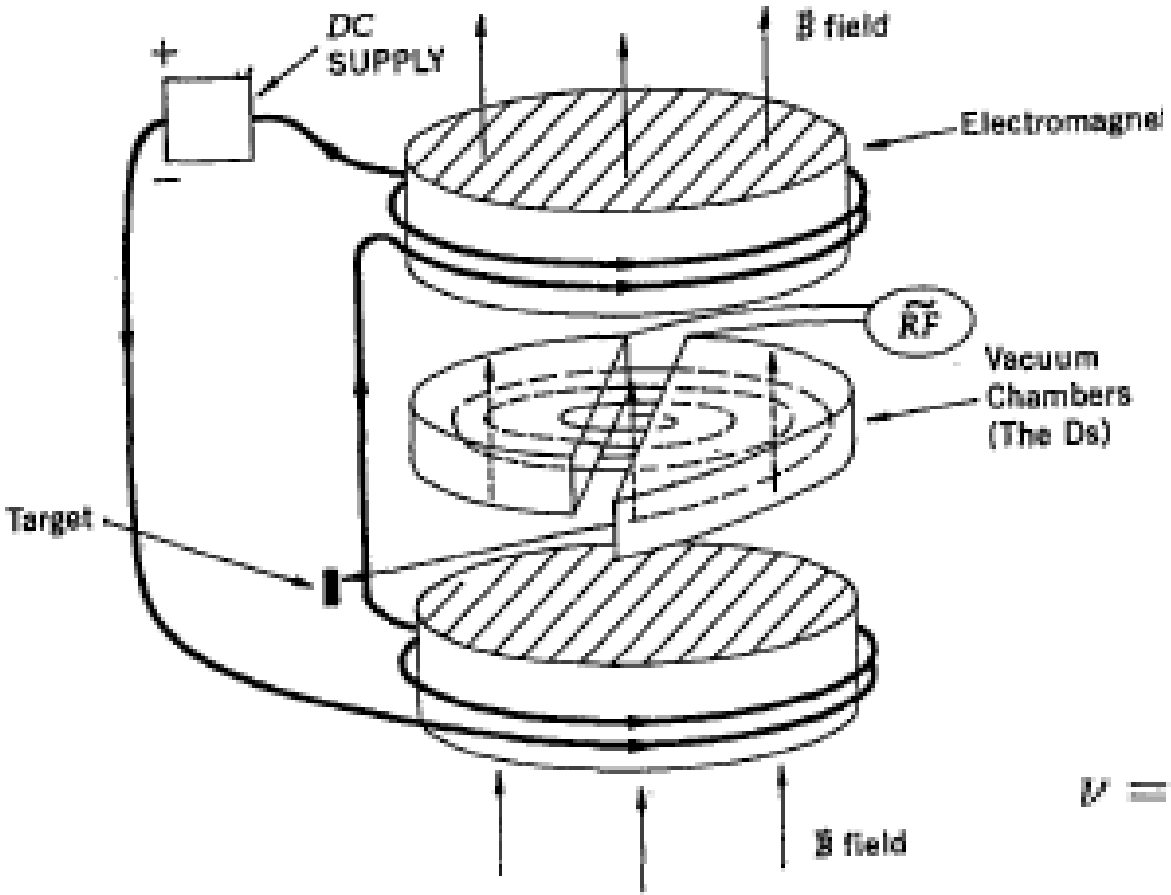
Fermilab Accelerator Complex





18 MeV cyclotron in Armenia

Two hollow evacuated D-shaped metal chambers: magnetic force causes centripetal acceleration for a circular orbit



$$m\frac{v^2}{r} = q\,\frac{vB}{c},$$

$$\text{or}\quad \frac{v}{r} = \frac{qB}{mc}.$$

Angular frequency

$$\omega = \frac{v}{r}.$$

$$\nu = \frac{\omega}{2\pi} = \frac{qB}{2\pi mc} = \frac{1}{2\pi}\left(\frac{q}{m}\right)\frac{B}{c}.$$

frequency

$$\nu = \frac{\omega}{2\pi} = \frac{qB}{2\pi mc} = \frac{1}{2\pi}\left(\frac{q}{m}\right)\frac{B}{c}$$

Maximum Kinetic Energy

$$T_{\max} = \frac{1}{2} m v_{\max}^2 = \frac{1}{2} m\omega^2 R^2$$

$$= \frac{1}{2} m \left(\frac{qB}{mc}\right)^2 R^2 = \frac{1}{2} \frac{(qBR)^2}{mc^2}$$

8.1 Protons are accelerated in a cyclotron by an electric field with oscillating frequency of 8 MHz. If the diameter of the magnet is 1 m, calculate the value of magnetic field and the maximum energy that the protons can reach.

Diameter = 1 m; radius =0.5 m

Frequency =8 MHz

$\omega=2\pi f= 2\pi.8\text{x}10^6/\text{s}= 5 \text{ x } 10^{7}$ rad/s

$$\nu = \frac{\omega}{2\pi} = \frac{qB}{2\pi mc} = \frac{1}{2\pi}\left(\frac{q}{m}\right)\frac{B}{c}$$

Magnetic Field?

$B= m\omega/Q$

$$B = \frac{(1.67\text{x}10^{-27}\text{ Kg})\ (5\text{x}10^{7}\text{ rad/s})}{1.6\text{x}10^{-19}\text{ C}} = 0.52 \text{ Tesla}$$

$$m\frac{v^2}{r} = q\frac{vB}{c},$$

$$\text{or} \quad \frac{v}{r} = \frac{qB}{mc}.$$

$$\text{Or } B= \frac{mc^2\omega}{Qc^2} = \frac{(mc^2)\ \omega.}{(\ Q\ )\ c^2}$$

$B=940\text{x}10^{6}\text{ eV } (5\text{x}10^{7}\text{ rad/s})/\ 9\text{x}10^{16}\text{m2/s2}$

B=0.52 Tesla

Maximum Energy that a proton can reach

$$T = \tfrac{1}{2} mv^2$$

$$= 1/2mc^2 (\omega R/c)^2$$

$$= 0.5(940\text{MeV}) \frac{(2.5 \times 10^7)^2}{(3\times10^8)^2} = 3.3 \text{ MeV}$$

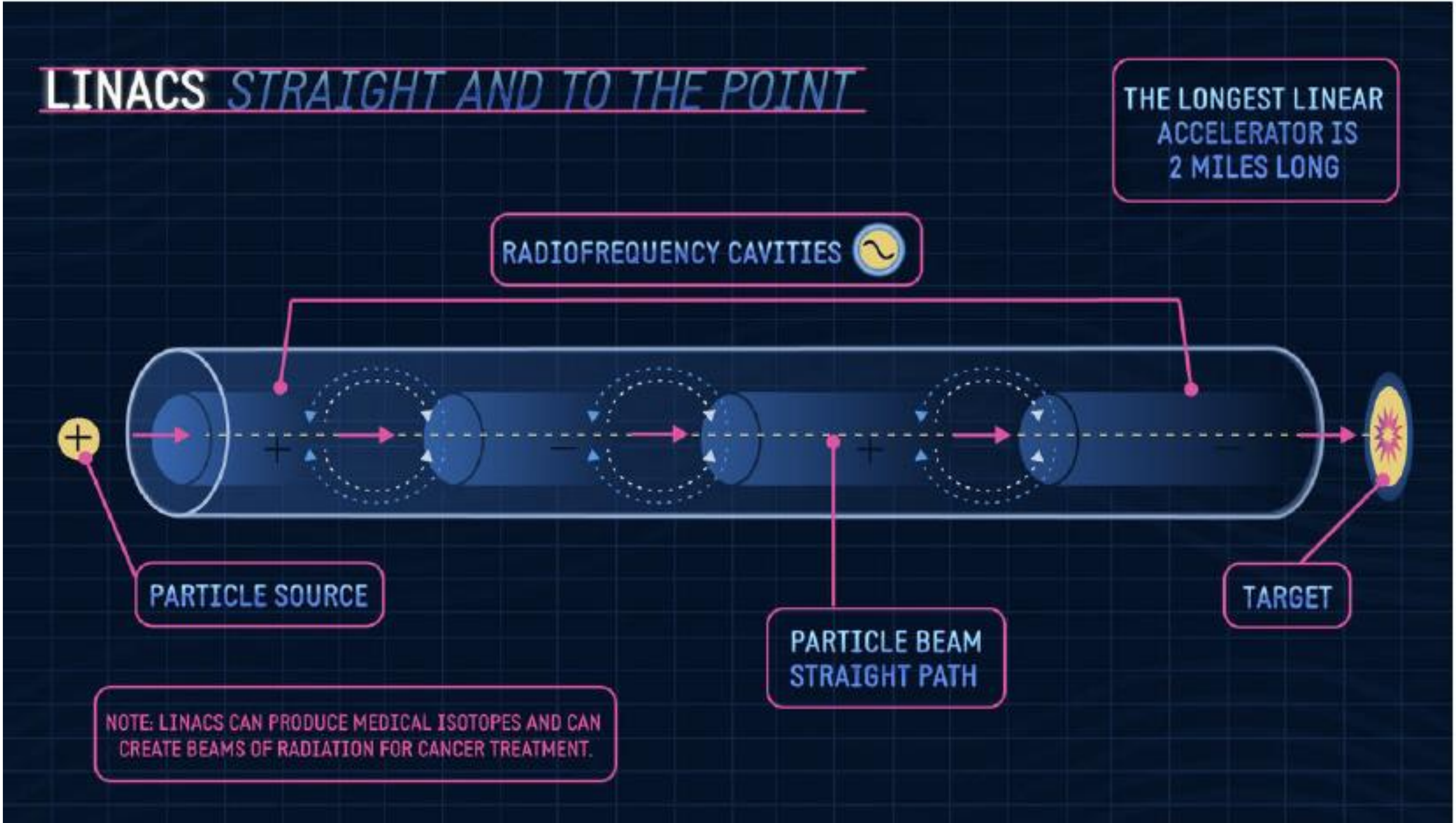
8.2 To achieve an energy of 20 TeV, each of the SSC main rings was to contain about 4000 dipole magnets, each 16-meters long, with a field of 7 T. This means that over half of the $\approx$ 60 mile SSC tunnel was to be taken up by dipoles. If you were to build a single synchrotron for use in fixed-target collisions of equivalent energy in the center-of-mass ($\sqrt{s}$ = 40 TeV), and used a similar magnet design, how long would your tunnel have to be?

$\sqrt{s} = 40$ TeV $=(2mE')^{1/2}$; E' beam energy

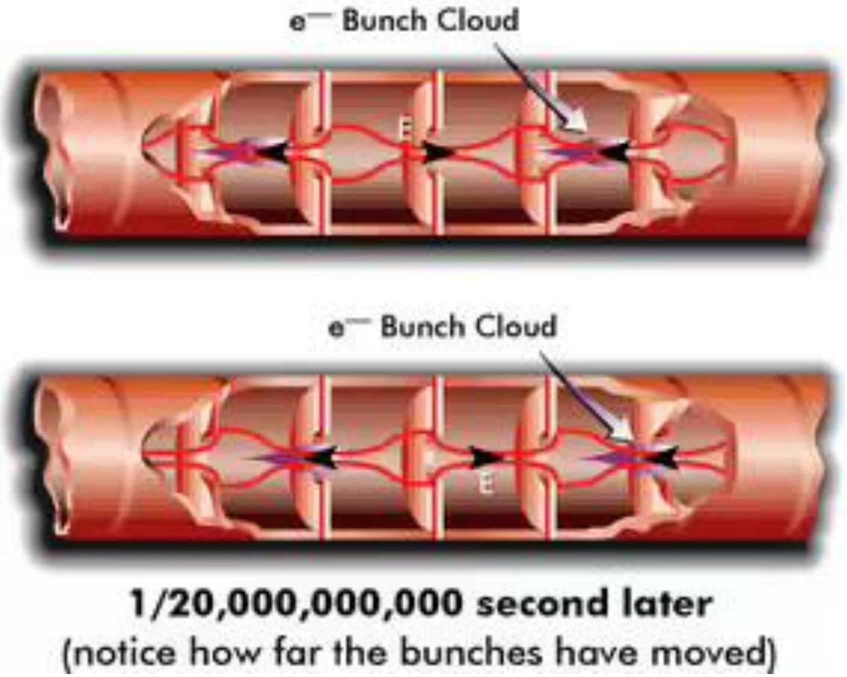
$$E' = \frac{(2\ ½)^2}{2\ mc^{22}} = \frac{1600 \times 10^{6}\ \text{GeV}}{2\ \text{GeV}} = 8 \times 10^5\ \text{TeV}$$

Circumference of circular tunnel will scale with energy.

$C'=C\,E'/E = 60$ miles $(8\times10^5$ TeV/20 TeV$) = 2.4 \times 10^{6}$ miles


LINACS STRAIGHT AND TO THE POINT
THE LONGEST LINEAR ACCELERATOR IS 2 MILES LONG
RADIOFREQUENCY CAVITIES
PARTICLE SOURCE
PARTICLE BEAM STRAIGHT PATH
TARGET
NOTE: LINACS CAN PRODUCE MEDICAL ISOTOPES AND CAN CREATE BEAMS OF RADIATION FOR CANCER TREATMENT.

Copper Tubes



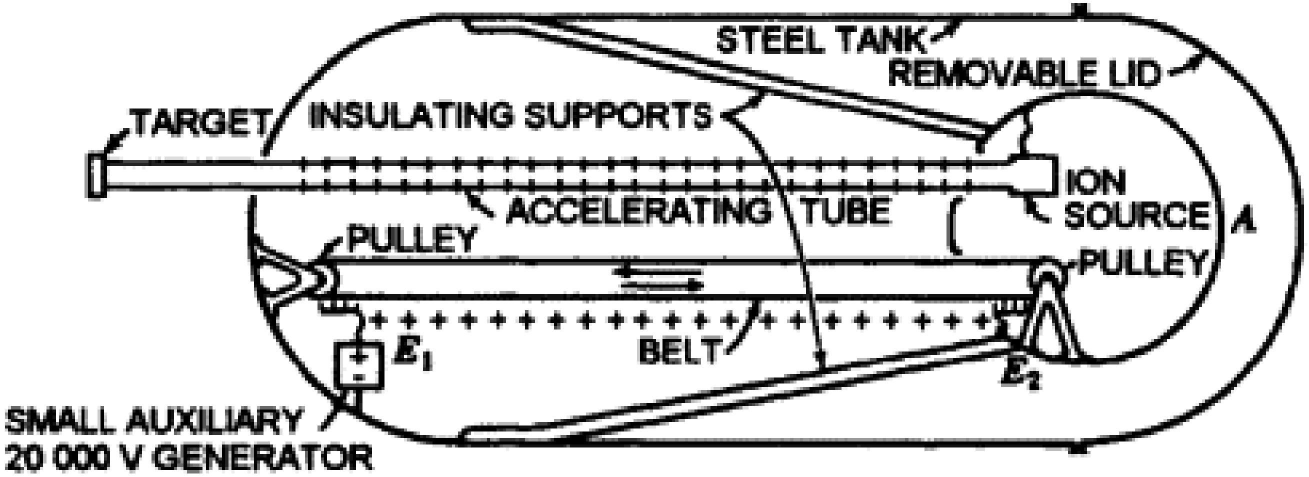
The major structure of the particle accelerator is the **copper tube**. The copper tube has a strong vacuum inside through which the particles travel. The tubes are made of copper because **copper conducts electricity and magnetism very well**. At the SLAC linac, the copper tube is made of more than 80,000 copper cylinders brazed together for more than 2 miles (3.2 km)!

Copper tube is arranged in a series of cells called cavities. The spacing of the cavities depend on the wavelength of the microwaves

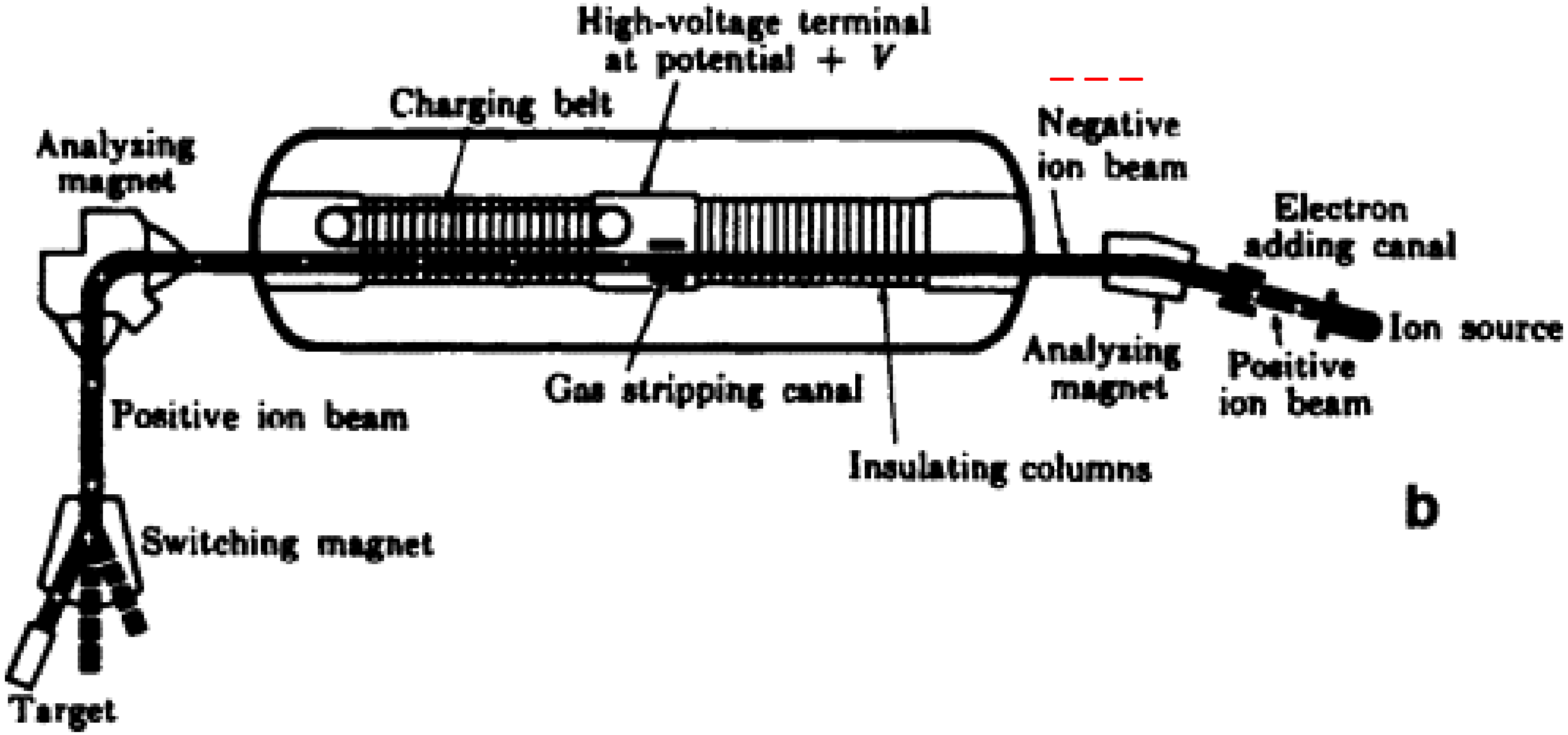
Van de Graaff Accelerators

Van de Graaff accelerators produce energetic beams of protons, deuterons, tritons, alpha particles, and ^3He particles. Secondarily, these charged particles can produce high-energy neutrons through a variety of nuclear reactions. Analytical applications with high-energy neutrons and energetic charged particles are dominated by reactions involving particle evaporation and usually produce neutron-deficient product nuclides.

Two other types of accelerators are the linear accelerator and the synchrotron, with both types used to accelerate electrons. Although electrons themselves have few analytical applications, the bremsstrahlung radiation (i.e., gamma rays) emitted when high-energy electrons interact with a tantalum or tungsten target can be used for photon activation analysis (PAA).

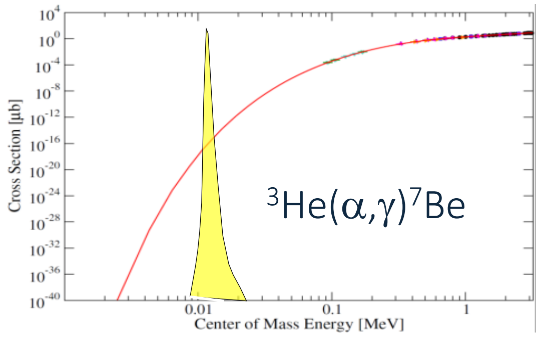

STEEL TANK
REMOVABLE LID
TARGET
INSULATING SUPPORTS
ION
SOURCE
A
ACCELERATING TUBE
PULLEY
PULLEY
BELT
E_1
E_2
SMALL AUXILIARY
20 000 V GENERATOR

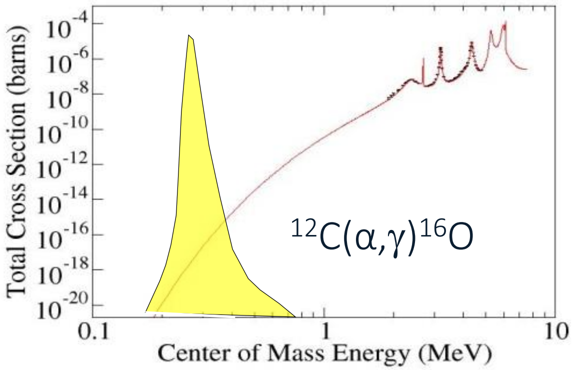
a

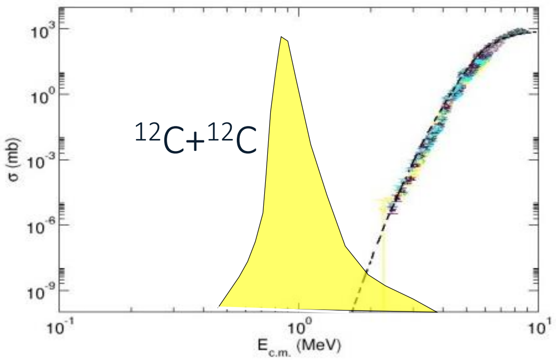

High-voltage terminal
at potential + V
Charging belt
Analyzing
magnet
Negative
ion beam
Electron
adding canal
Ion source
Analyzing
magnet
Positive
ion beam
Gas stripping canal
Insulating columns
Positive ion beam
Switching magnet
Target

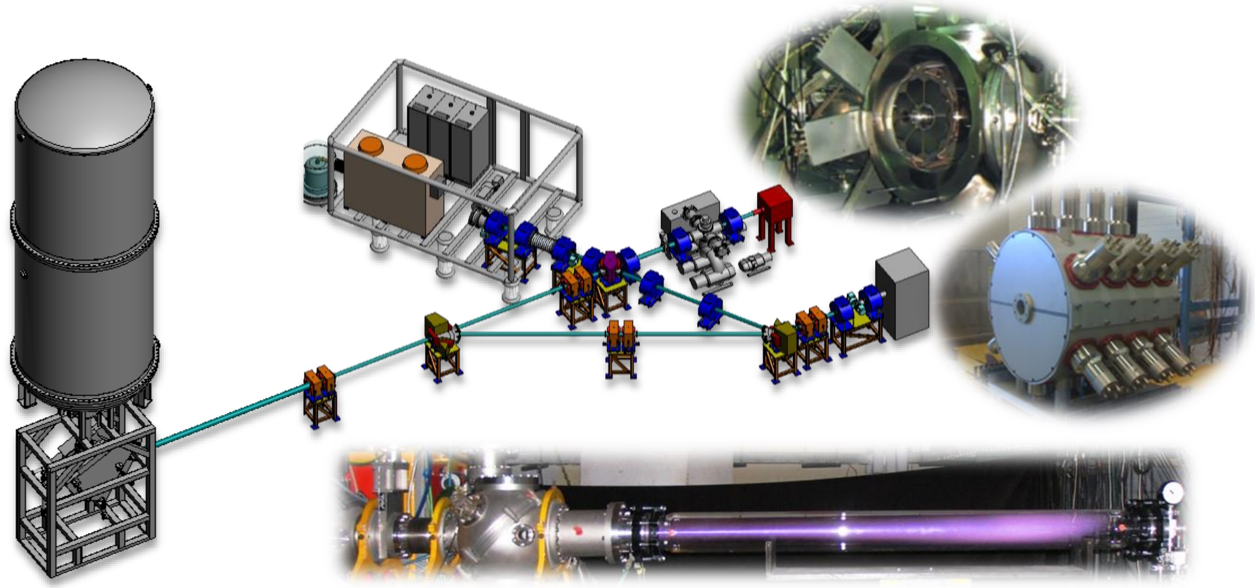
b

Experiments with Charged Particles



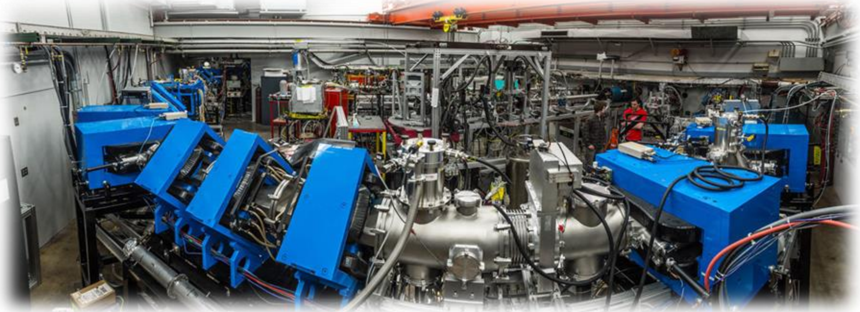




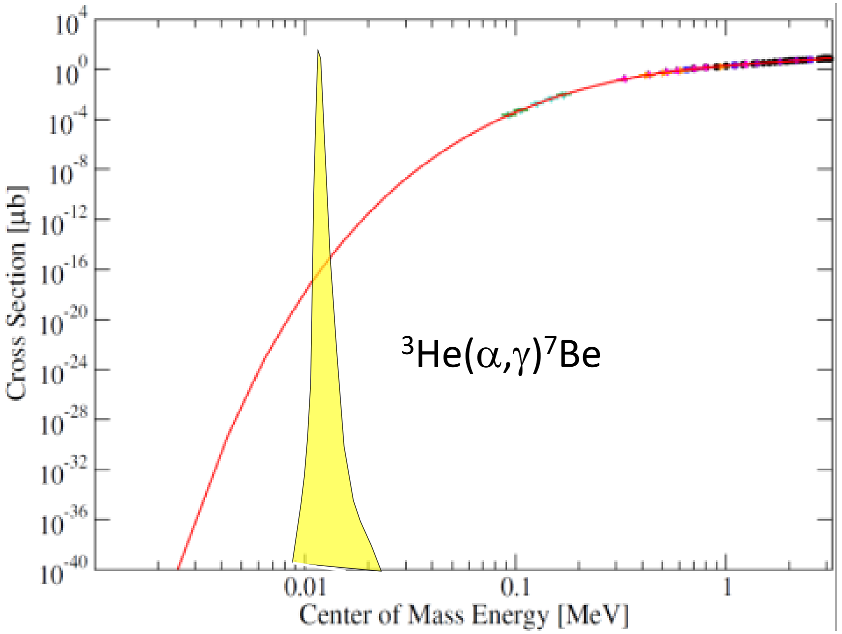


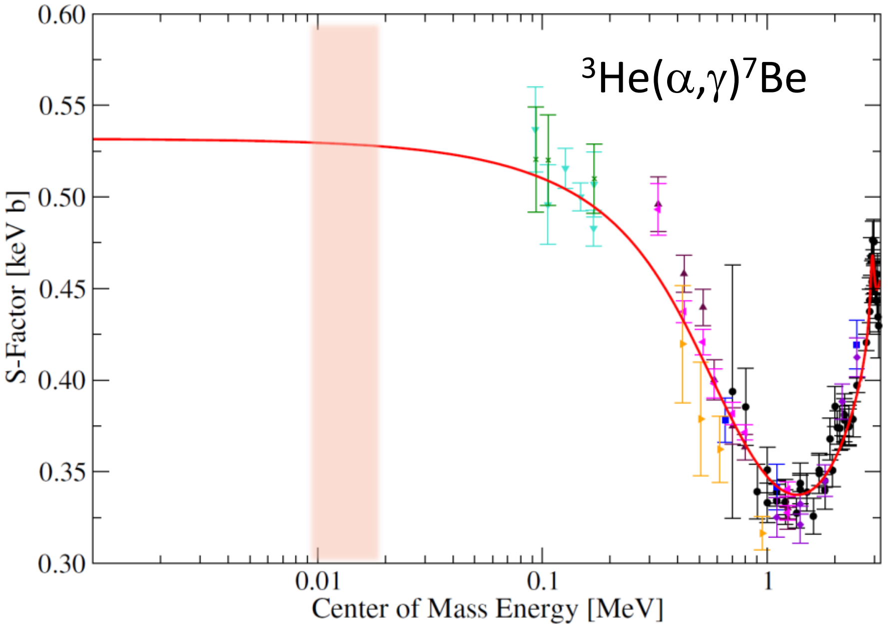
Forward kinematics underground with radiation detection

inverse kinematics with recoil separation and detection



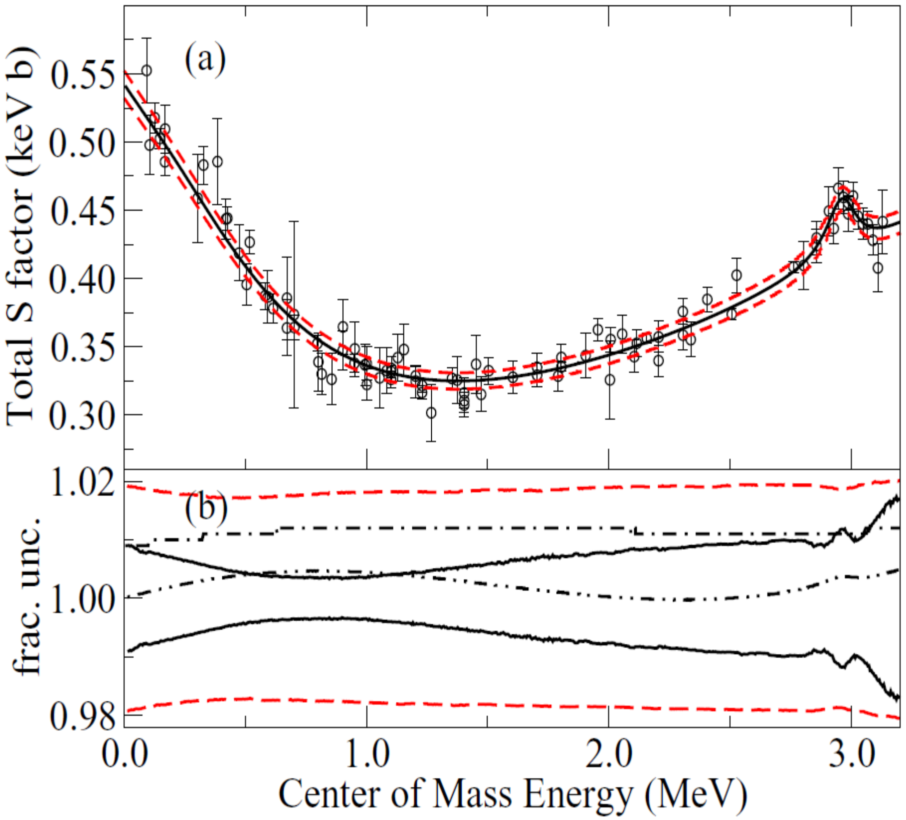
Nuclear reactions in context

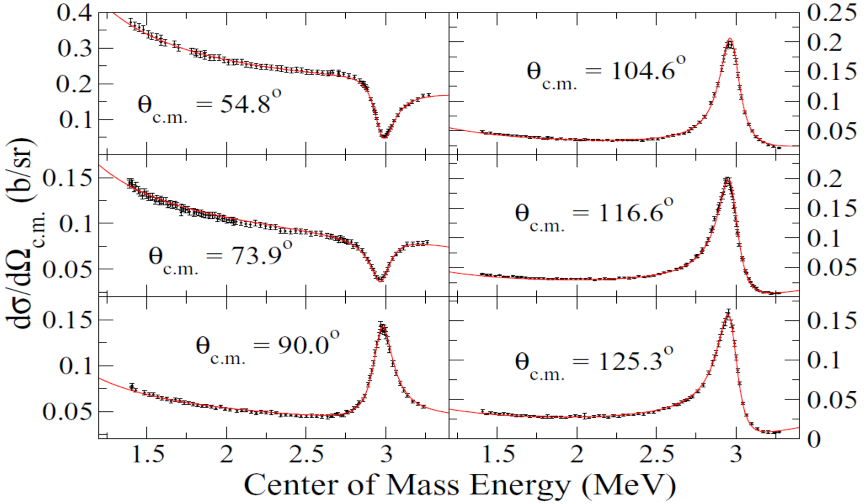


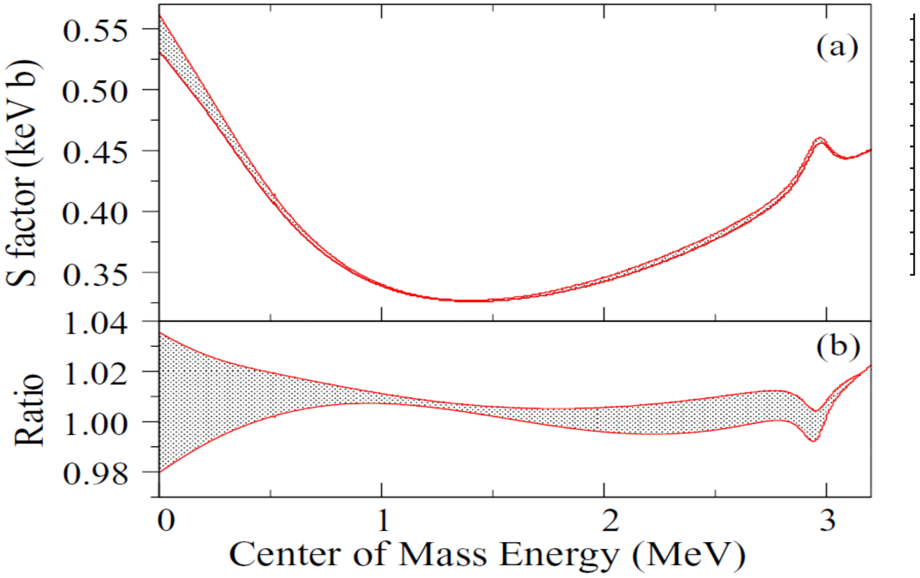


A direct measurement of a charged particle cross section for stellar burning is more than unlikely! A comprehensive analysis of the reaction rate at stellar energies, requires a full understanding of the reaction mechanism and the reaction components to be fully integrated into the extrapolation process. First principle nuclear models are limited, phenomenological models (R-matrix) are limited, but multi-channel approach with a wide-range of data seem promising!

Extrapolations







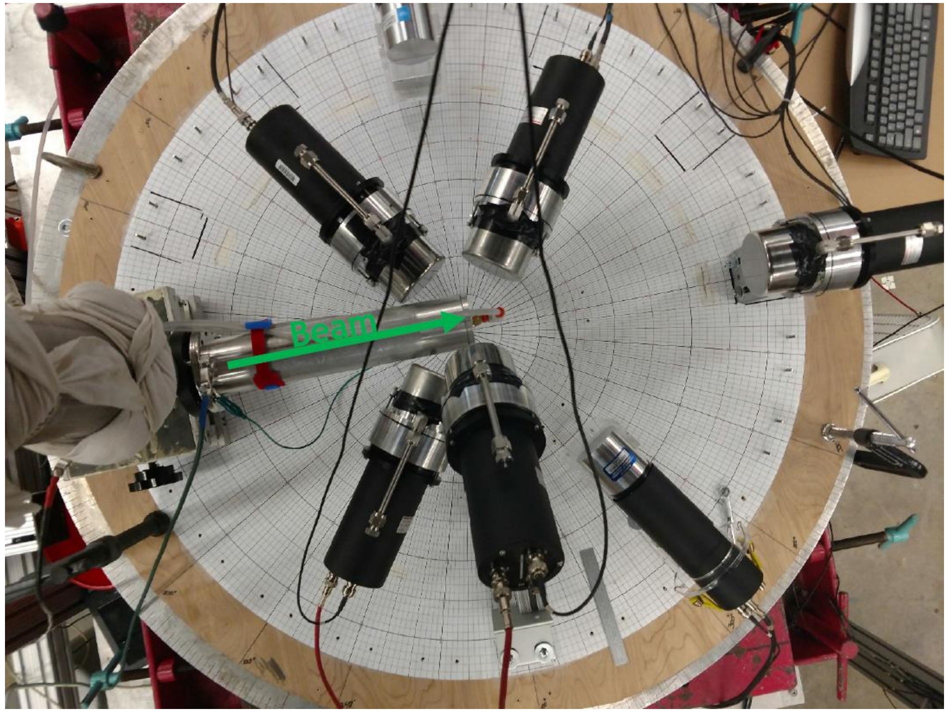
A. Kontos et al. PRC C **87**, 065804 (2013)

R.J. DeBoer et al. PRC C **90**, 035804 (2014)

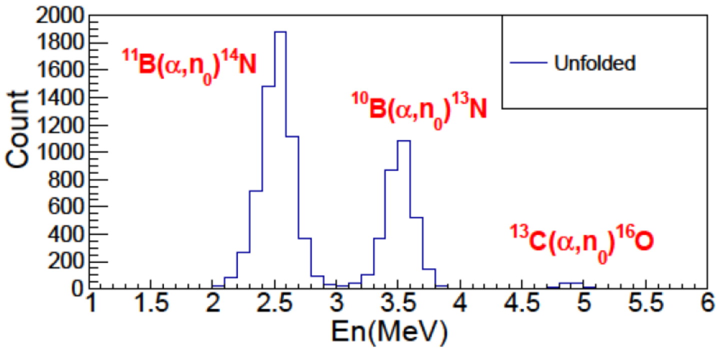
Neutron detection techniques

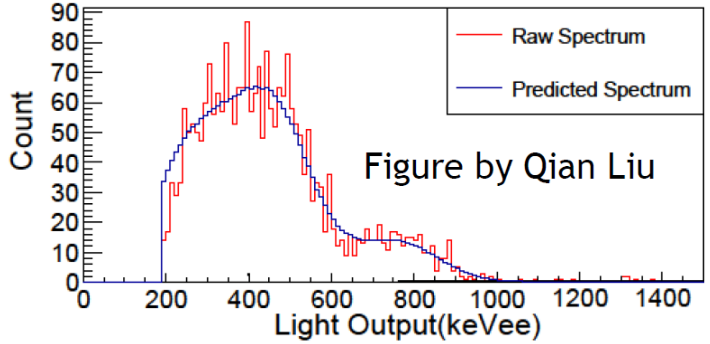
Standard ^{3}He counter system with 24 ^{3}He tubes – problems with beam induced neutron background, e.g. $^{13}C(\alpha,n)$. Alternative are deuterated liquid scintillators with response function analysis.

EJ315



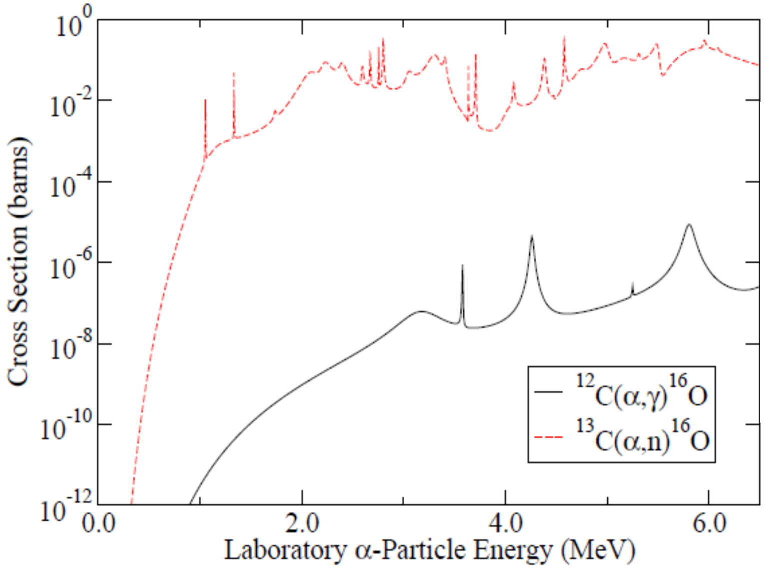
C_6D_6 deuterated polyethylene detectors
Febbraro, ORNL



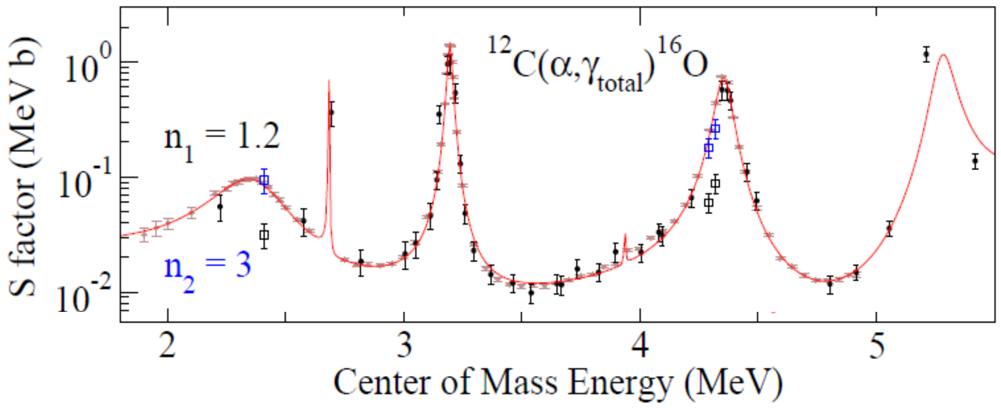


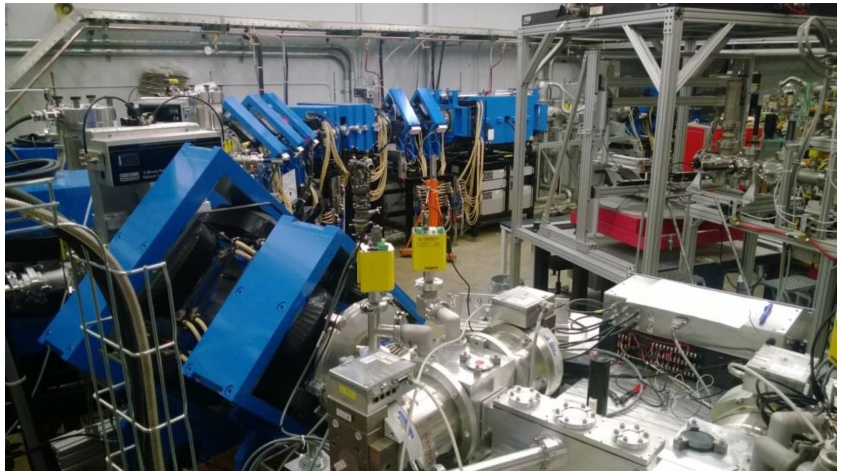
Unfolding techniques

Experimental Efforts > 50 yrs



Conversion of cross section data to S-factor

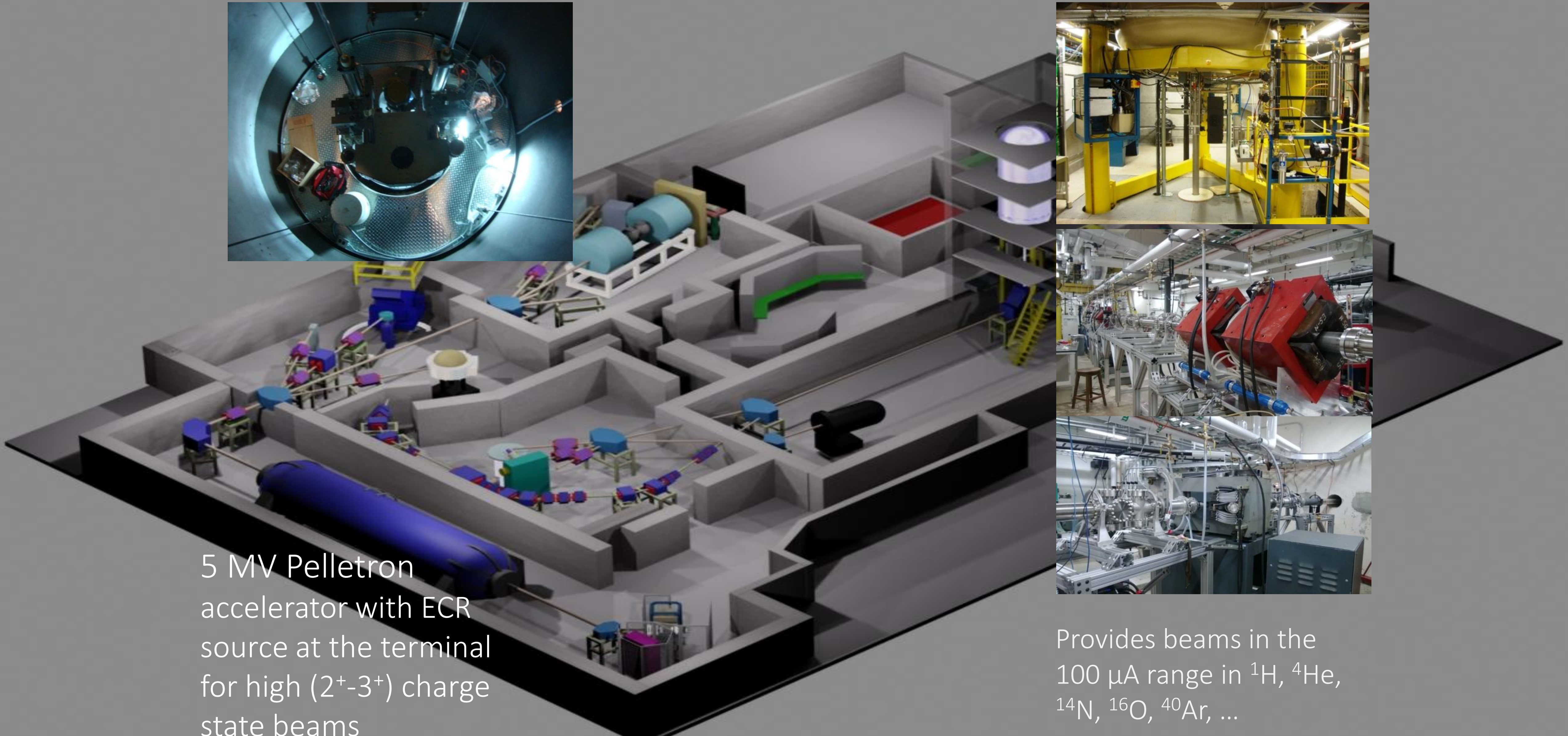




Experimental Techniques

Laboratory based nucleosynthesis

Experimental Facilities at Notre Dame

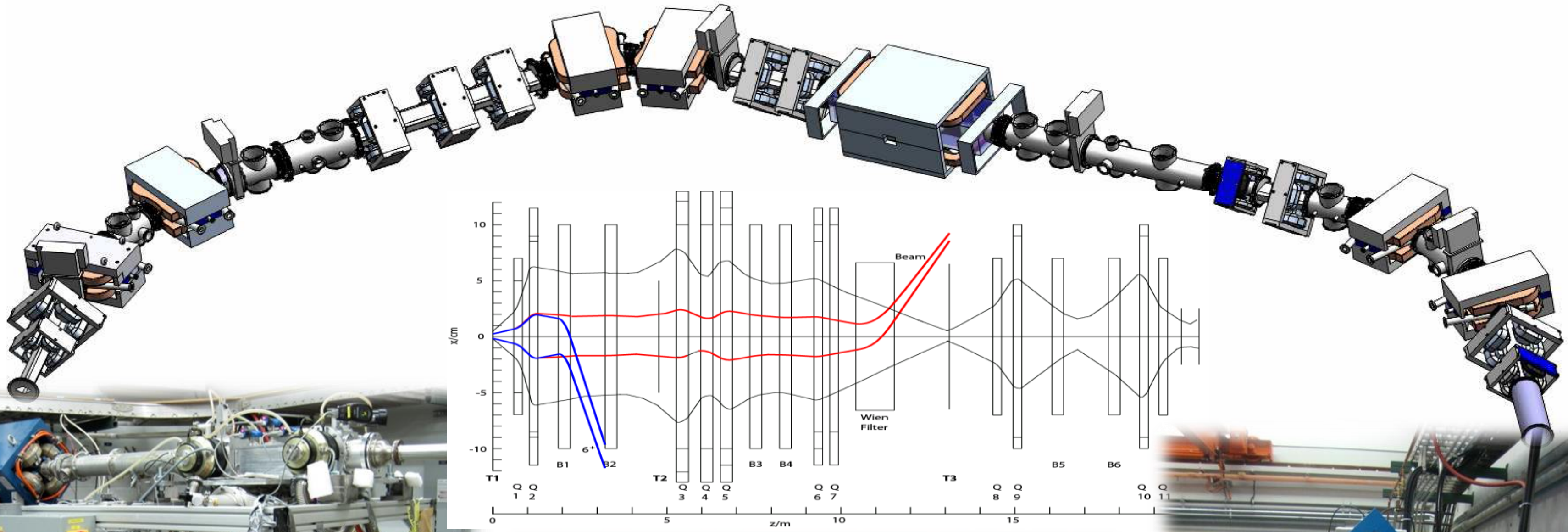


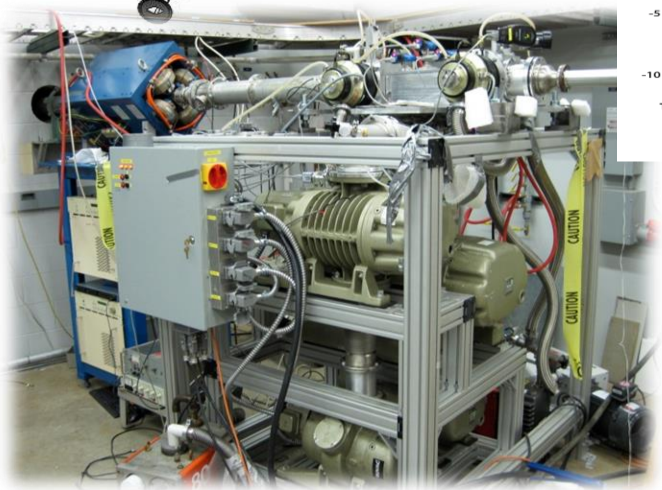
5 MV Pelletron accelerator with ECR source at the terminal for high (2^+-3^+) charge state beams

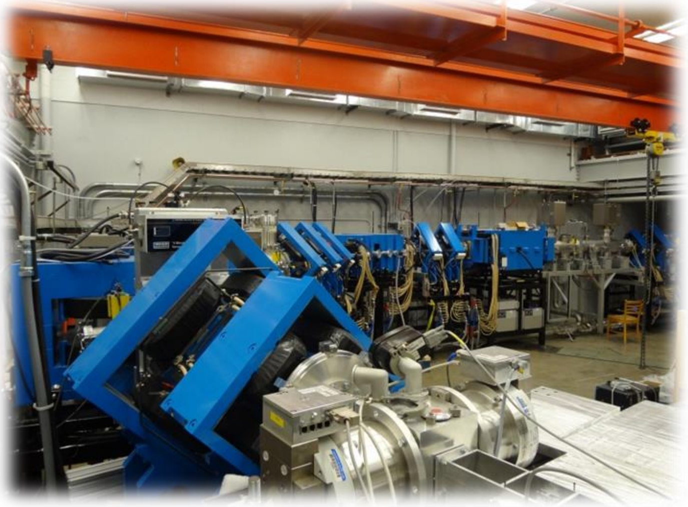
Provides beams in the 100 μA range in ^{1}H, ^{4}He, ^{14}N, ^{16}O, ^{40}Ar, …

St. George Separator

Strong **G**radient **E**lectro-magnetic **O**nline **R**ecoil separator for capture **G**amma ray **E**xperiments





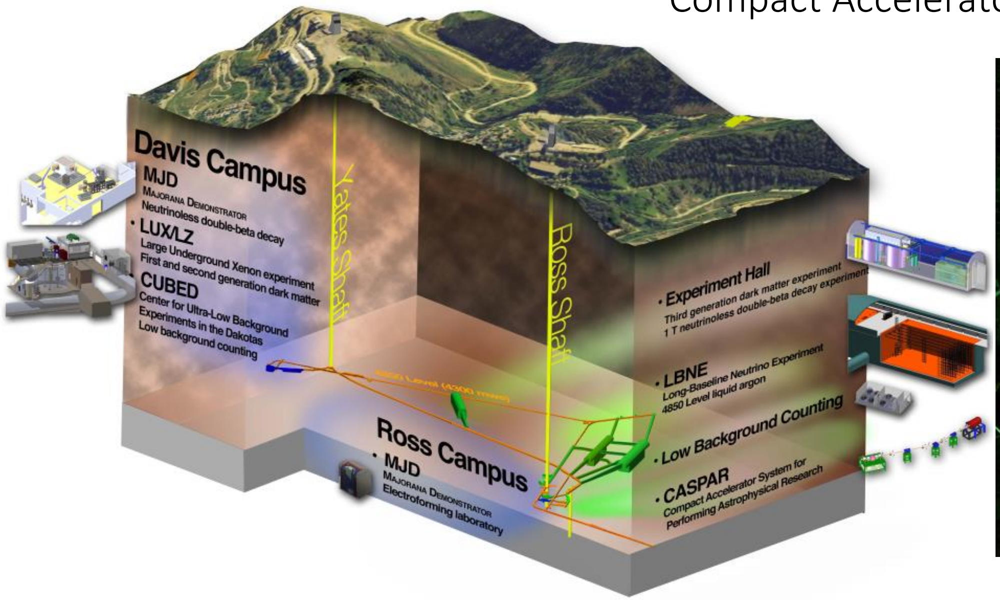


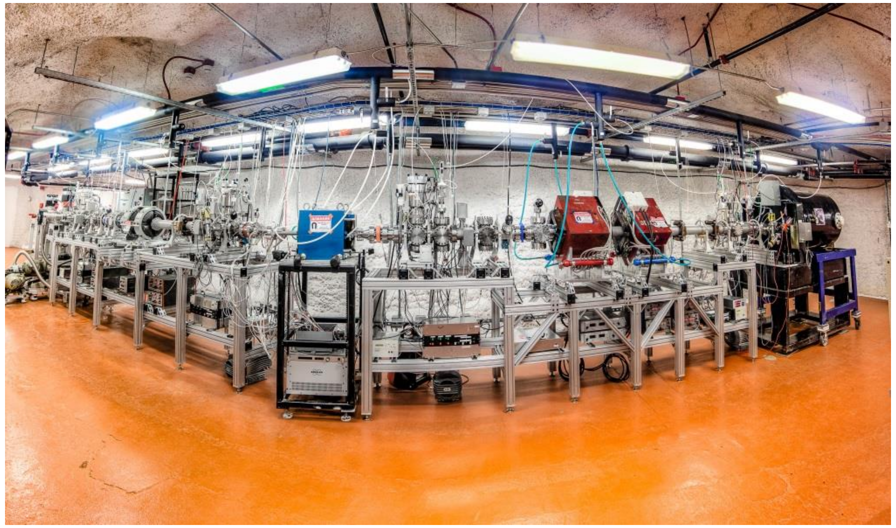
HIPPO jet gas target system
(**HI**gh **P**ressure **PO**int-like gas target)

CASPAR Facility one mile under ground

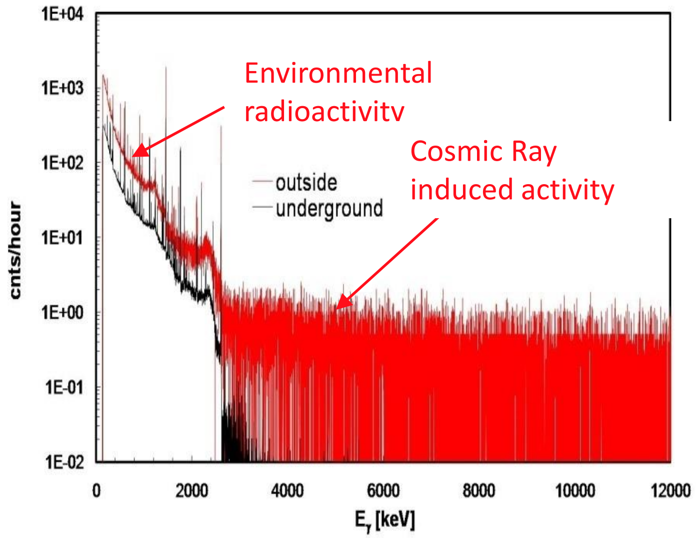
CASPAR underground accelerator

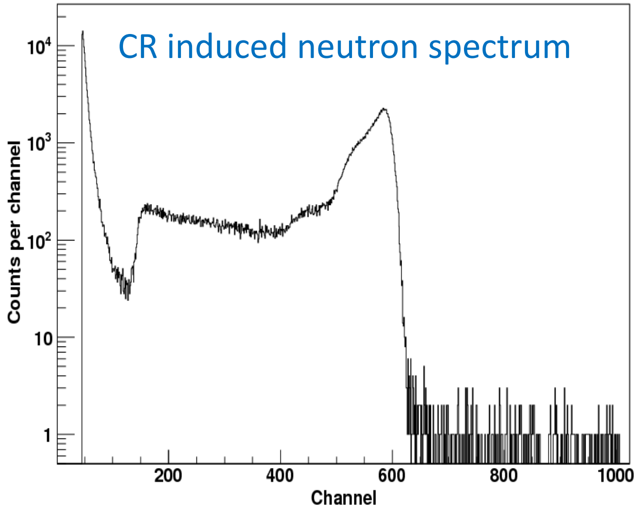
Compact Accelerator for Performing Astrophysical Research

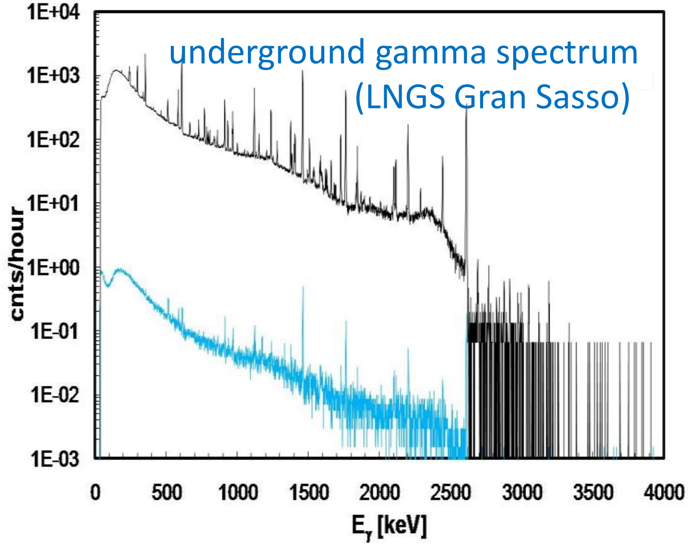


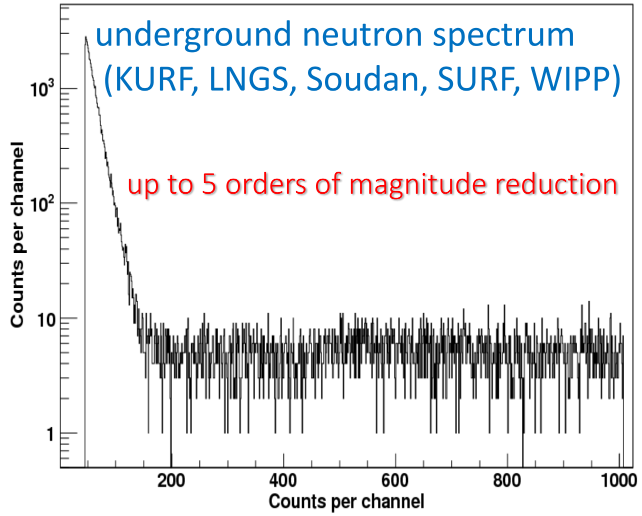


Advantage of underground physics







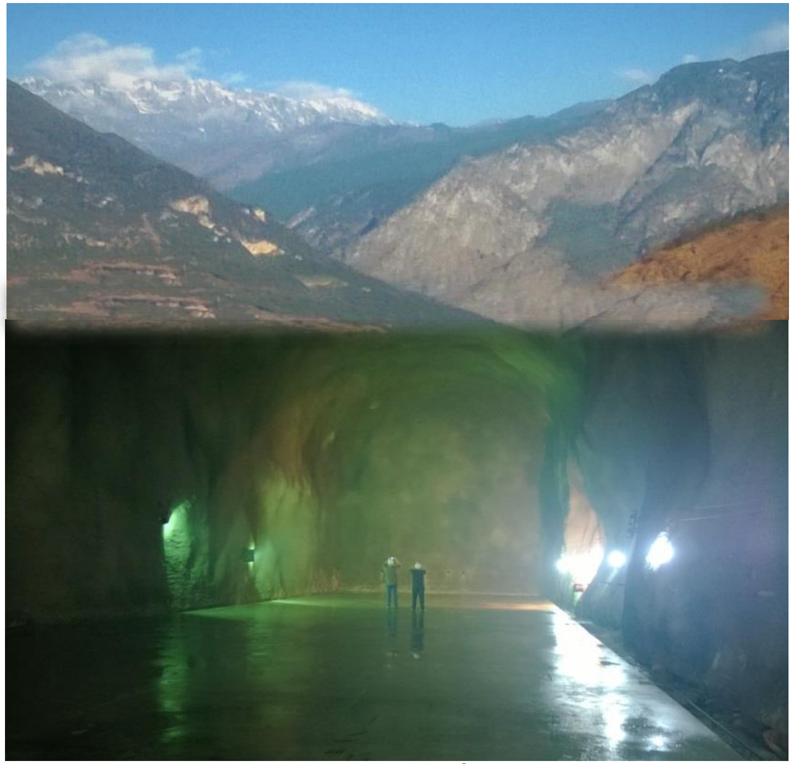


Two Ways towards improved Experiments for stellar Helium Burning

Background reduction by moving to cosmic ray free underground environments (LUNA, JUNA, CASPAR) or to inverse kinematics techniques with recoil separators (DRAGON, St. GEORGE, ERNA)

Light ion on heavy target measuring light reaction product yield in reduced background environment, limited by detection efficiency.

Heavy ion on light target measuring ion recoil yield, limited by initial beam intensity and acceptance of recoil separator



Jinping Mountains: Sichuan Province