From Few-body Physics to Many-body Physics: A layman's narrative of the subject through the epochs, from Big Bang to present

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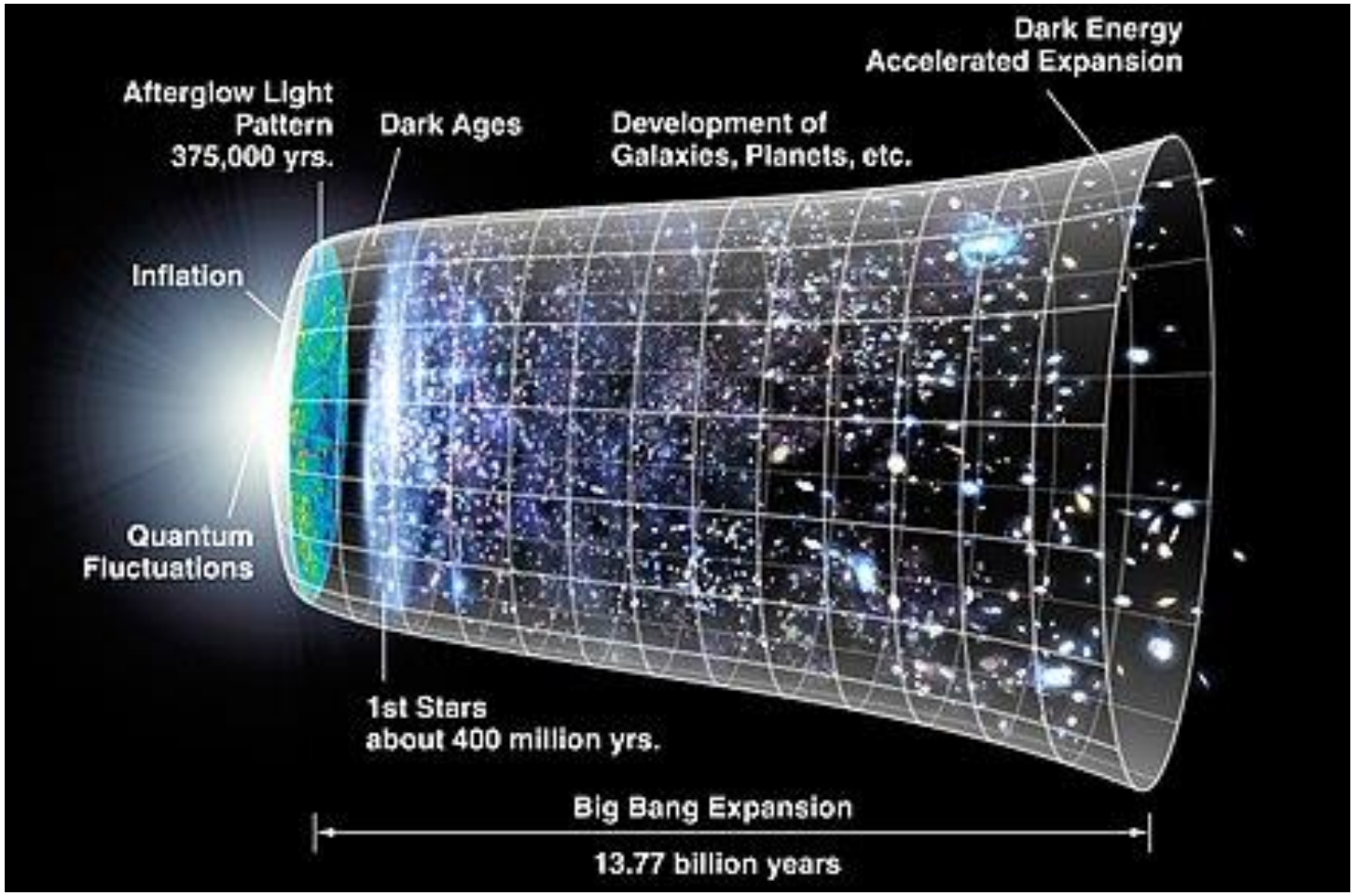
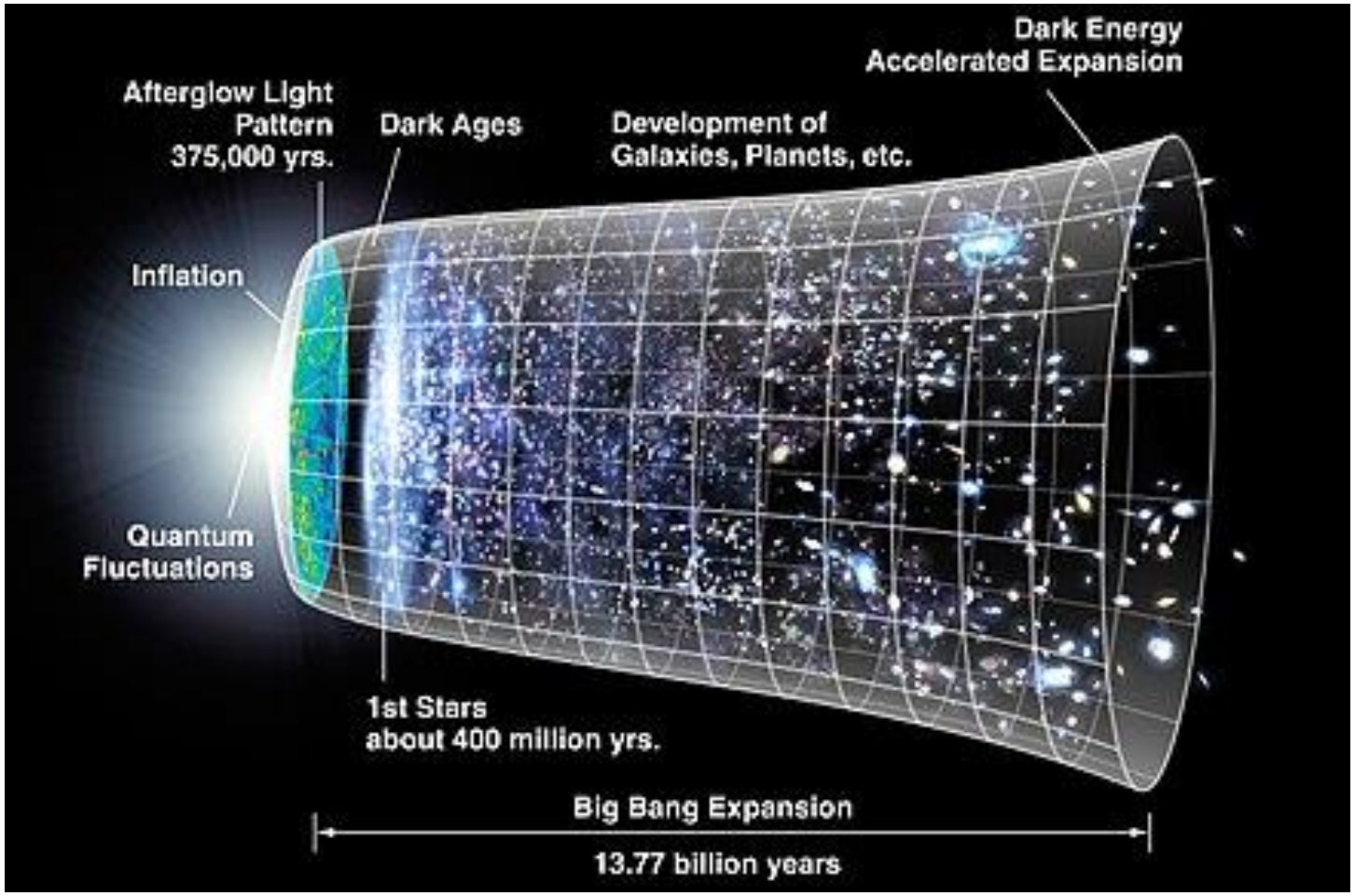
Inaugural lecture, Thursday 23 August 2018 @ Thamsanqa Kambule Auditorium, Unisa Florida Campus

UNIVERSE



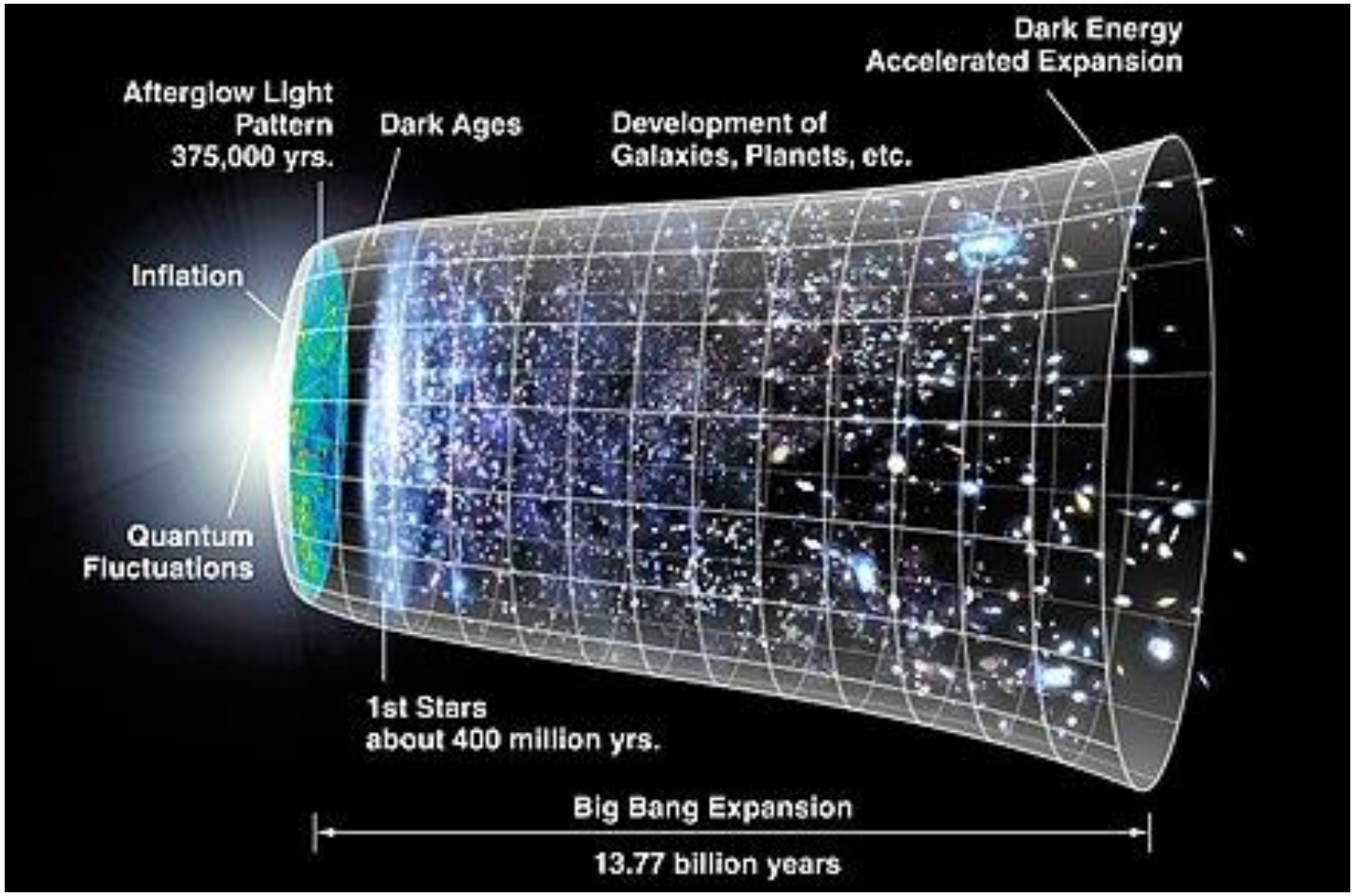
- **Very early universe**
- **Early universe**
- **Dark ages & large scale structure universe**
- **Universe as it appears now**

UNIVERSE



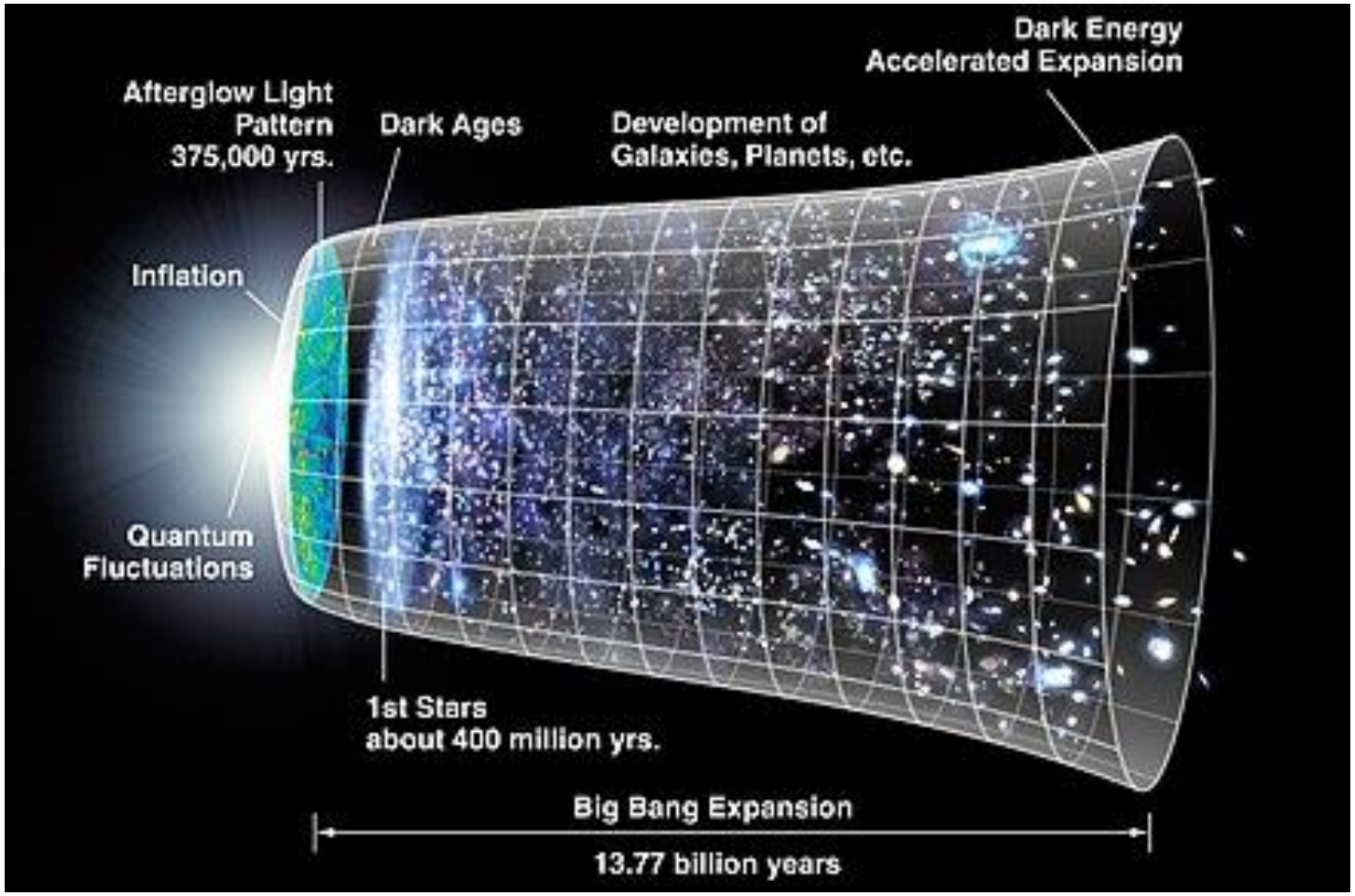
- **Very early universe**
  - ✓ **Planck epoch (10^{-12} seconds)**
  - ✓ **Grand Unification epoch**
- **Early universe**
  - ✓ **Lasted ~ 377000 years**
  - ✓ **Primordial nucleosynthesis**
- **Dark ages & large scale structure universe**
  - ✓ **377000 years → 1 billion years**
  - ✓ **Generation of galaxies**
- **Universe as it appears now**
  - ✓ **From 1 billion years → now**

UNIVERSE



- Very early universe
  - ✓ Planck e[illegible] (10^{-12} seconds)
  - ✓ Grand U[illegible]ation epoch
- Early universe
  - ✓ Lasted ~ 377000 years
  - ✓ Primordial nucleosynthesis
- Dark ages & large scale structure universe
  - ✓ 377000 years → 1 billion years
  - ✓ Generation of galaxies
- Universe as it appears now
  - ✓ From 1 billion years → now

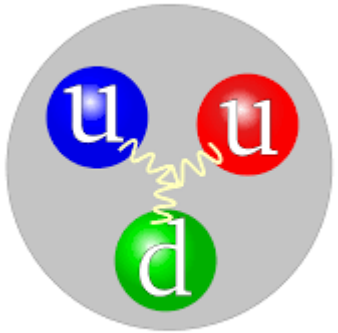
UNIVERSE



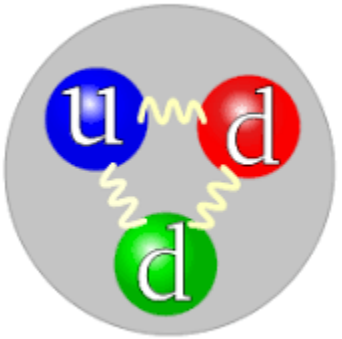
- **Gravity**
- **Electromagnetic force**
- **Weak force**
- **Strong force**

HADRONS (BARYONS + MESONS)

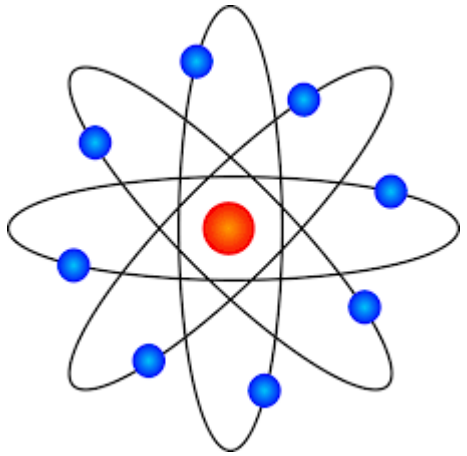
PROTON



NEUTRON



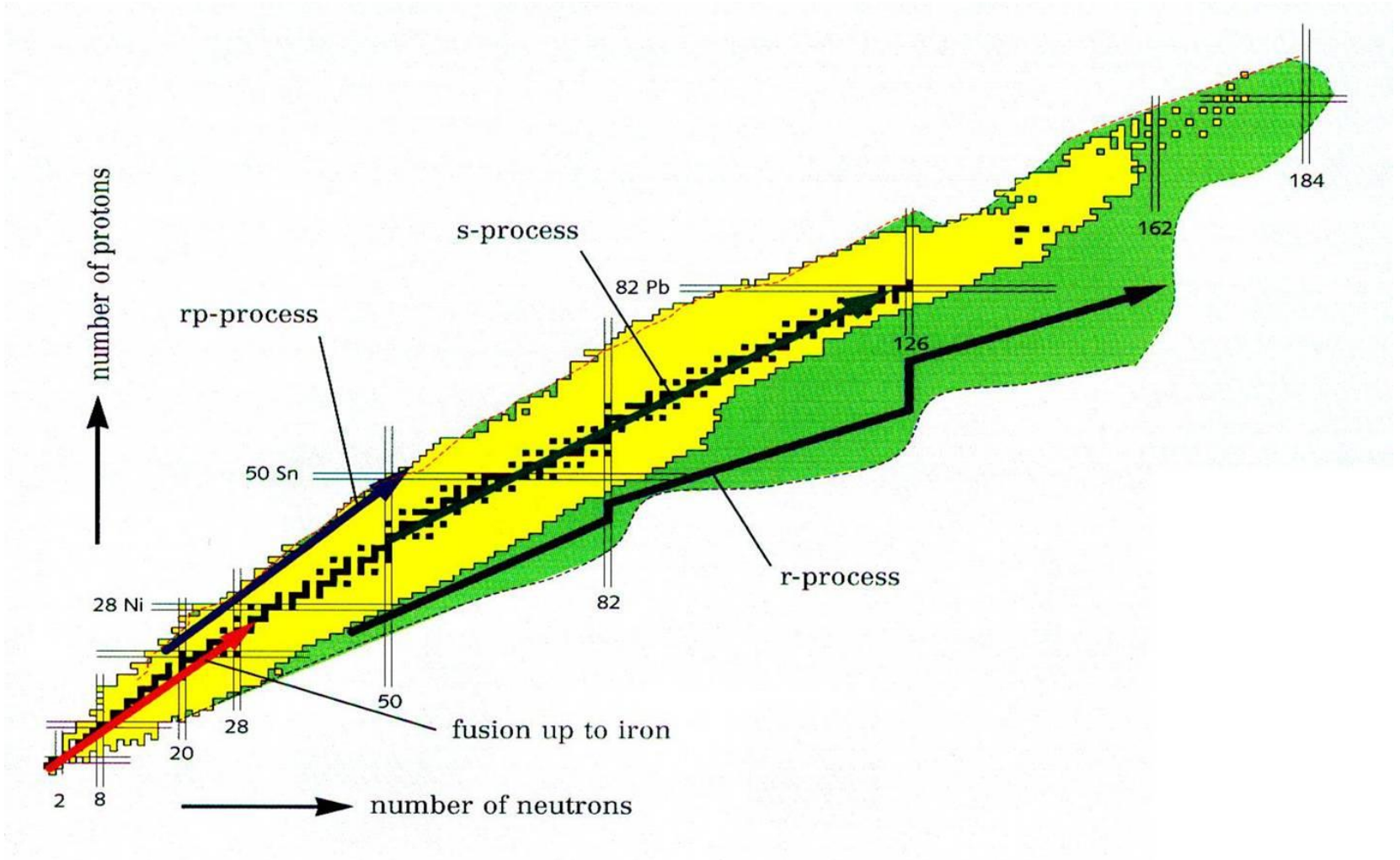
NUCLEONS **(NUCLEON-NUCLEON INTERACTION)**



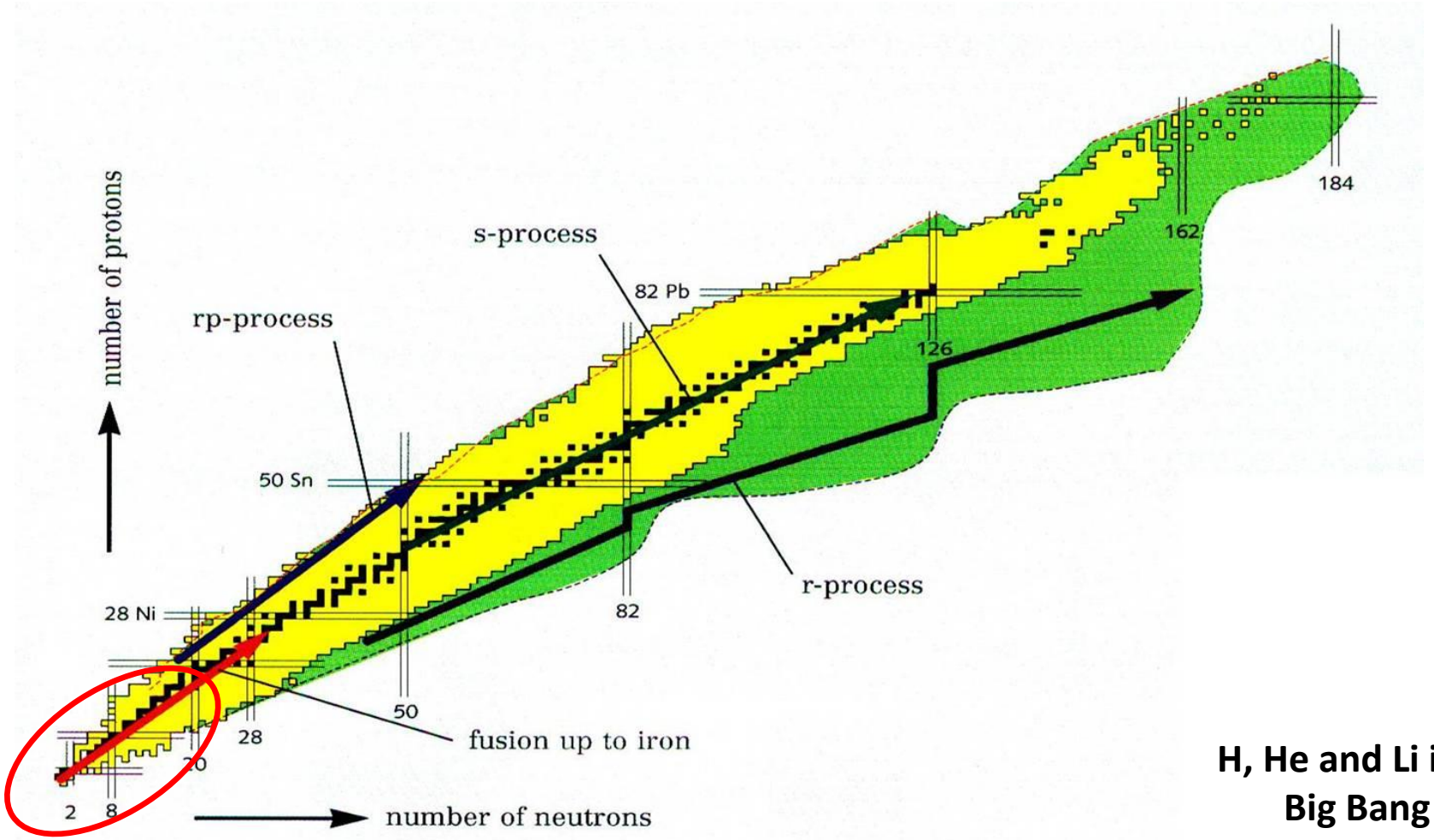
Nucleus = protons + neutrons

Electrons

PLAYGROUND

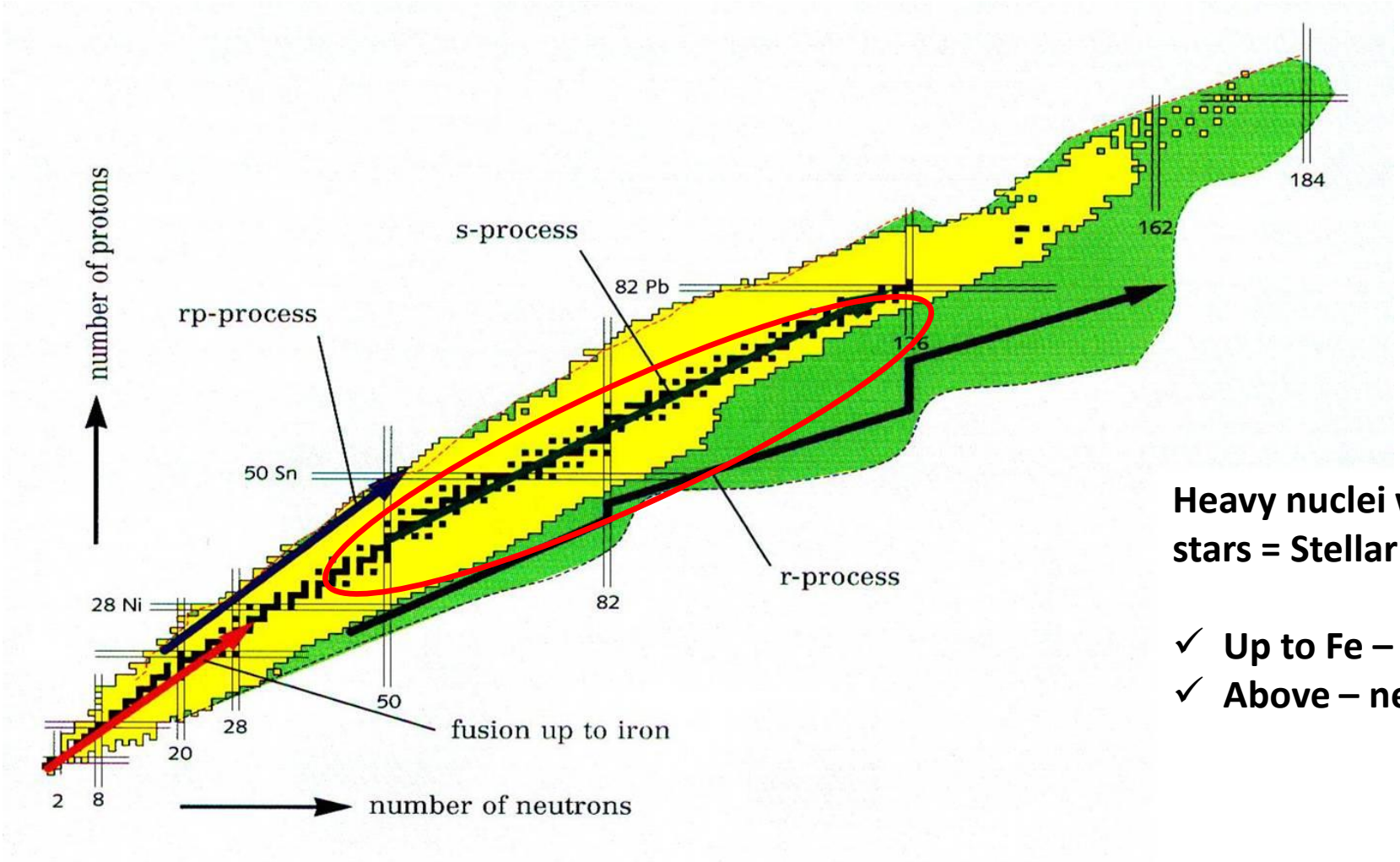

number of protons
number of neutrons
s-process
rp-process
r-process
fusion up to iron
82 Pb
50 Sn
28 Ni
184
162
126
82
50
28
20
8
2

PLAYGROUND…



H, He and Li isotopes are formed during Big Bang nucleosynthesis epoch

PLAYGROUND…



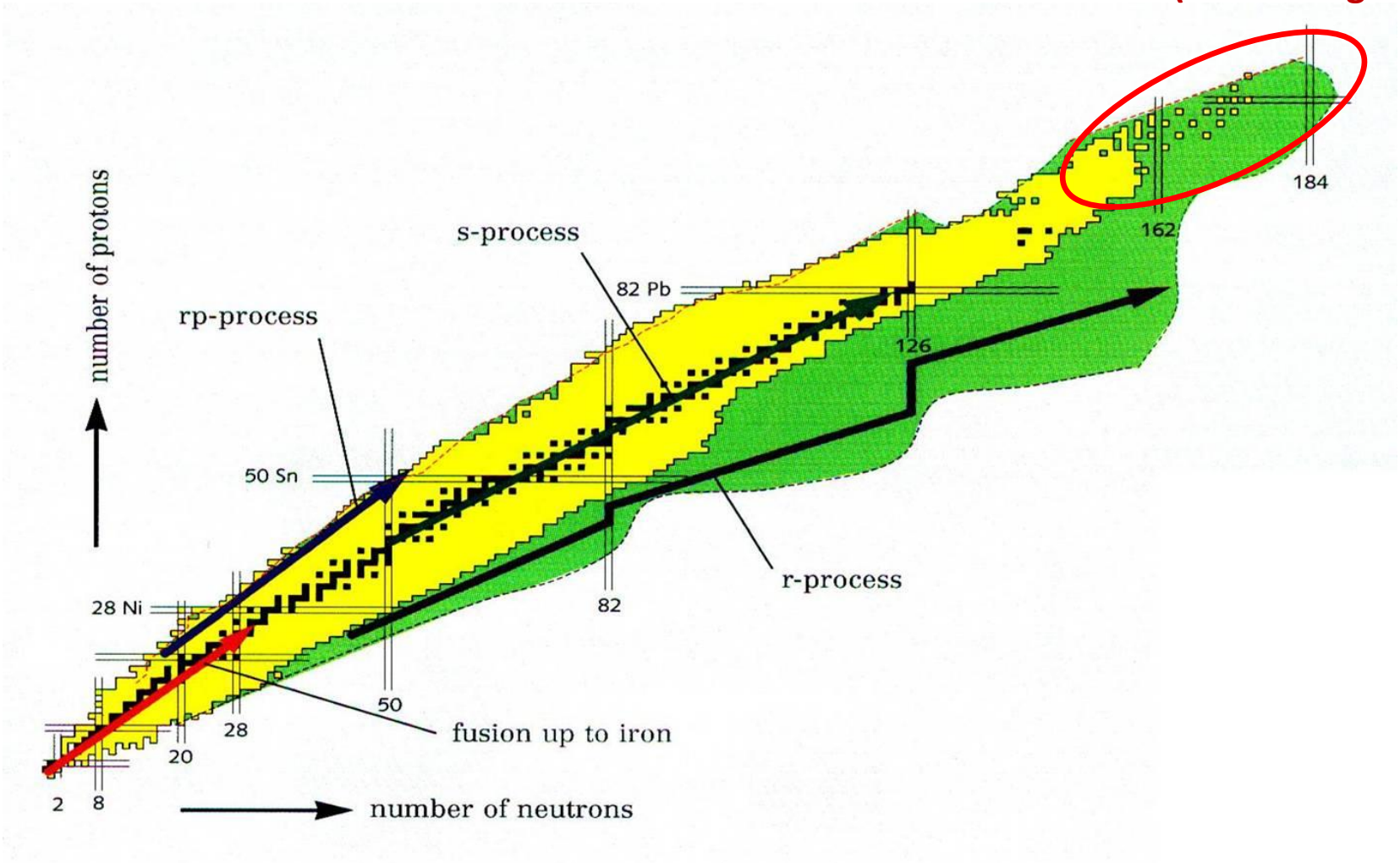
Heavy nuclei were produced in stars = Stellar nucleosynthesis epoch.

- ✓ **Up to Fe – fusion,**
- ✓ **Above – neutron, proton capture**

PLAYGROUND…

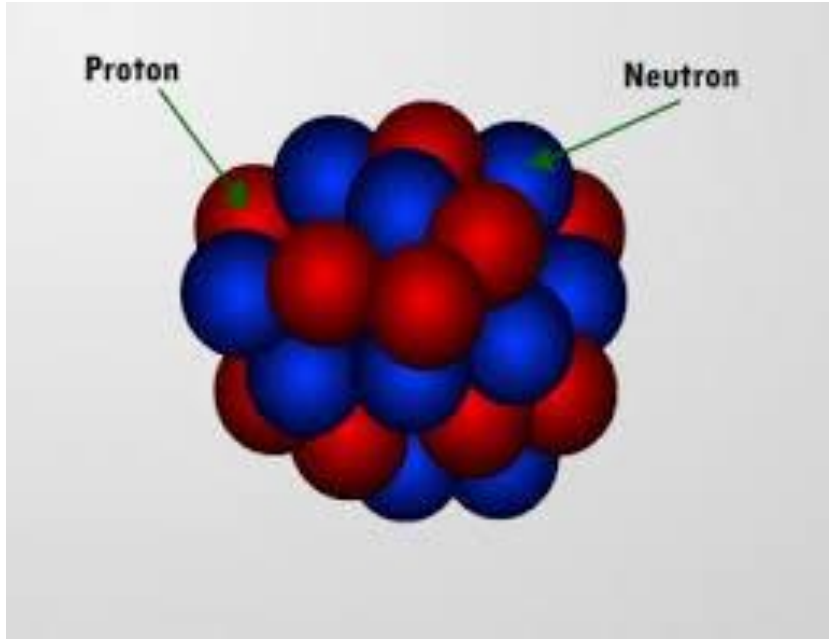
Super heavy elements, believed to be produced in neutron starts.

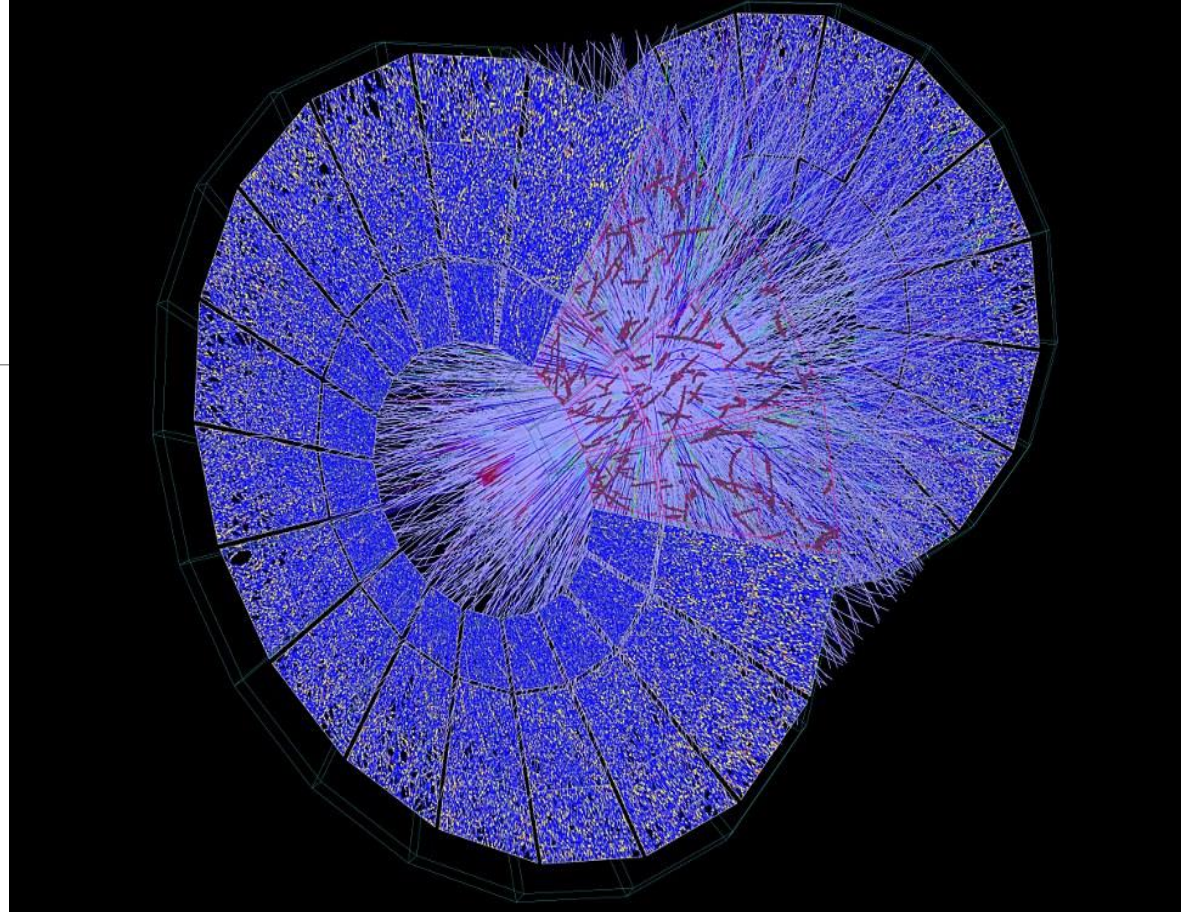
(terra incognito – island of stability)



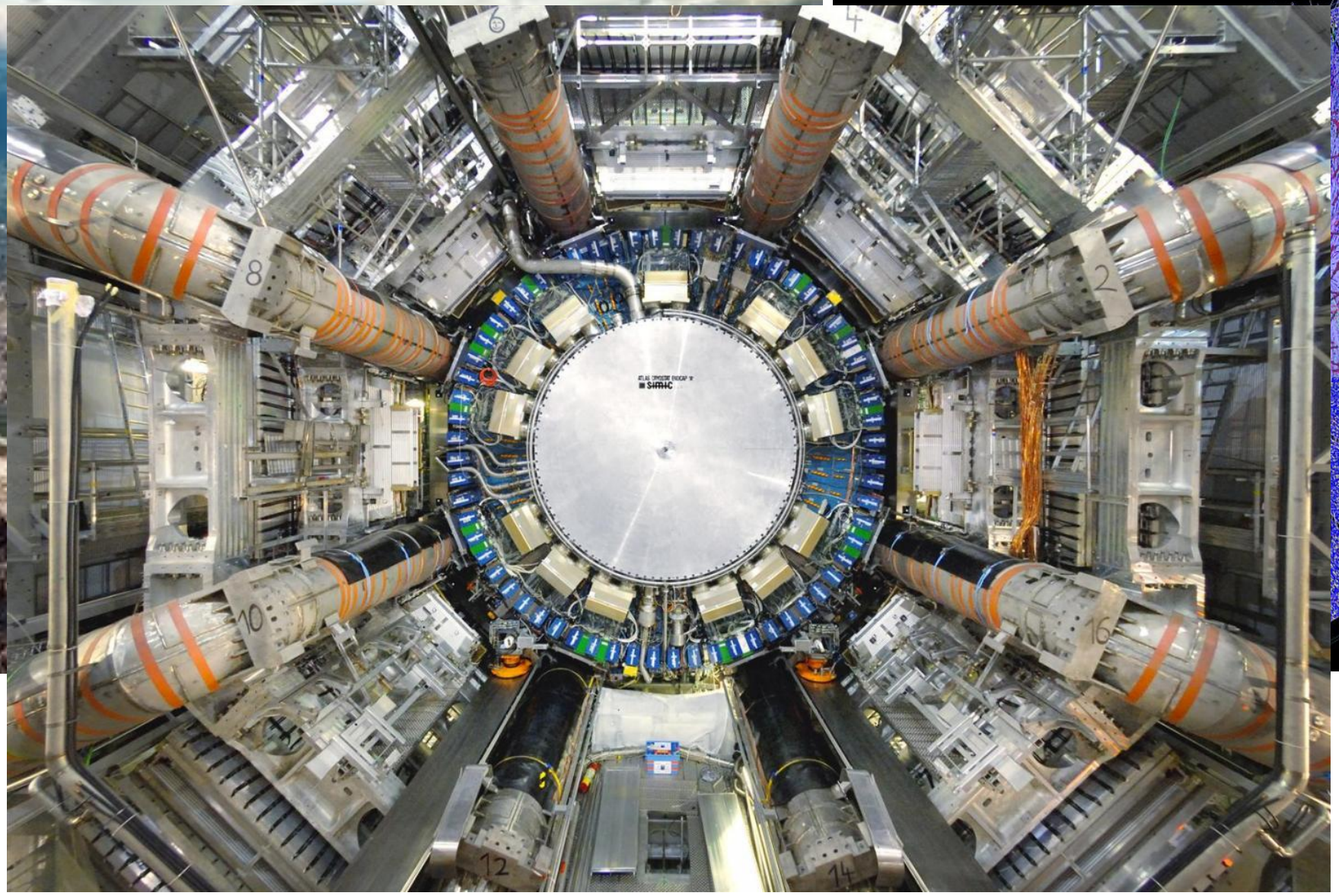
FUNDAMENTAL GOAL OF NP

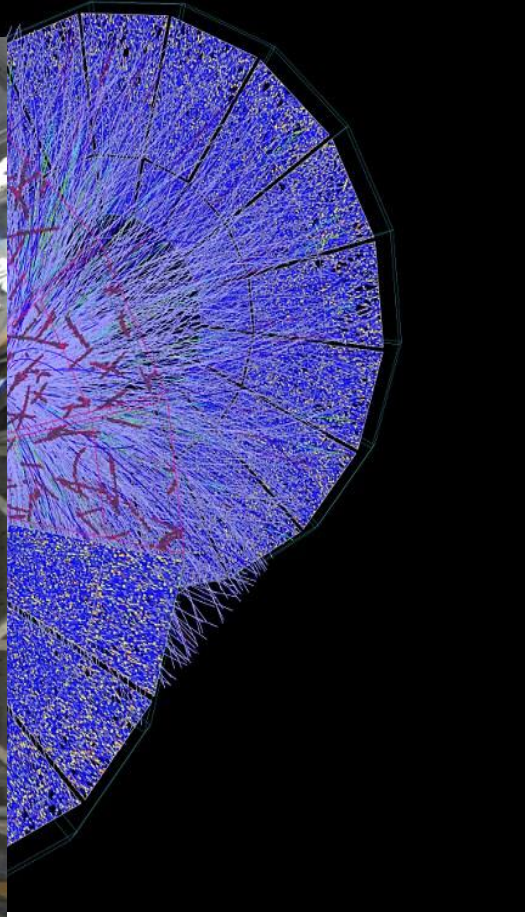
- To understand the nature of the Nucleon-Nucleon interaction (strong interaction)





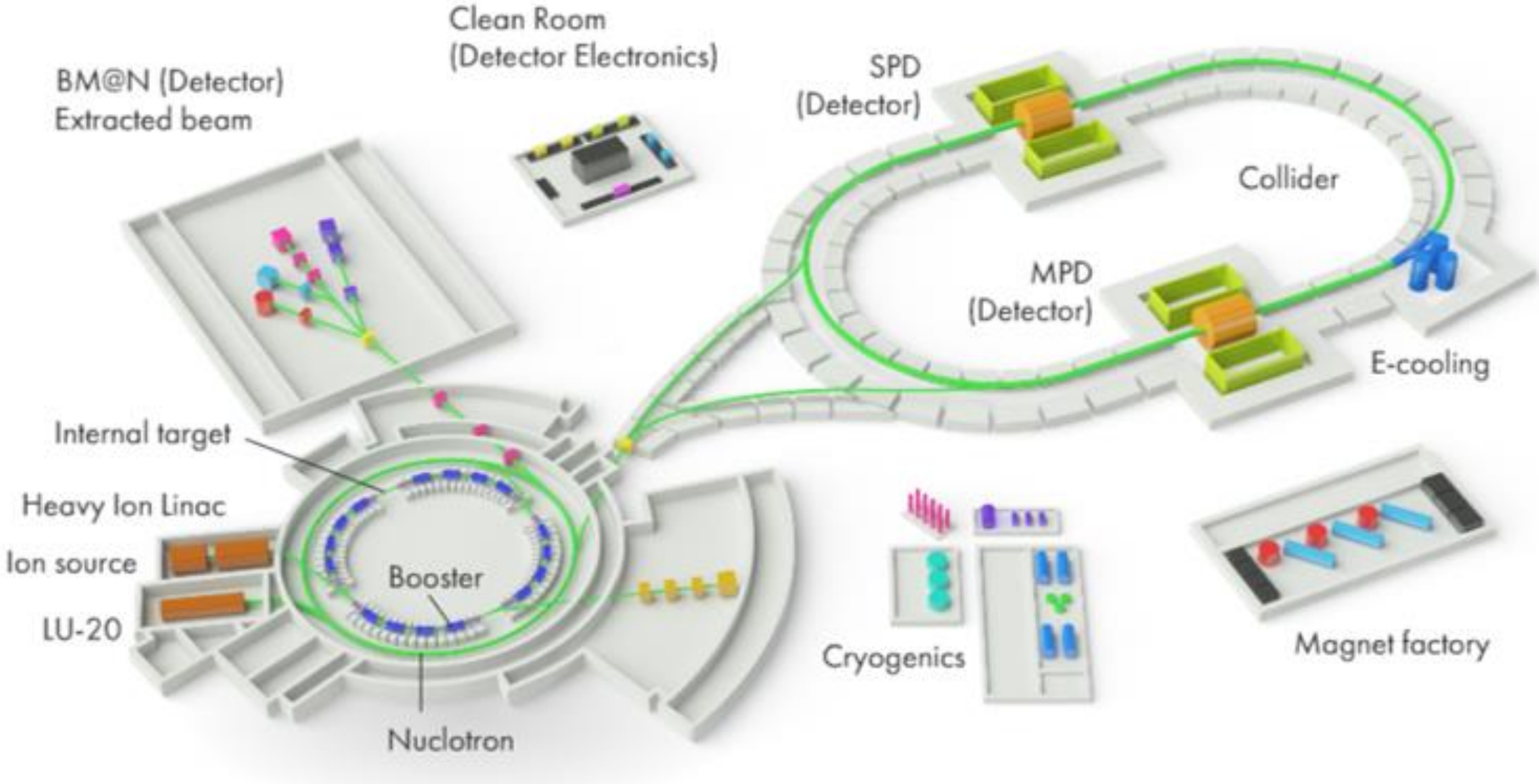
LHC (Large Hadron Collider)





Dimensions: 46 metres long, 25 metres in diameter, and weighs about 7,000 tonnes; it contains ~3000 km of cable

NICA Complex



E.g. OPEN FUNDAMENTAL QUESTIONS

- The nuclear interaction and its connection with QCD: where does the nuclear force which binds nuclei together get its main characteristics from?

- Nuclear structure and nuclear reactions: why is the nuclear landscape so rich and so complex, and where does such complexity come from?

- Hadronic physics and QCD: how can we connect the world of quarks and gluons with that of hadrons?

OPEN FUNDAMENTAL QUESTIONS…

- Relativistic heavy ion collisions: how can we understand the different nuclear phases, which lead from nuclear liquid to quark-gluon plasma?

- Nuclear astrophysics: how can we understand ultimately where the elements come from, and how does nuclear physics affect the early stage and the evolution of our Universe?

OVERVIEW

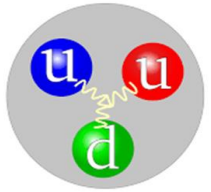
- What is Few-body Physics?
- Fundamental equations of few-body physics
- Applications of Few-body Physics (snapshot of our work)
- Summary / Conclusions

WHAT IS FEW-BODY PHYSICS

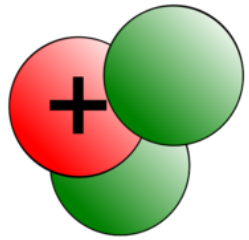
Definition

- A sufficiently simple & isolated system that permits:
  - ✓ A complete experiment on the system.
  - ✓ This definition depends on the current state of the art in experimental physics, theoretical physics, and computational physics.

E.g.



Proton



Triton

^{3}He ^{4}He ^{6}He

WHAT IS FEW-BODY PHYSICS

Definition:

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Theories should satisfy:

- ❑Quantum theory
- ❑Relativistically invariant
- ❑Should be possible to do ab-initio computations
- ❑Should satisfy cluster properties (link between few-body and many-body problems)

FUNDAMENTAL EQUATIONS

$$\left[-\frac{\hbar^2}{2\mu}\nabla^2 + V\right]\Psi = -i\hbar\frac{\partial\Psi}{\partial t}$$

(1887 – 1961)

$$\left[-\frac{\hbar^2}{2\mu}\nabla^2 + V\right]\Psi = E\Psi$$

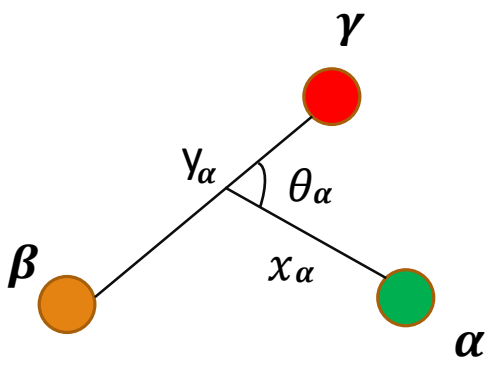
2B (tractable). 3B (intractable)

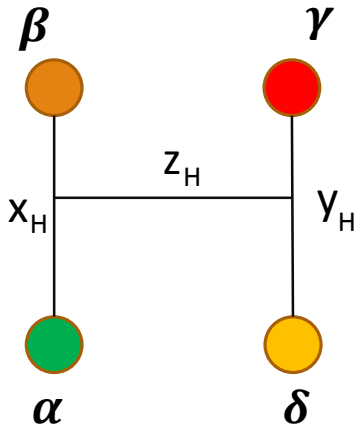
FUNDAMENTAL EQUATIONS

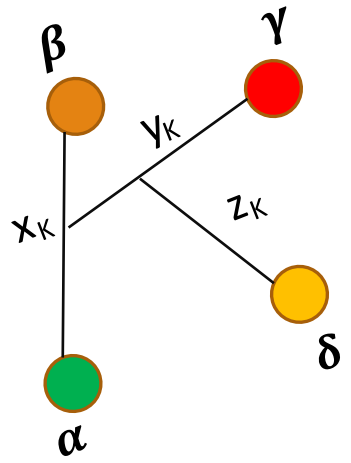
3 BODY SYSTEM

4 BODY SYSTEM

(JACOBI COORDINATES)



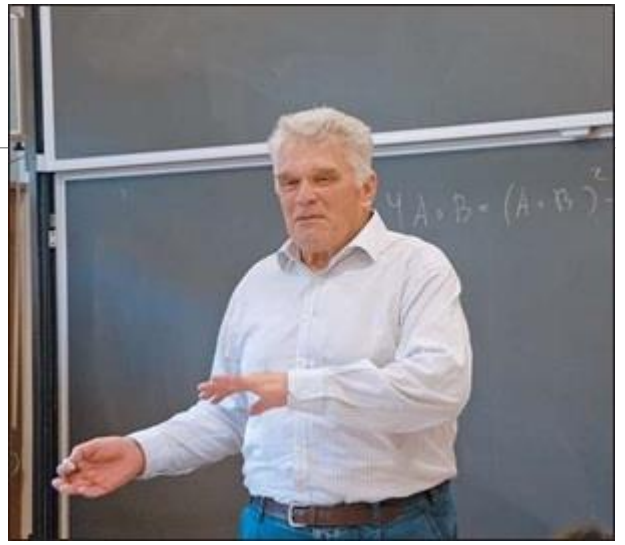




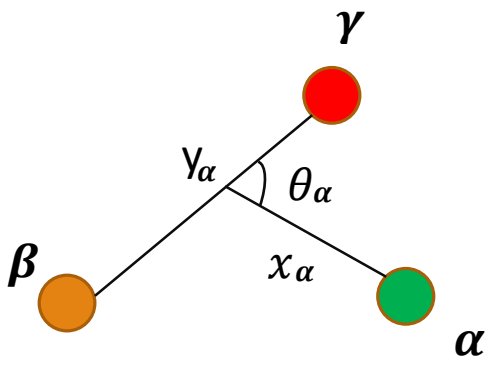
FUNDAMENTAL EQUATIONS

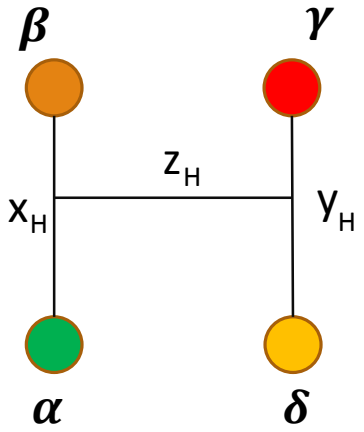
$$\boldsymbol{\Psi_{3B}}(x,y) = \sum_{i=\alpha,\beta,\gamma} \psi_i(x_i, y_i)$$

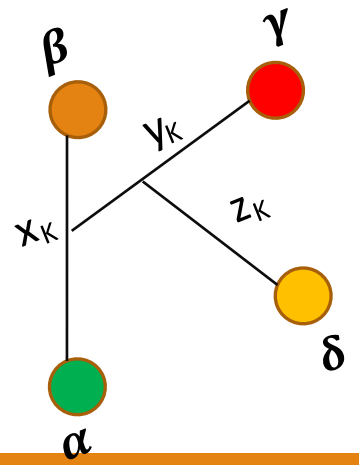
$$(H_0 + V_\alpha(r_\alpha) - E_{3B})\psi_\alpha = -V_\alpha(\psi_\beta + \psi_\gamma)$$



(1934 – 2017)



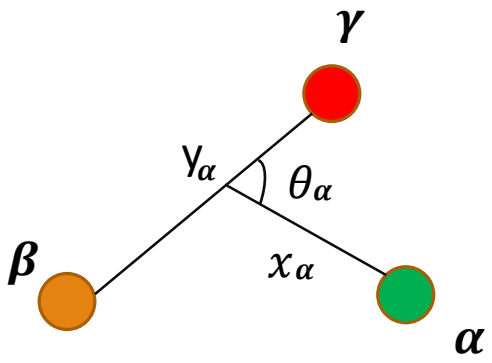


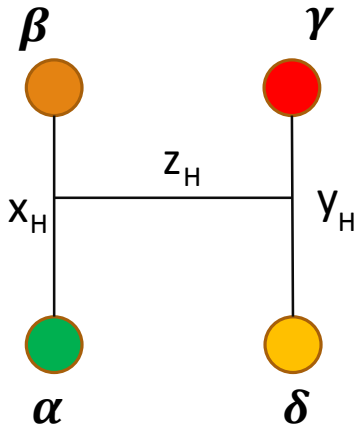


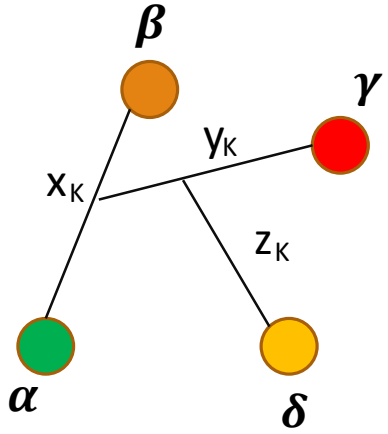
FUNDAMENTAL EQUATIONS

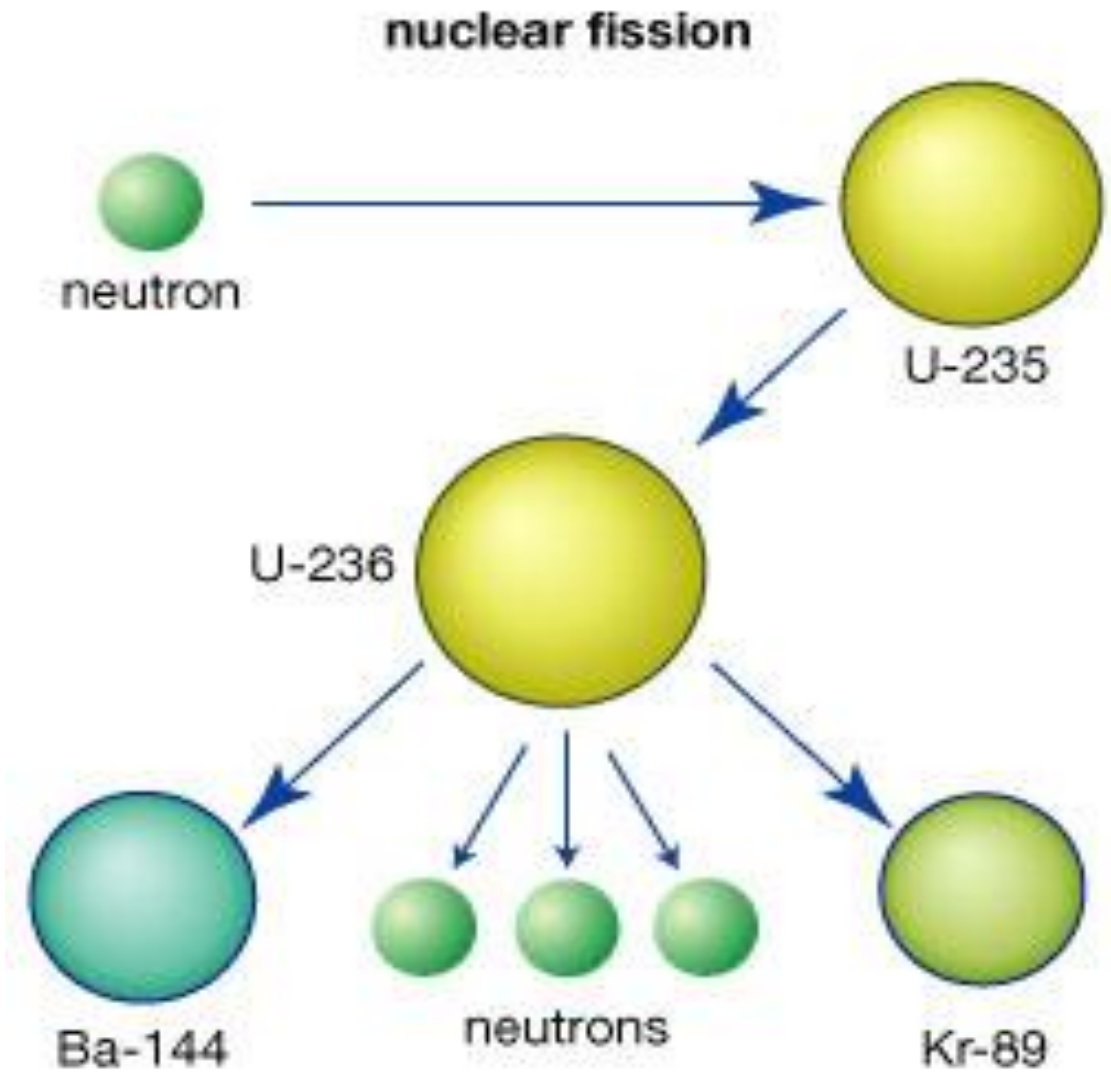
$$\left(H_0 + V_{\alpha\beta} - E_{4B}\right)\psi_{(\alpha\beta)(\gamma\delta)} = -V_{\alpha\beta}\left(\psi^{\beta}_{\gamma\delta,\alpha} + \psi^{\alpha}_{\gamma\delta,\beta} + \psi_{(\gamma\alpha)(\alpha\beta)}\right)$$

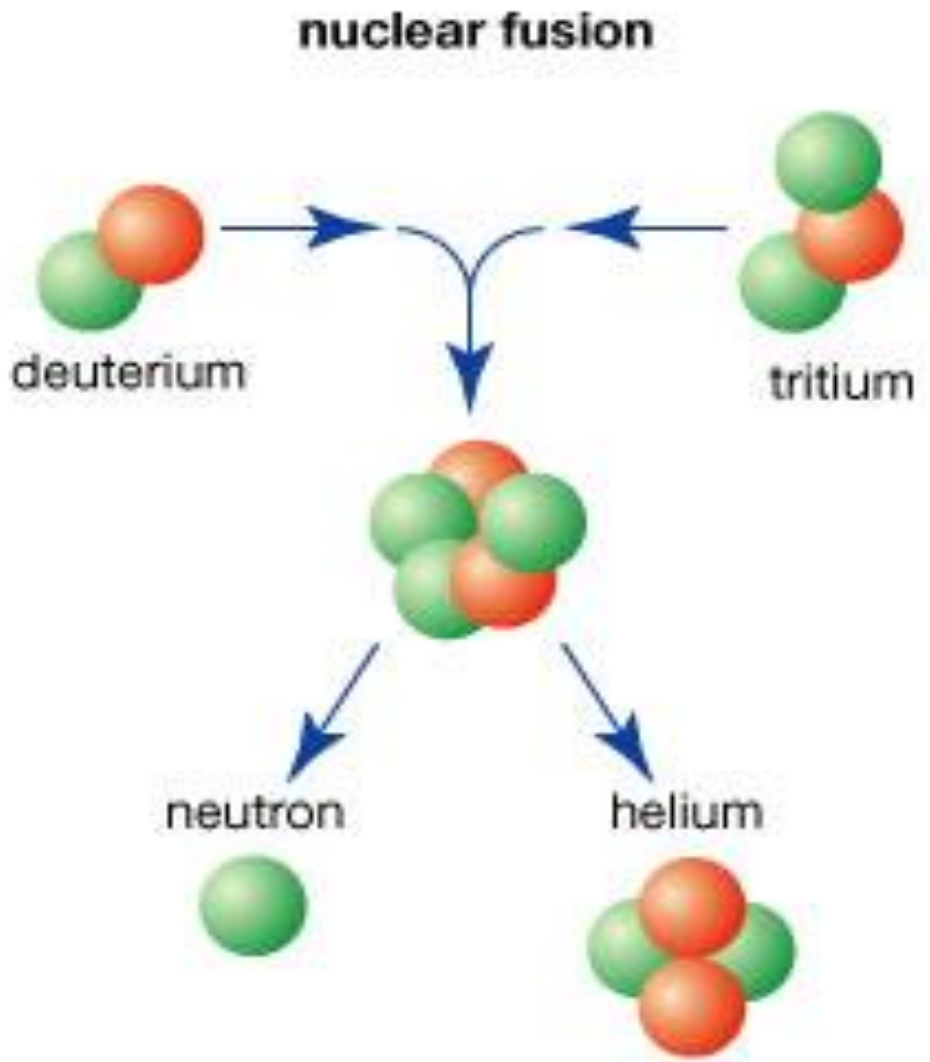
$$\left(H_0 + V_{\alpha\beta} - E_{4B}\right)\psi^{\delta}_{\alpha,\beta,\gamma} = -V_{\alpha\beta}\left(\psi^{\delta}_{\alpha\gamma,\beta} + \psi^{\beta}_{\alpha\gamma,\delta} + \psi_{(\alpha\gamma)(\beta\delta)} + \psi^{\delta}_{\beta\gamma,\alpha} + \psi^{\alpha}_{\beta\gamma,\delta} + \psi_{(\beta\gamma)(\alpha\delta)}\right)$$








nuclear fission
neutron
U-235
U-236
Ba-144
neutrons
Kr-89


nuclear fusion
deuterium
tritium
neutron
helium

NUCLEAR REACTIONS

Available online at www.sciencedirect.com
ScienceDirect
Nuclear Physics A 969 (2018) 60–67
NUCLEAR PHYSICS A
www.elsevier.com/locate/nuclphysa

Role of projectile resonances on breakup and fusion cross sections in the $^{6}Li + ^{144}Sm$ reaction

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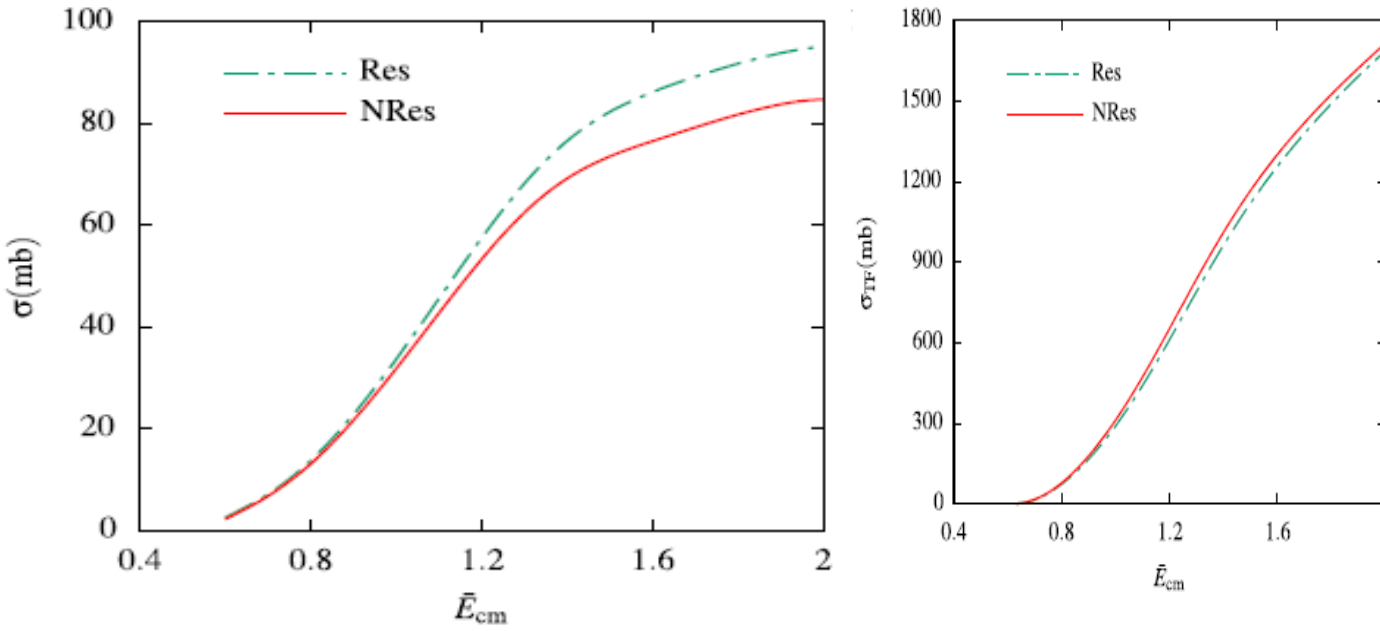
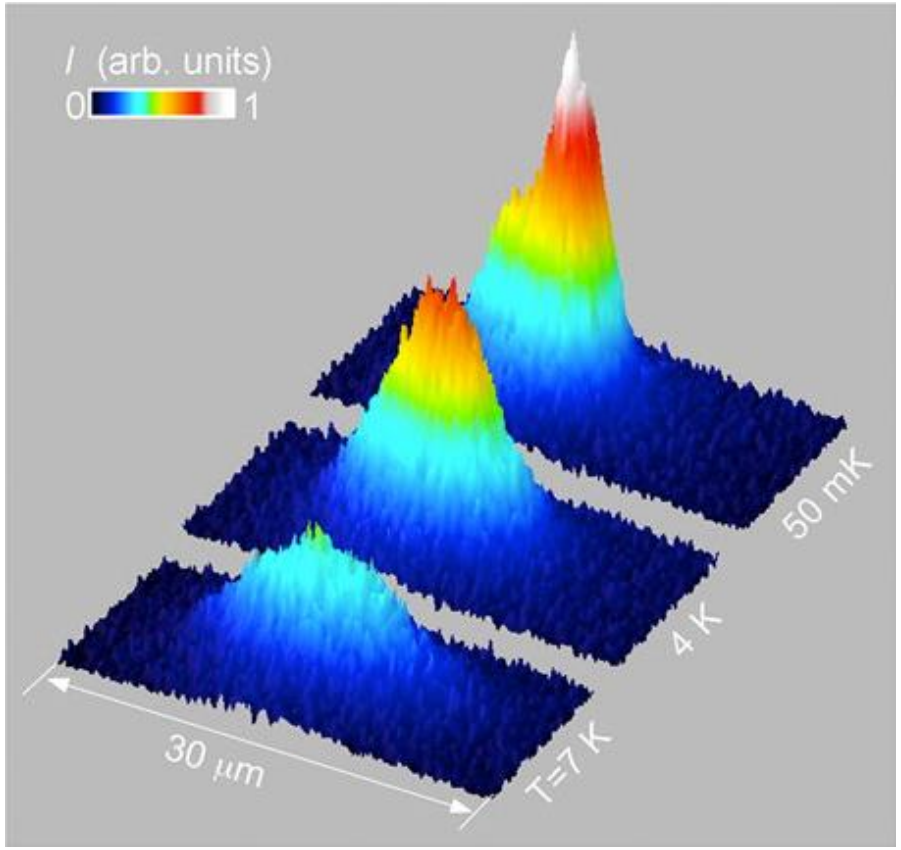
For energies above the Coulomb barrier

- breakup cross sections are increased by inclusion of resonances (~10%),
- fusion cross sections are reduced (~4%).



BOSE-EINSTEIN CONDENSATION



JILA Experiment (1995)

Path to Bose-Einstein Condensation

- **A dilute gas of alkali atoms**
- **Extremely good vacuum & evaporative cooling**
- **Tune the interaction strength between particles by using Feshbach resonances**
- **Shape the trap**

Theories for Bose-Einstein Condensates

- **The many-body Schrodinger equation [MBSE] (very difficult to solve)**
- **Most approximate method to solve MBSE: Gross-Pitaevskii theory**

MOLECULAR SYSTEMS

Few-Body Syst
DOI 10.1007/s00601-013-0705-2

S. A. Sofianos · T. K. Das · B. Chakrabarti · M. L. Lekala ·
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Spectral analysis of molecular resonances in erbium isotopes: Are they close to semi-Poisson?

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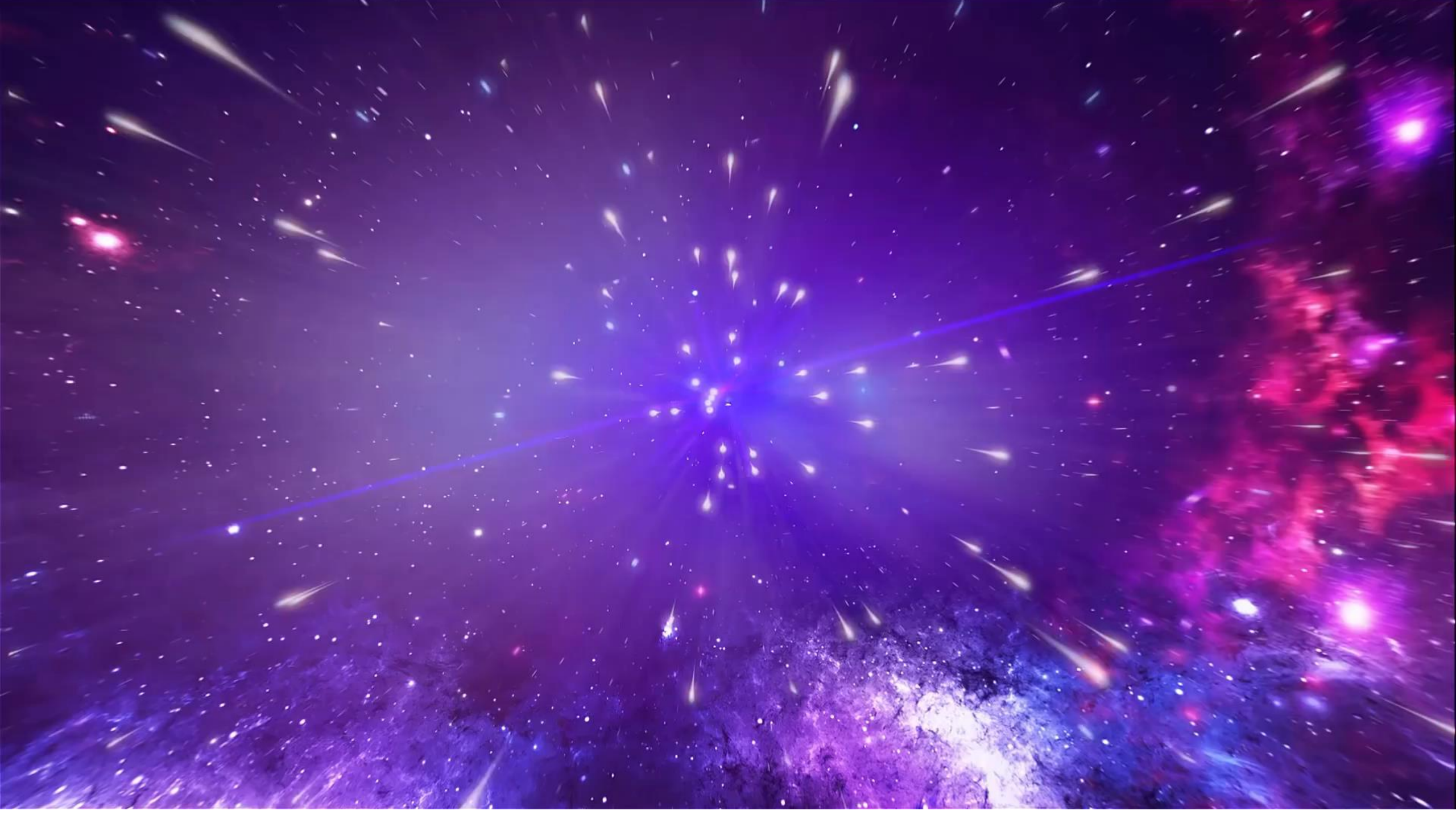

SUMMARY

- The field of Few-Body Physics is a very active and exciting field.

- Few-body physics techniques are applicable to studying systems and phenomenon in a wide range of fields, from few-body systems to many-body systems such as e.g. BEC, etc.

- The FB techniques can be applied to reveal the rich structure of the fundamental components of matter. Thus the understanding of the Universe.

Veni, vidi, vici.
(I came, I saw, I conquered.)

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- MA NAUMENKO

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- I FILIKHIN
- V SUSLOV
- M DUKIC

CHINA

- YUBING DONG
- BAODONG SUN

EXTRAS