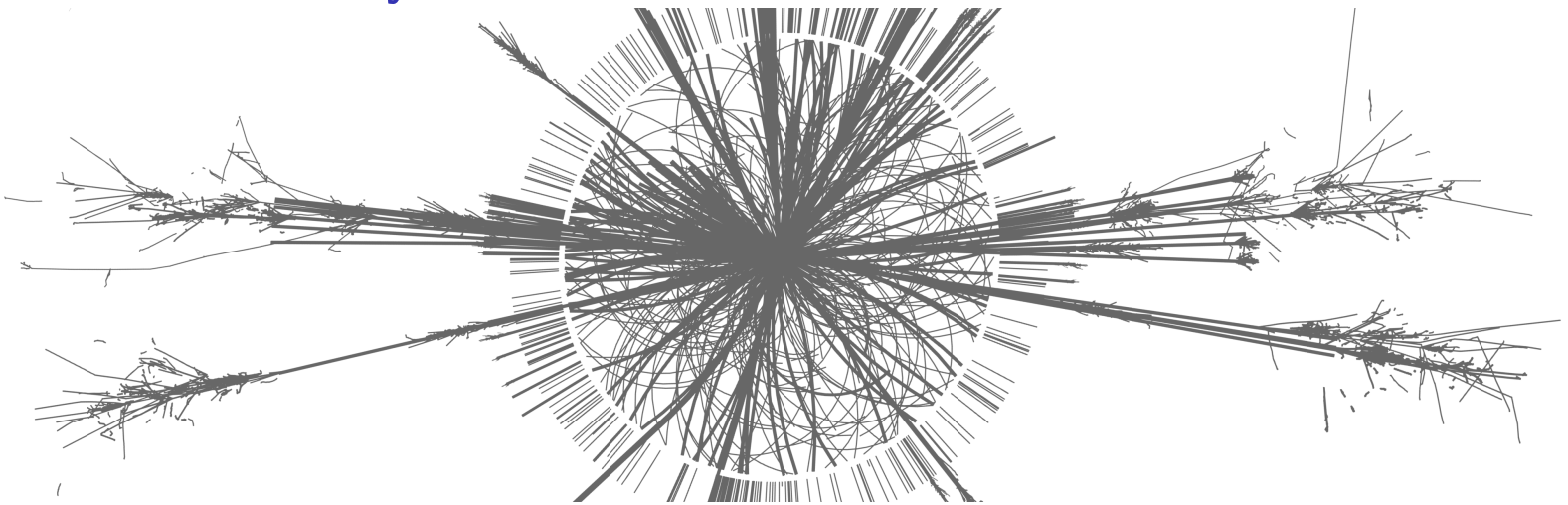
Elementary Particle Physics

Journey to the Innards of Our Universe



Maciej Trzebiński

Institute of Nuclear Physics
Polish Academy of Sciences

Vilnius University

22nd February 2019

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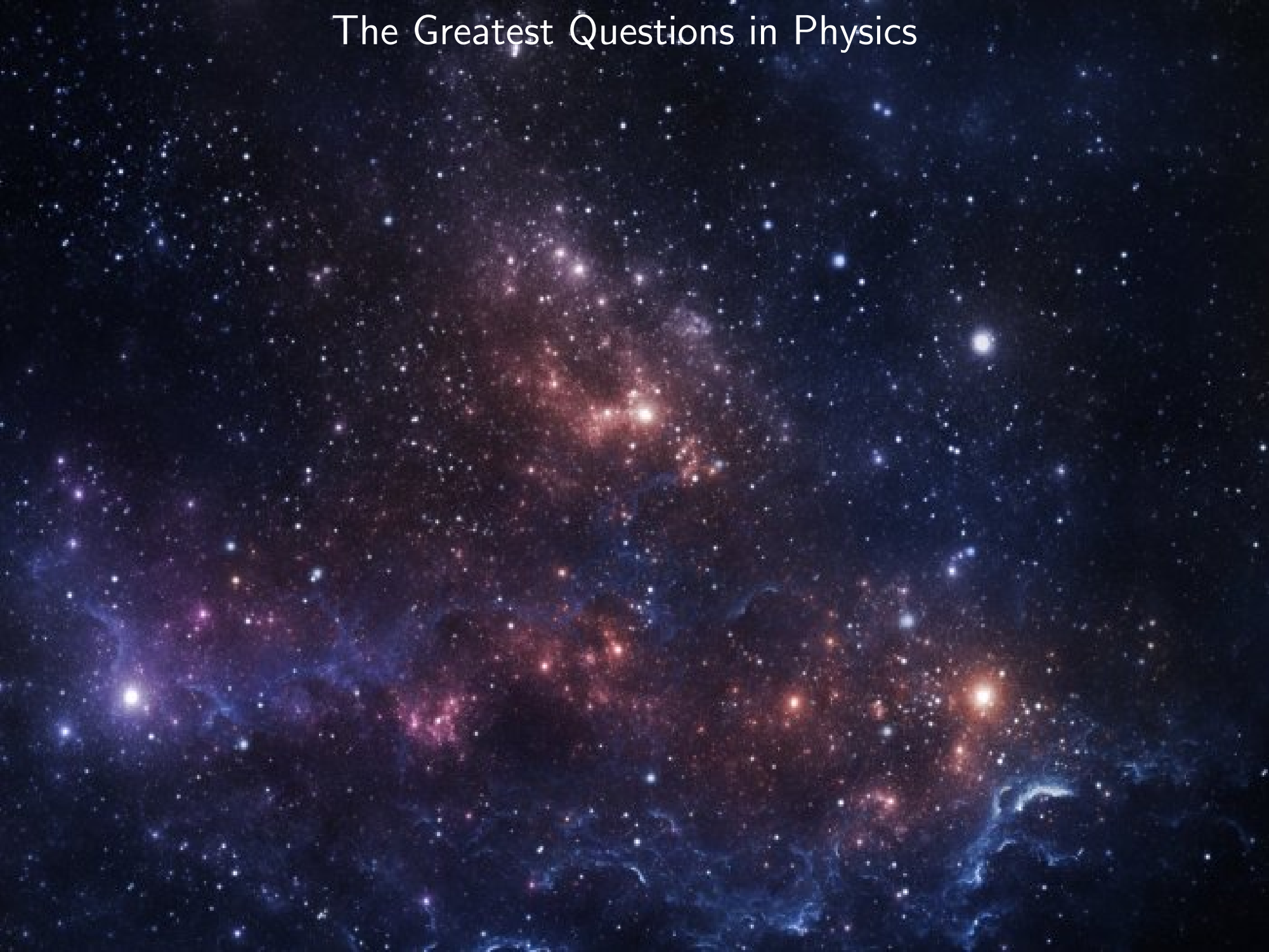
The Greatest Questions in Physics



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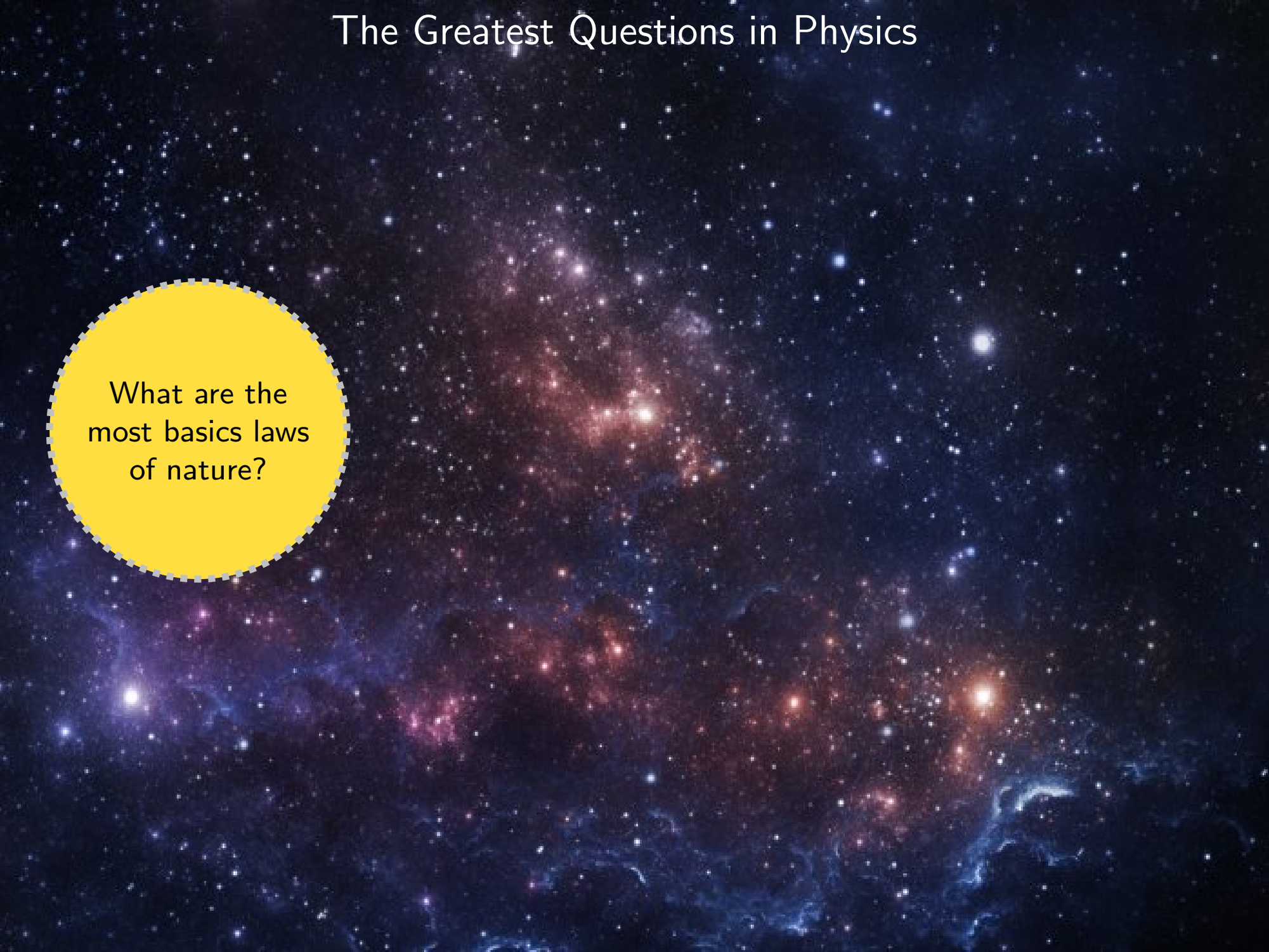

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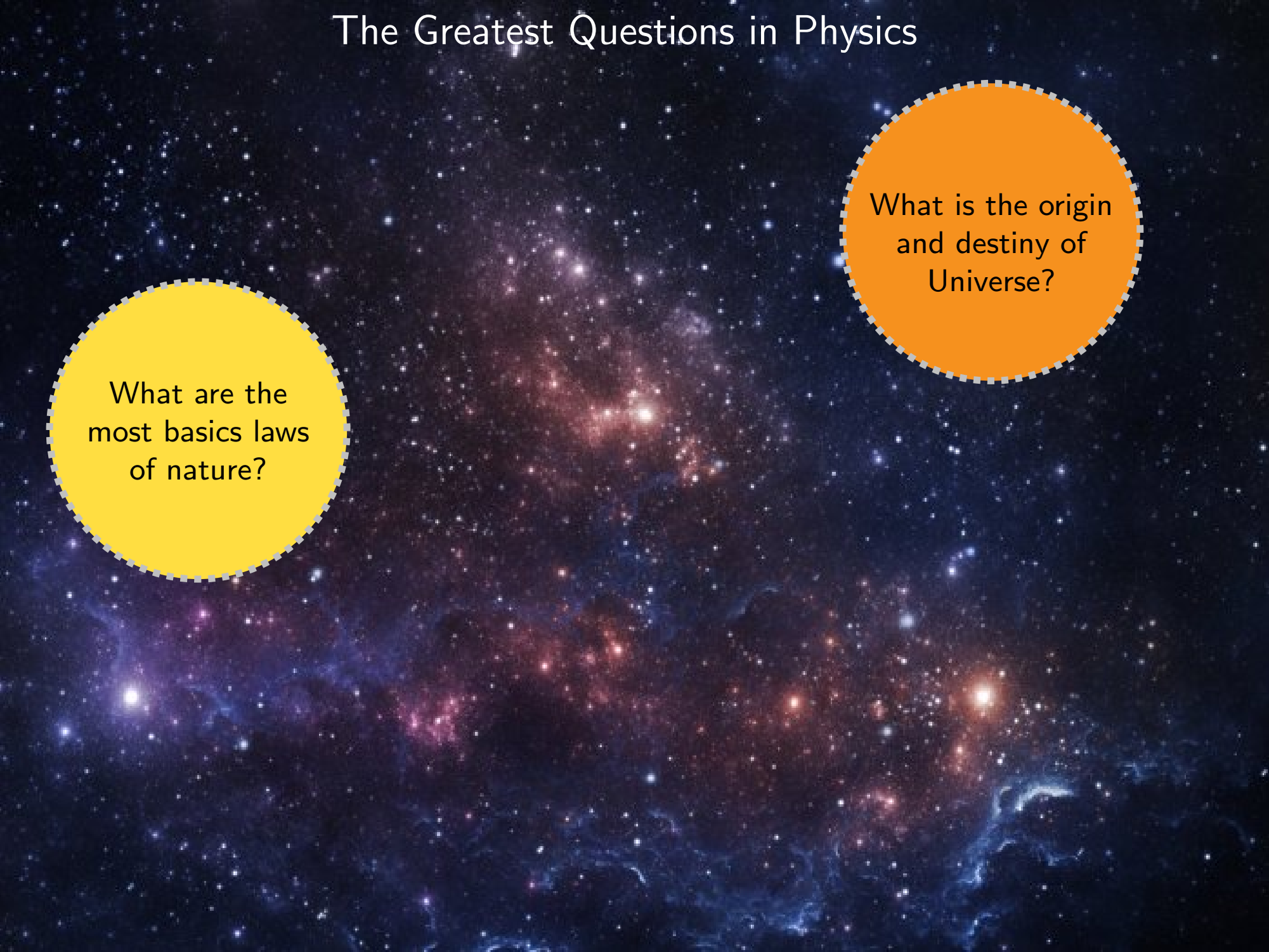

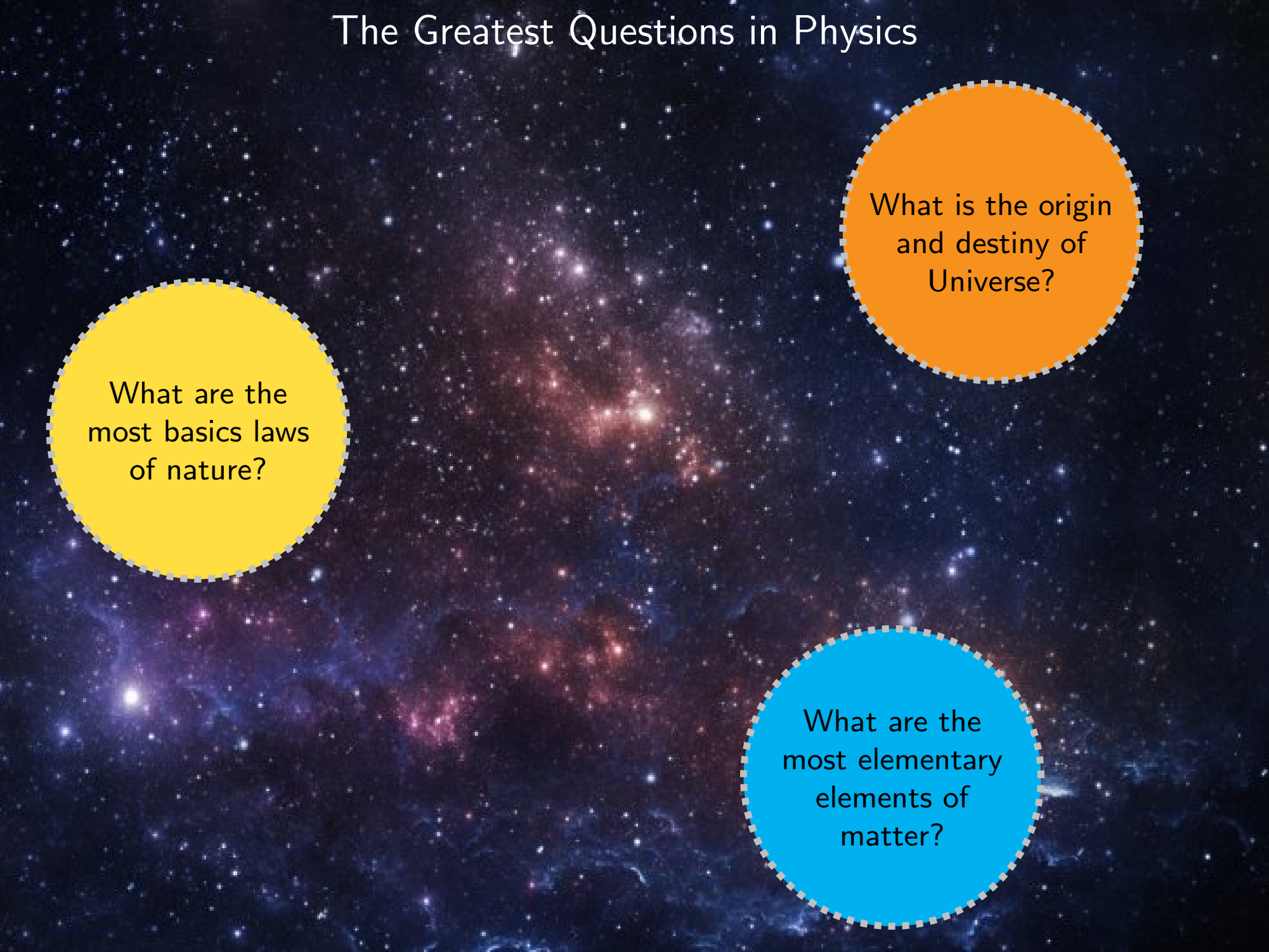
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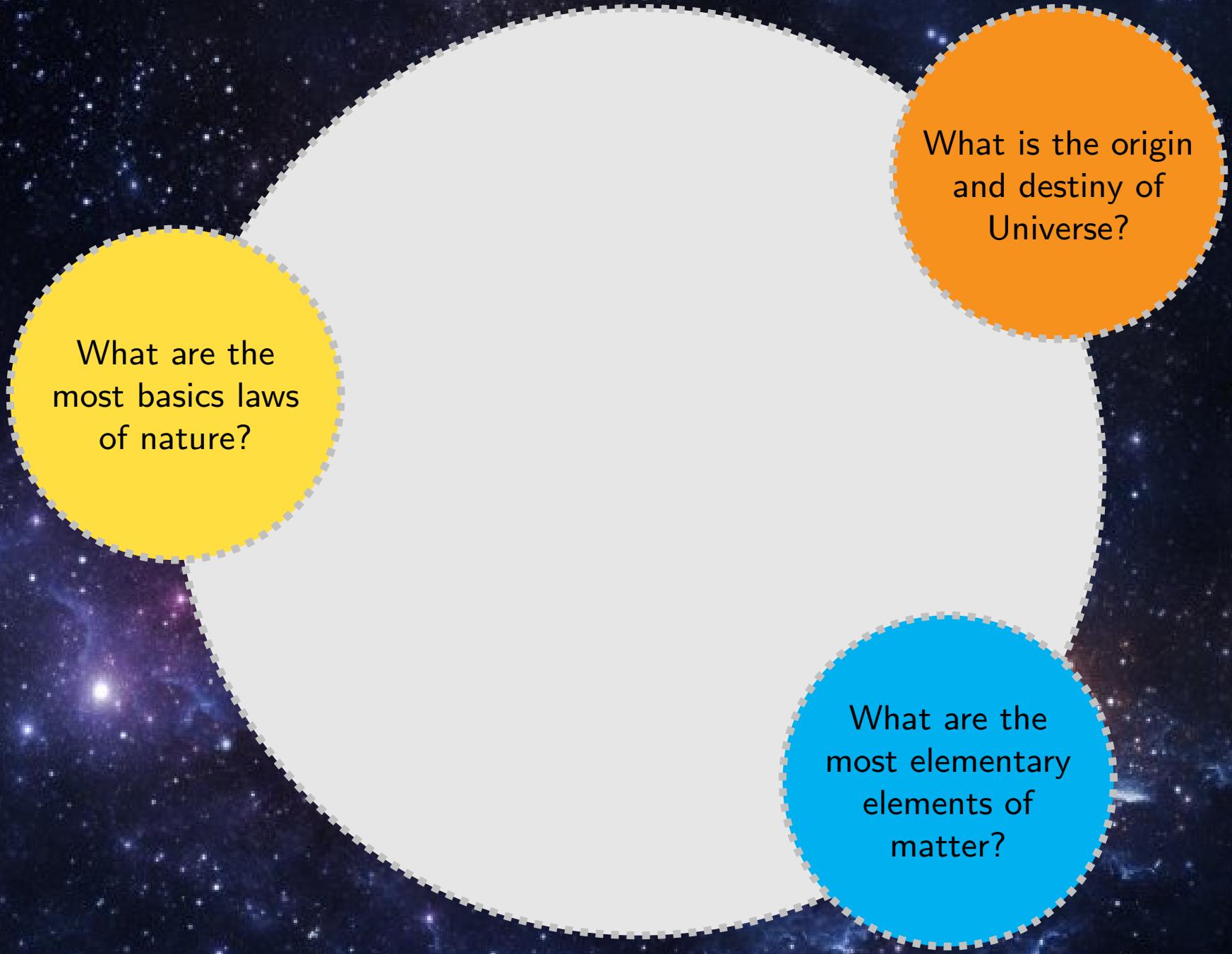

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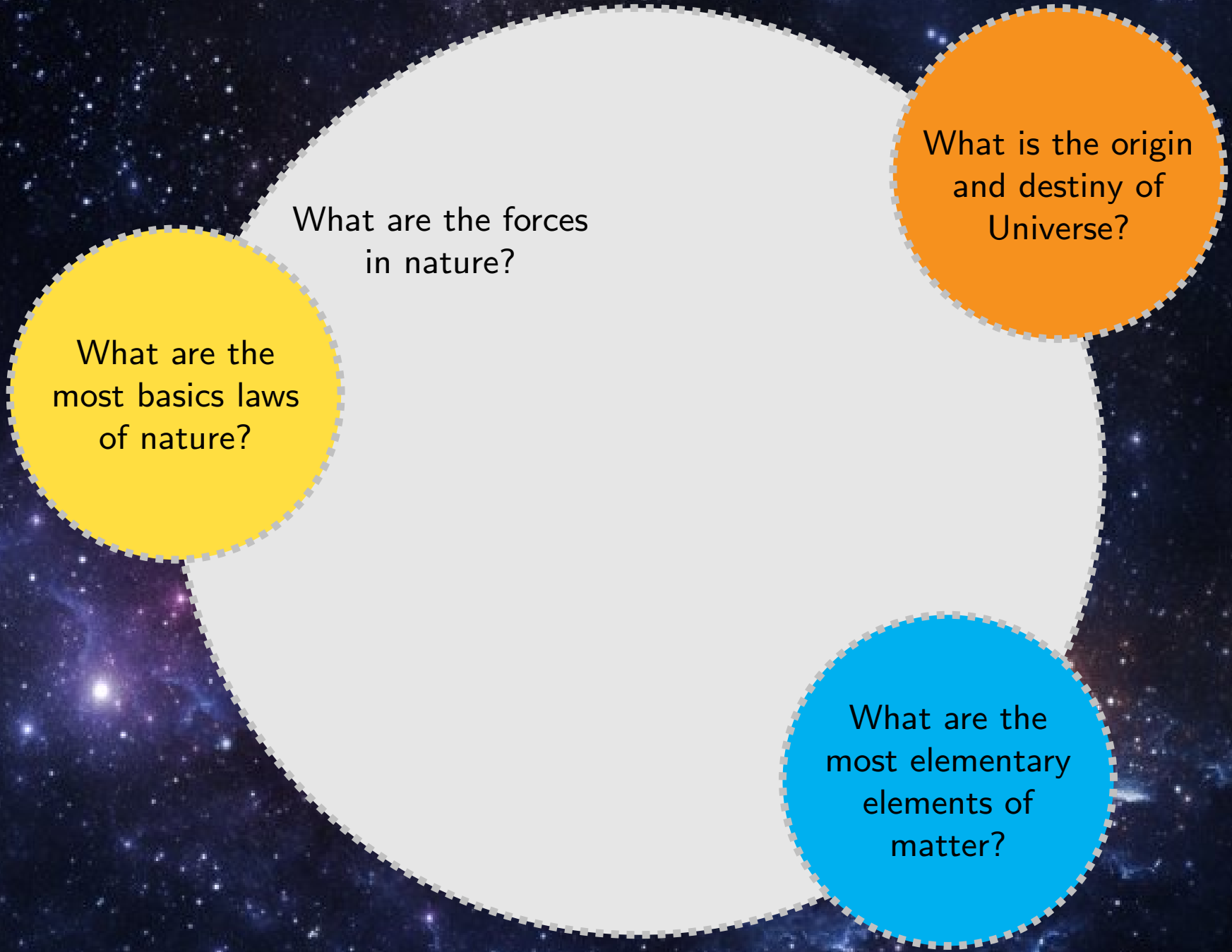

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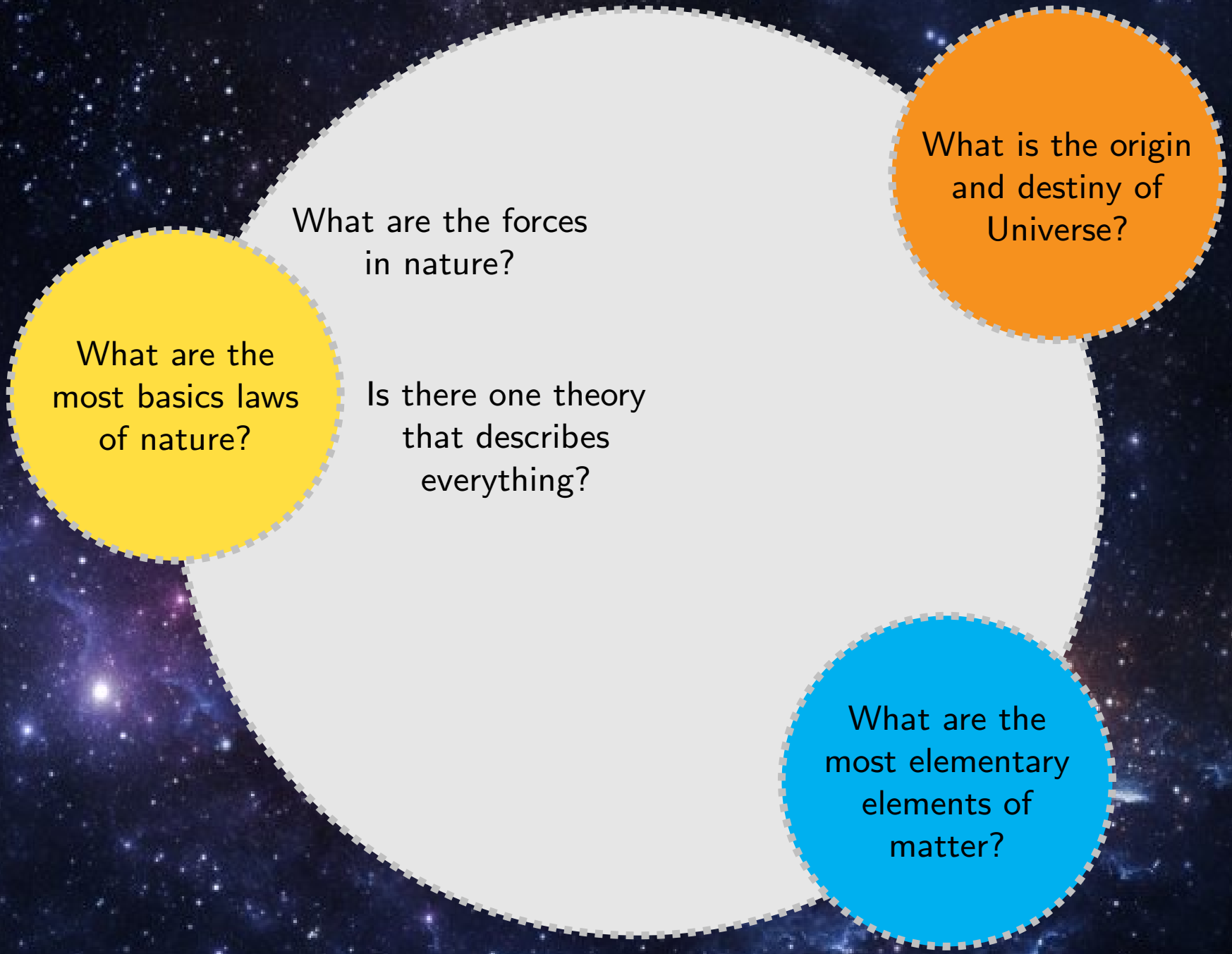

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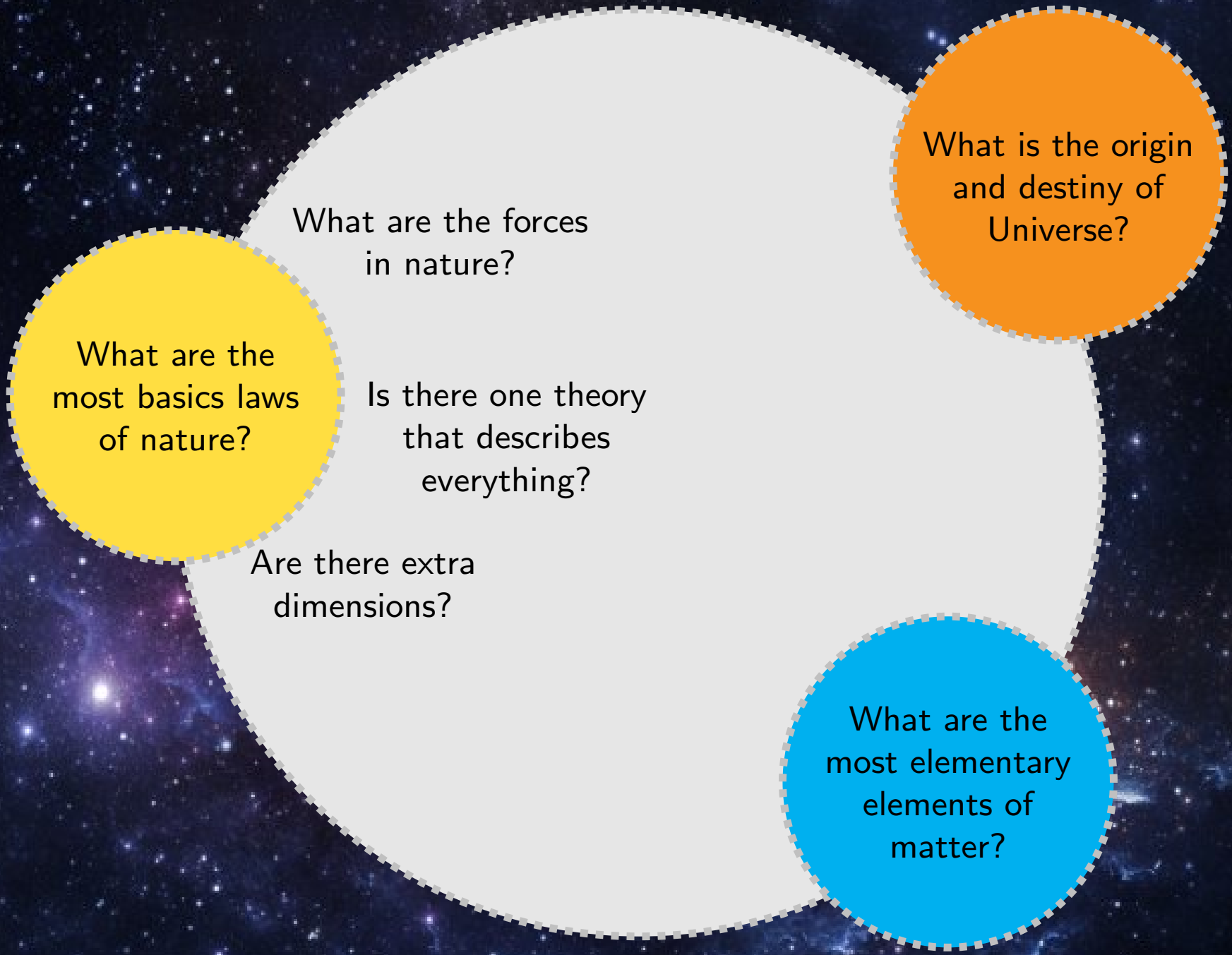

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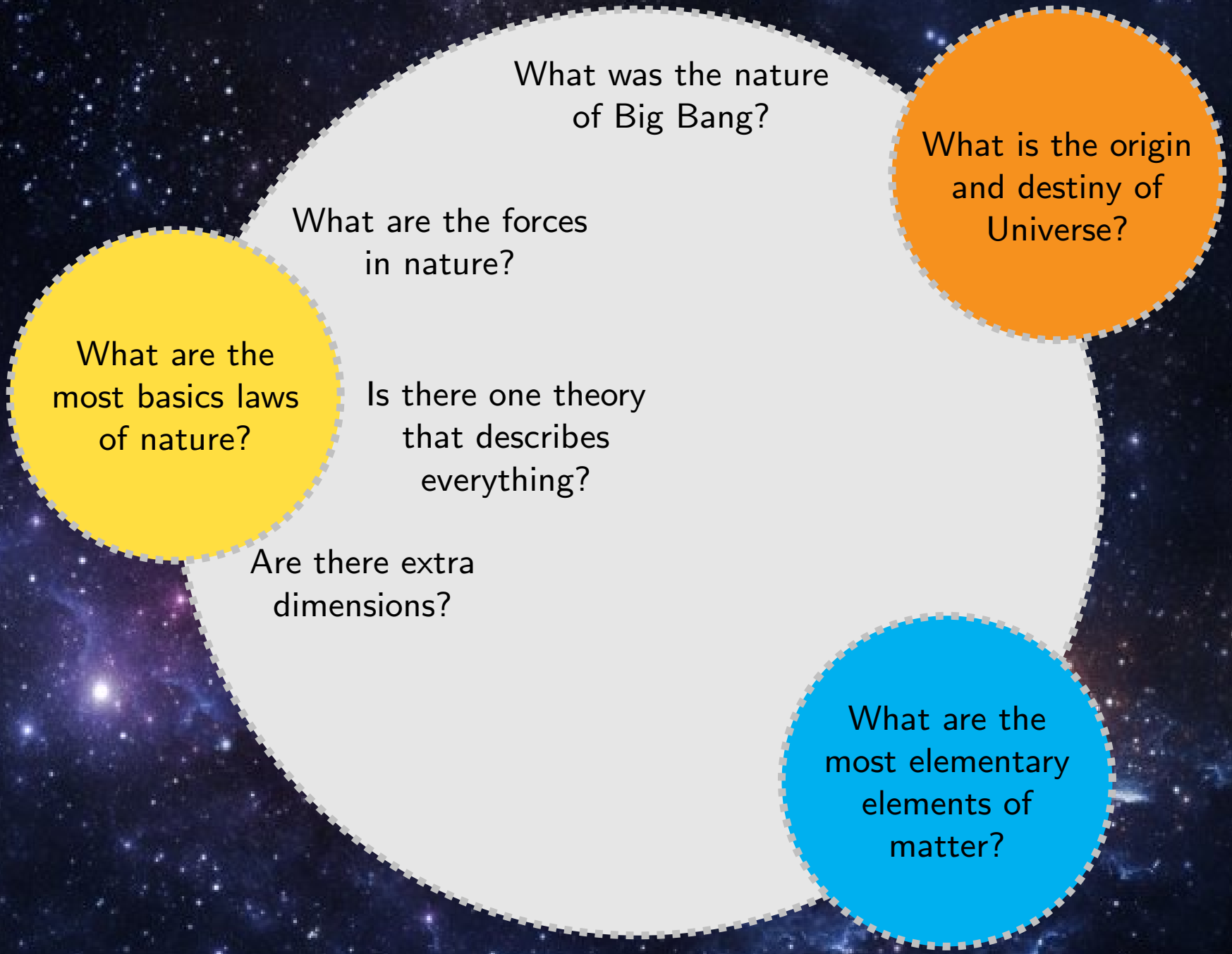

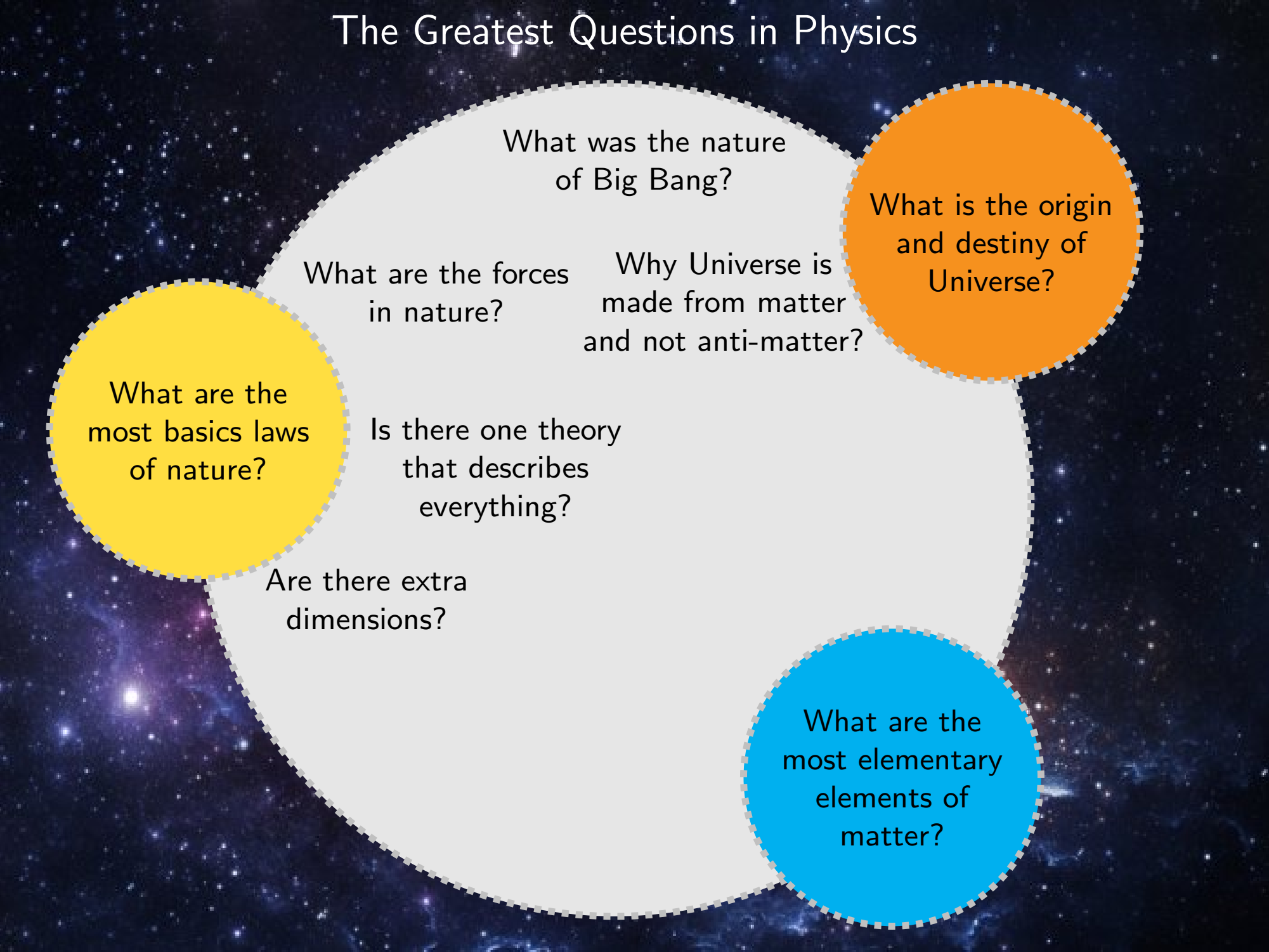
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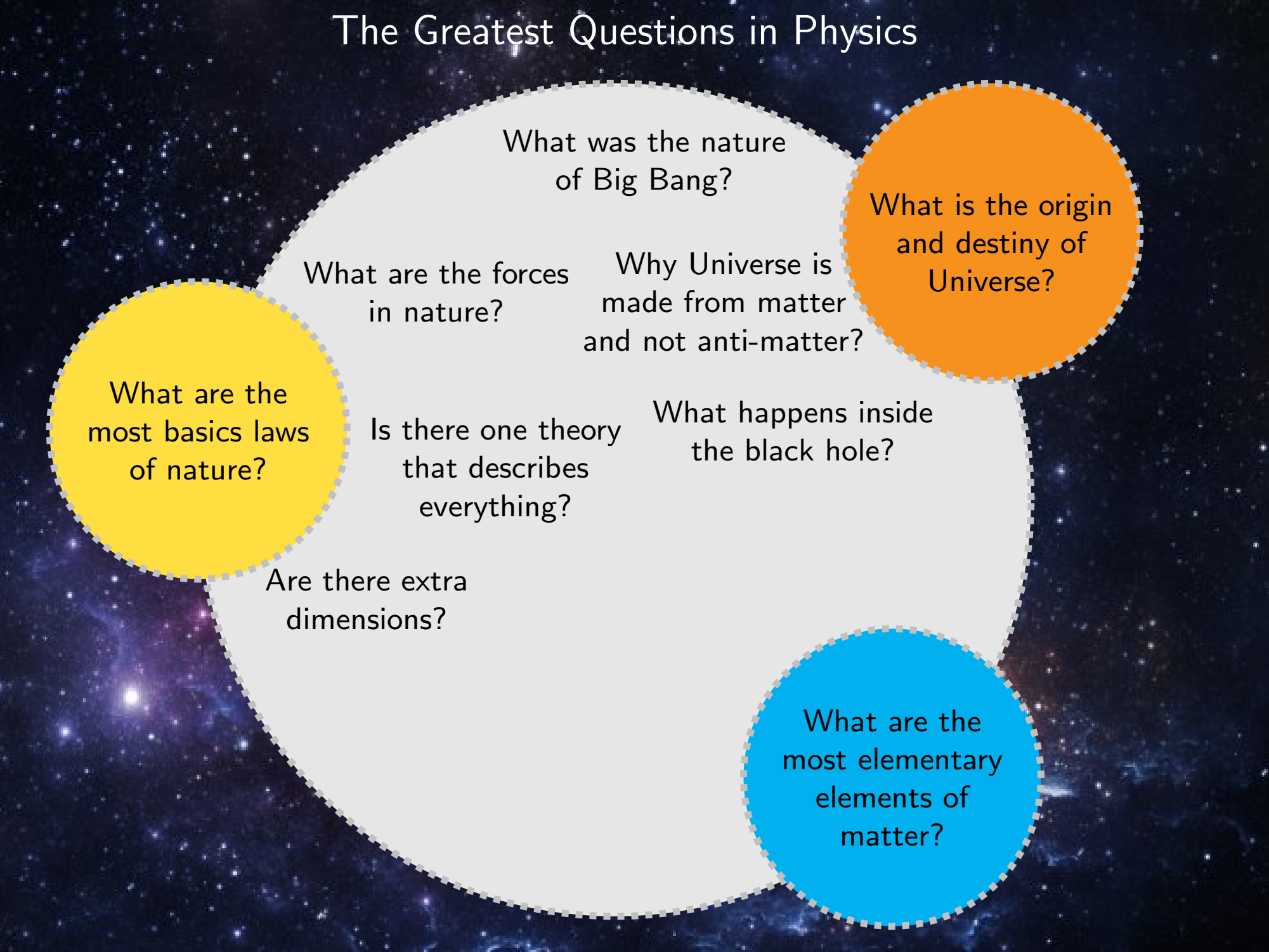
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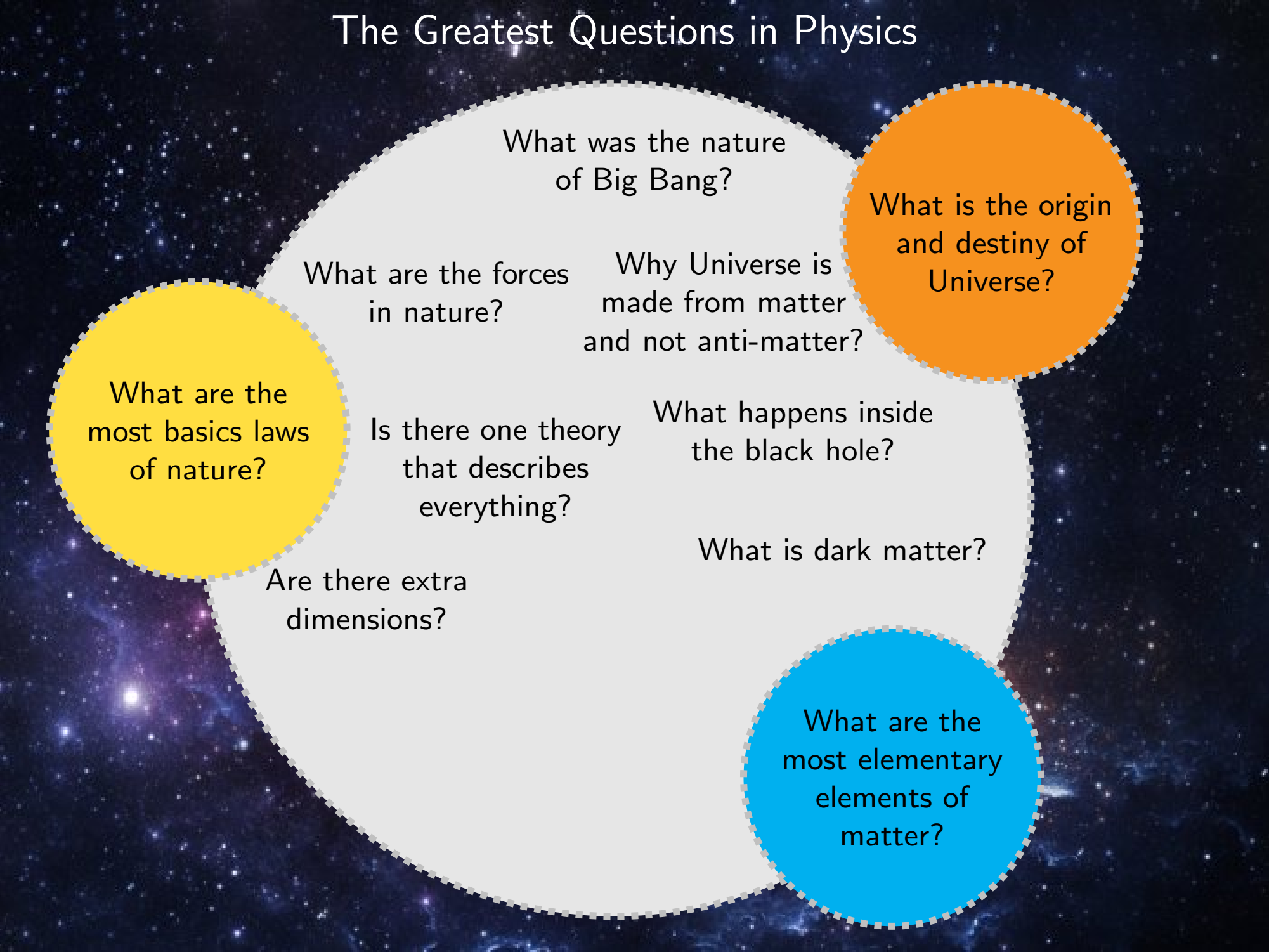
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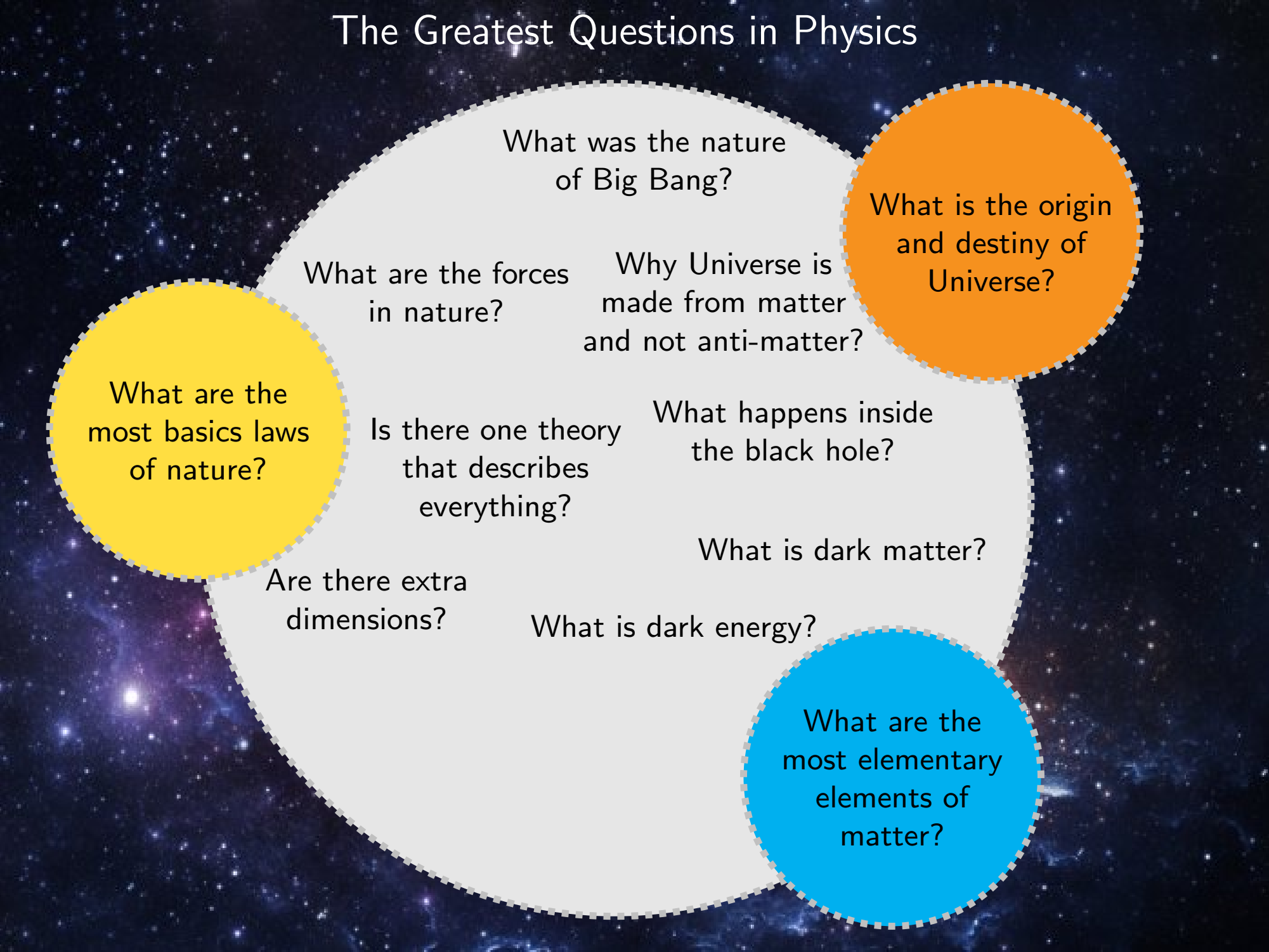
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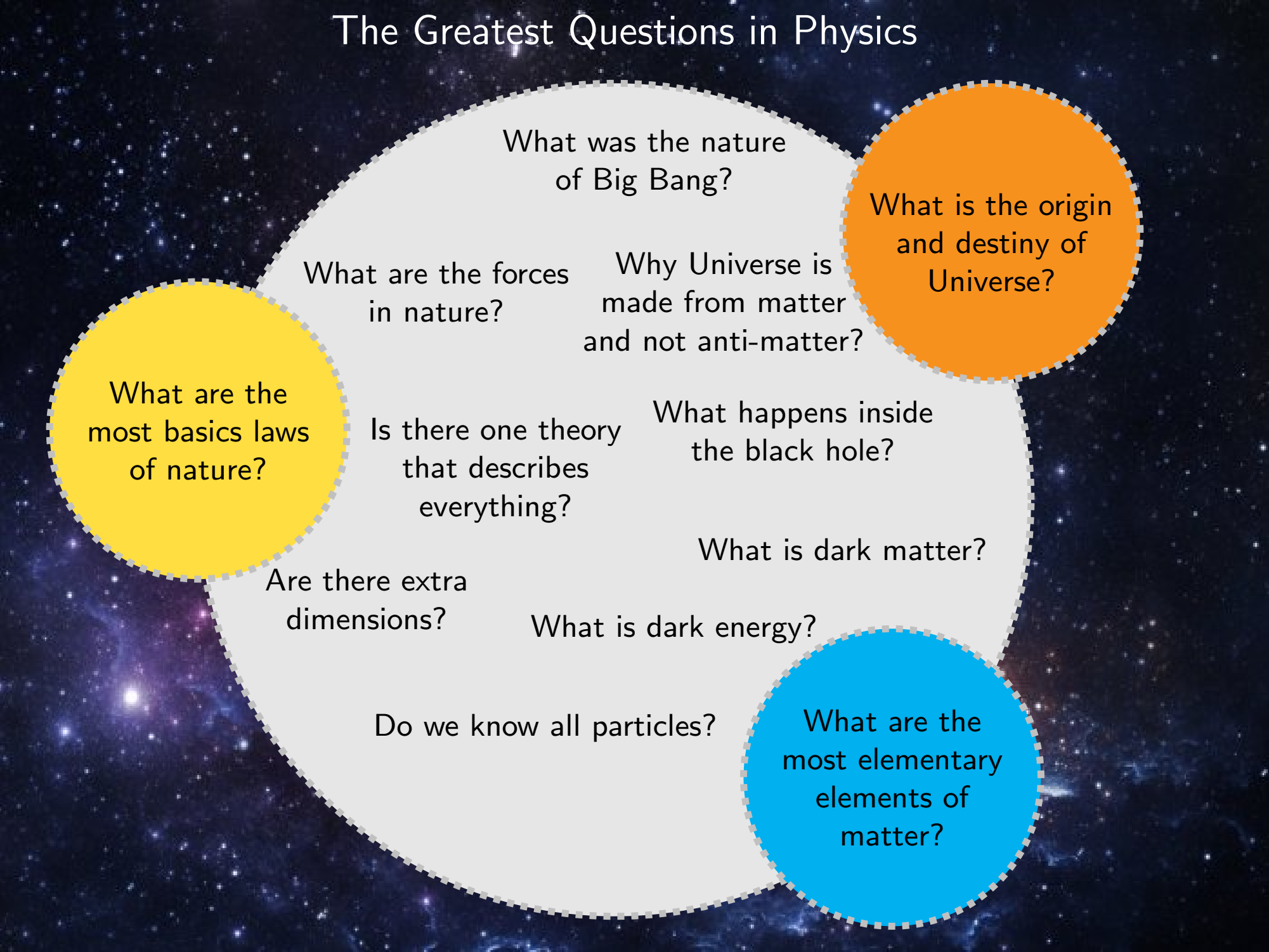
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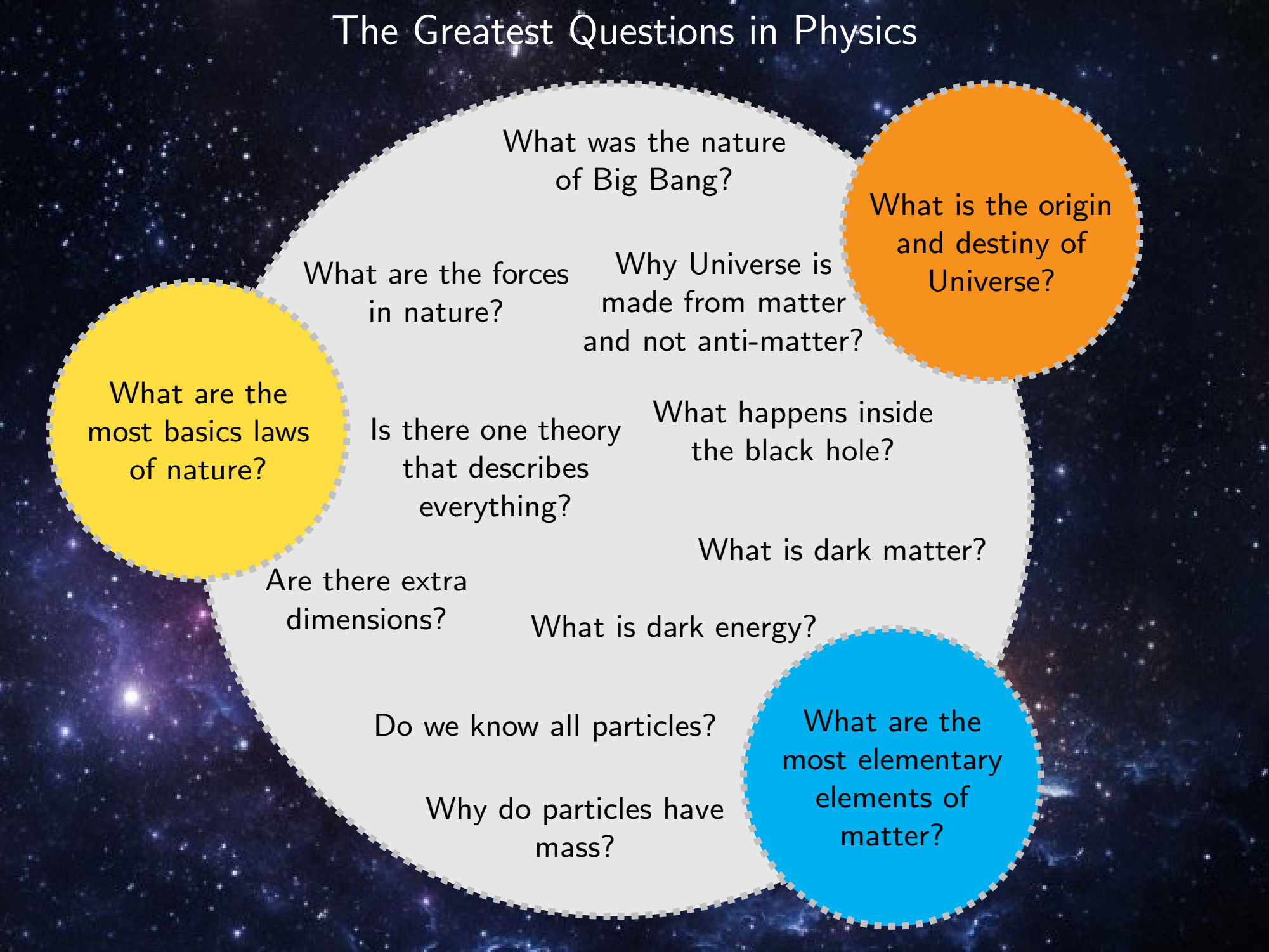
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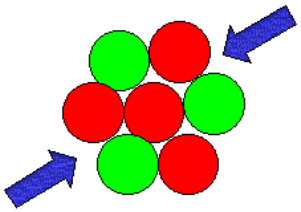
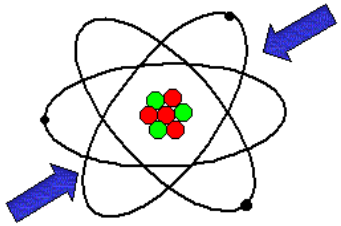
Why do particles have mass?

Forces in Nature

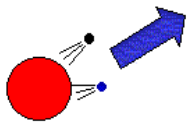
Four fundamental forces?



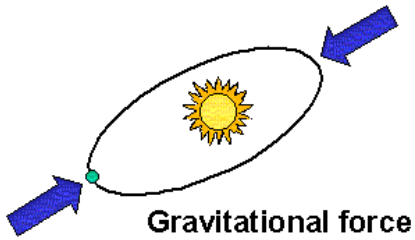
Strong force
binds the nucleus



Electromagnetic
force binds atoms

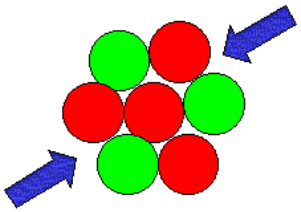


Weak force in
radioactive decay



Gravitational force
binds the solar system

Four fundamental forces?



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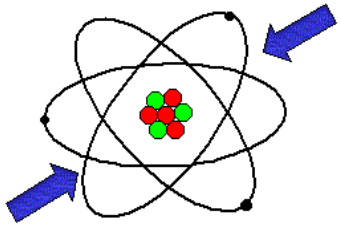

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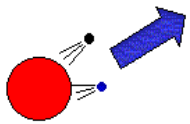

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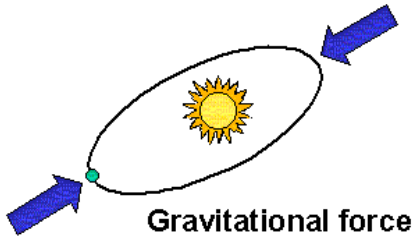
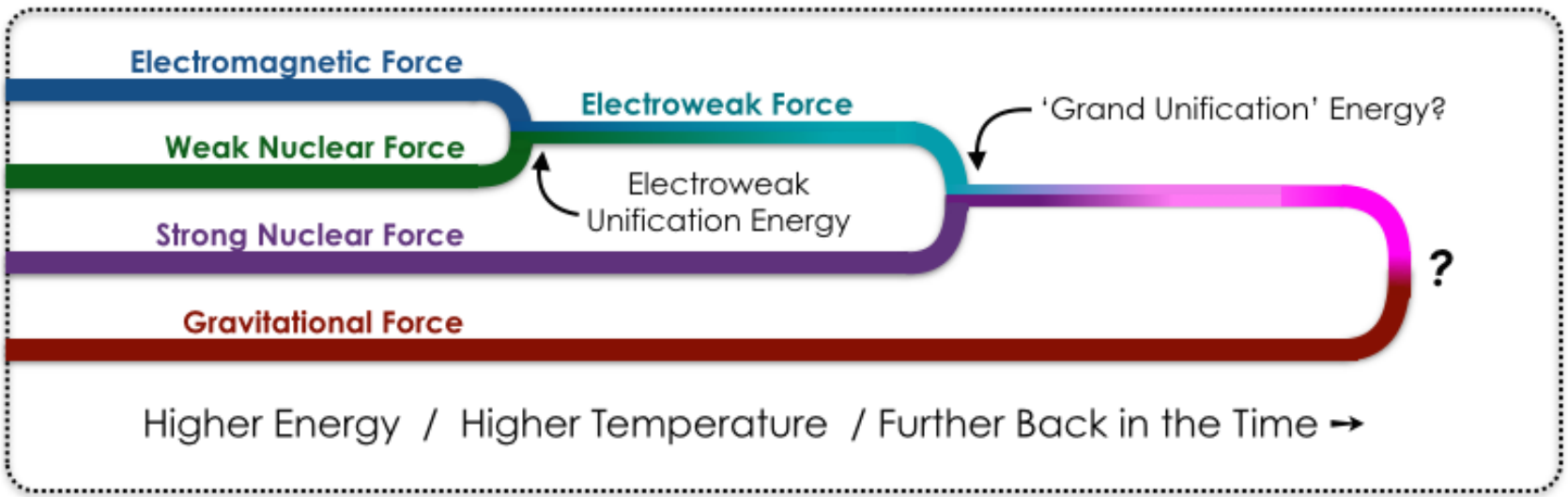


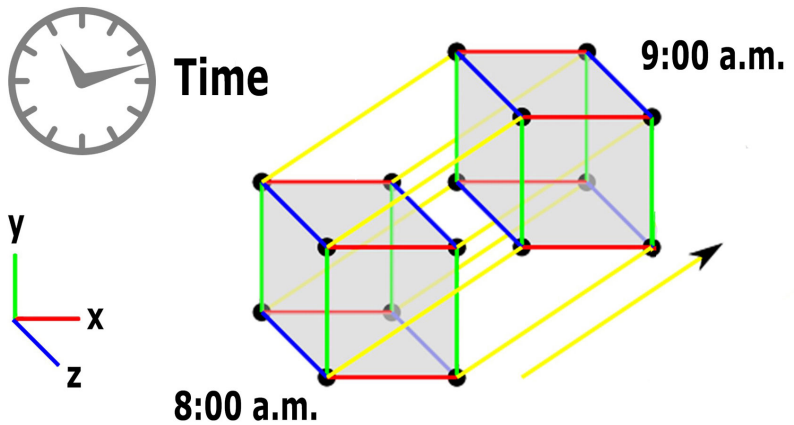
Gravitational force
binds the solar system

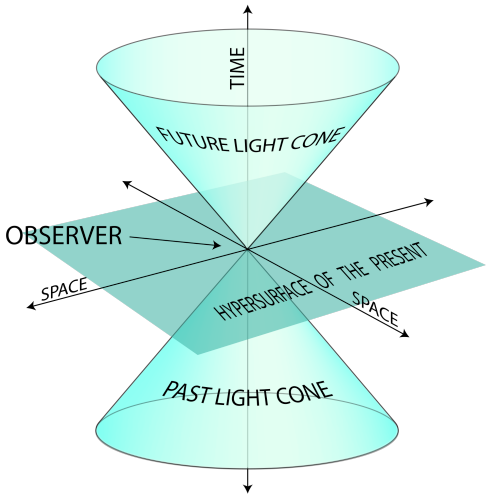
Or just one 'superforce'?



Dimensions

3 space and 1 time?





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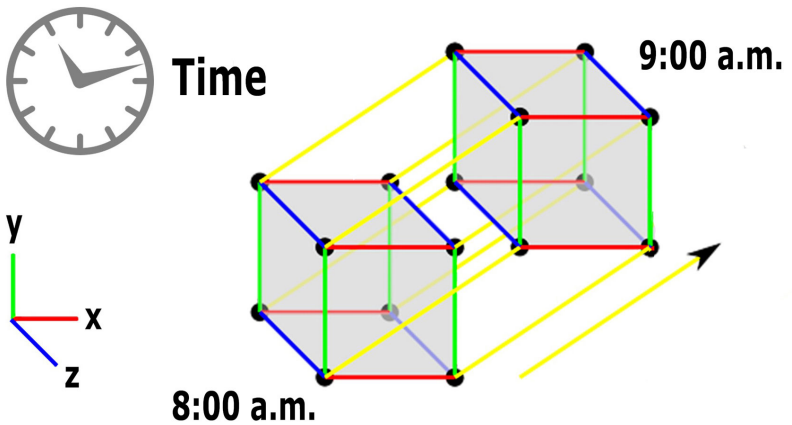
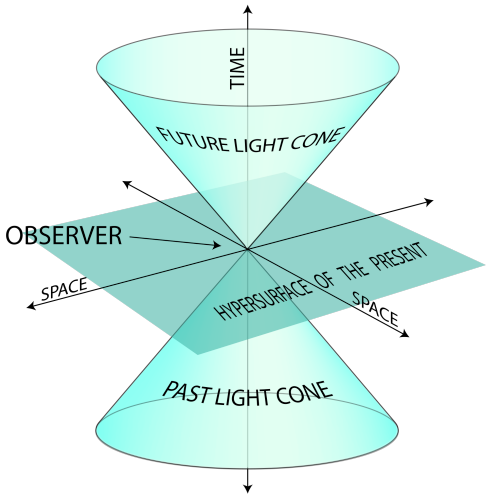
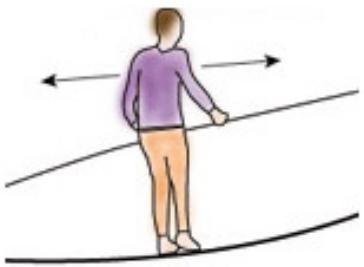
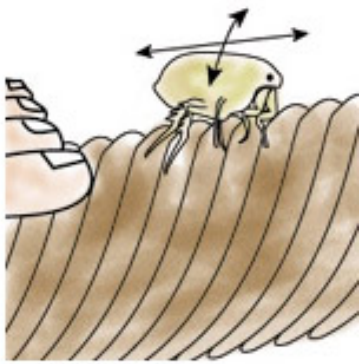




Or more?

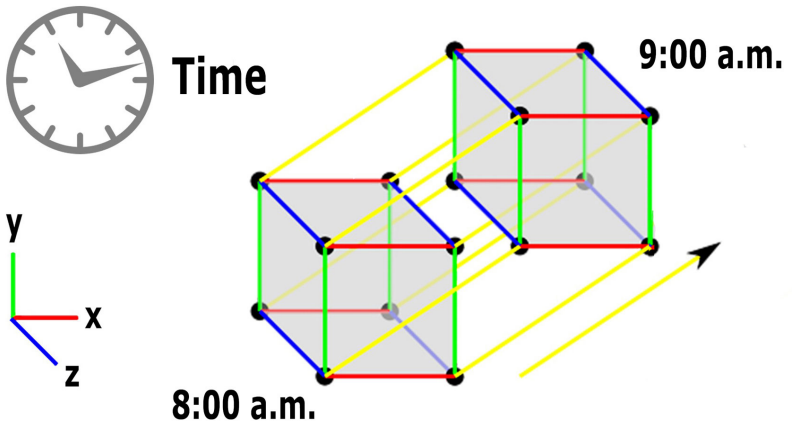


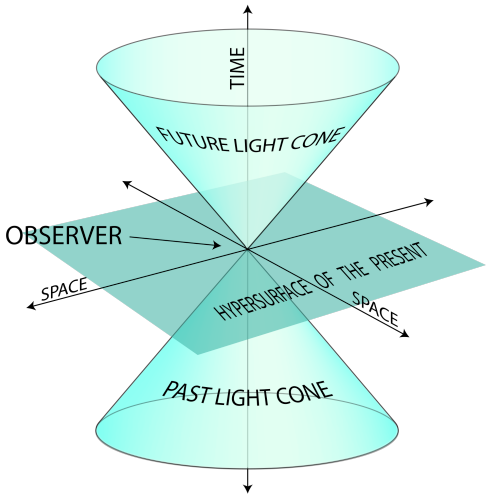
An acrobat can only move in one dimension along a rope..



...but a flea can move in two dimensions.

3 space and 1 time?





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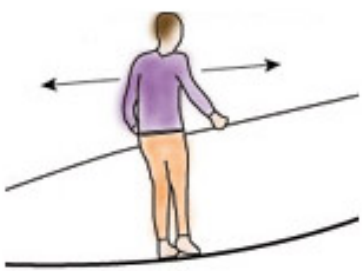

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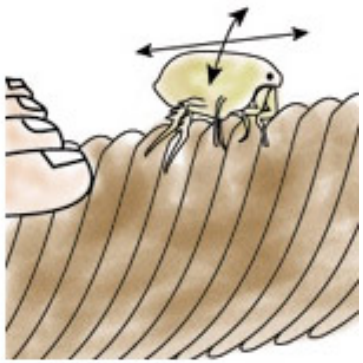

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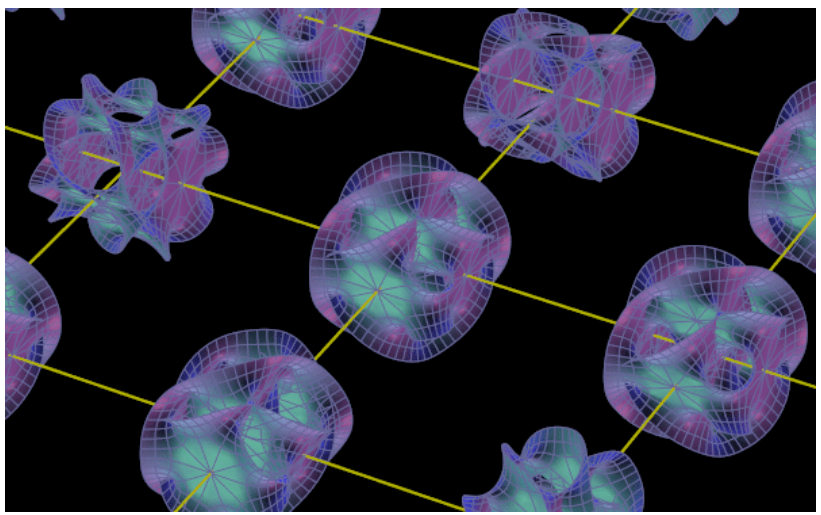
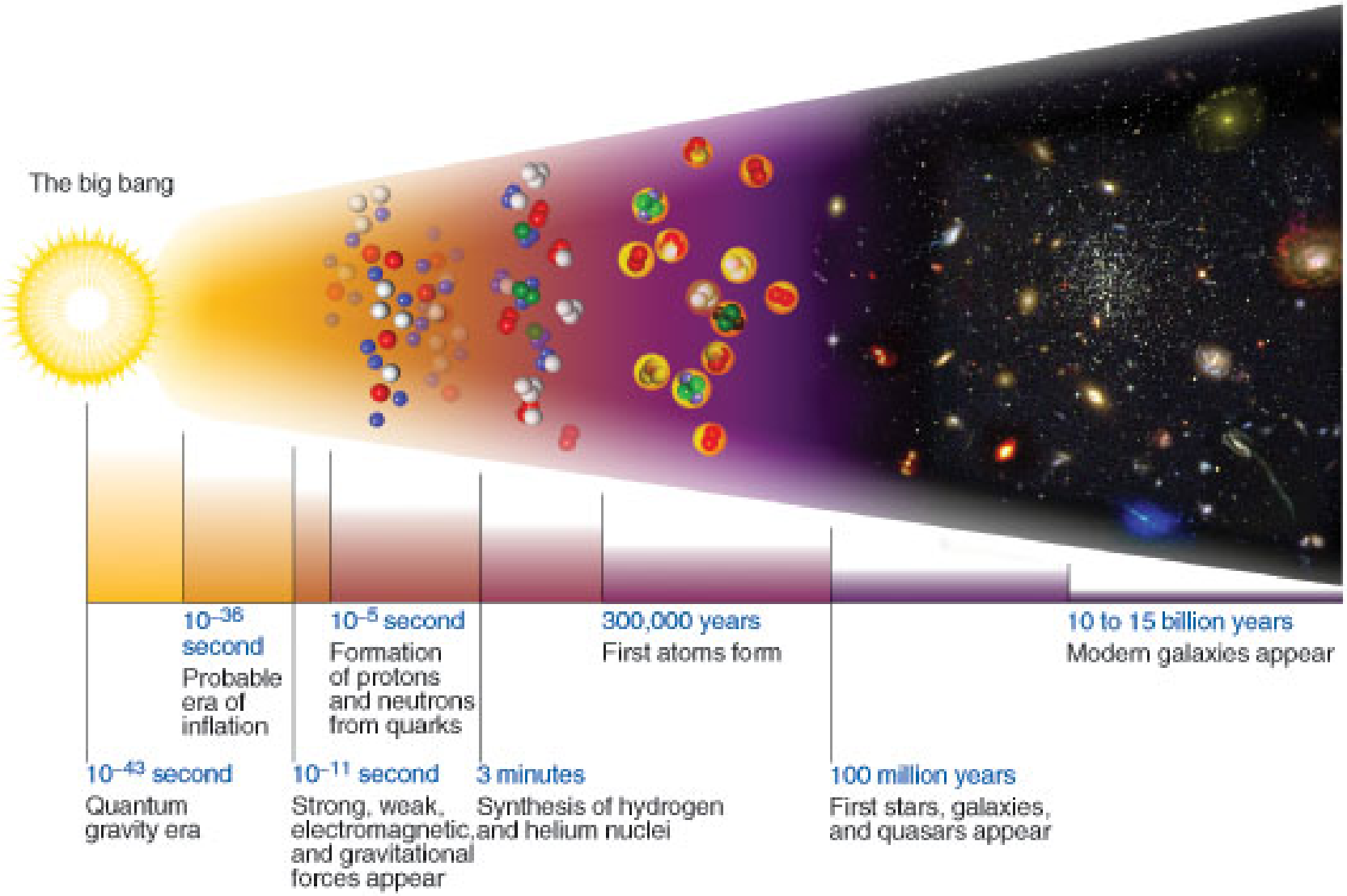


Big Bang and Evolution of Universe



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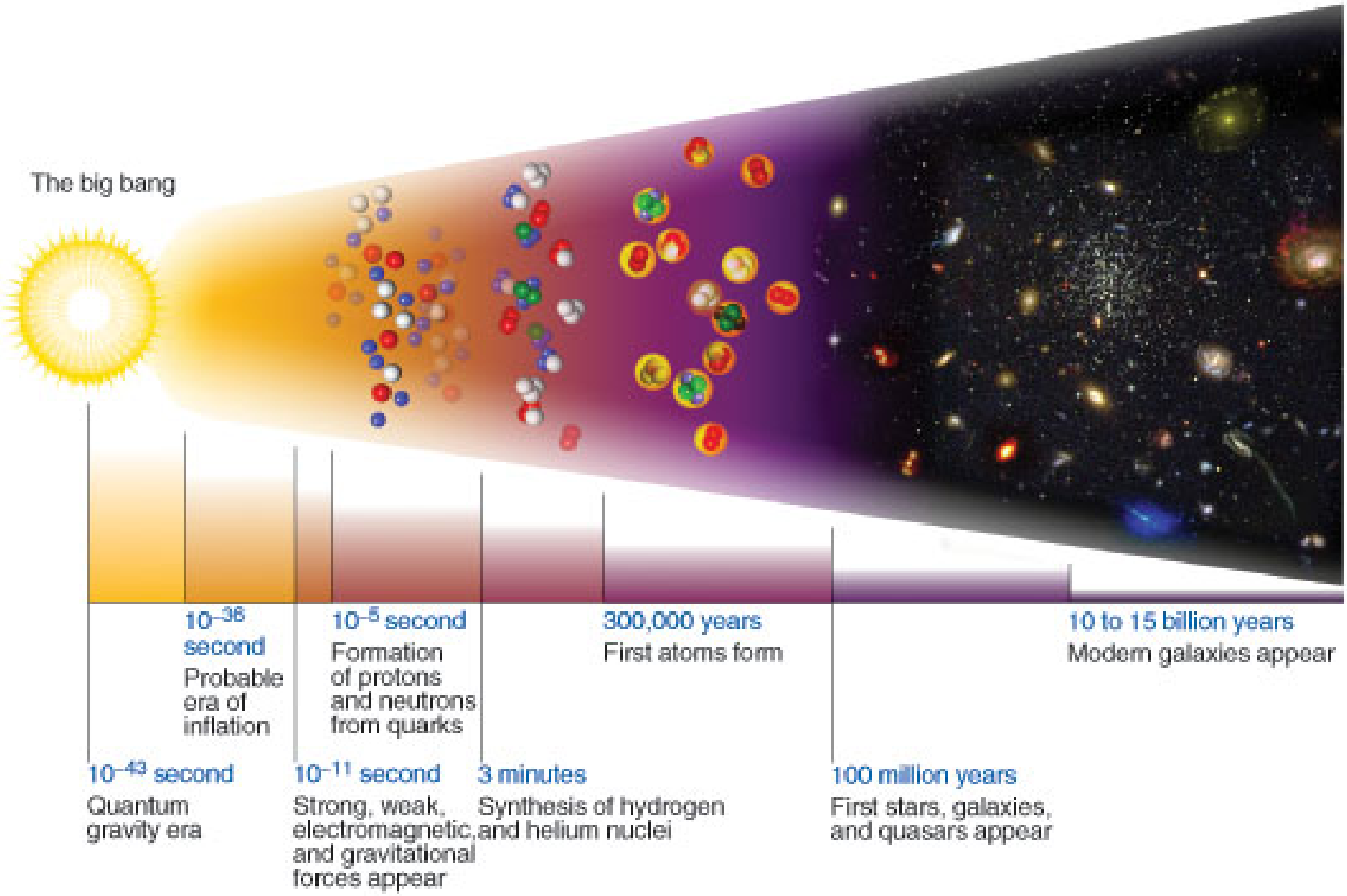

Quark-gluon plasma.

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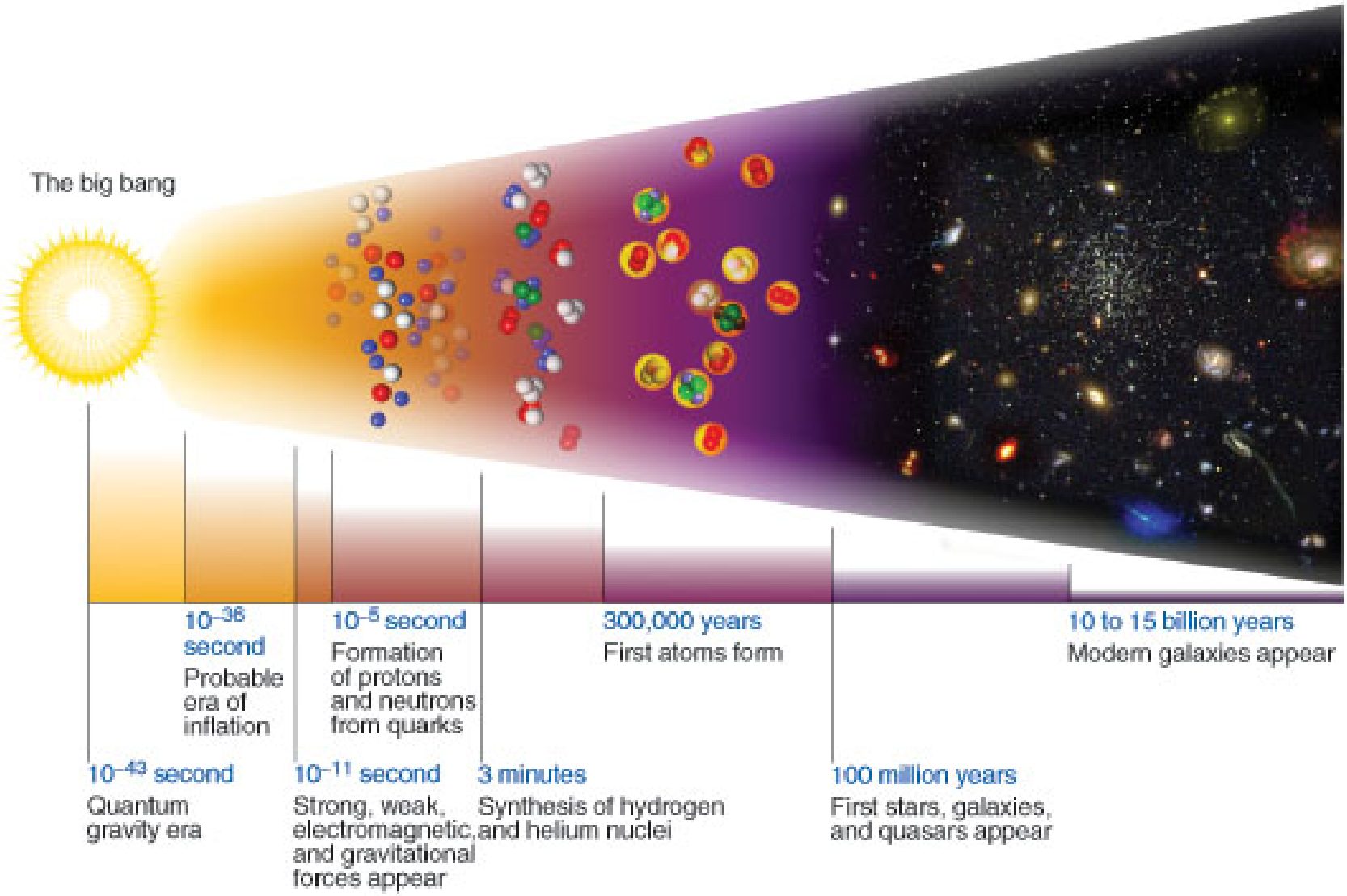

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Matter-antimatter asymmetry riddle.

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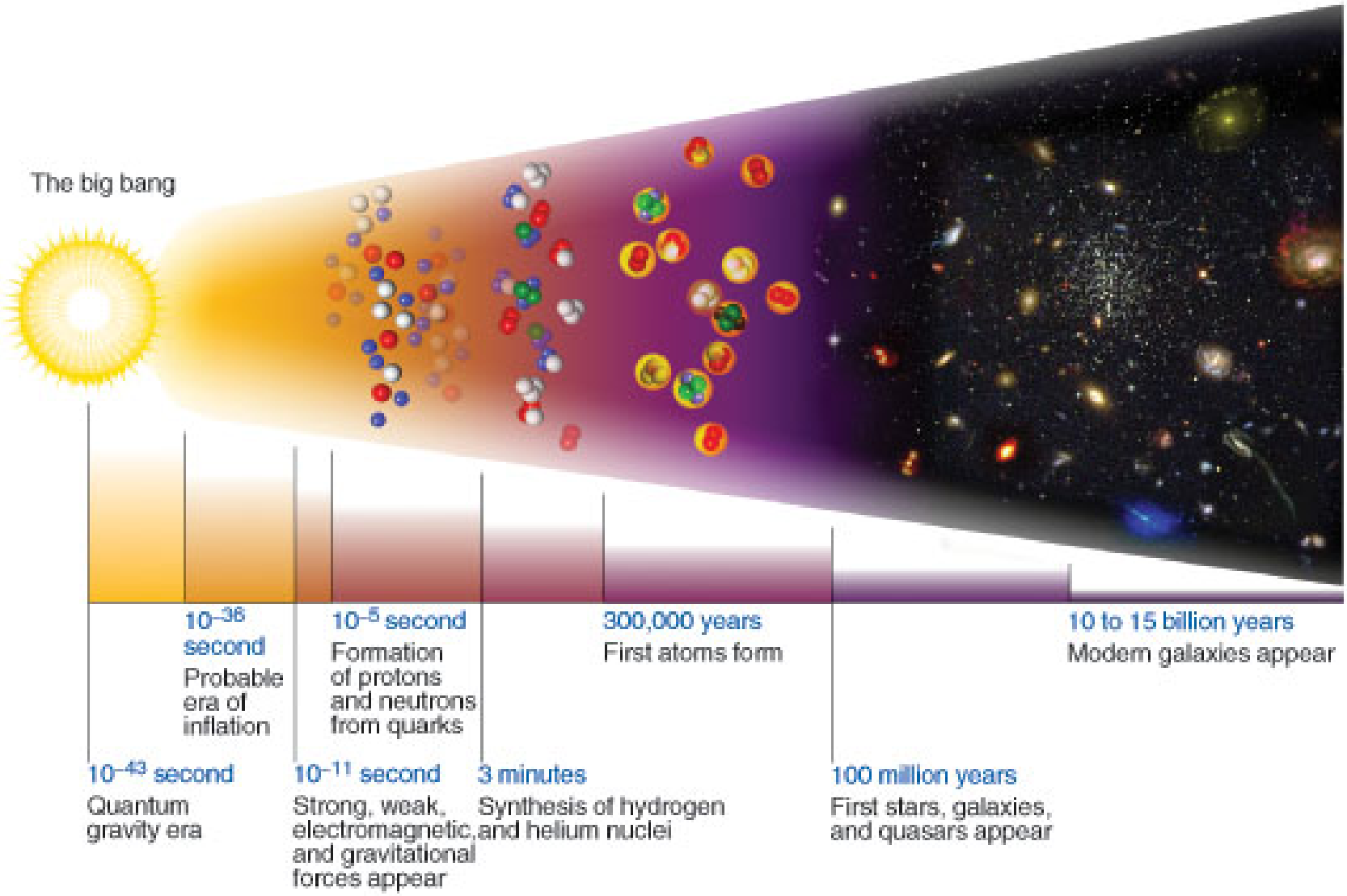

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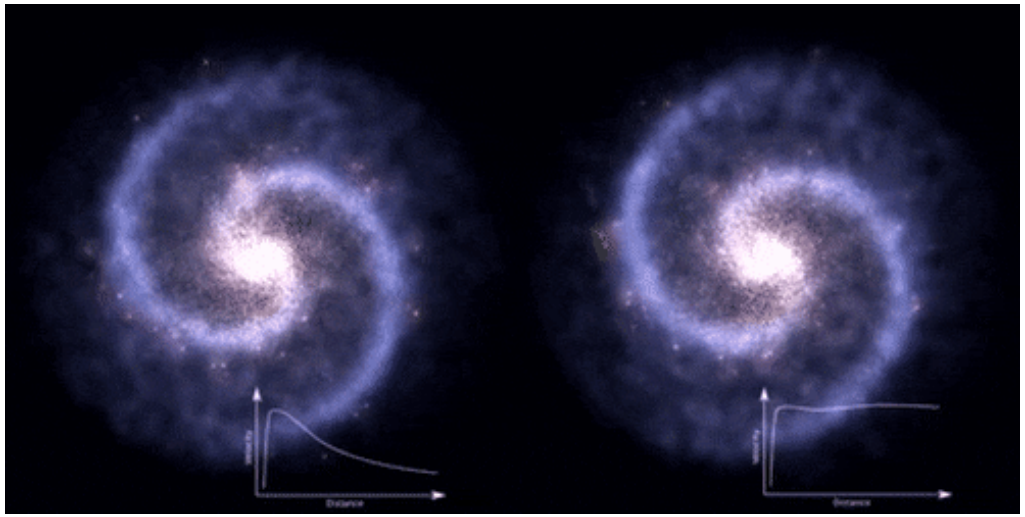
Open questions: inflation? origin and cause of Big Bang? era before Big Bang?

Components of Universe

Galaxies rotation – dark matter?



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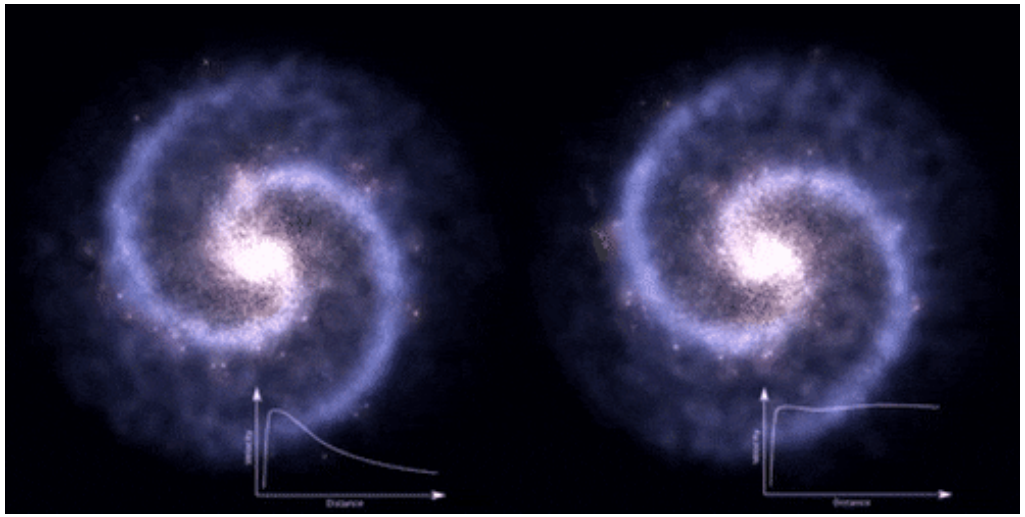
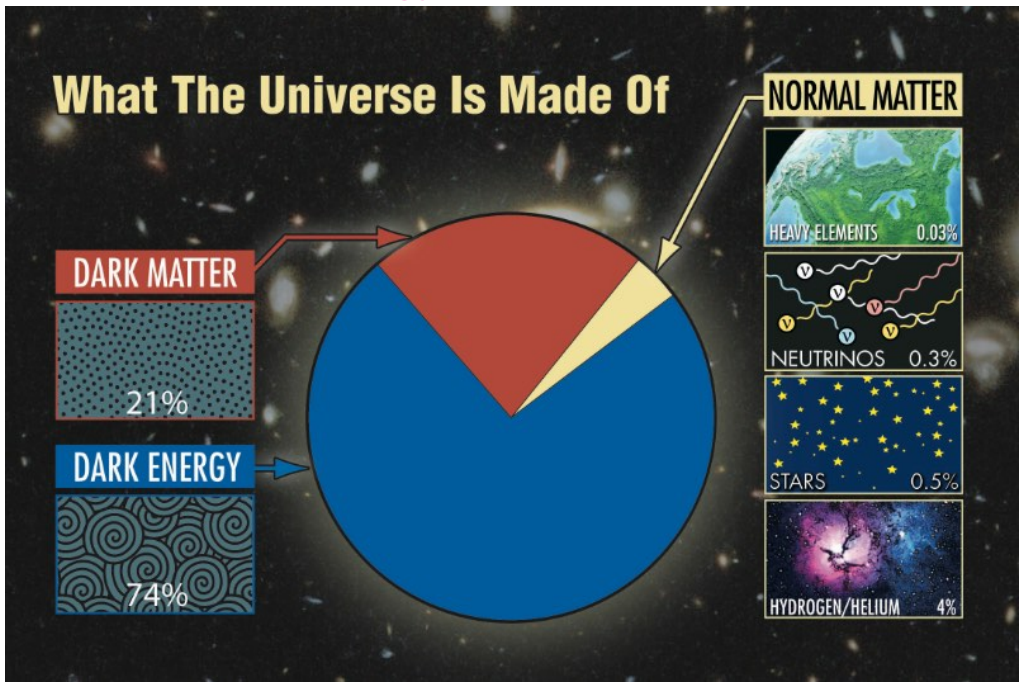
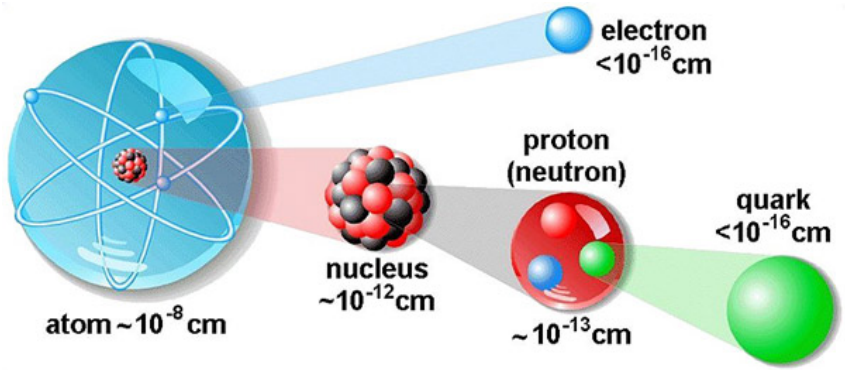
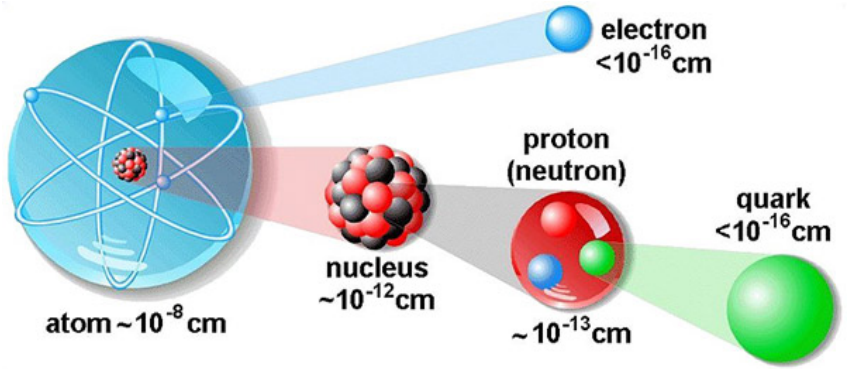


Expansion of Universe – dark energy?

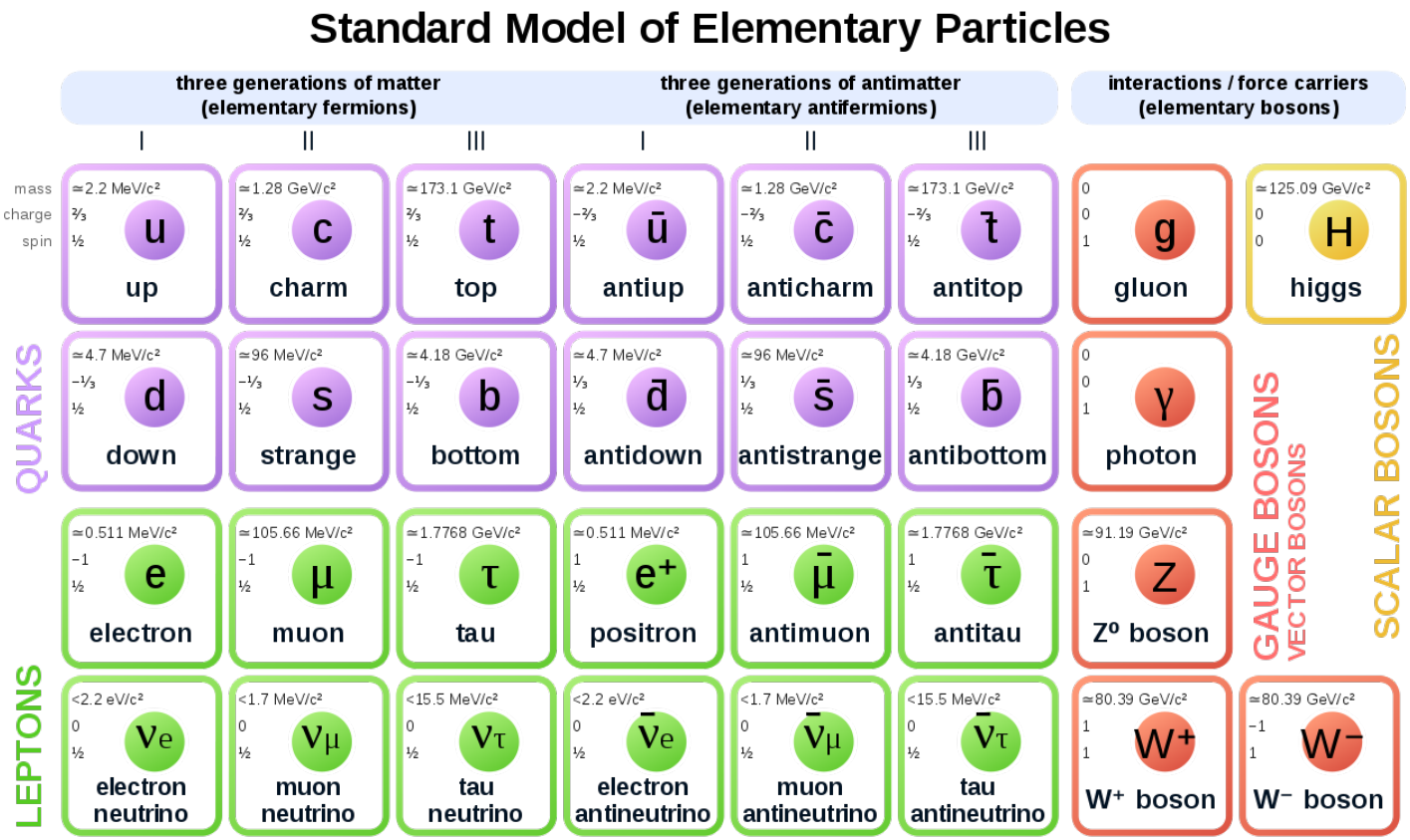


Components of Matter





Our current best understanding of matter components:



Analogy: the Higgs field $\rightarrow$ a room full of people

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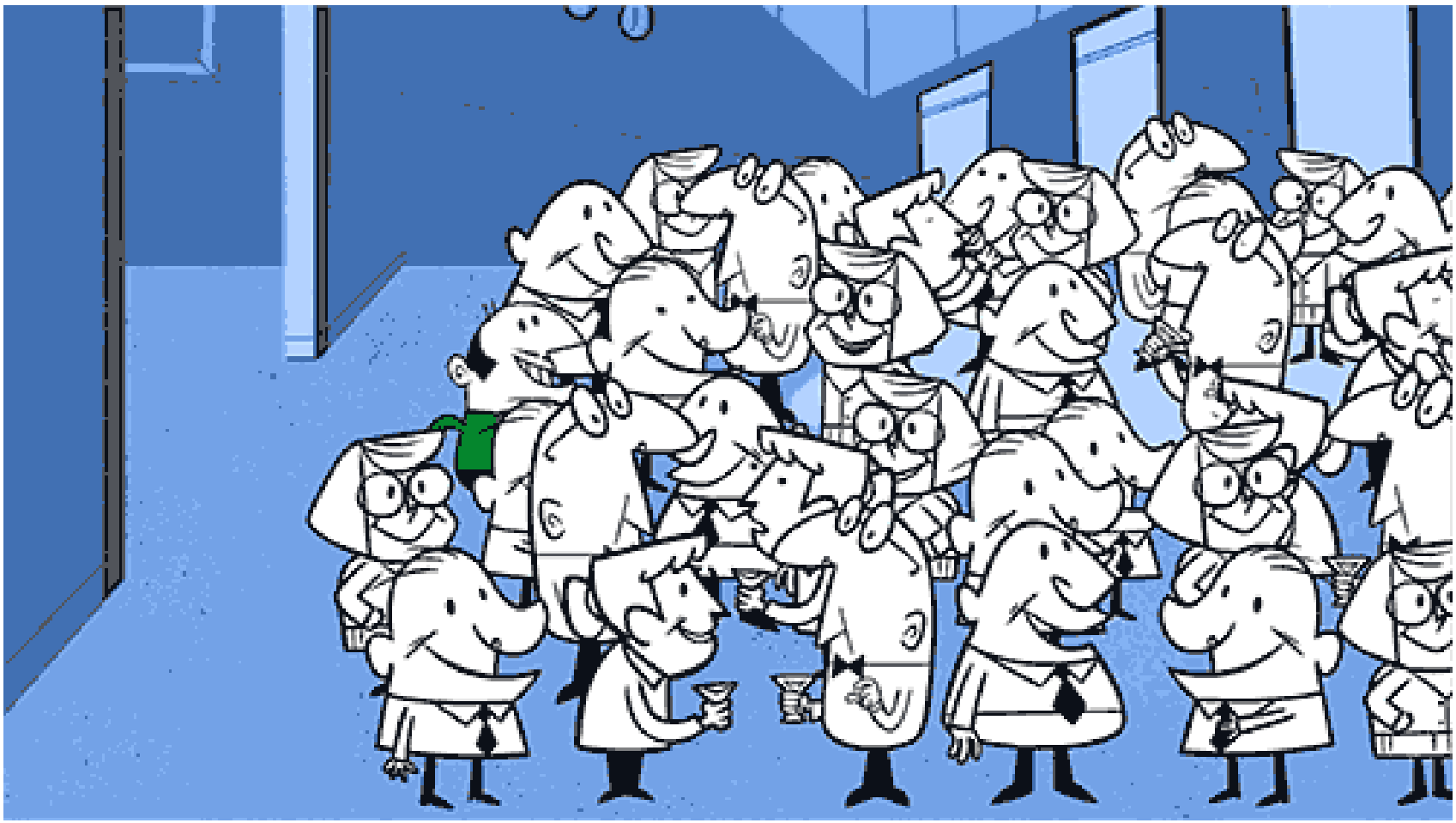
no interaction with Higgs field $\rightarrow$ massless particle $\rightarrow$ travels with the speed of light



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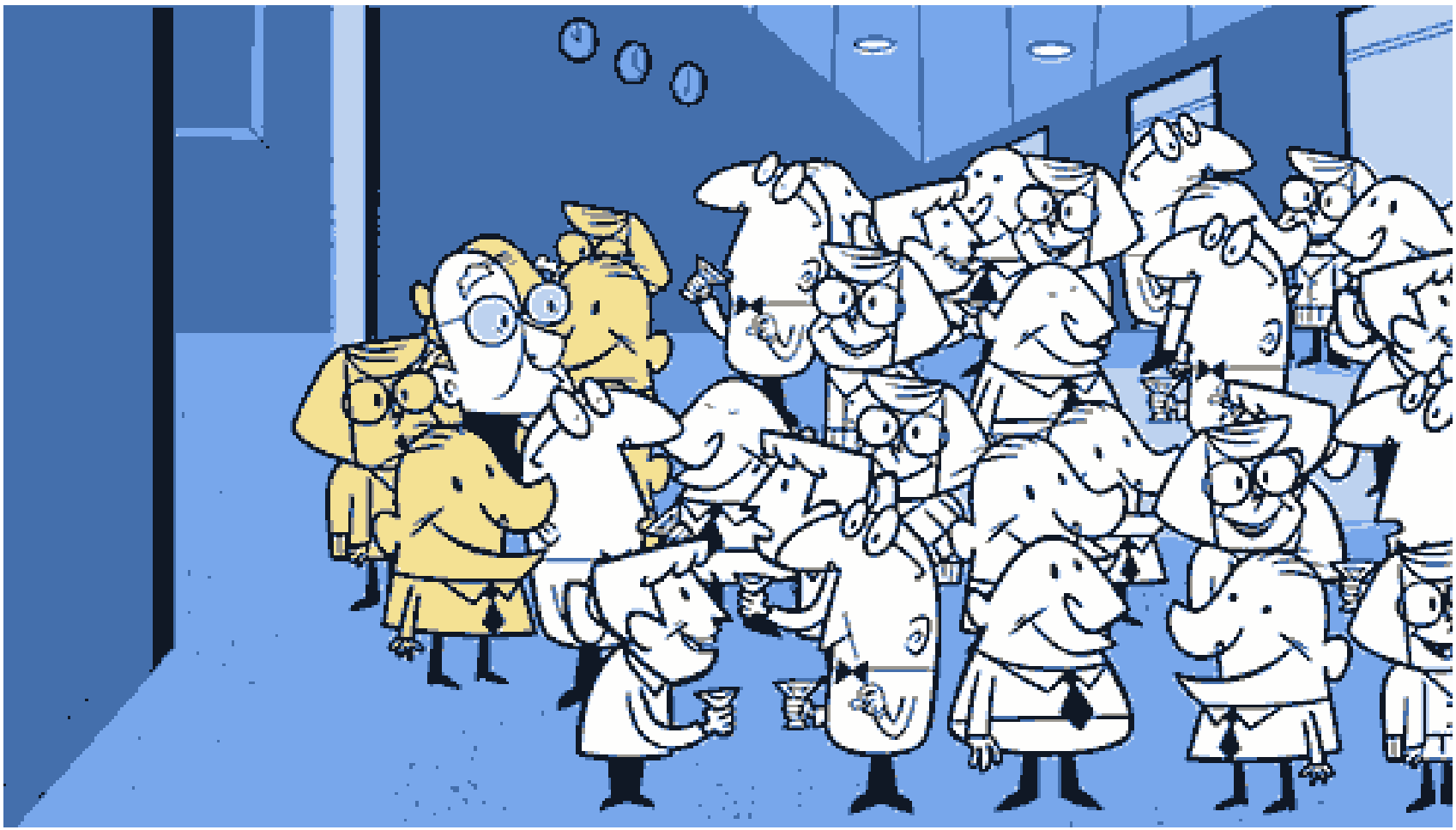

Analogy: the Higgs field $\rightarrow$ a room full of people

self interaction (fluctuation) of the Higgs field $\rightarrow$ the Higgs boson

CLASSICAL PHYSICS

ISAAC NEWTON

LAWS OF MOTION

LAW OF UNIVERSAL GRAVITATION

GRAVITY

ORBITS

CALCULUS

$\int x^2\,dx$ $\frac{dy}{dx}$

COSMOLOGY

ASTROPHYSICS

PRISM

OPTICS

REFLECTION
REFRACTION
DIFFRACTION

MICROSCOPE

TELESCOPE

CLASSICAL MECHANICS

WAVES

TRANSVERSE

LONGITUDINAL

ELECTRIC FIELDS

MAGNETIC FIELDS

JAMES CLERK MAXWELL

ELECTROMAGNETISM

FLUID MECHANICS

FLOW

LIFT

AERODYNAMICS

ELECTRICITY

LIGHT

THERMODYNAMICS

ENERGY

HEAT

TEMPERATURE

ENTROPY

CHAOS THEORY

RELATIVITY

CONSTANT SPEED OF LIGHT

ALBERT EINSTEIN

GENERAL THEORY OF RELATIVITY

SPECIAL THEORY OF RELATIVITY

$E=mc^2$

TIME

SPACE

SPACETIME

PHILOSOPHY

PHILOSOPHY OF SCIENCE

FREE WILL

HOW COME?

NATURE OF REALITY

JUST... WHY?

THE CHASM OF IGNORANCE

THE FUTURE

QUANTUM GRAVITY

STRING THEORY

LOOP QUANTUM GRAVITY

DARK ENERGY

DARK MATTER

AND MANY MORE...

QUANTUM PHYSICS

QUANTUM FIELD THEORY

QUANTUM ELECTRO DYNAMICS

THE STANDARD MODEL

ATOMIC THEORY

NUCLEAR PHYSICS

FISSION

FUSION

CONDENSED MATTER PHYSICS

QUANTUM INFORMATION

COMPUTERS

LASERS

PARTICLE PHYSICS

YOUTUBE.COM/USER/DOMINICWALLIMAN @DOMINICWALLIMAN

Fundamental problems:

- When?
- Why?
- How?
- Components?
- Principles?

High Energy Physics addresses these questions by studying the behaviour of the Nature at the smallest possible distances, where its elementary ingredients interact.

- Structure of matter?
- Mass hierarchy?
- Particle interactions?

One Way of Learning: Accelerator Experiments

How to Observe (in macro-scale)?

How to Observe (in macro-scale)?

Basic 'tool': our eyes.
Resolution: 0.03 mm (about 25 cm from eye).

Resolution

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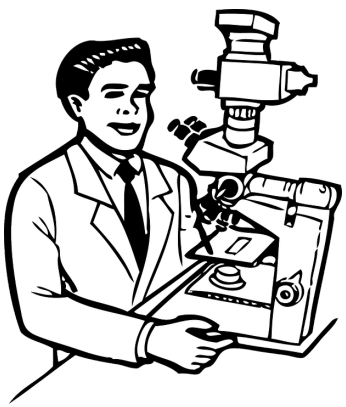
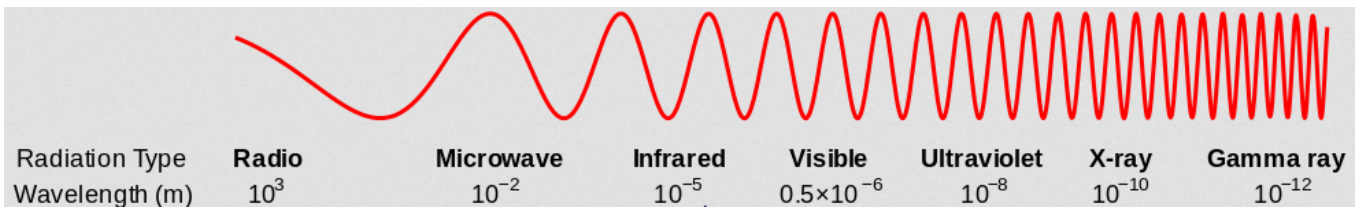


Microscope:

- visible light – magnification up to 1500x,
- ultraviolet – magnification up to 3500x.



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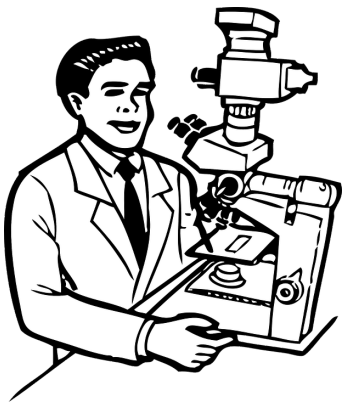

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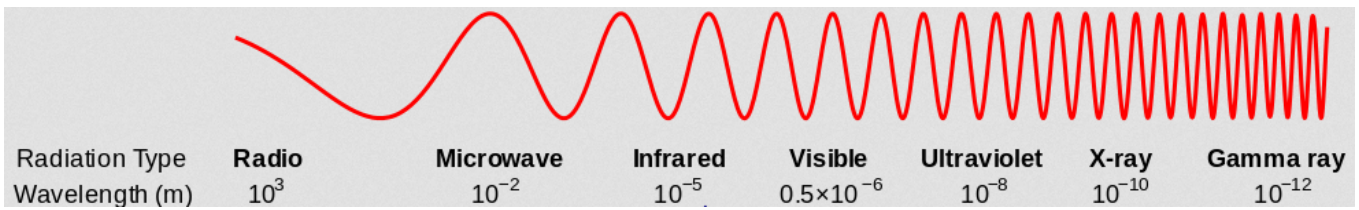
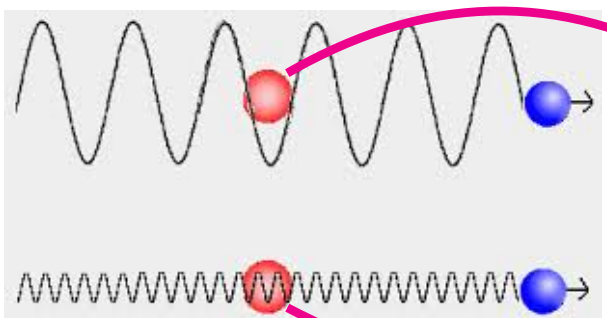
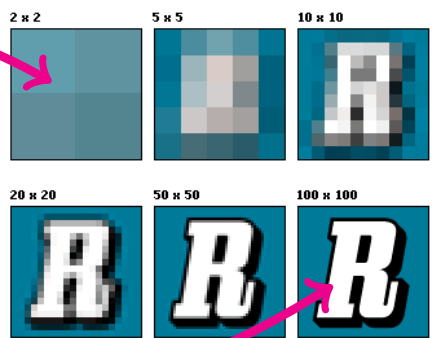


Observation Conditions

The wavelength must be shorter than the size of the object.





Corpuscular-wave Duality

Matter has properties of both: corpuscles and waves. In particular, each particle has a corresponding wavelength, which is in inverse proportion to its energy:

wavelength $\sim$ 1/particle energy

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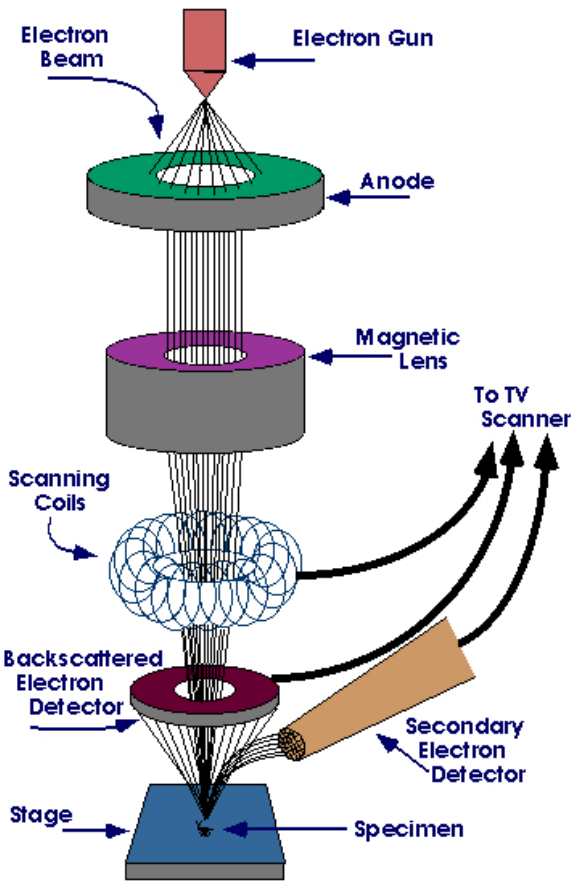

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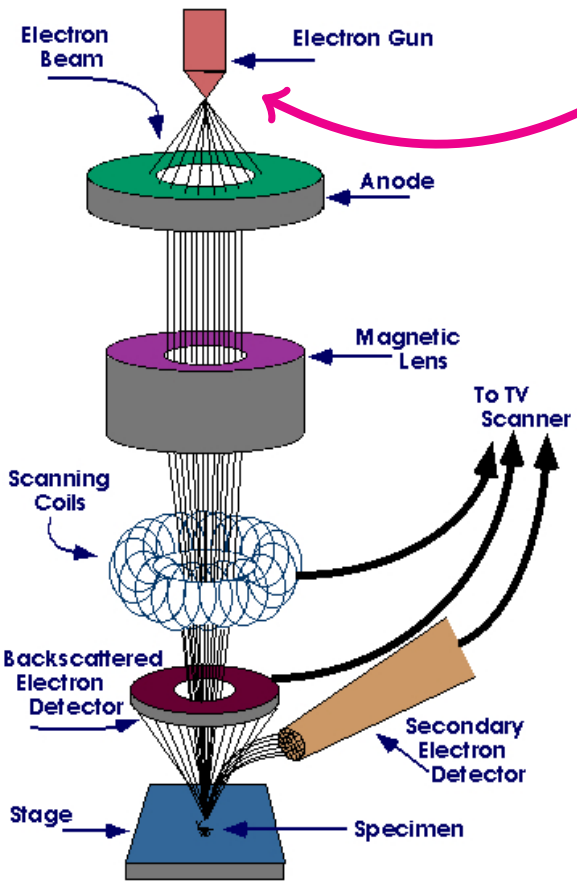

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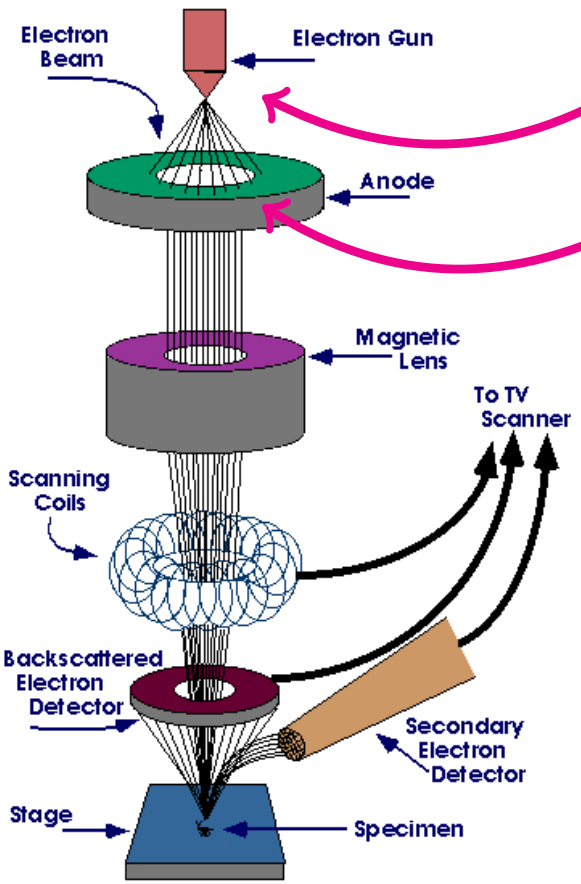

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acceleration (energy increase) in the electric field

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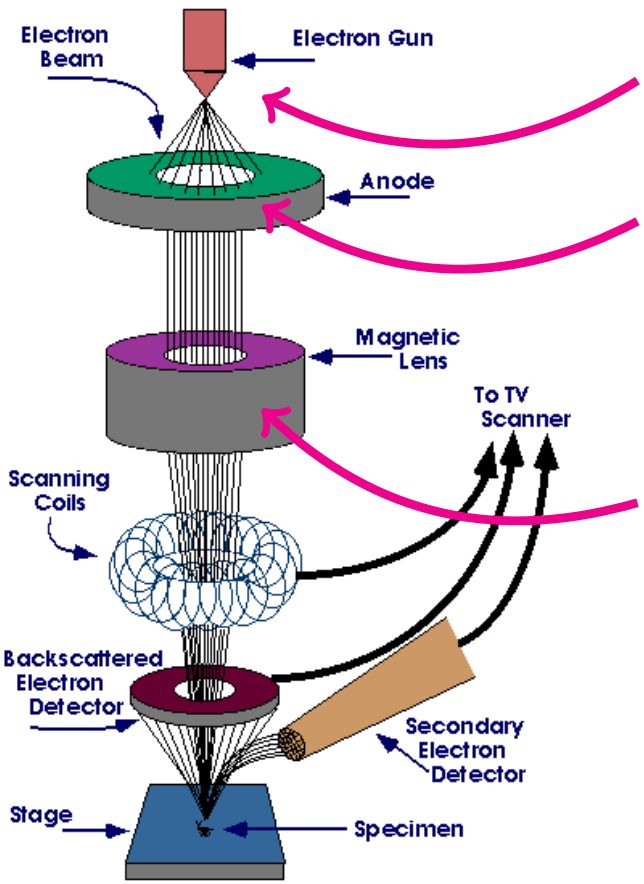

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focusing in the magnetic field

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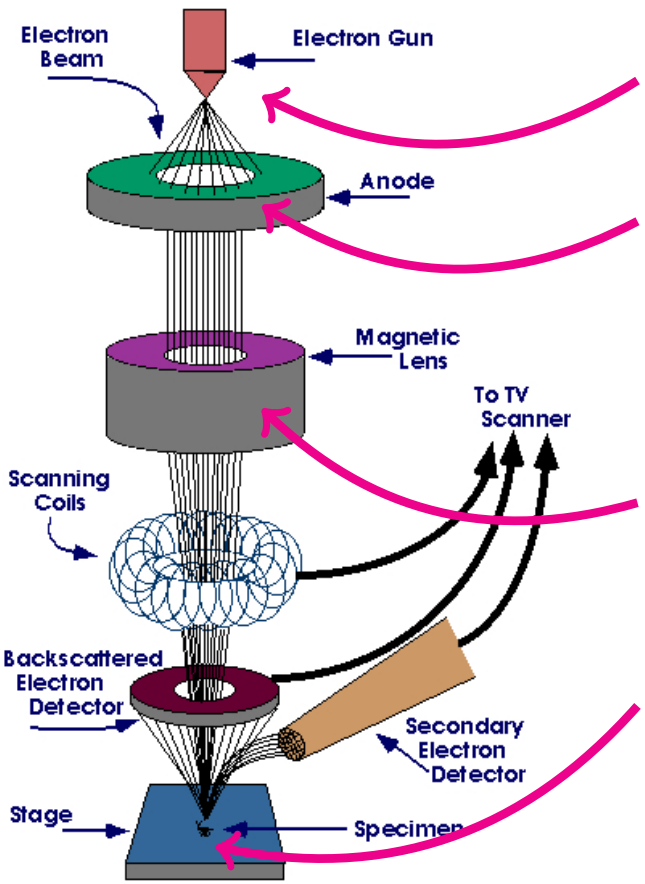

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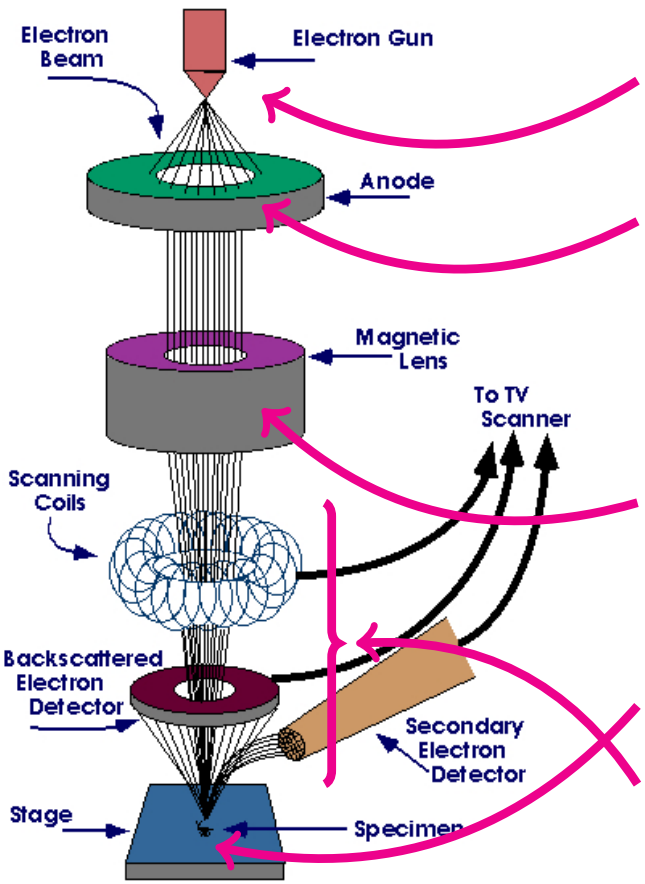

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data readout

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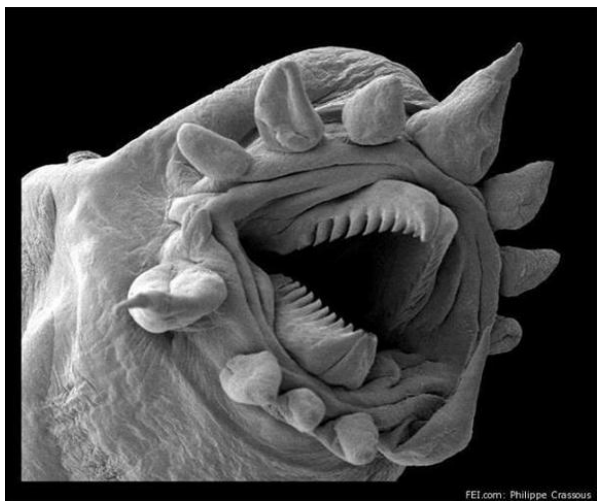


Conseil **E**uropen pour la **R**echerche **N**uclaire
European Organization for Nuclear Research

CERN:

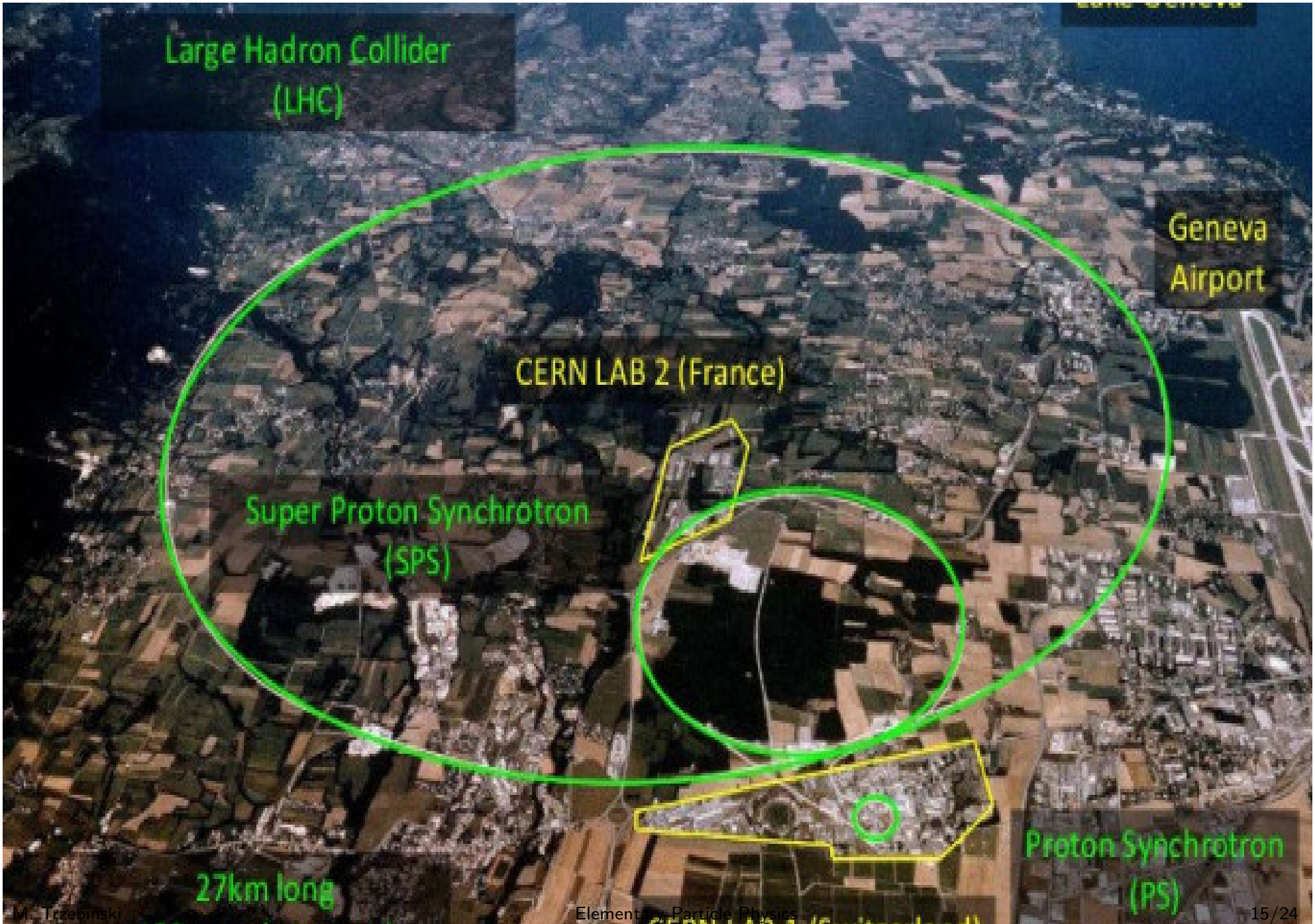
- created: 29 September 1954 (decided in 1952),
- the biggest lab in the world devoted for fundamental research,
- $\sim$2600 employees and $\sim$13000 users (scientists and engineers) from all over the world,
- side 'technologies': www, touch screen, ...

(Some) scientific equipment:

- accelerators: Proton Synchrotron, Super Proton Synchrotron, Large Hadron Collider,
- LHC detectors[1]: ATLAS, CMS, ALICE, LHCb, TOTEM, LHCf, MoEDAL.

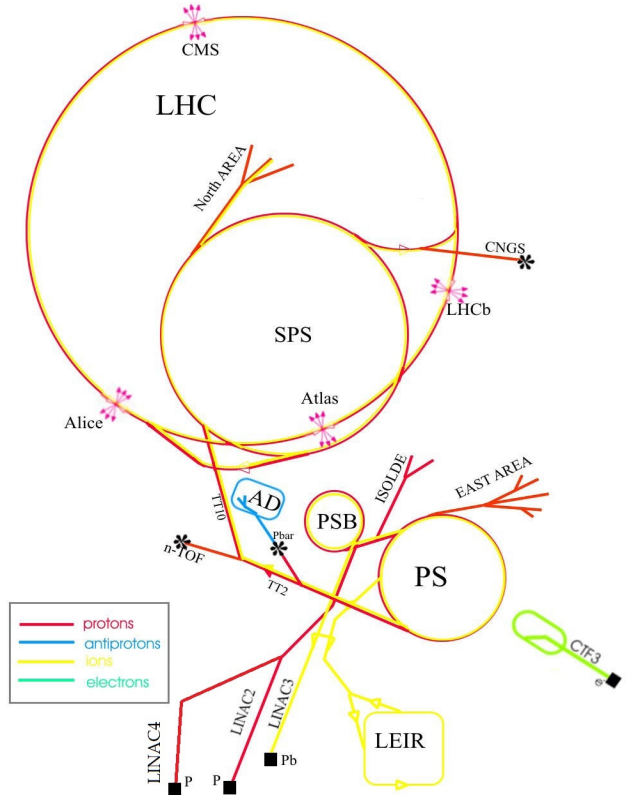
[1] At CERN we have about 60 other experiments: e.g. COMPASS, NA61/SHINE, ...

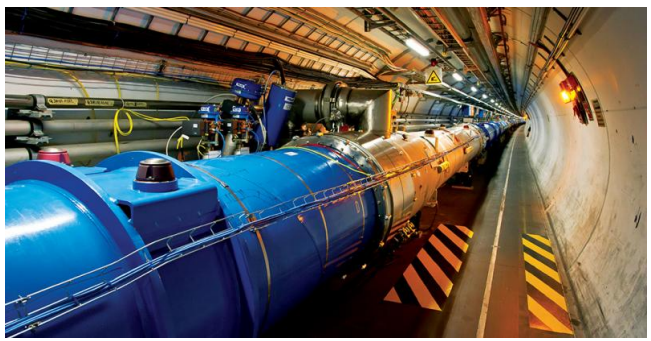
CERN – **C**onseil **E**uropen pour la **R**echerche **N**uclaire



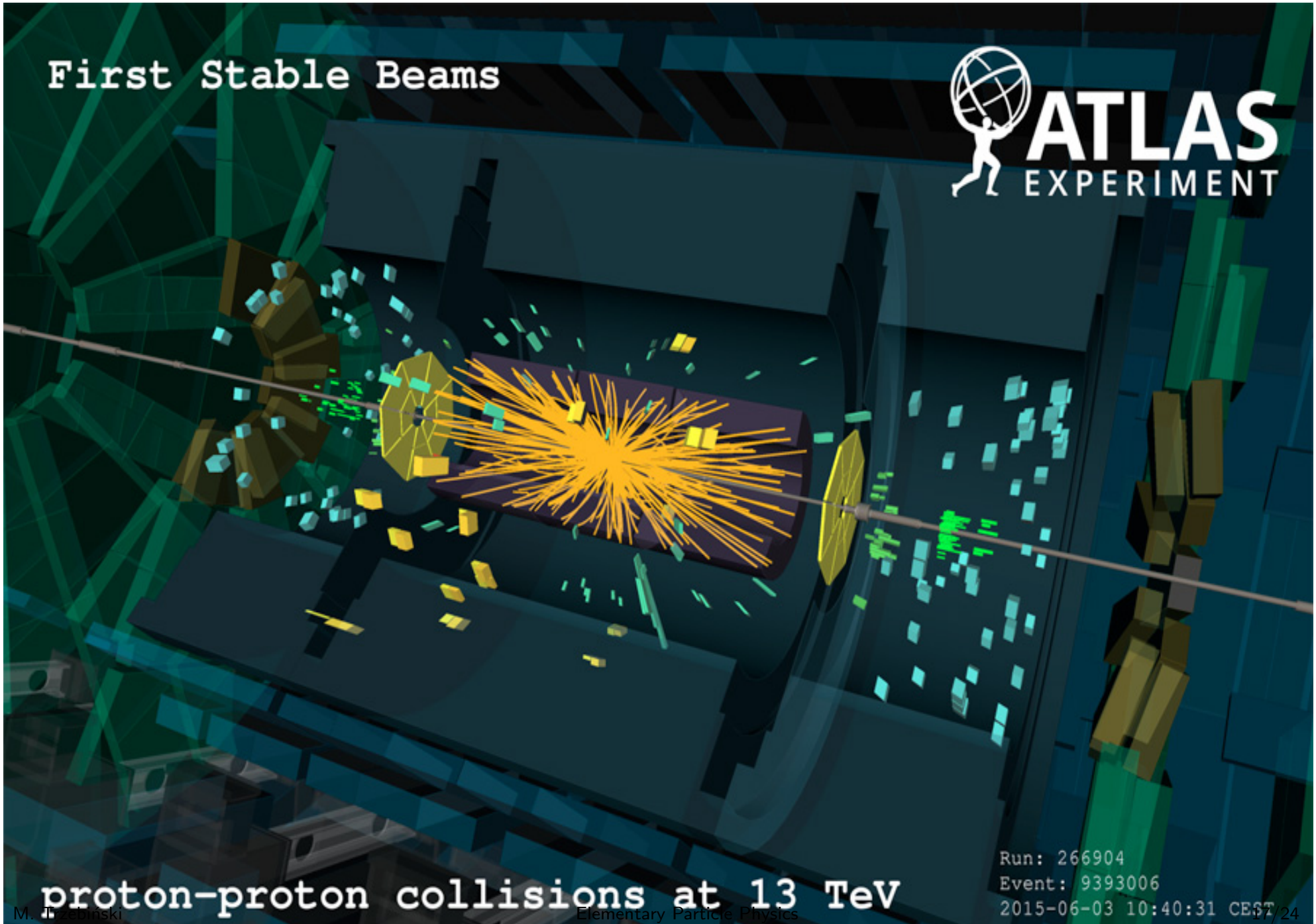
Large Hadron Collider

- The most powerful accelerator built (so far): 27 km of circumference.
- Started in 2008.
- Superconducting electromagnets: 1232 dipoles and 858 quadrupoles.
- Temperature of magnets: 1.9 K (-271.3 ^{0}C).
- Magnetic field: (up to) 8.33 T.
- Ultra-high vacuum 10^{-13} atm.
- Accelerates protons to 14 TeV or heavy ions to 2.76 GeV/nucl.
- Particles are accelerated to $0.999999991 \times c$.
- Discovery of the Higgs boson by ATLAS and CMS experiments $\rightarrow$ Nobel prize for Francois Englert and Peter Higgsa in 2013.



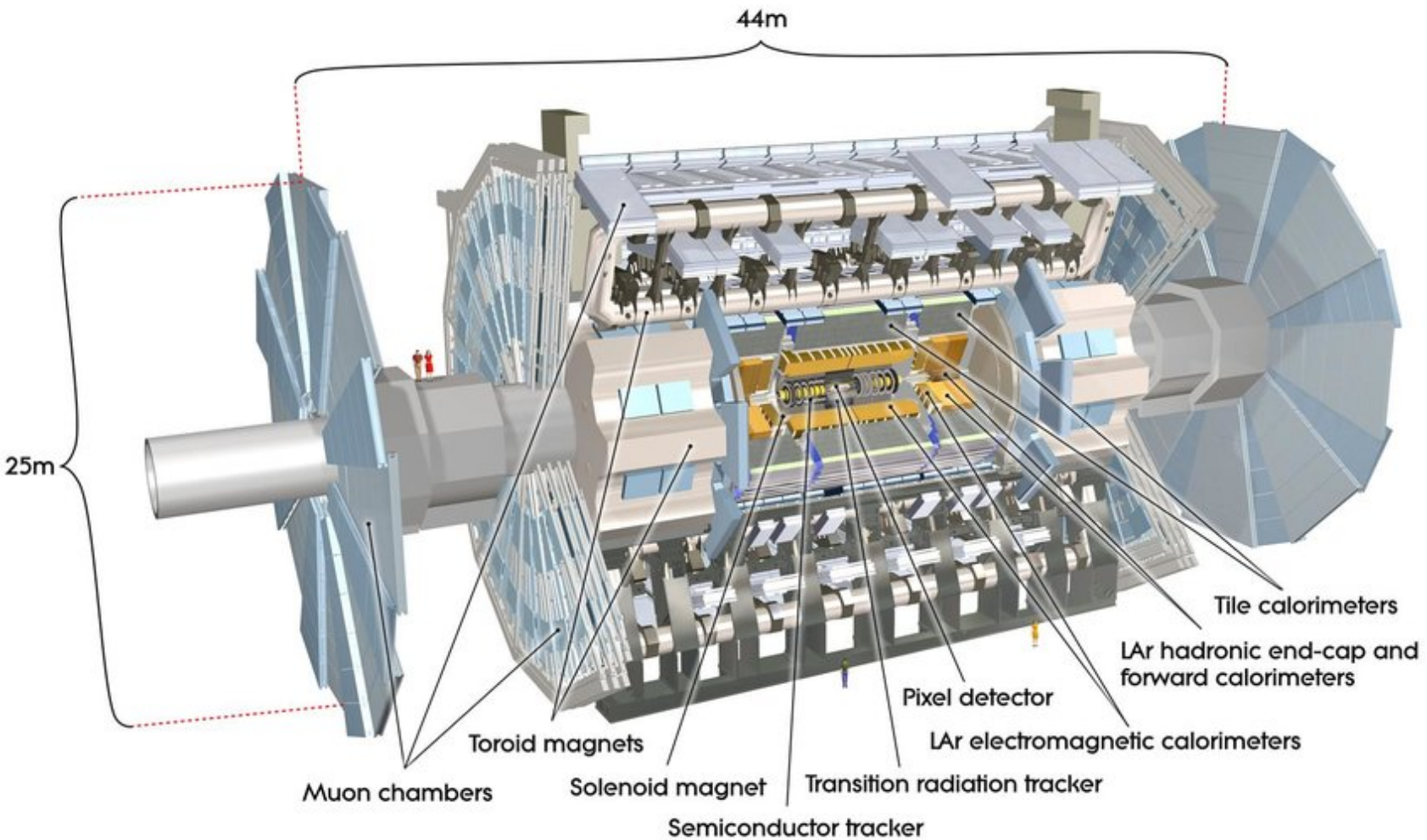


Particle Collisions



Particle Detectors (on example of ATLAS@LHC)

Usually huge, but very precise equipment:



composed of sub-detectors.

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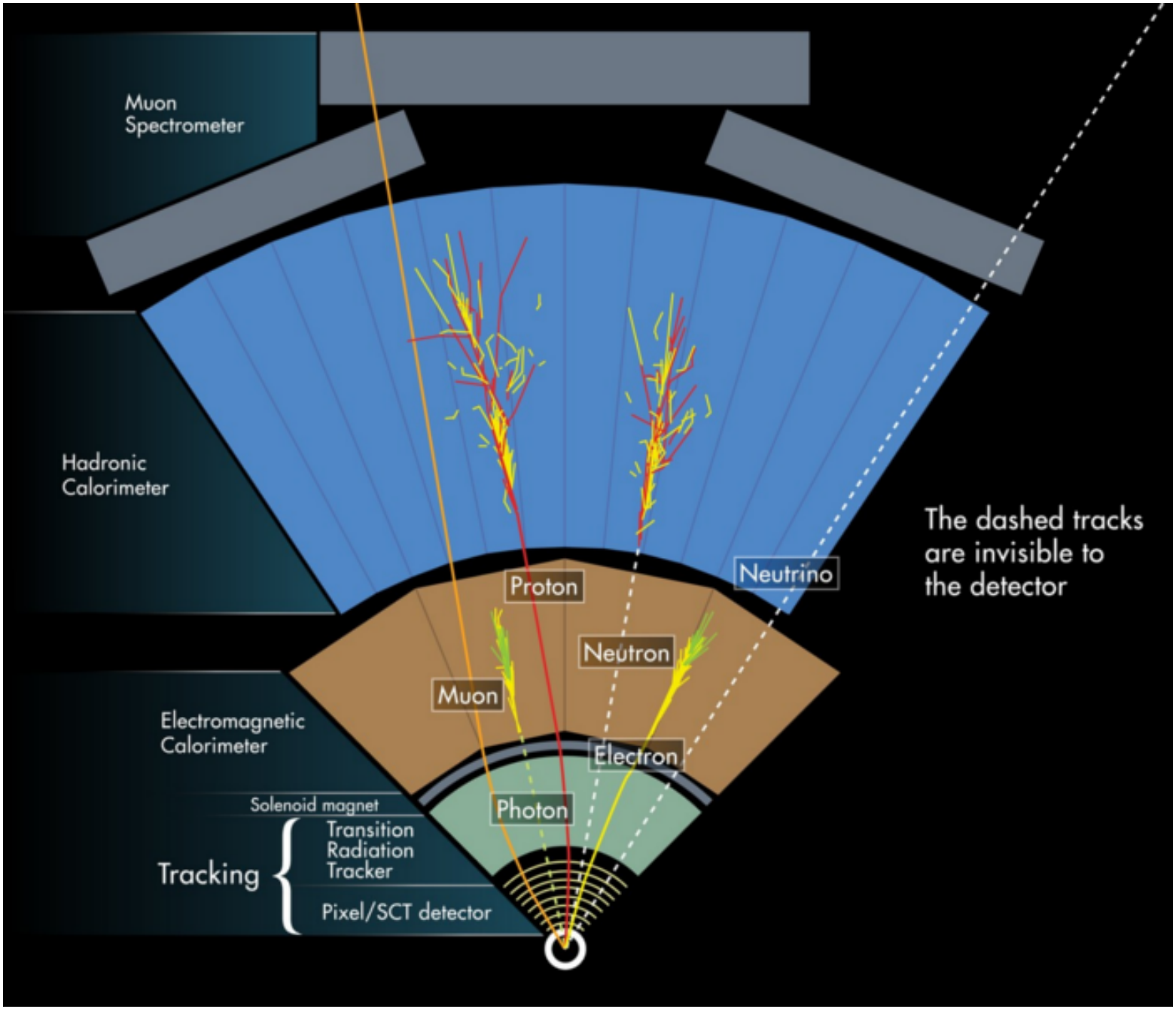
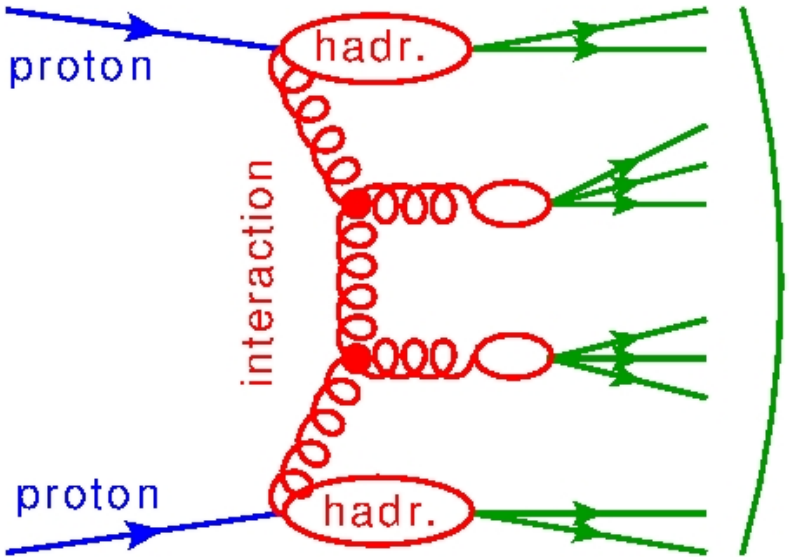


Interaction Point

how we **describe** the interaction



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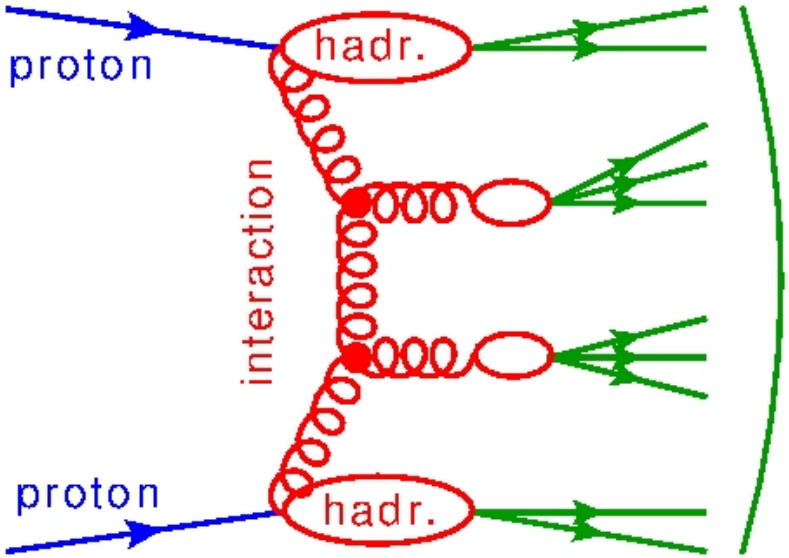

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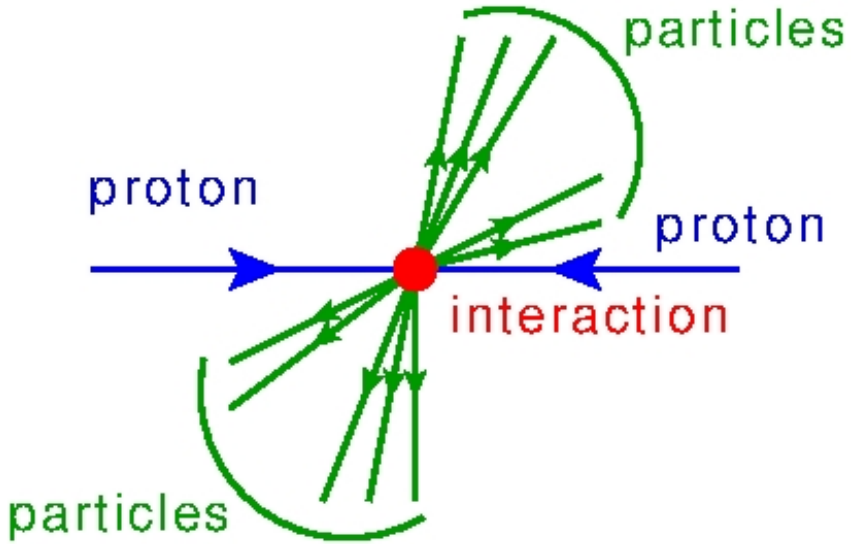

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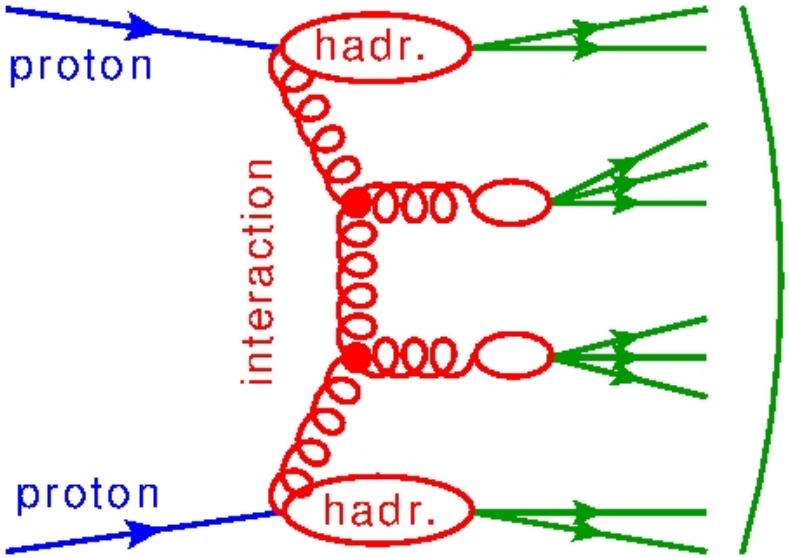

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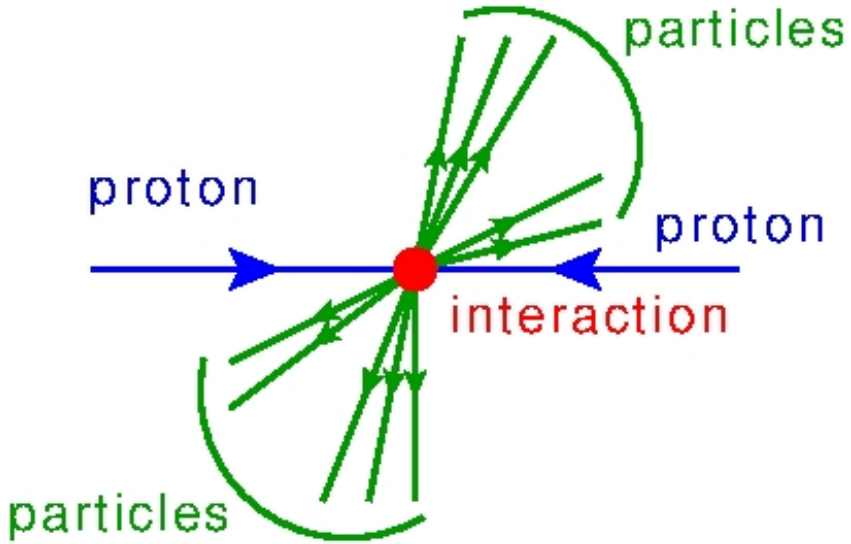

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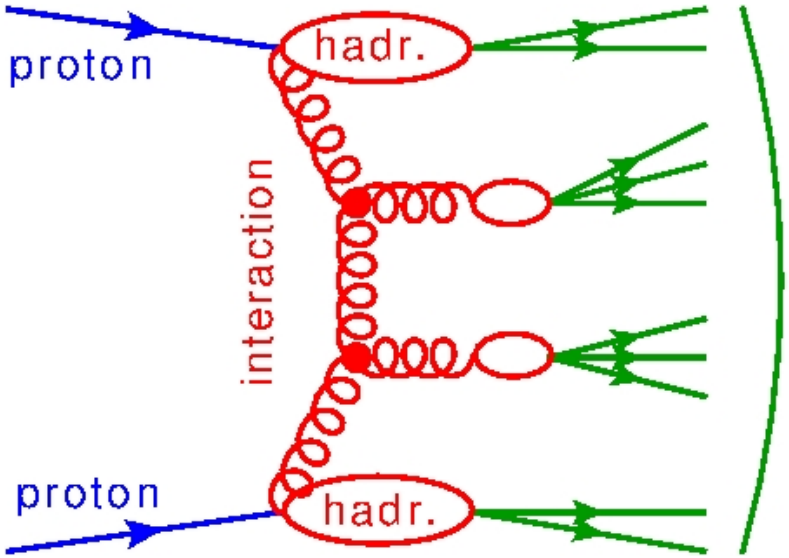

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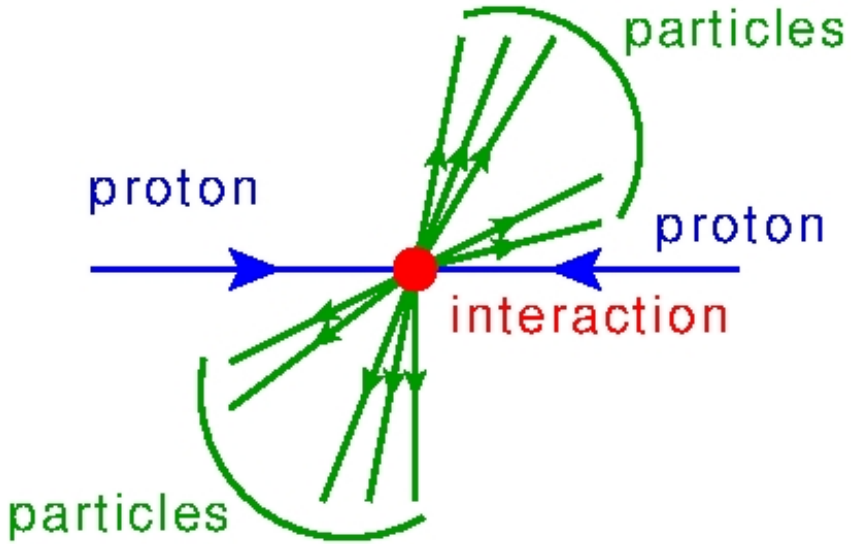

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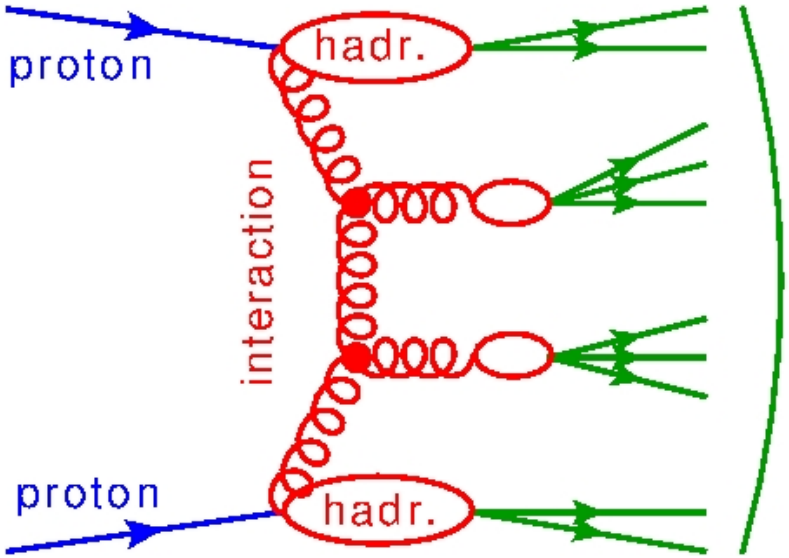

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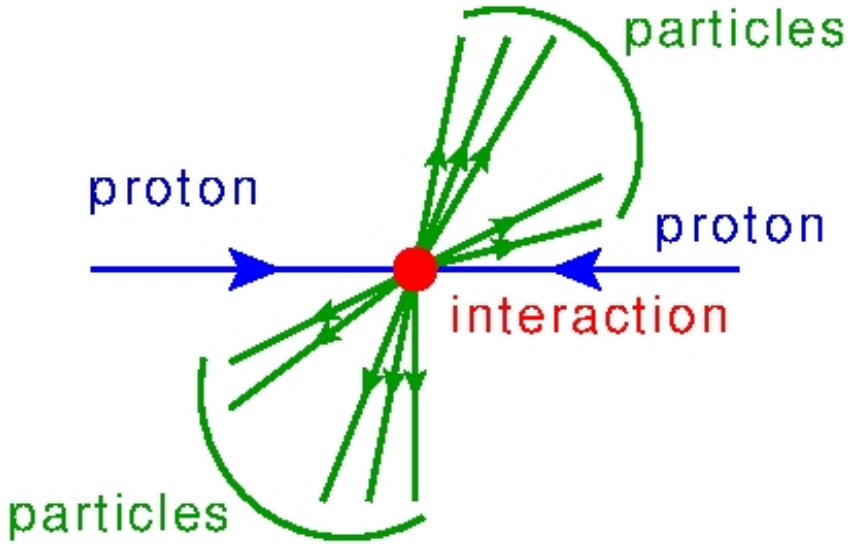

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BUT

by studying behaviour and properties of products we can make conclusions.

Example: Higgs Boson Search

Lets assume that based on theoretical predictions we would like to find a Higgs boson decaying into four muons.

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Please note that this is a VERY simplified view – just to give you an idea!

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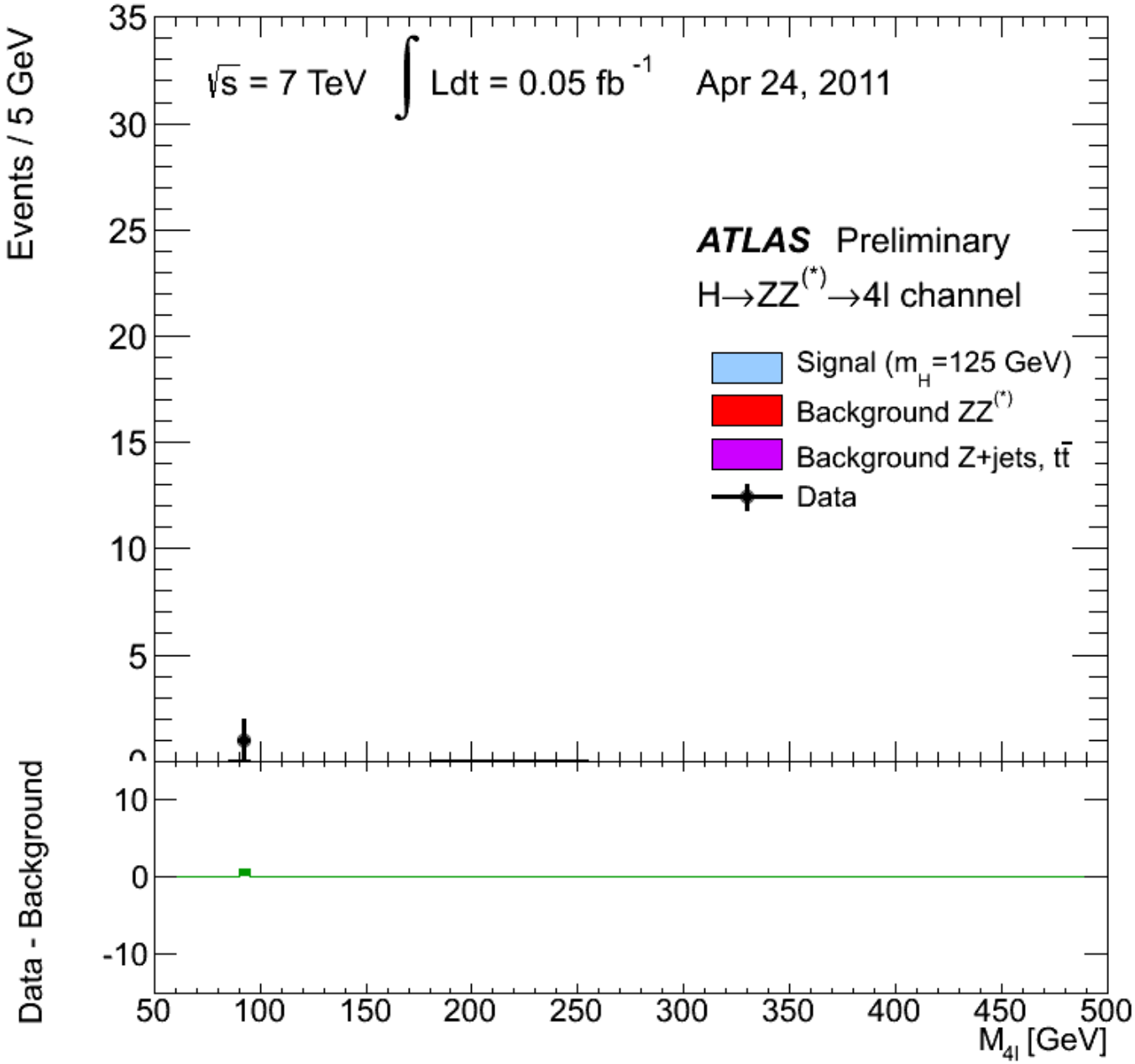

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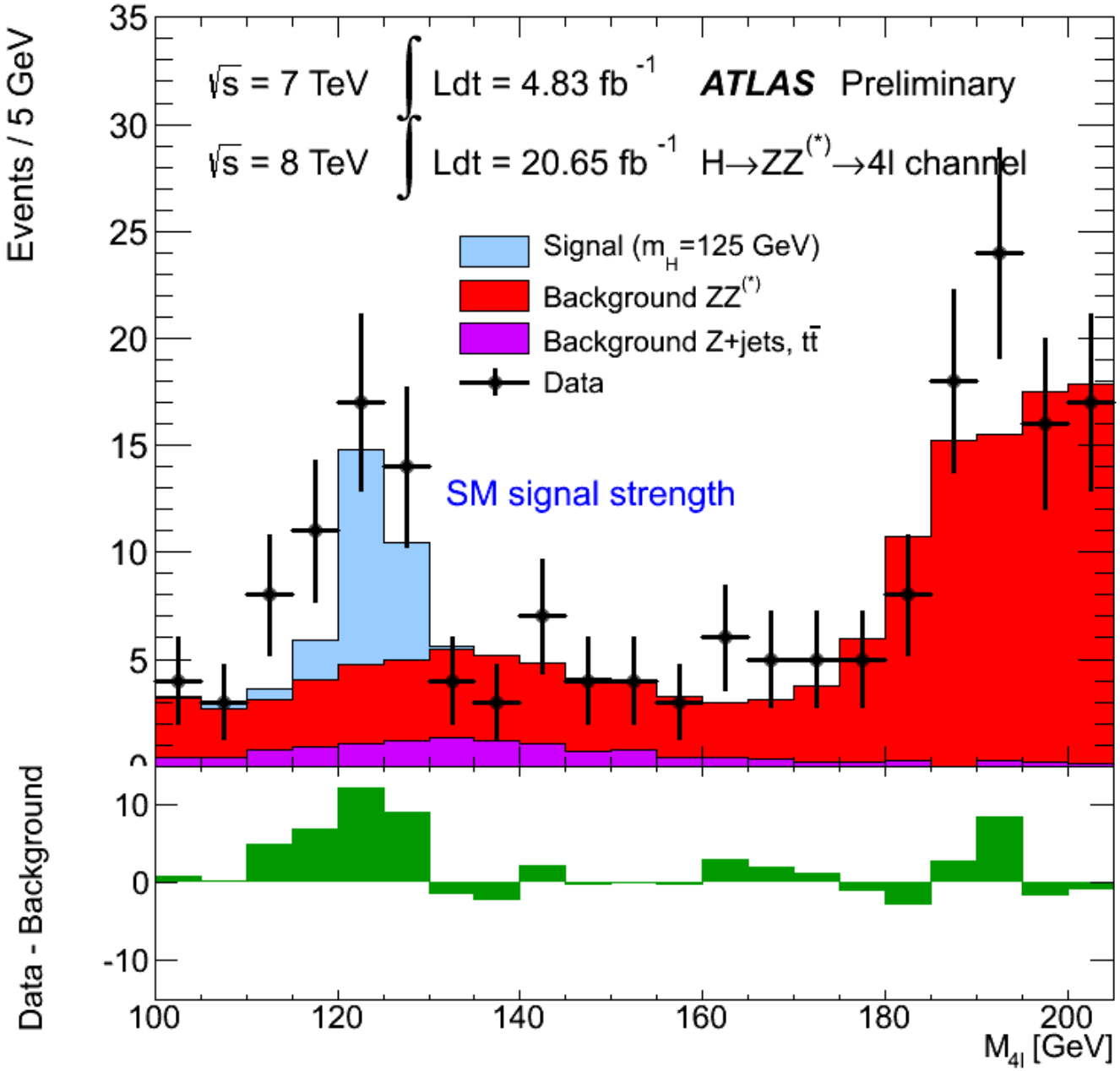
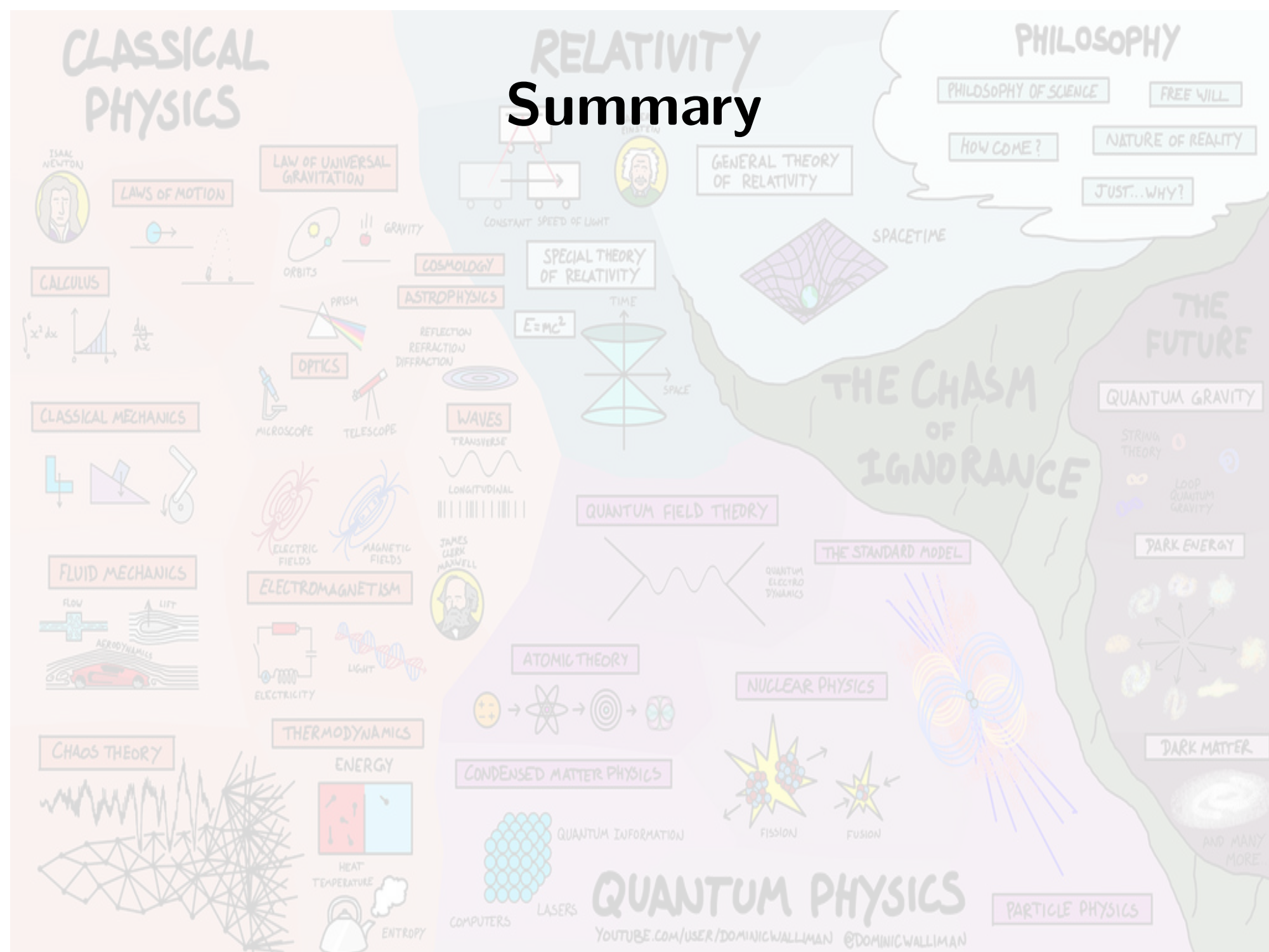


Summary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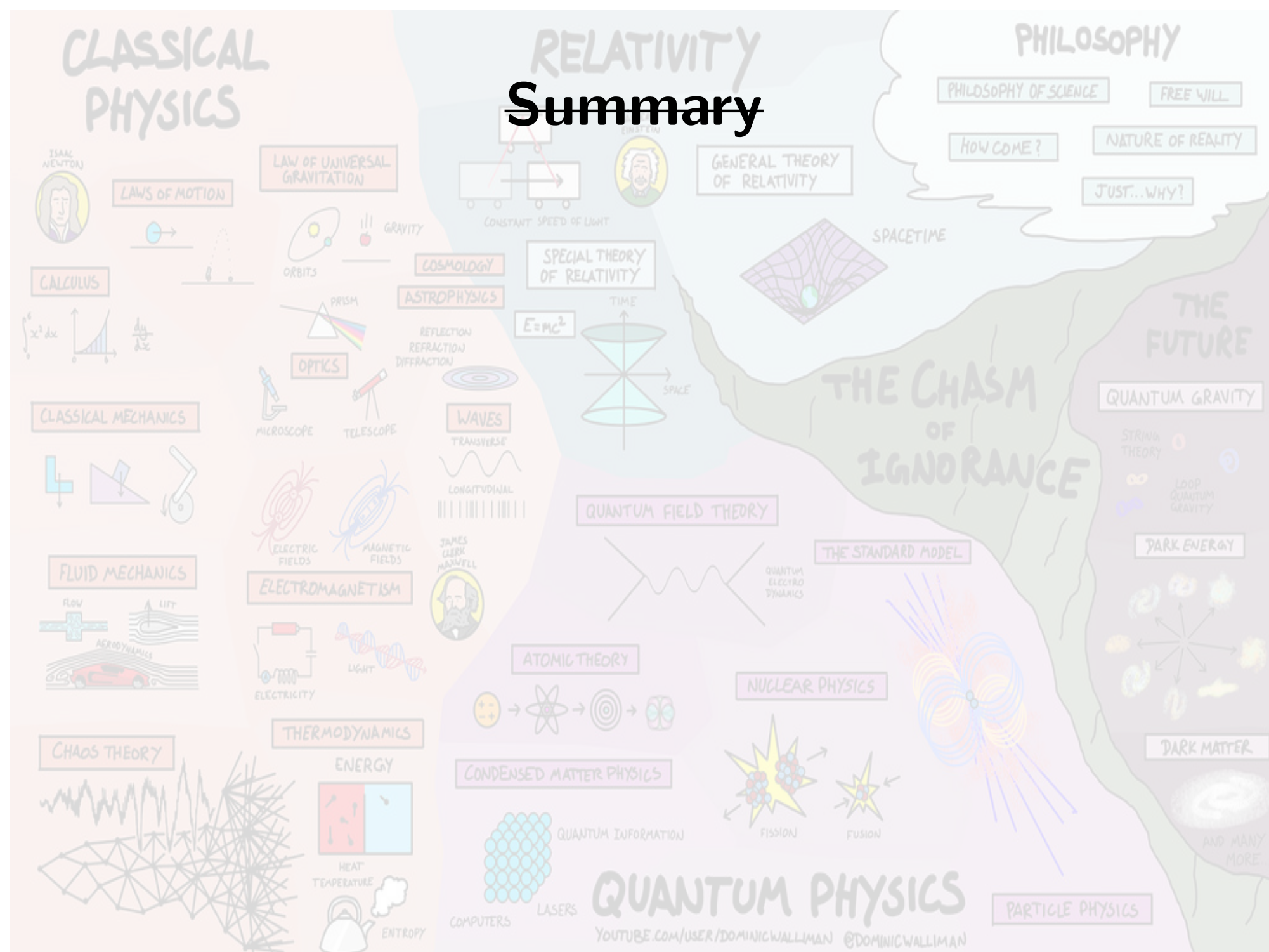
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PARTICLE PHYSICS

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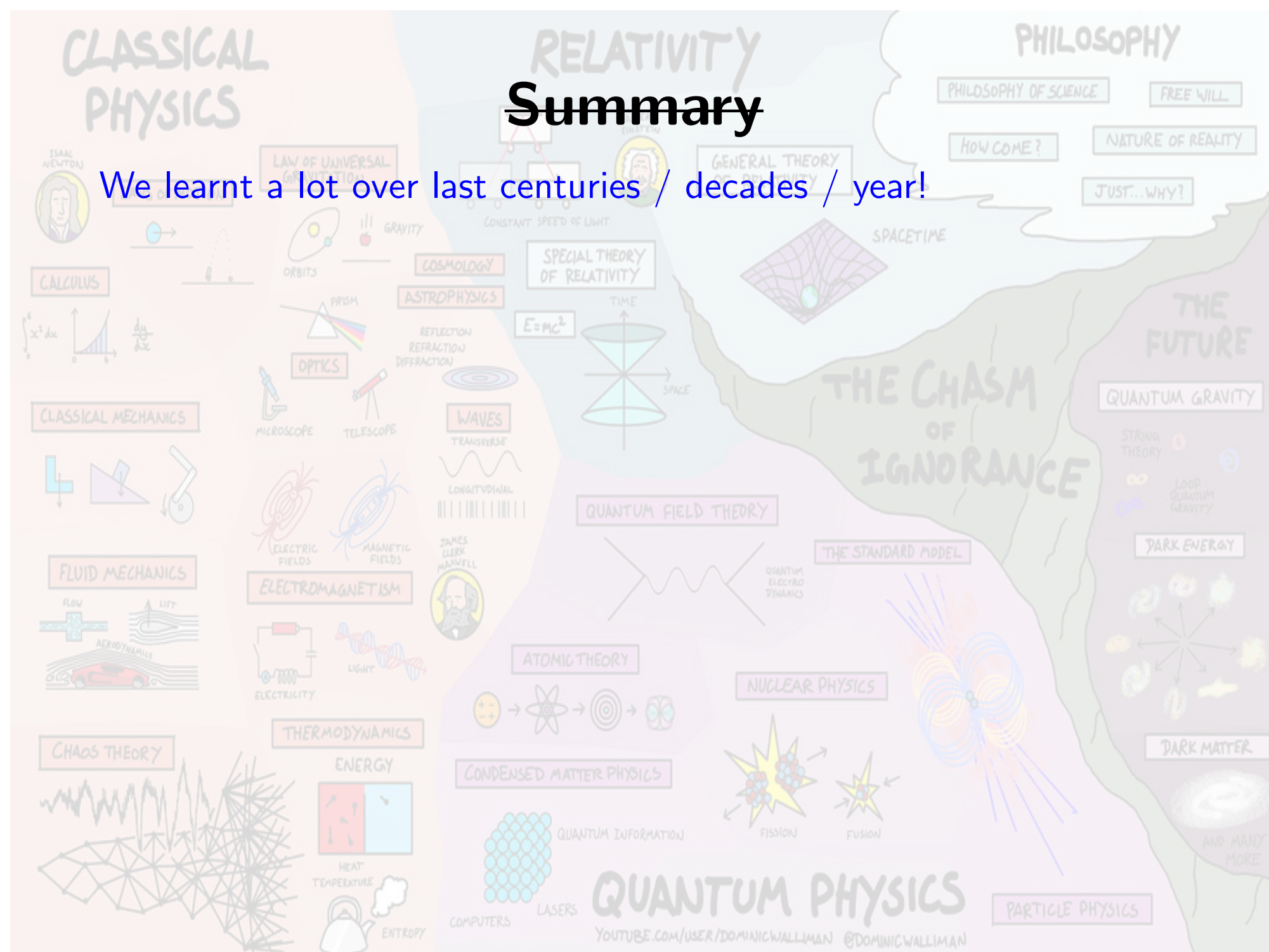

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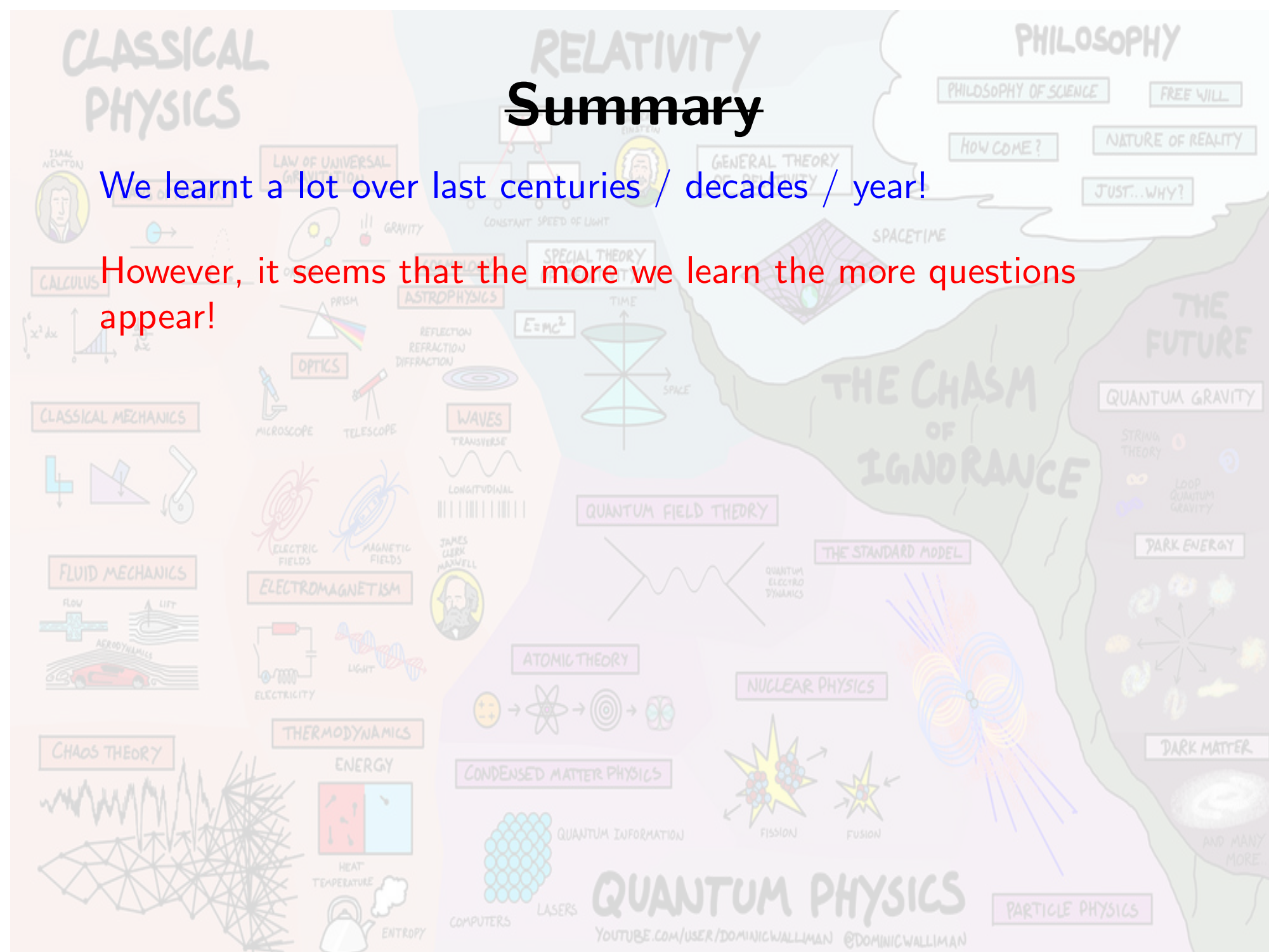
However, it seems that the more we learn the more questions appear!



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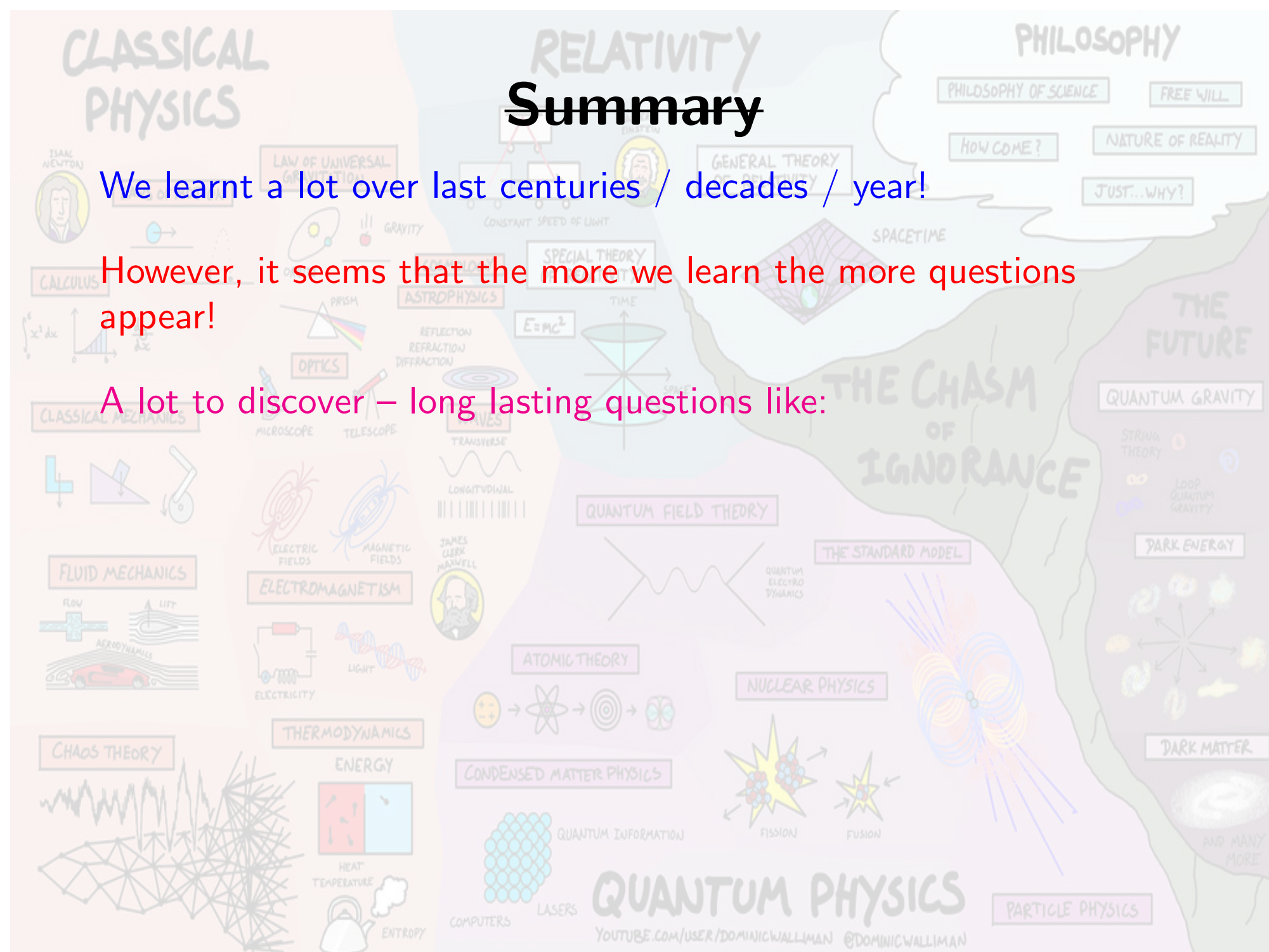

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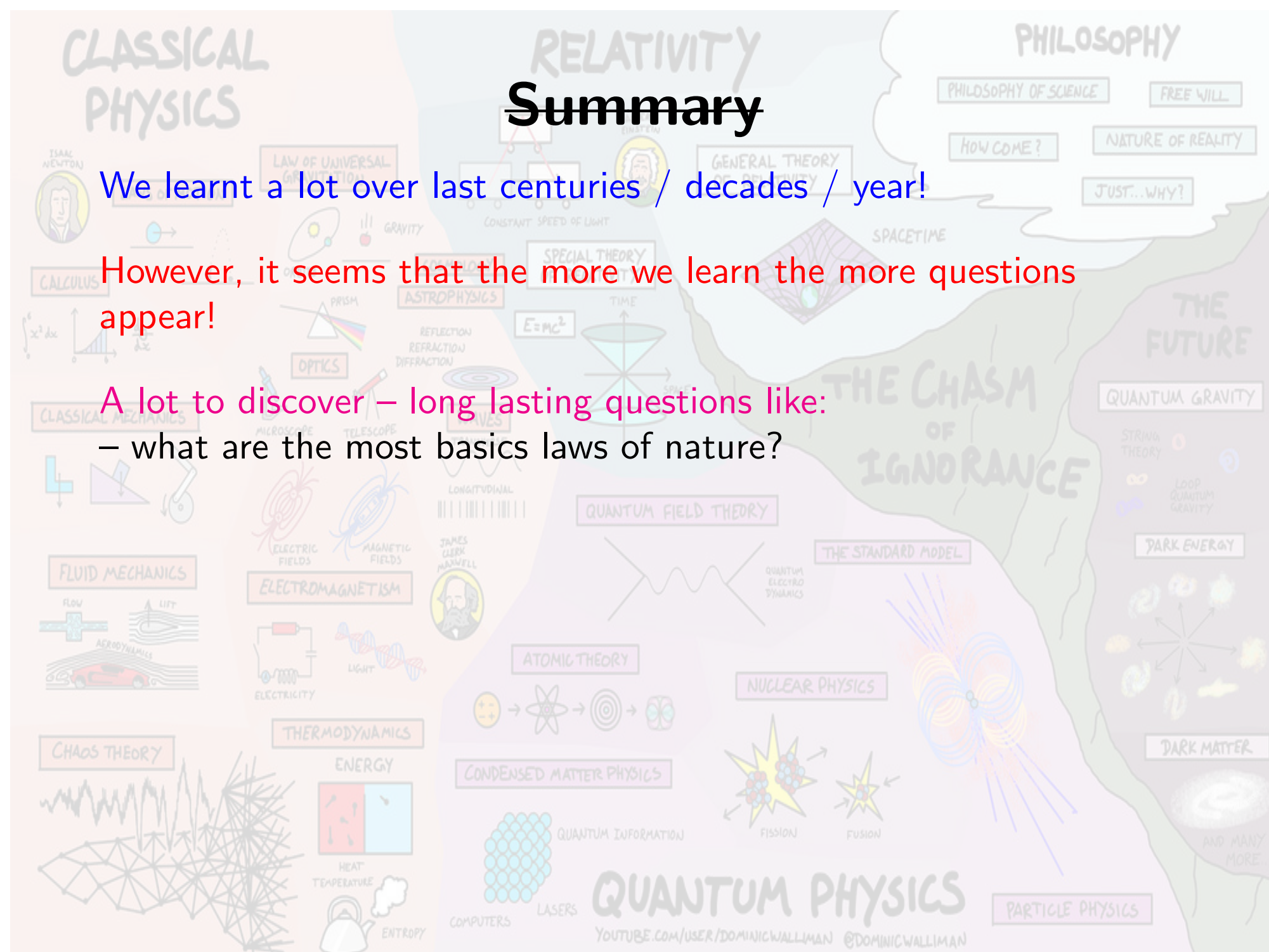
A lot to discover – long lasting questions like:

– what are the most basics laws of nature?



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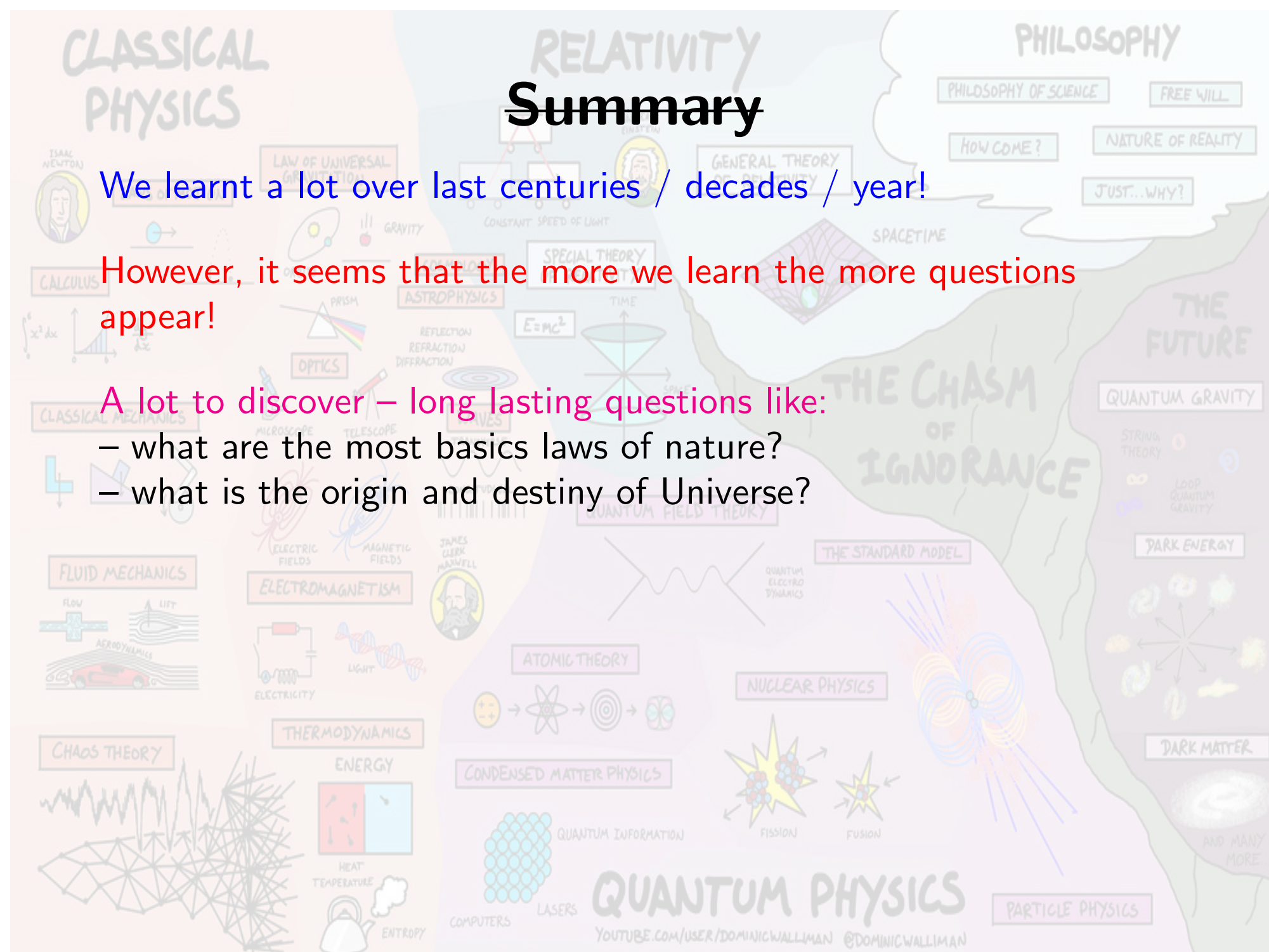

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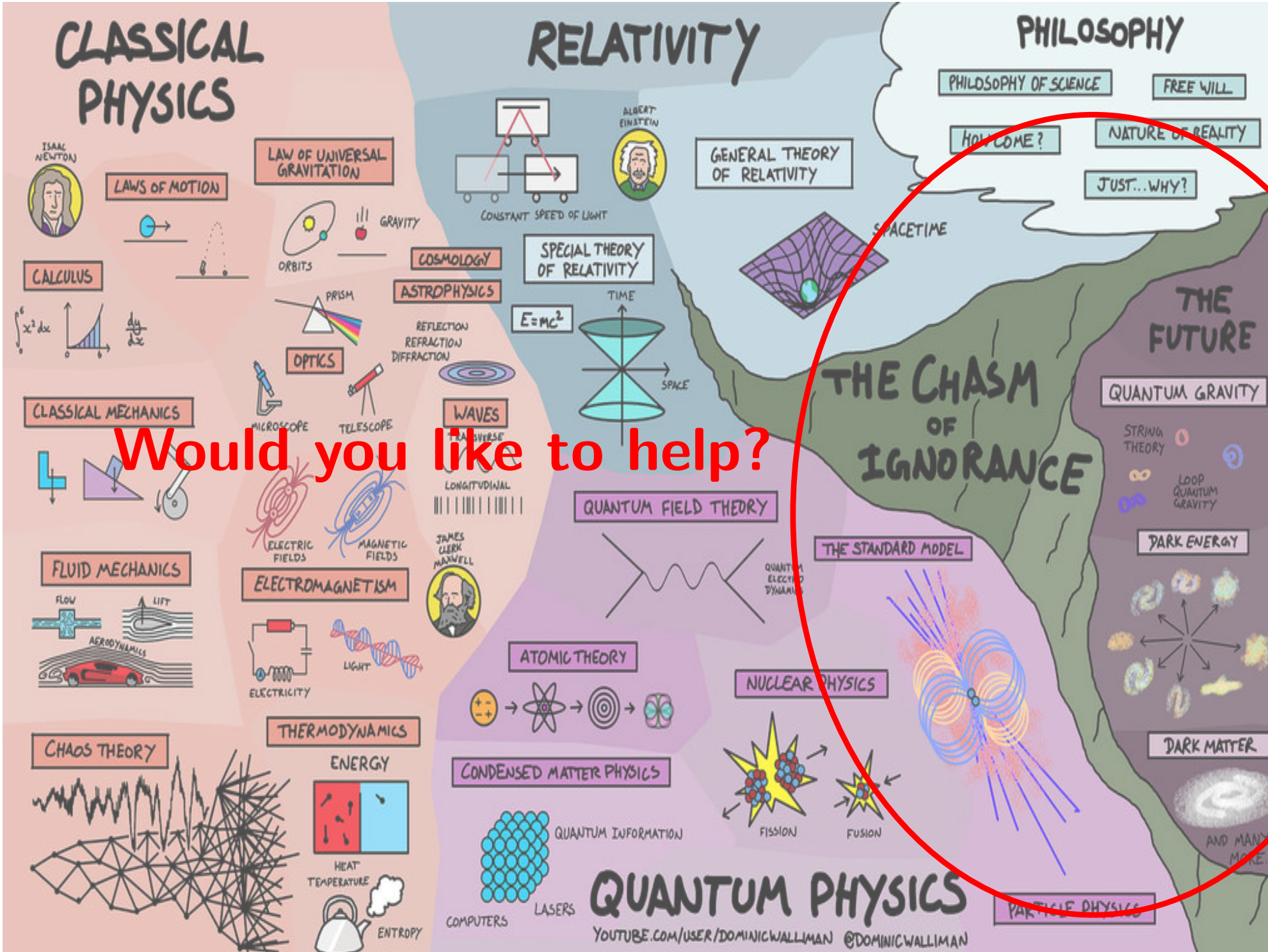
Tools: particle accelerators and detectors.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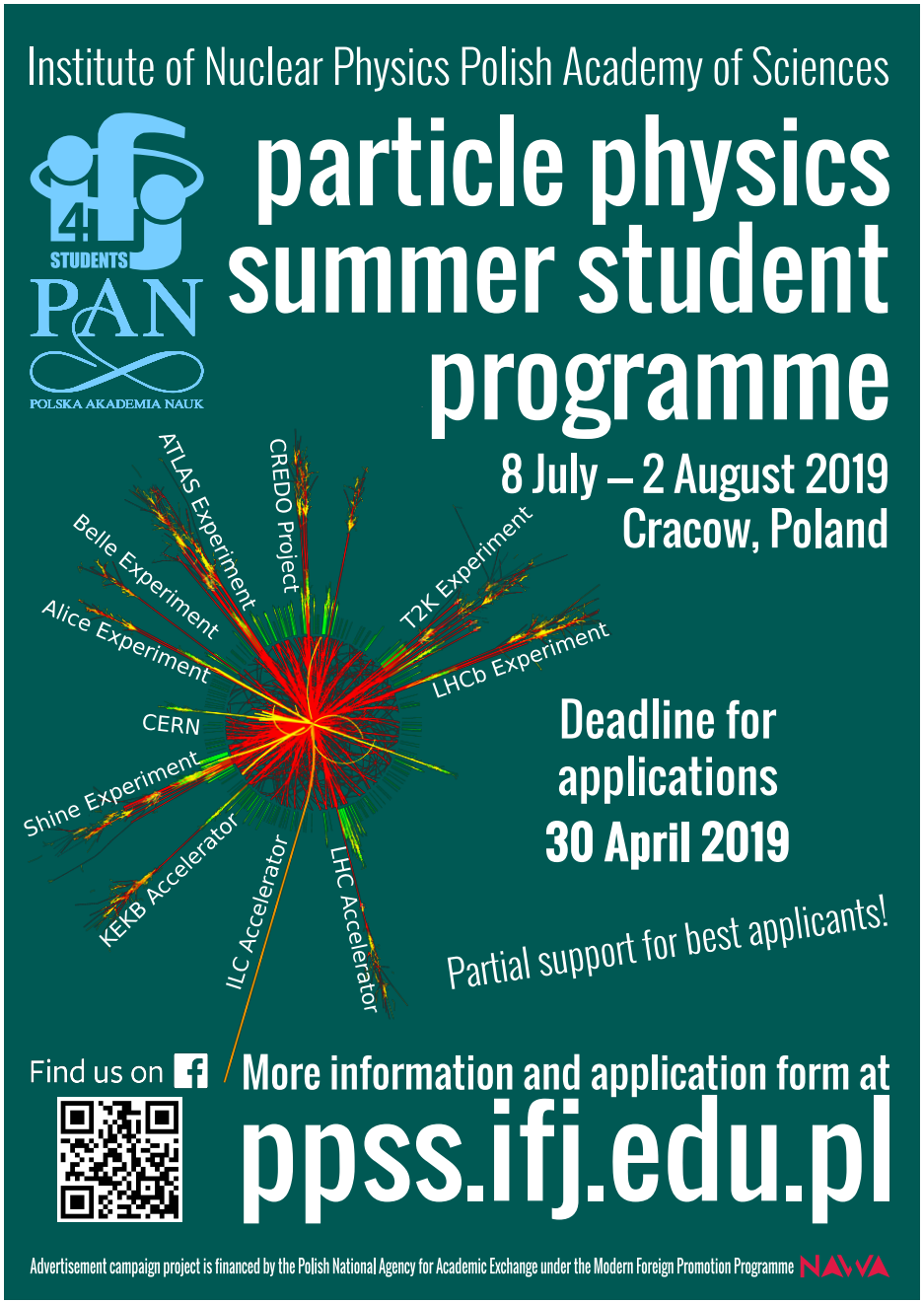

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