
**INSPYRE 2023**

**Catalina Curceanu**

**INFN-LNF, Frascati (Roma)**


INFN
INSPYRE
International School on Modern Physics and Research
FROM QUARKS TO BLACK HOLES:
LET'S GET INSPYRED!
Directors
Catalina Curceanu
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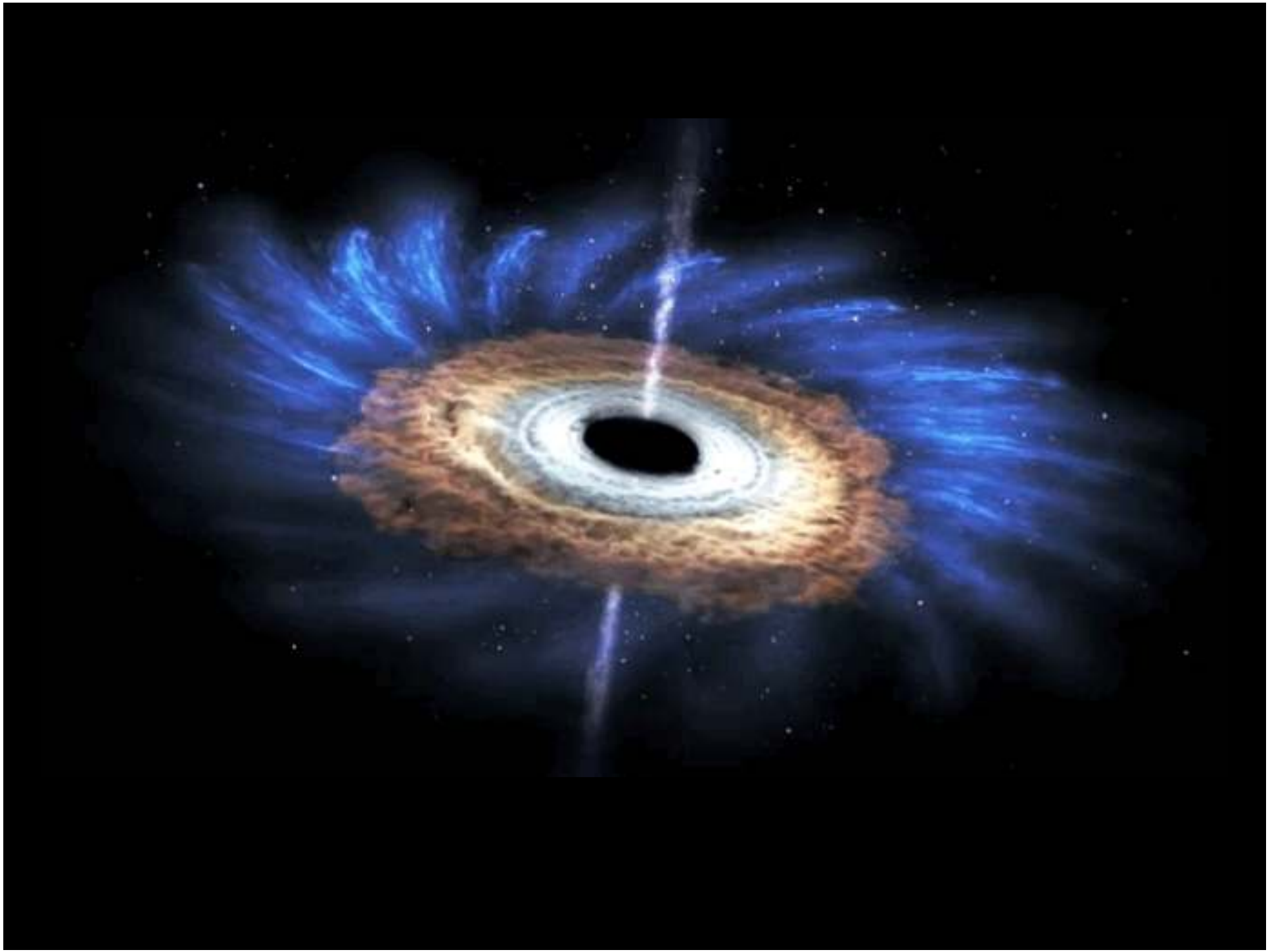


GIFsBOOM
.net


20°
22°
24°
26°
28°
30°
48°
46°
44°
0 50 100 mi
0 80 160 km
UKRAINE
Chernivtsi
Dorohoi
Satu Mare
Botoşani
Baia Mare
Borşa
Suceava
Debrecen
Câmpulung Moldovenesc
MOLDOVA
HUNGARY
Zalău
Oradea
Dej
Bistriţa
Piatra-Neamţ
Iaşi
Chişinău
Salonta
Cluj-Napoca
Reghin
Bicaz
Roman
Vaslui
Gheorgheni
Turda
Târgu Mureş
Bacău
ROMANIA
Aiud
Arad
Alba Iulia
Sighişoara
Oneşti
Bârlad
Mediaş
Sfântu Gheorghe
Deva
Sebeş
Făgăraş
Tecuci
UKRAINE
Timişoara
Lugoj
Sibiu
Hunedoara
Braşov
Săcele
Focşani
Galaţi
Petroşani
Reşiţa
Sinaia
Câmpulung
Brăila
Sulina
Rămnicu Târgu Vâlcea
Curtea de Argeş
Buzău
Tulcea
Făurei
Jiu
Ploieşti
Belgrade
Moldova Nouă
Piteşti
Târgovişte
Drobeta-Turnu Severin
Tăndărei
SERBIA
Bucharest
BLACK SEA
Slatina
Călăraşi
Medgidia
Năvodari
Craiova
Videle
Constanţa
Calafat
Alexandria
Giurgiu
Mangalia
Ruse
BULGARIA
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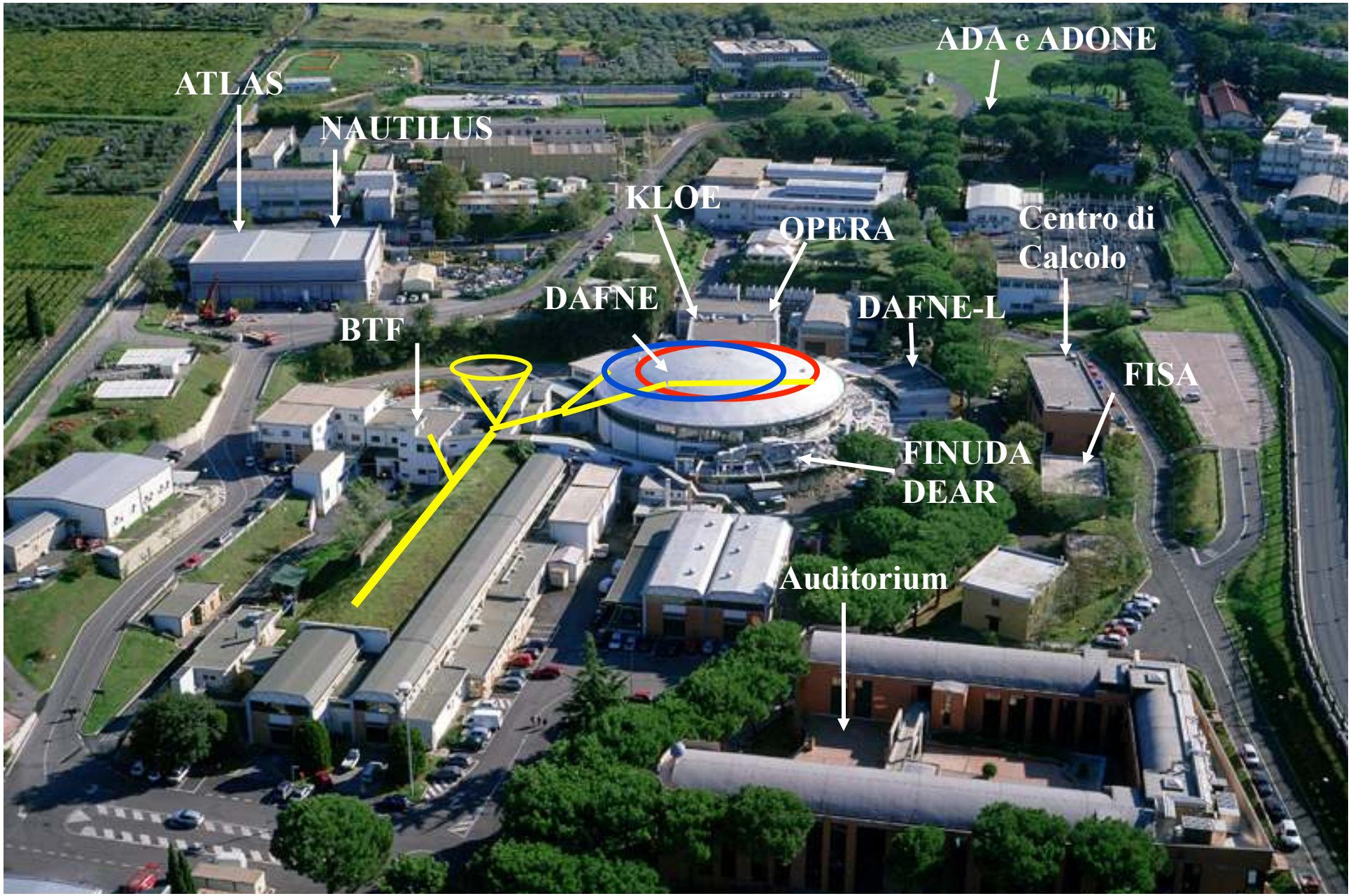
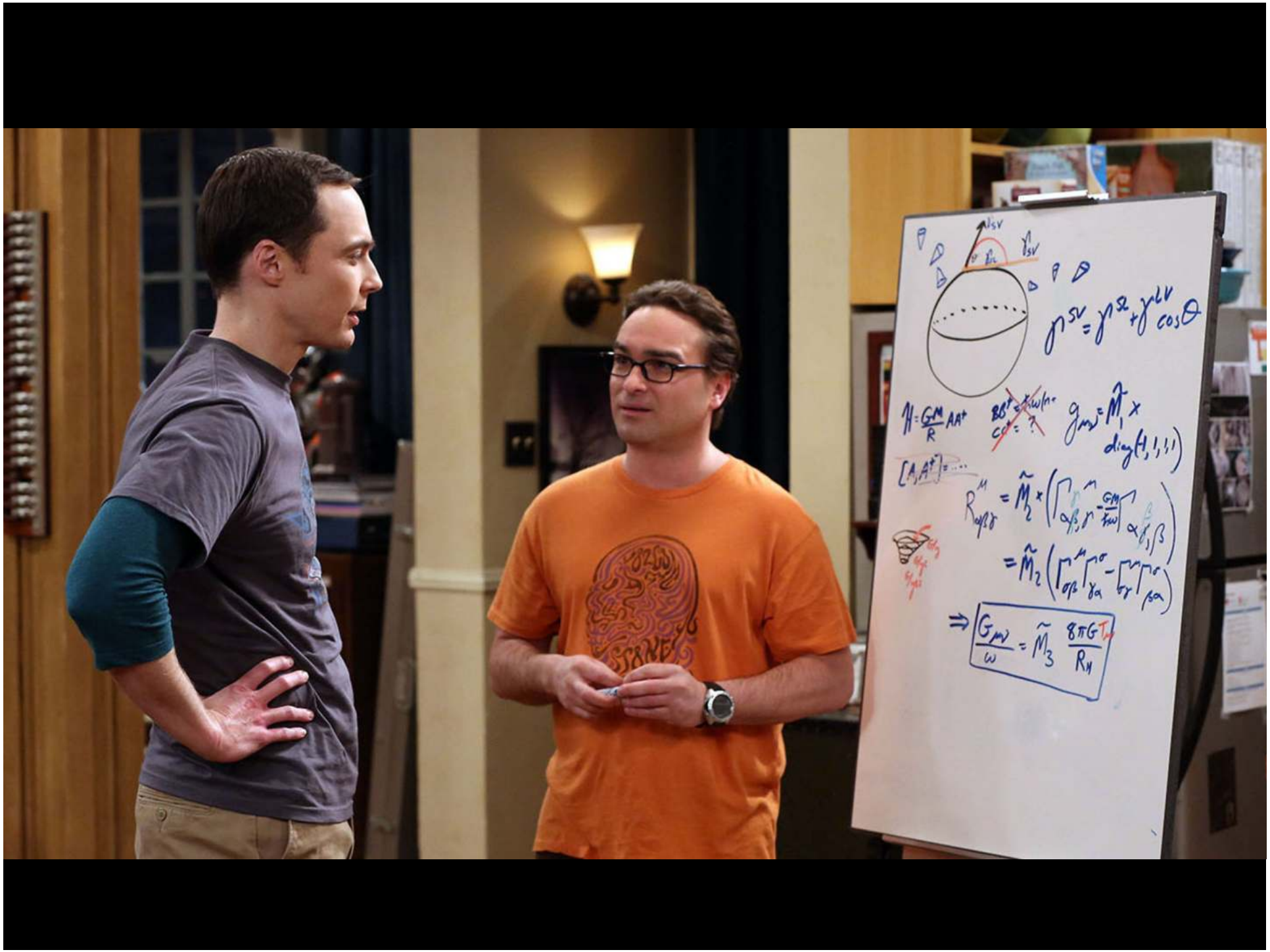
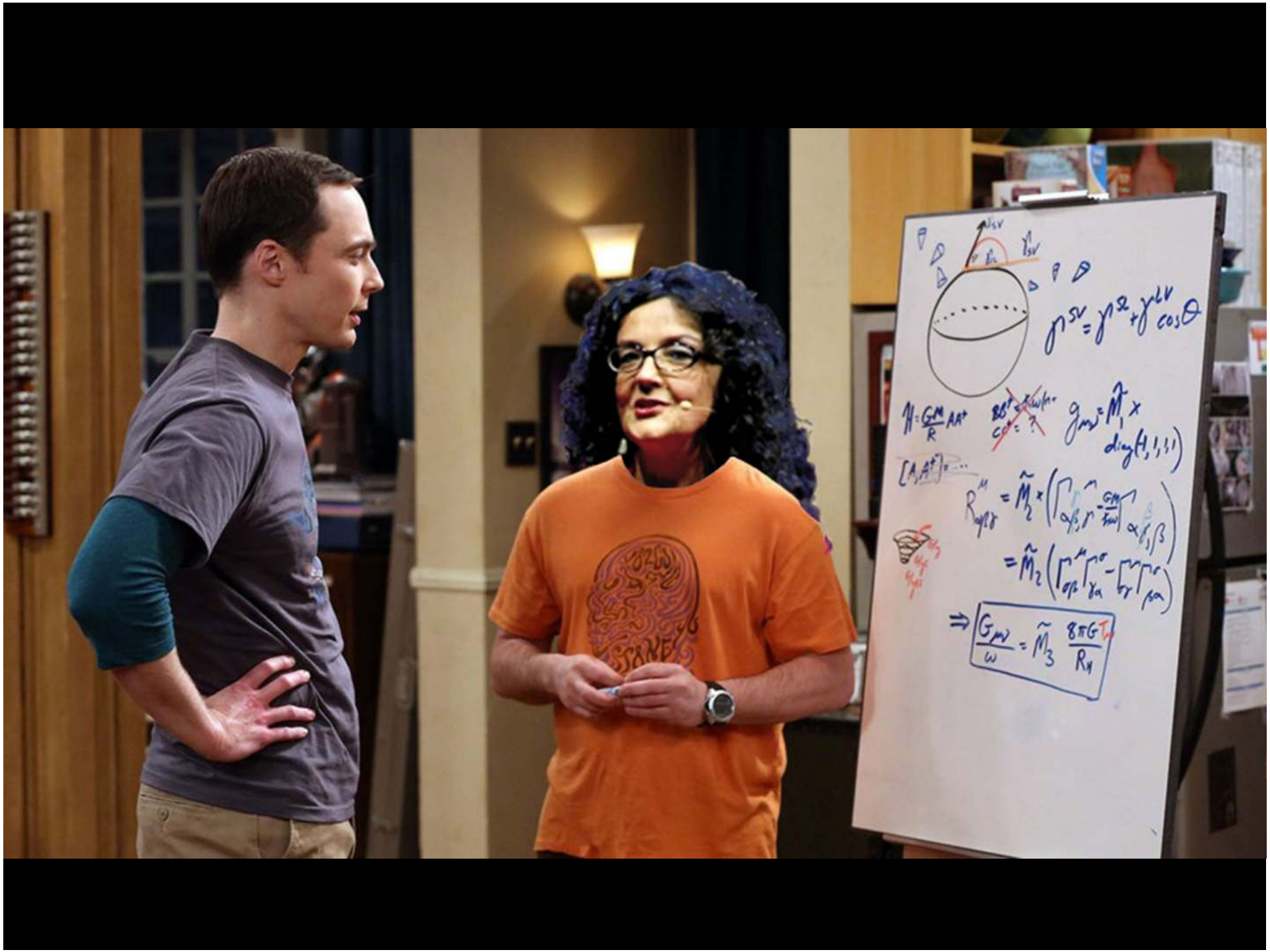
gifs.com

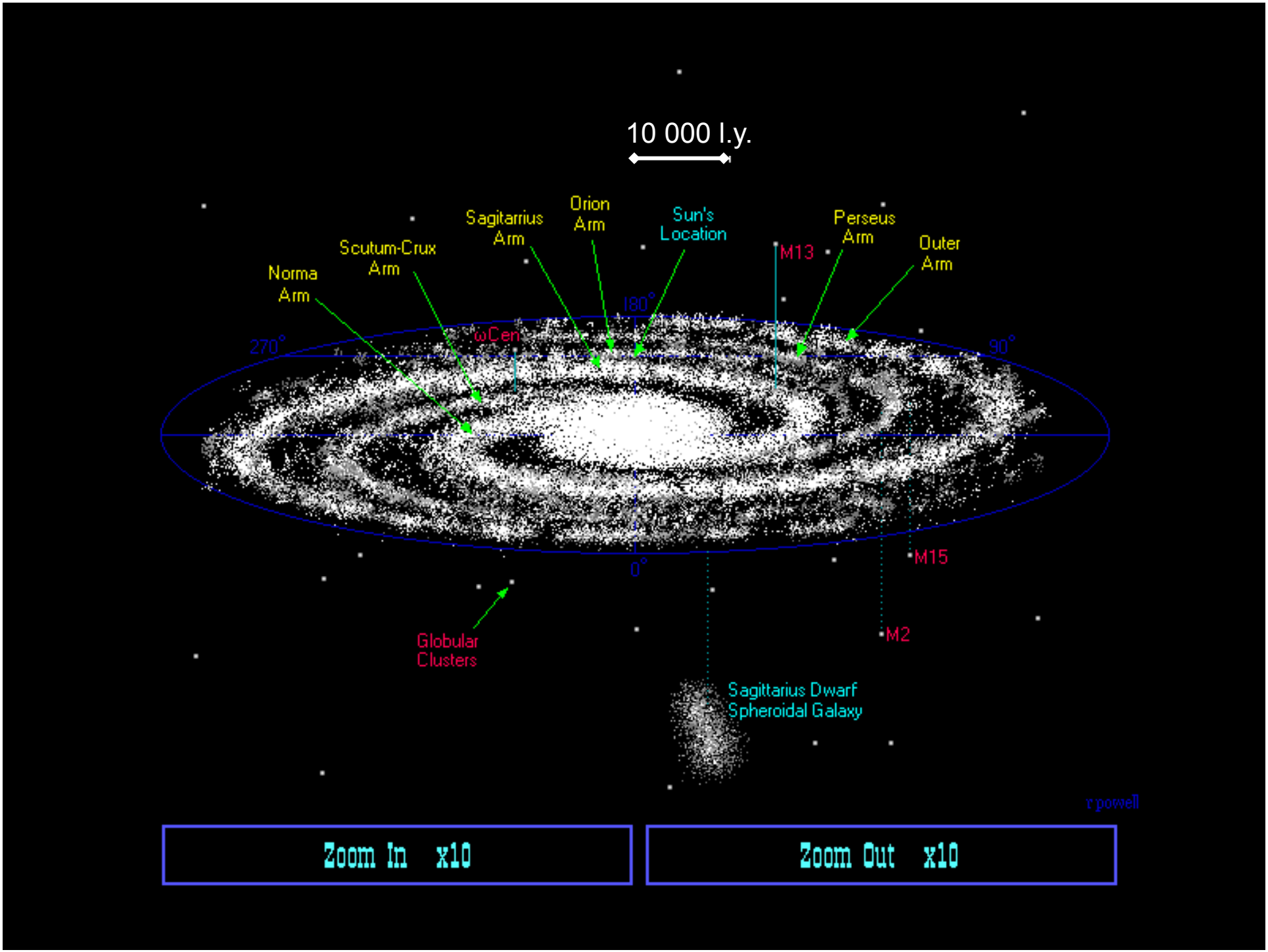
# *Laboratori Nazionali di Frascati*

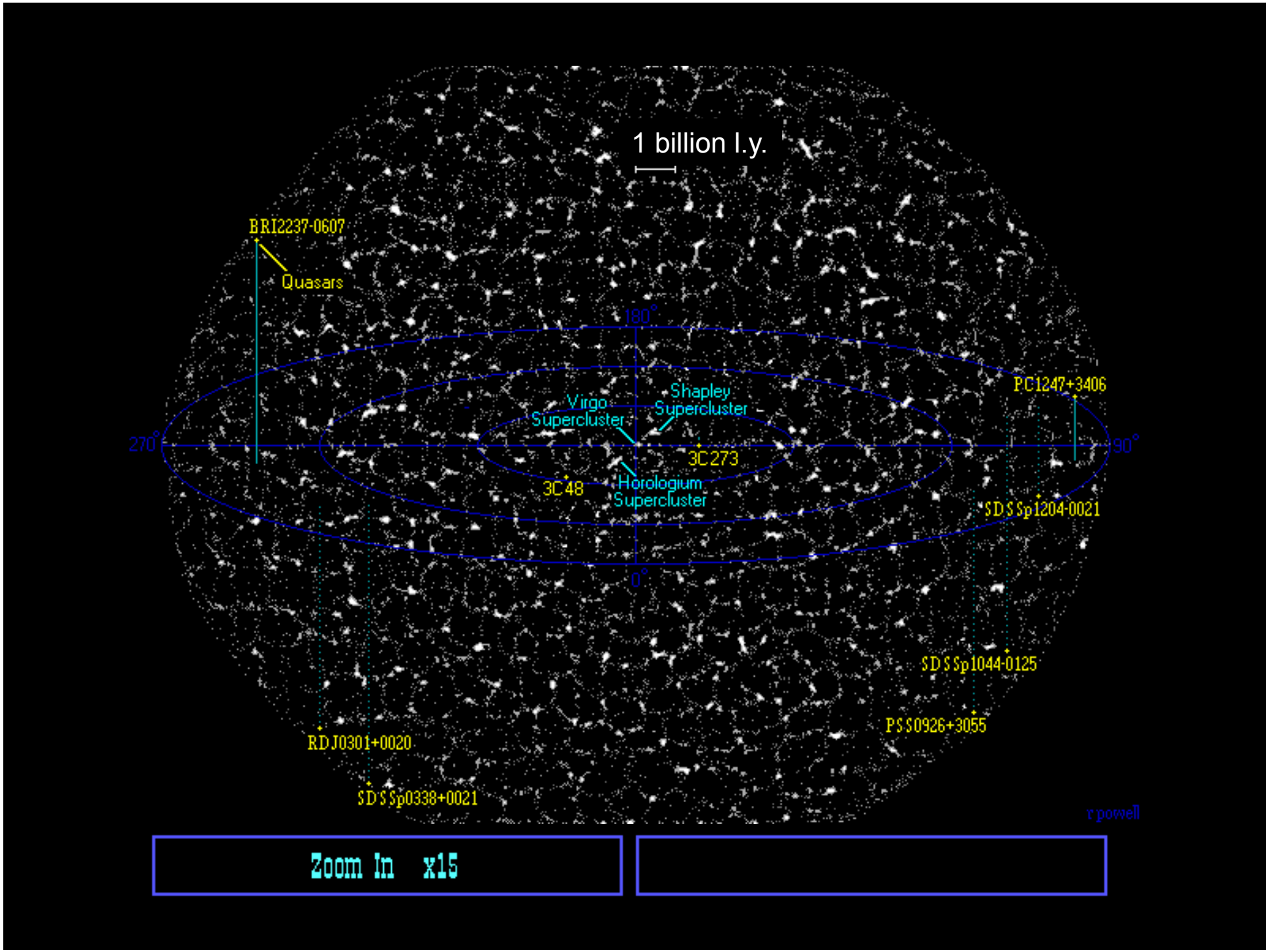



$g^{SV} = g^{\Omega} + g^{LV}\cos\theta$
$N = \frac{GM}{R} AA^{\dagger}$
$g_{\mu\nu} = \tilde{M}_1 \times \mathrm{diag}(1,1,1,1)$
$[A, A^{\dagger}] = \ldots$
$R^{\mu}_{\alpha\beta\gamma} = \tilde{M}_2 \times \left(\Gamma^{\mu}_{\alpha\beta,\gamma} - \frac{GM}{r_{sw}} \Gamma^{\alpha}_{\gamma\beta}\right)$
$= \tilde{M}_2 \left(\Gamma^{\mu}_{\sigma\beta}\Gamma^{\sigma}_{\gamma\alpha} - \Gamma^{\mu}_{\sigma\gamma}\Gamma^{\sigma}_{\beta\alpha}\right)$
$\Rightarrow \frac{G_{\mu\nu}}{\omega} = \tilde{M}_3 \frac{8\pi G T_{\mu\nu}}{R_H}$

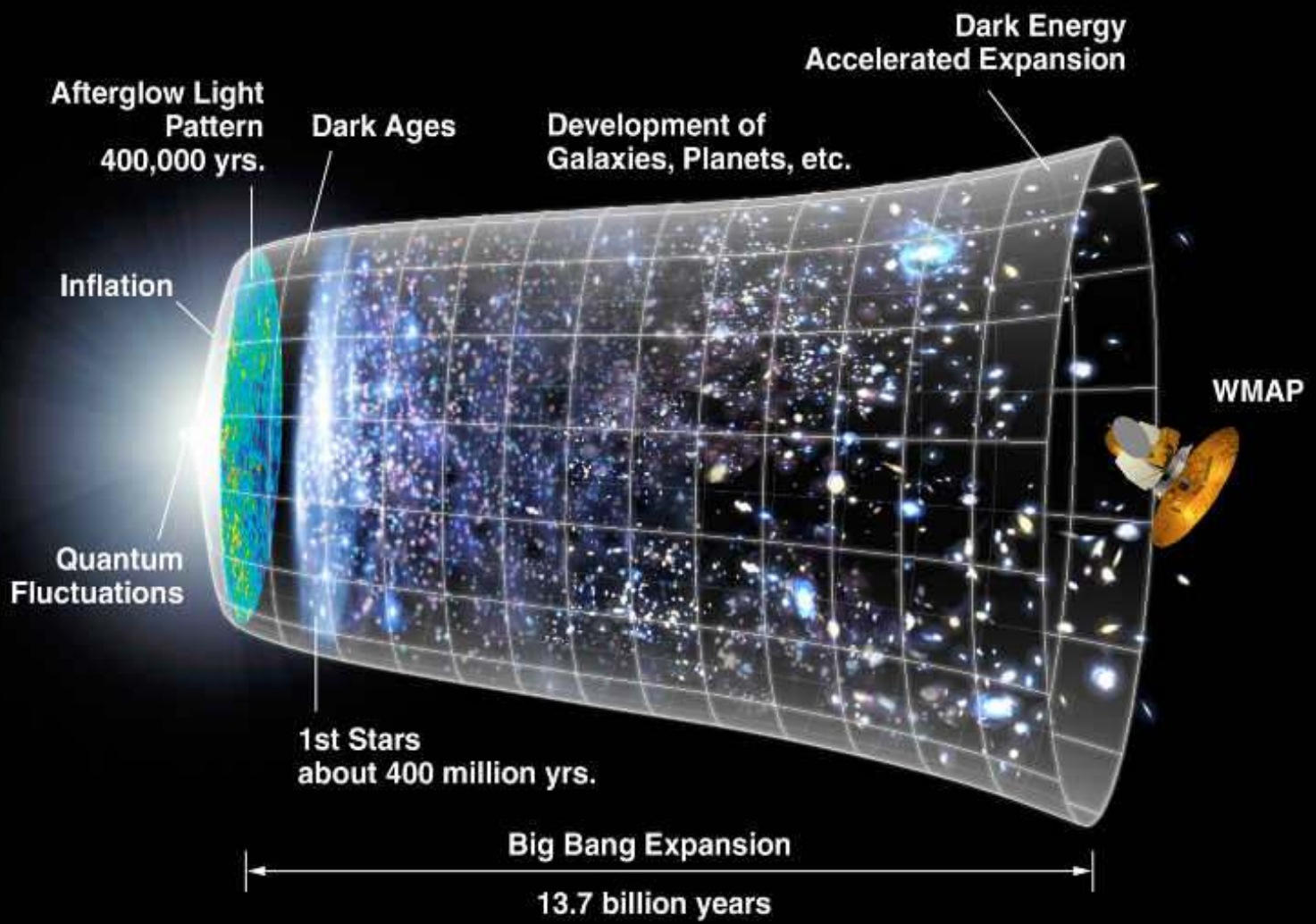

$\gamma^{SV} = \gamma^{S2} + \gamma^{LV}\cos\theta$
$g_{\mu\nu} = \tilde{M}_1 \times \mathrm{diag}(1,1,1,1)$
$R^{\mu}_{\alpha\beta\gamma} = \tilde{M}_2 \times \left(\Gamma^{\mu}_{\alpha\beta,\gamma} - \Gamma^{\mu}_{\alpha\gamma,\beta} + \Gamma^{\mu}_{\sigma\gamma}\Gamma^{\sigma}_{\alpha\beta} - \Gamma^{\mu}_{\sigma\beta}\Gamma^{\sigma}_{\alpha\gamma}\right)$
$\Rightarrow \frac{G_{\mu\nu}}{\omega} = \tilde{M}_3 \frac{8\pi G T_{\mu\nu}}{R_H}$


MIHURA

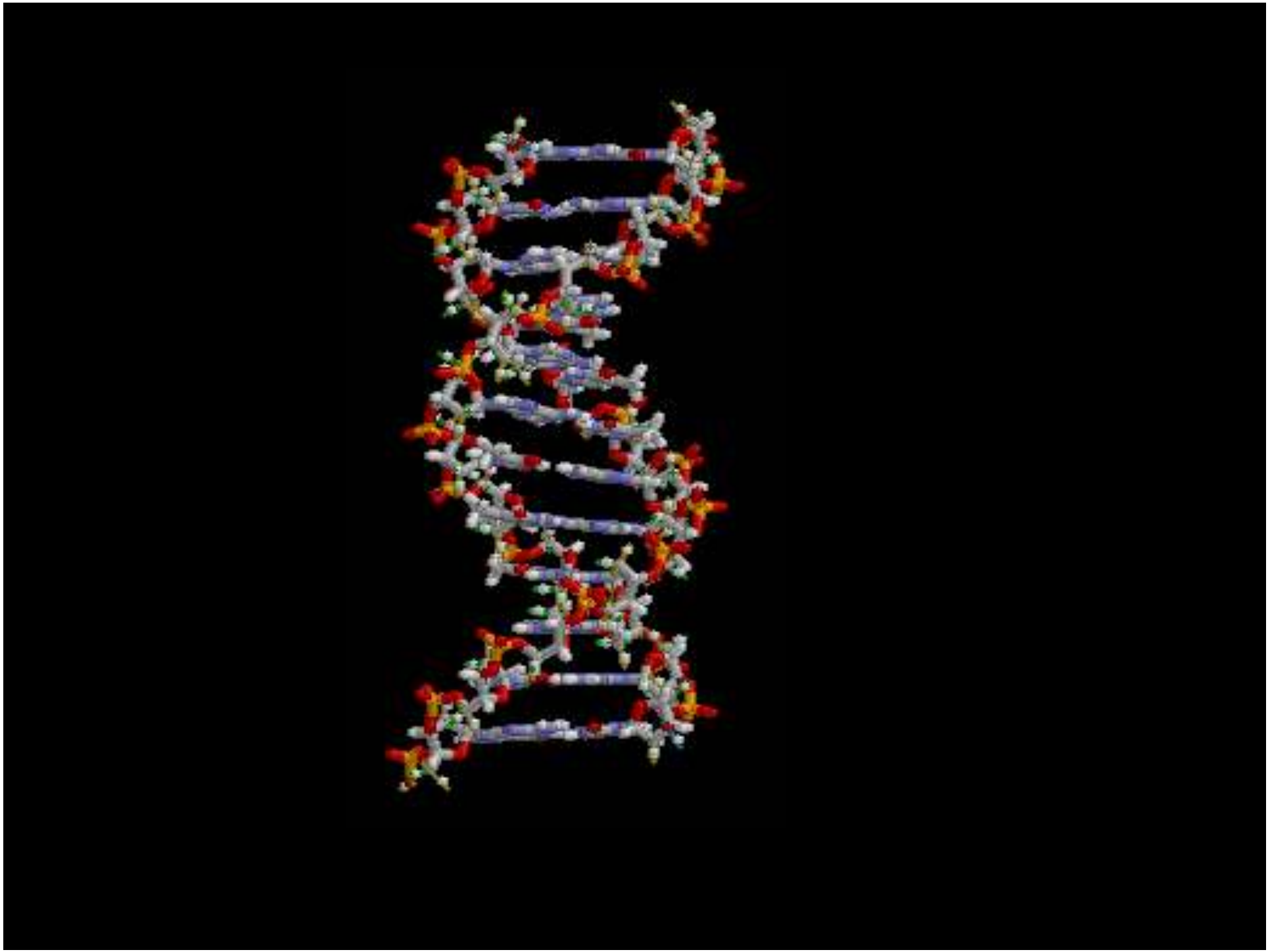

10 000 l.y.
Norma Arm
Scutum-Crux Arm
Sagitarrius Arm
Orion Arm
Sun's Location
M13
Perseus Arm
Outer Arm
180°
270°
ωCen
90°
0°
M15
M2
Globular Clusters
Sagittarius Dwarf Spheroidal Galaxy
r powell
Zoom In x10
Zoom Out x10


1 billion l.y.
BRI2237-0607
Quasars
180°
270°
90°
0°
Virgo
Supercluster
Shapley
Supercluster
3C273
3C48
Horologium
Supercluster
PC1247+3406
SDSSp1204-0021
SDSSp1044-0125
PSS0926+3055
RDJ0301+0020
SDSSp0338+0021
r powell
Zoom In x15

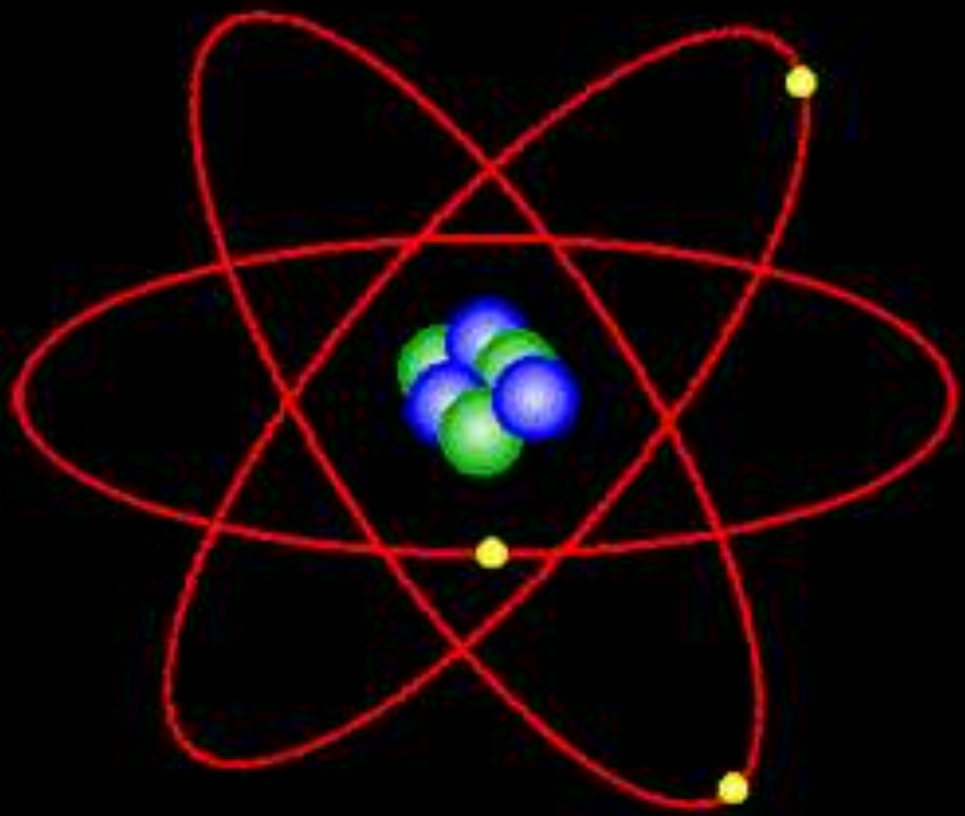
# The Big Bang Model




H2O
H
H
O



# STRUCTURE OF AN ATOM



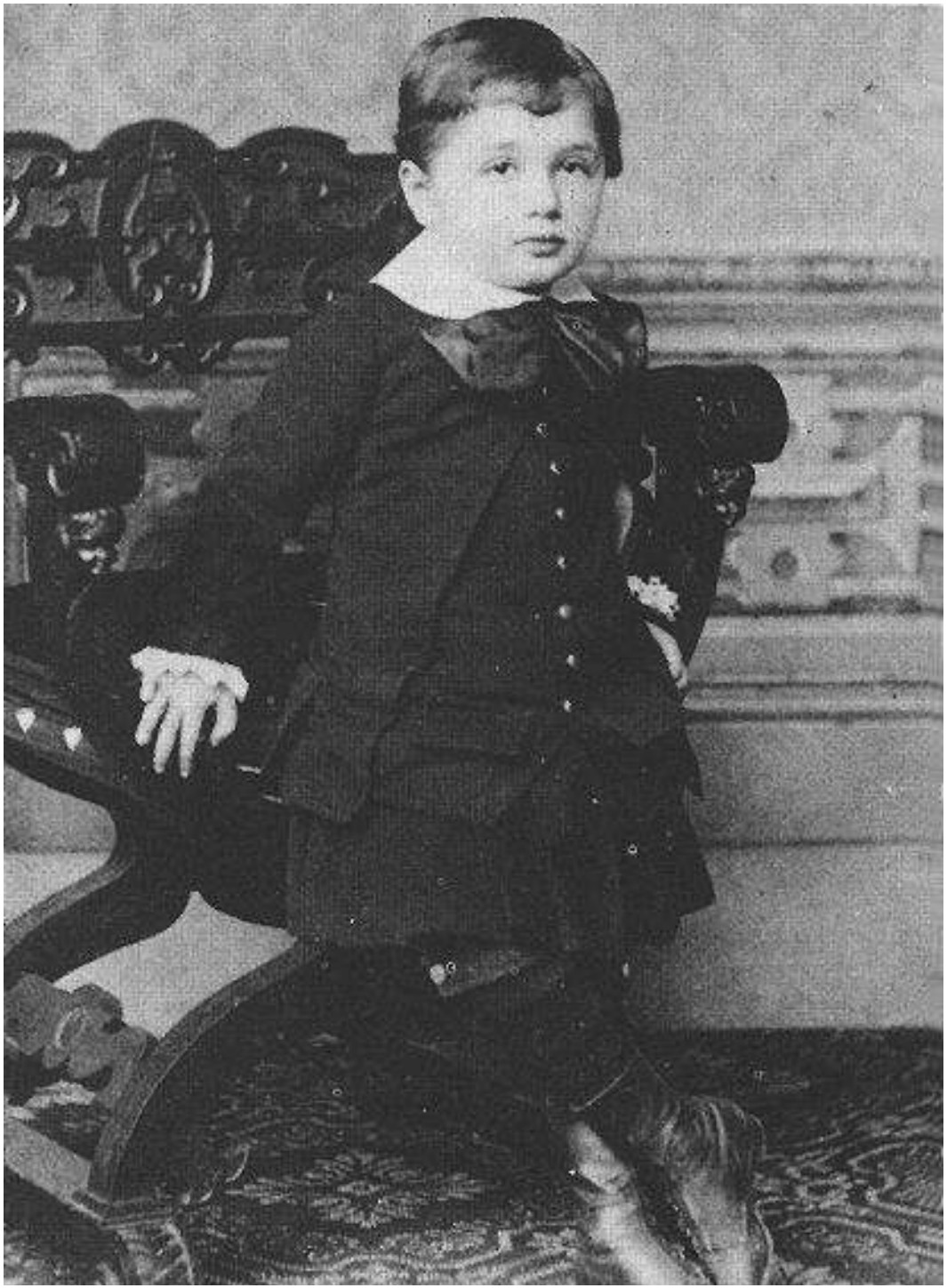
# Modern Physics Pillars:

Two big scientific revolutions

- **Relativity**
- **Quantum Mechanics**

**” Non troverai mai la verità se non sei disposto ad accettare anche ciò che non ti aspetti “. Eraclito**

# La Relativita'



# Special relativity

$$v_{AC} + v_{AB} = v_{BC}$$

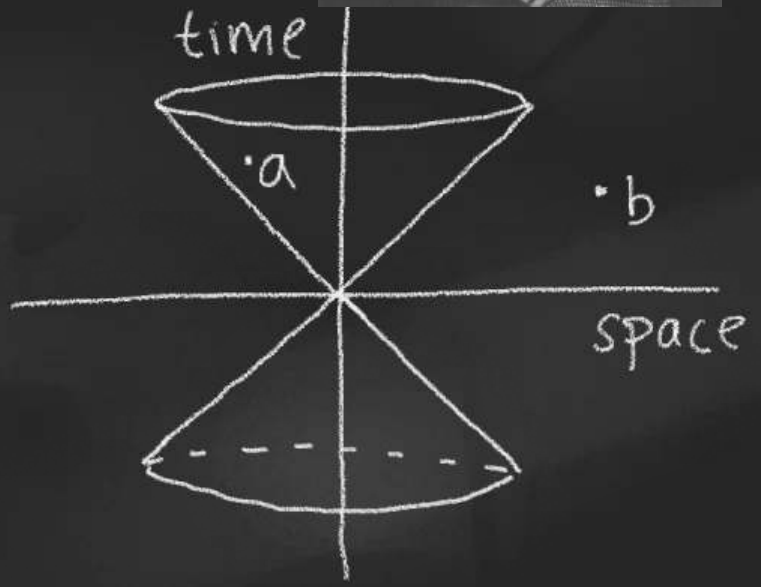
$$v_{AC} = \frac{v_{AB} + v_{BC}}{1 + \frac{v_{AB}\, v_{AC}}{c^2}}$$

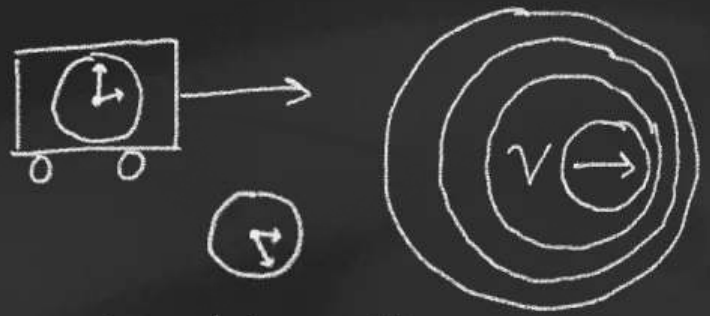
$$E = mc^2$$

$$L = \frac{1}{\gamma} L_0$$

$$T = \gamma T_0$$

$$c \approx 3 \times 10^8 \text{ m/s}$$




simultaneity

Lorentz Transformations:

$$x' = \gamma(x - vt) \qquad t' = \gamma\left(t - \frac{v}{c^2} x\right)$$

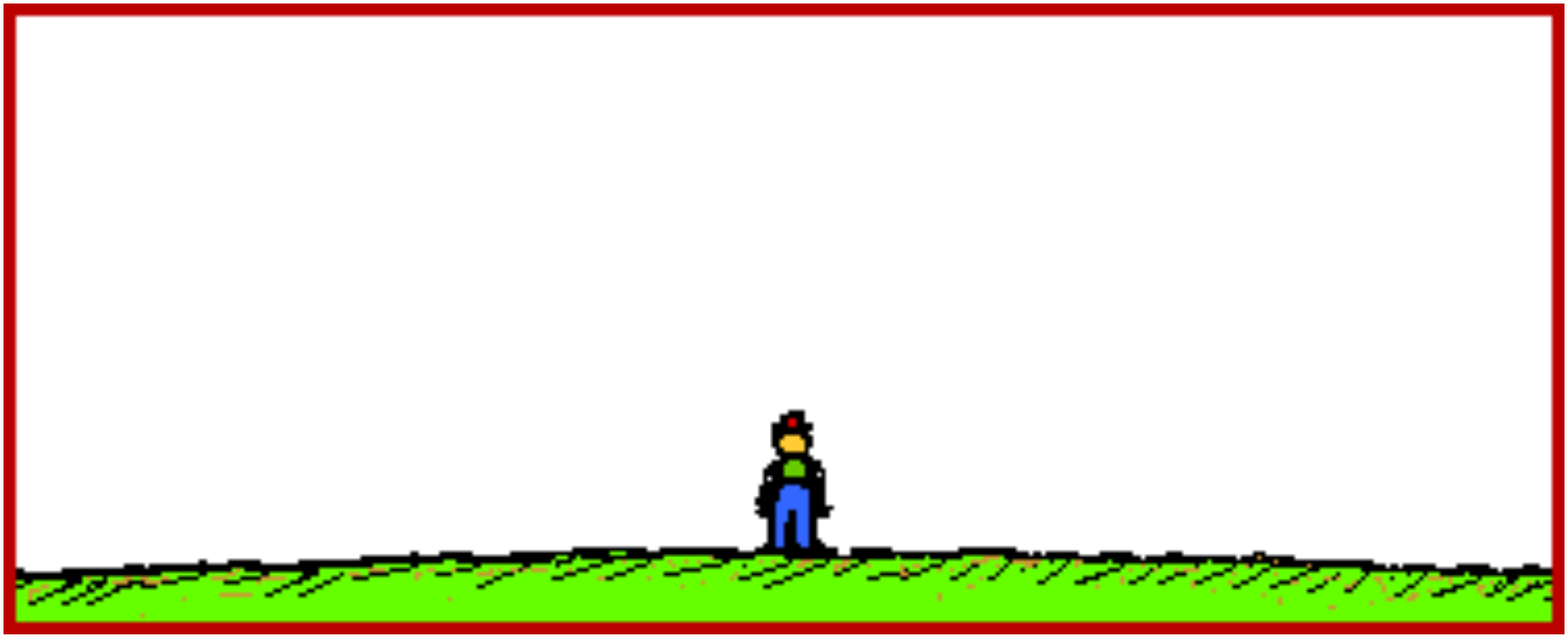
$$y' = y$$

$$z' = z$$

$$\gamma = \frac{1}{\sqrt{1 - v^2/c^2}}$$

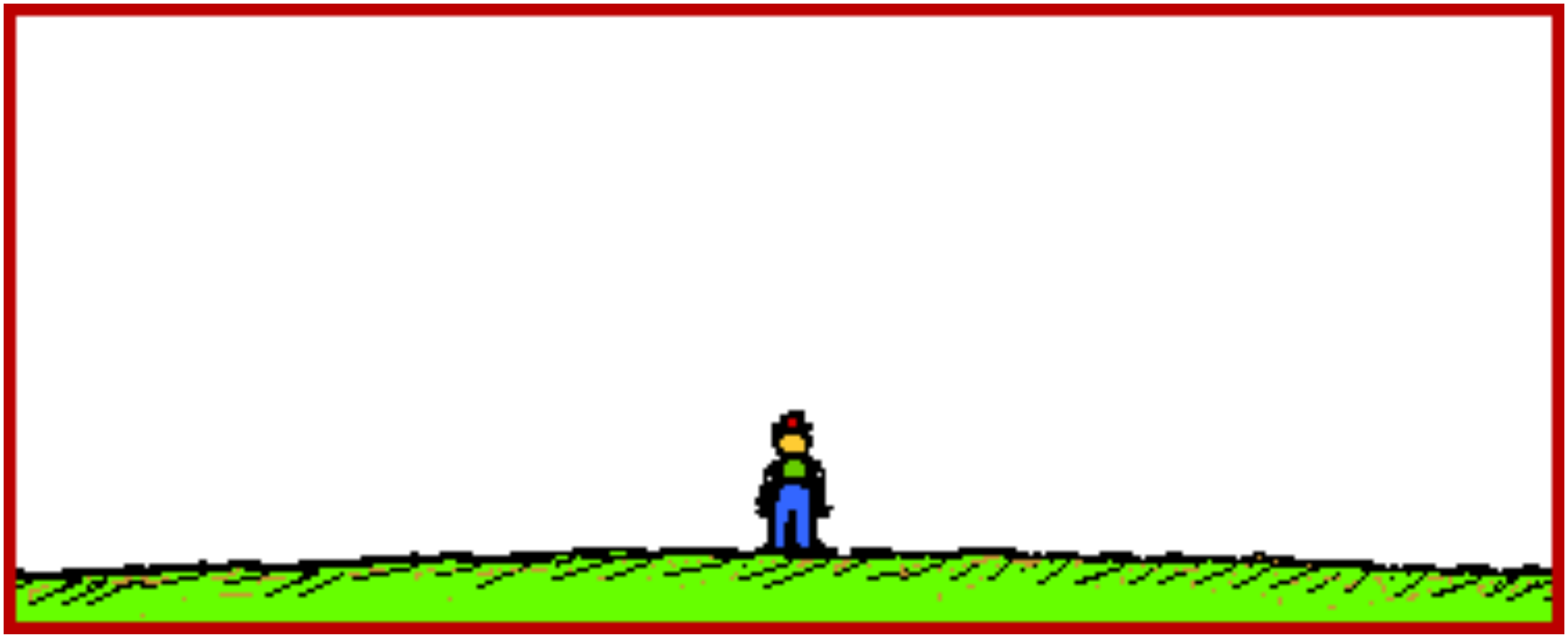
# Length contraction

- 10% light speed



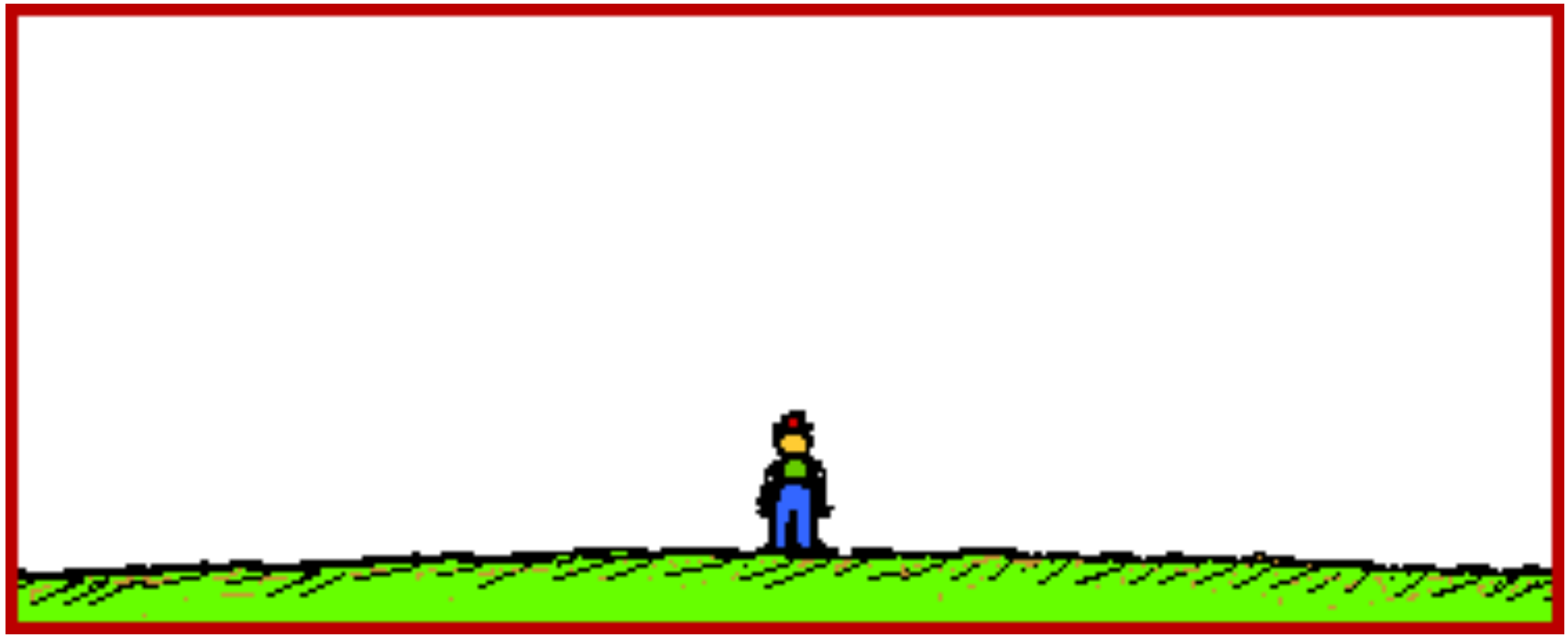
# Length contraction

- 86% light speed



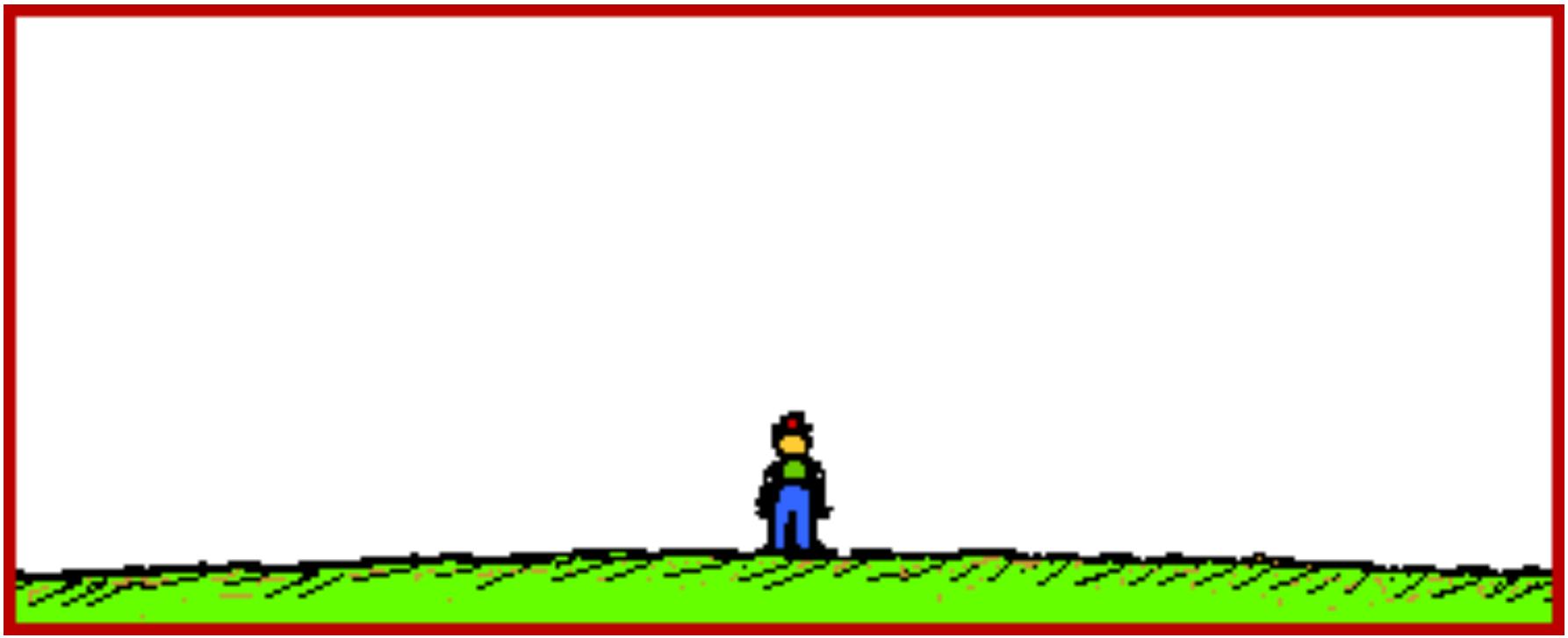
# Length contraction

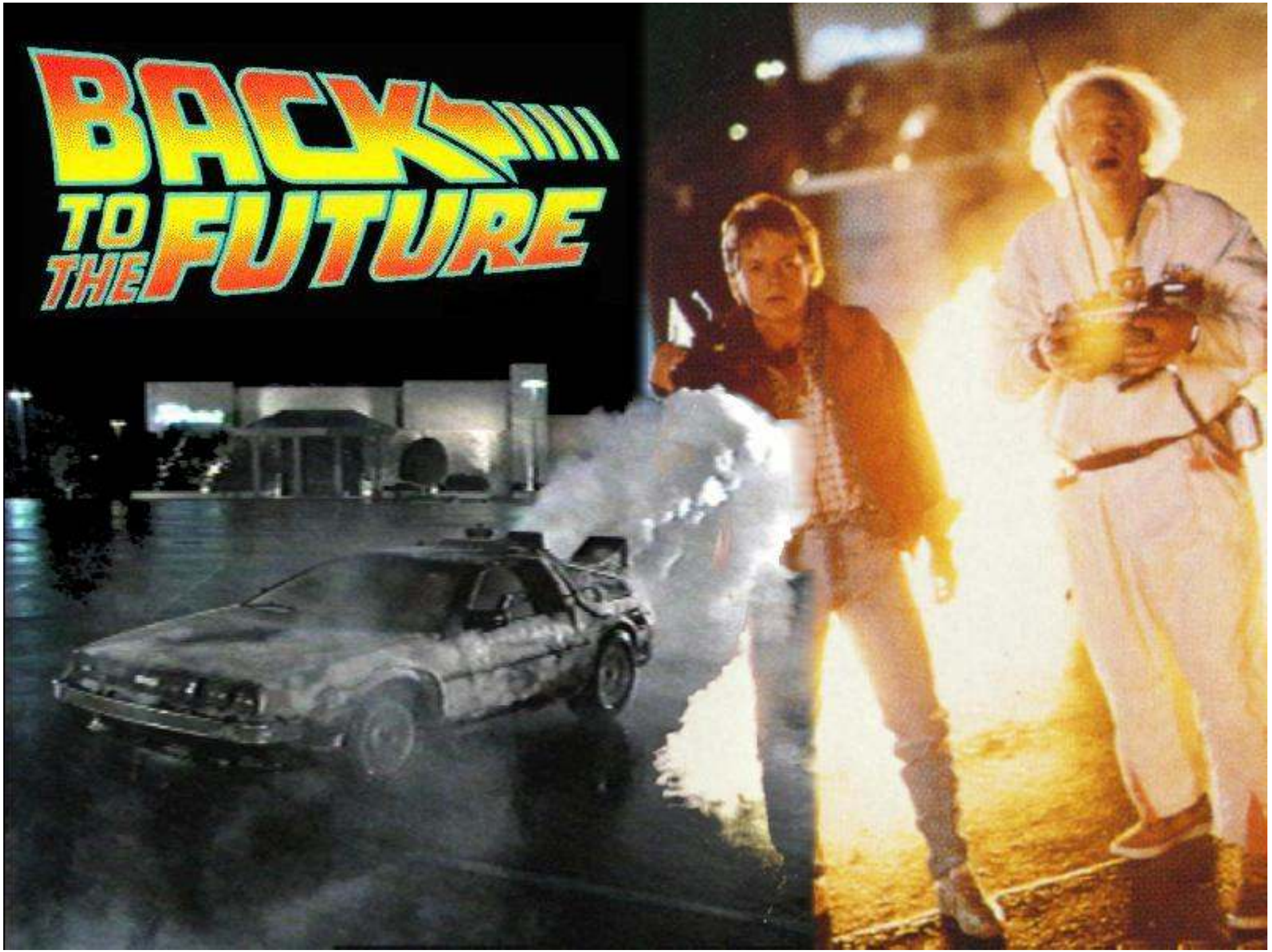
- 99% light speed



# Length contraction

- 99.99% light speed

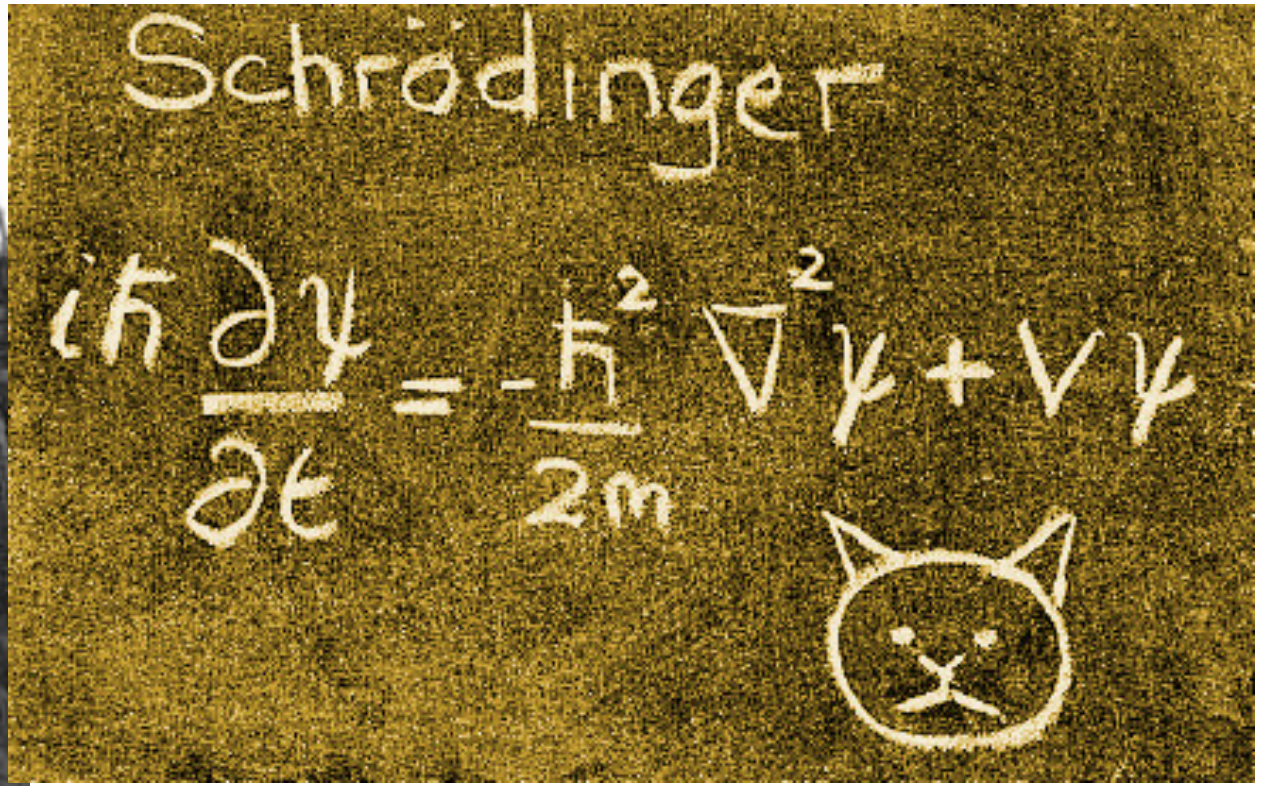


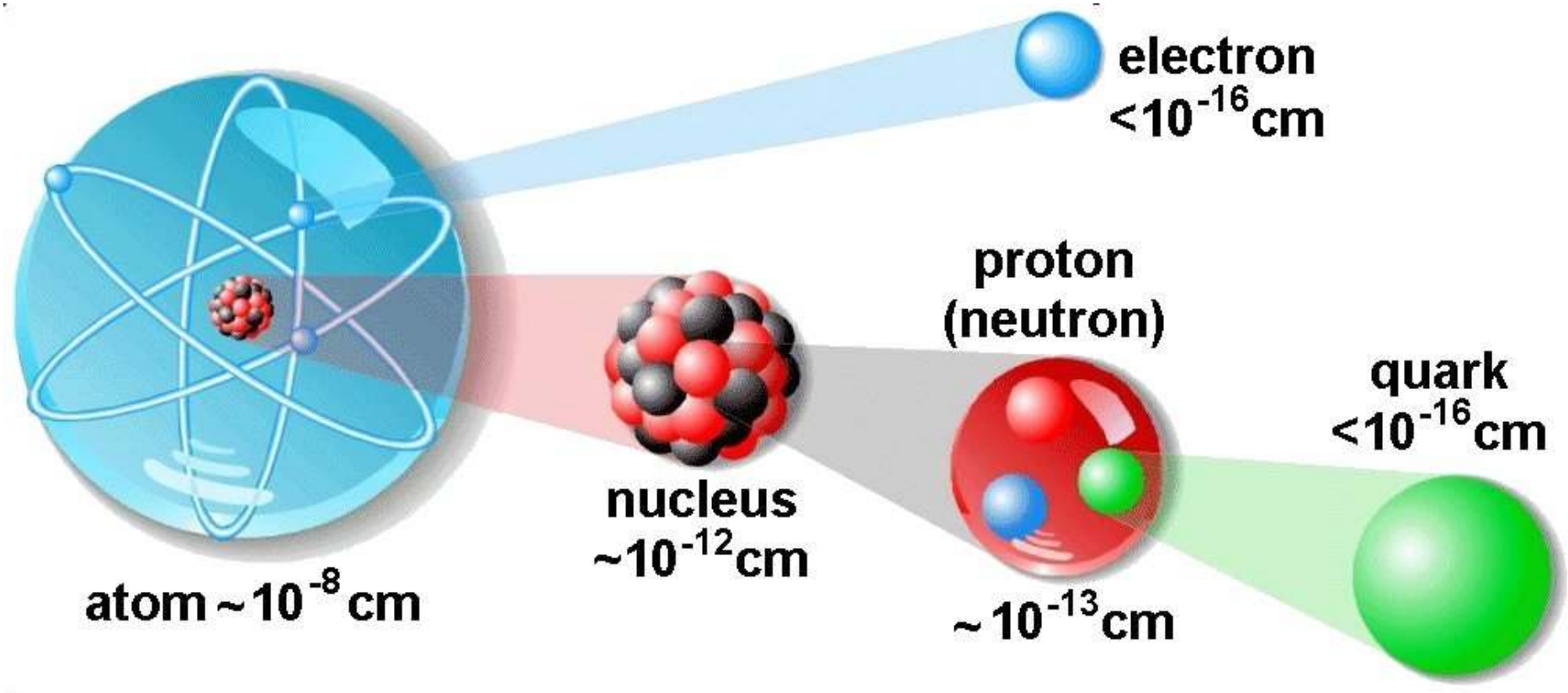

BACK
TO THE FUTURE

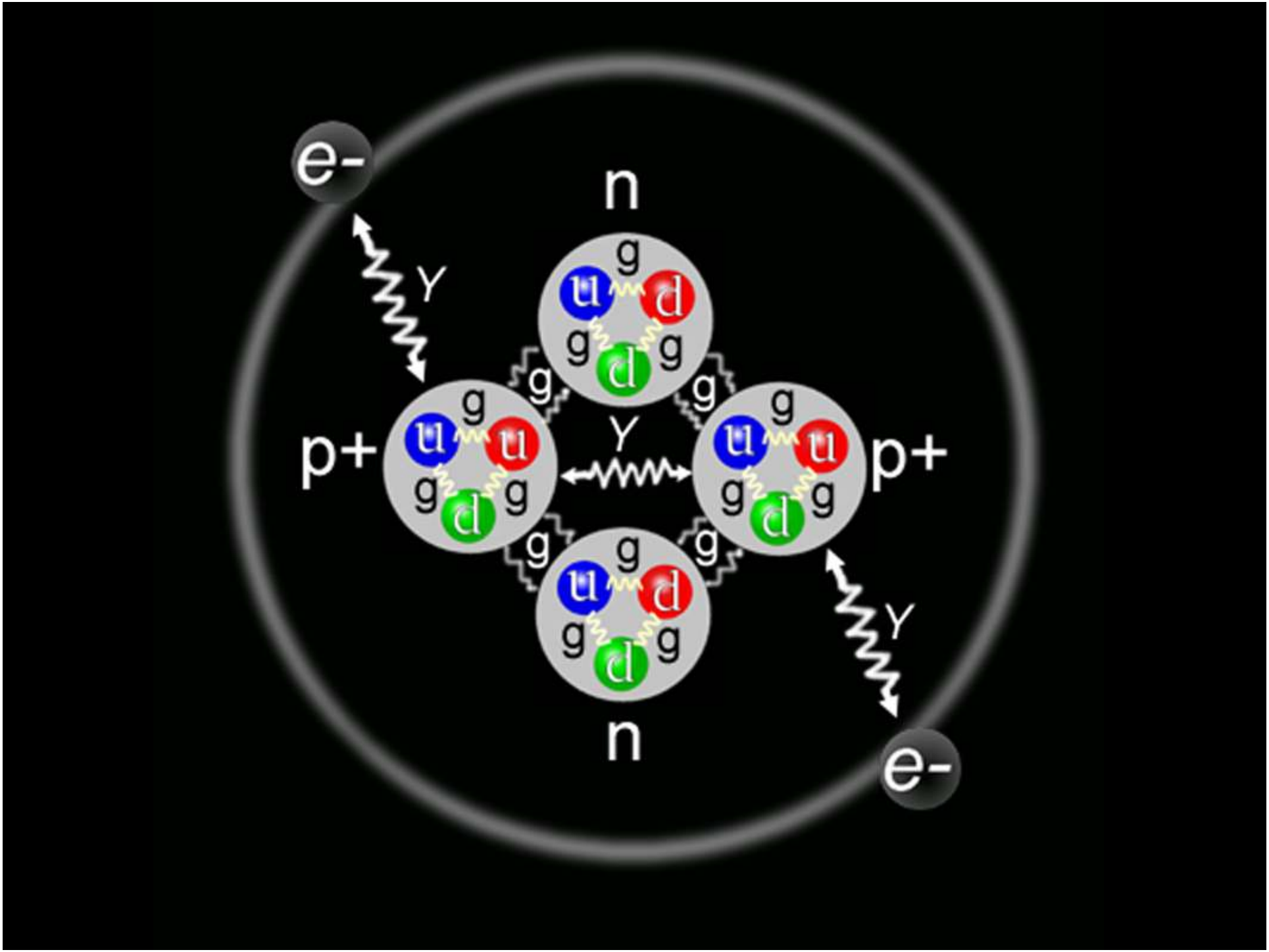
# Quantum mechanics

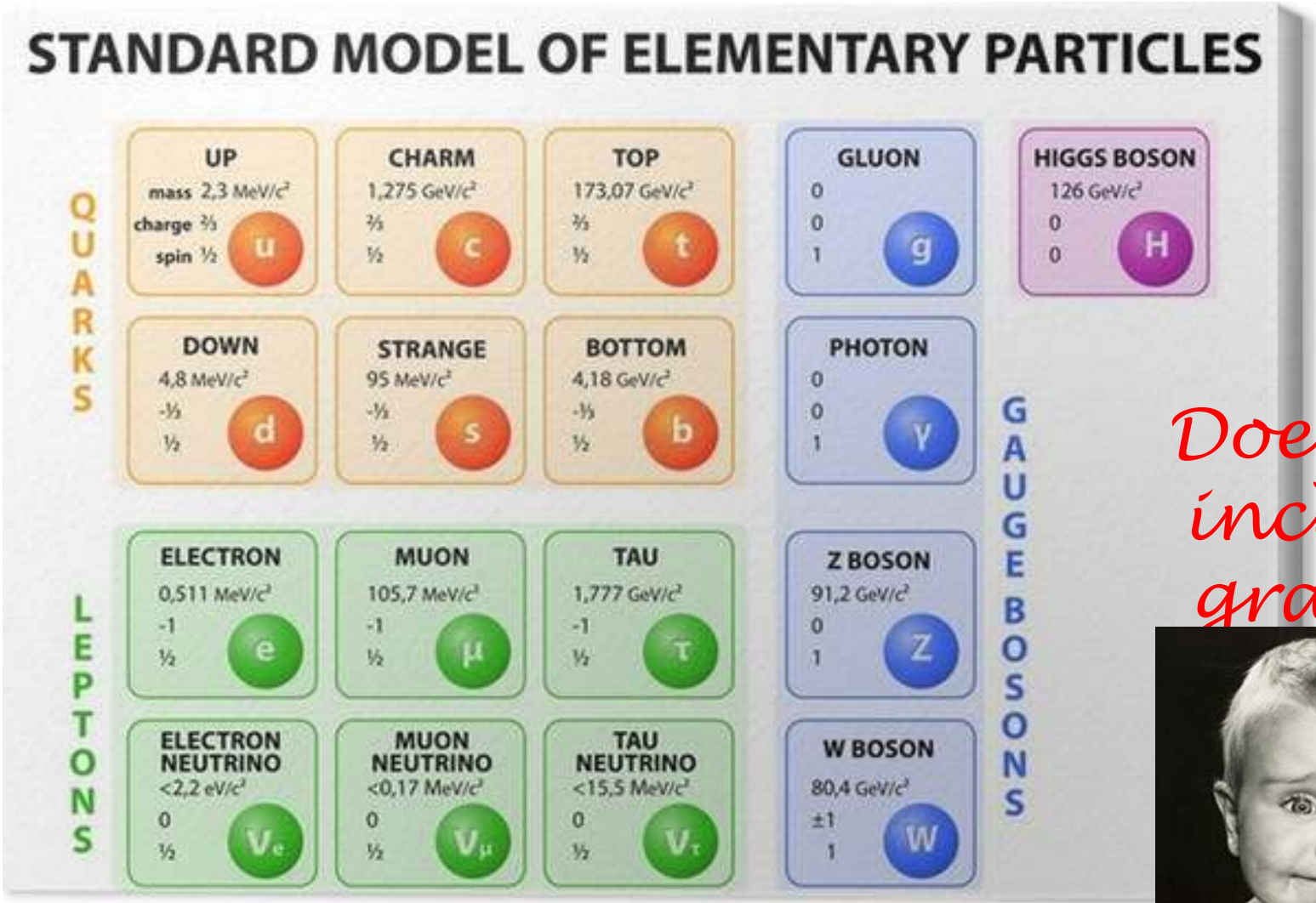

**Conferenza di Solvay (1927)**

# Schroedinger

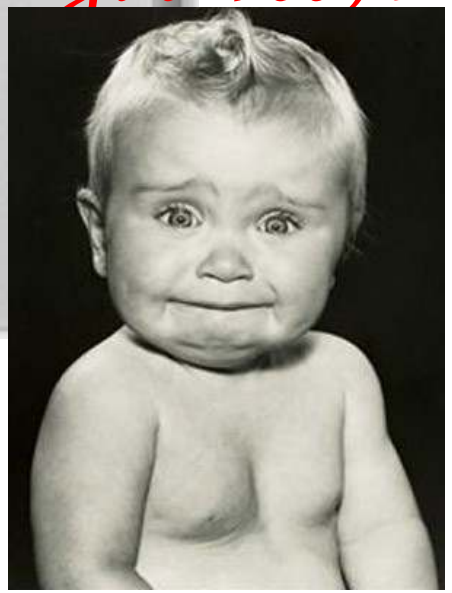



electron
<10^-16 cm
proton
(neutron)
quark
<10^-16 cm
nucleus
~10^-12 cm
atom ~10^-8 cm
~10^-13 cm


e-
n
Y
g
u
d
p+
Y
p+
g
Y
n
e-



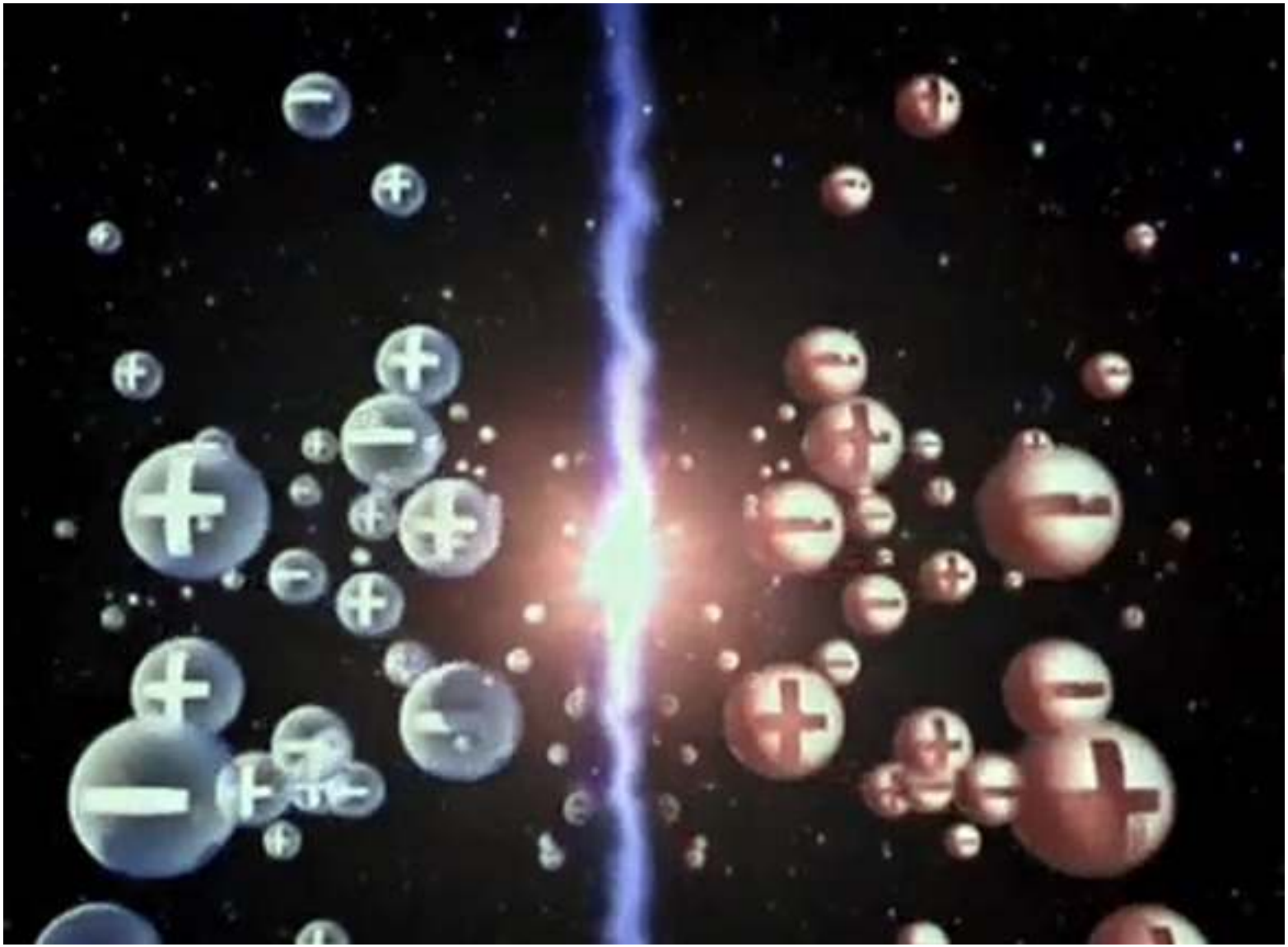

*Does not include gravity!*

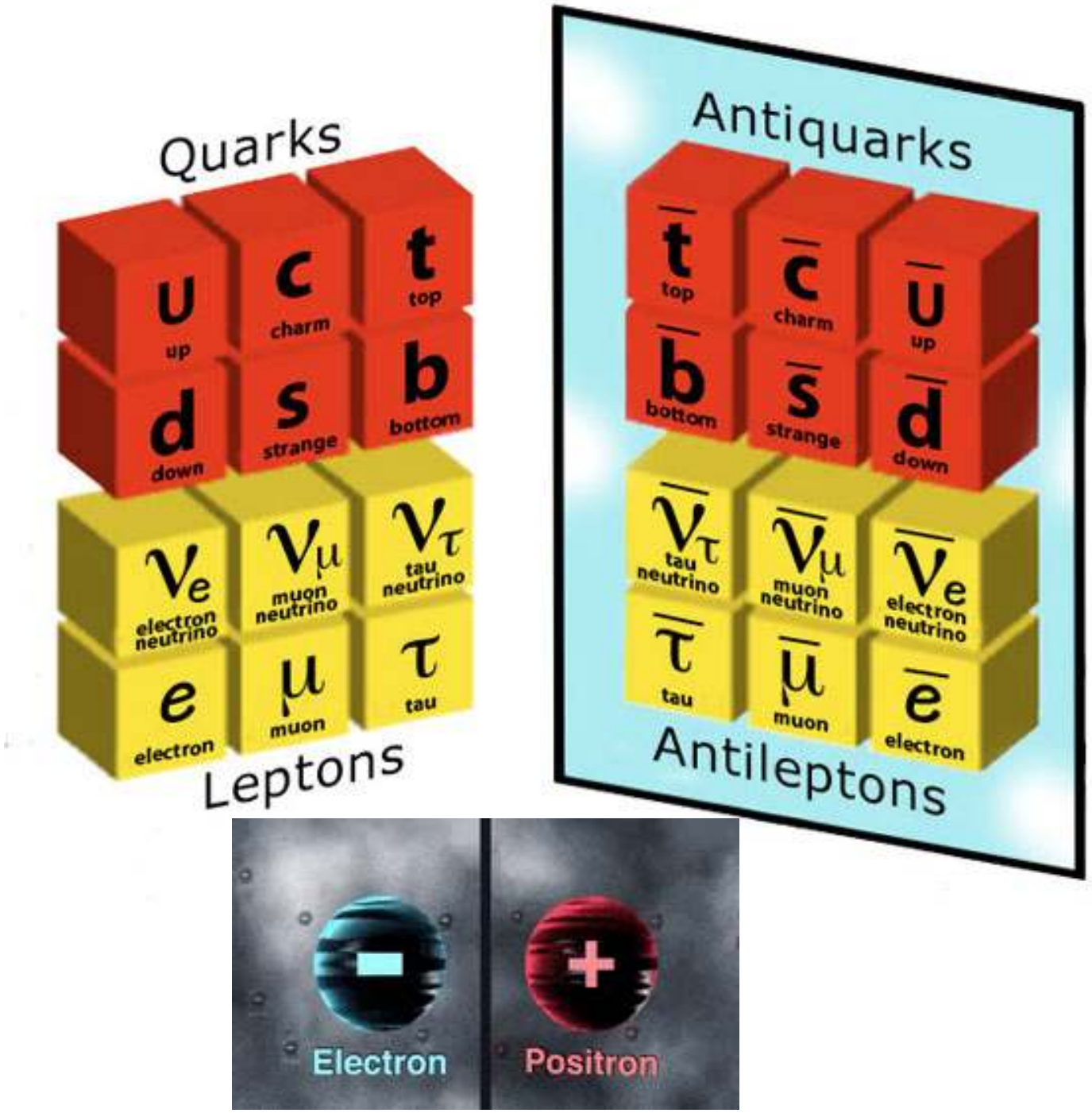


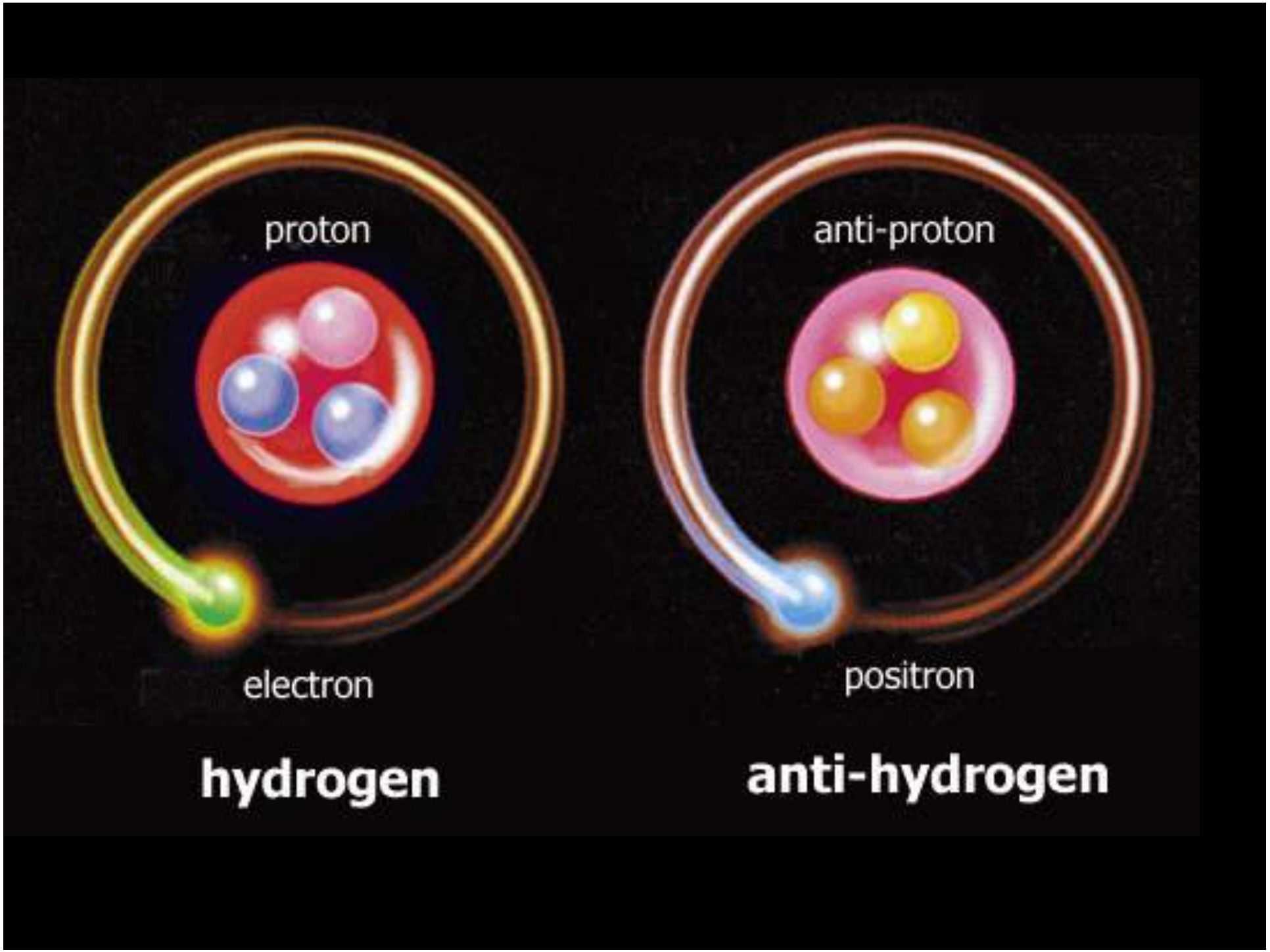
# 7 Open problems of Modern Physics:

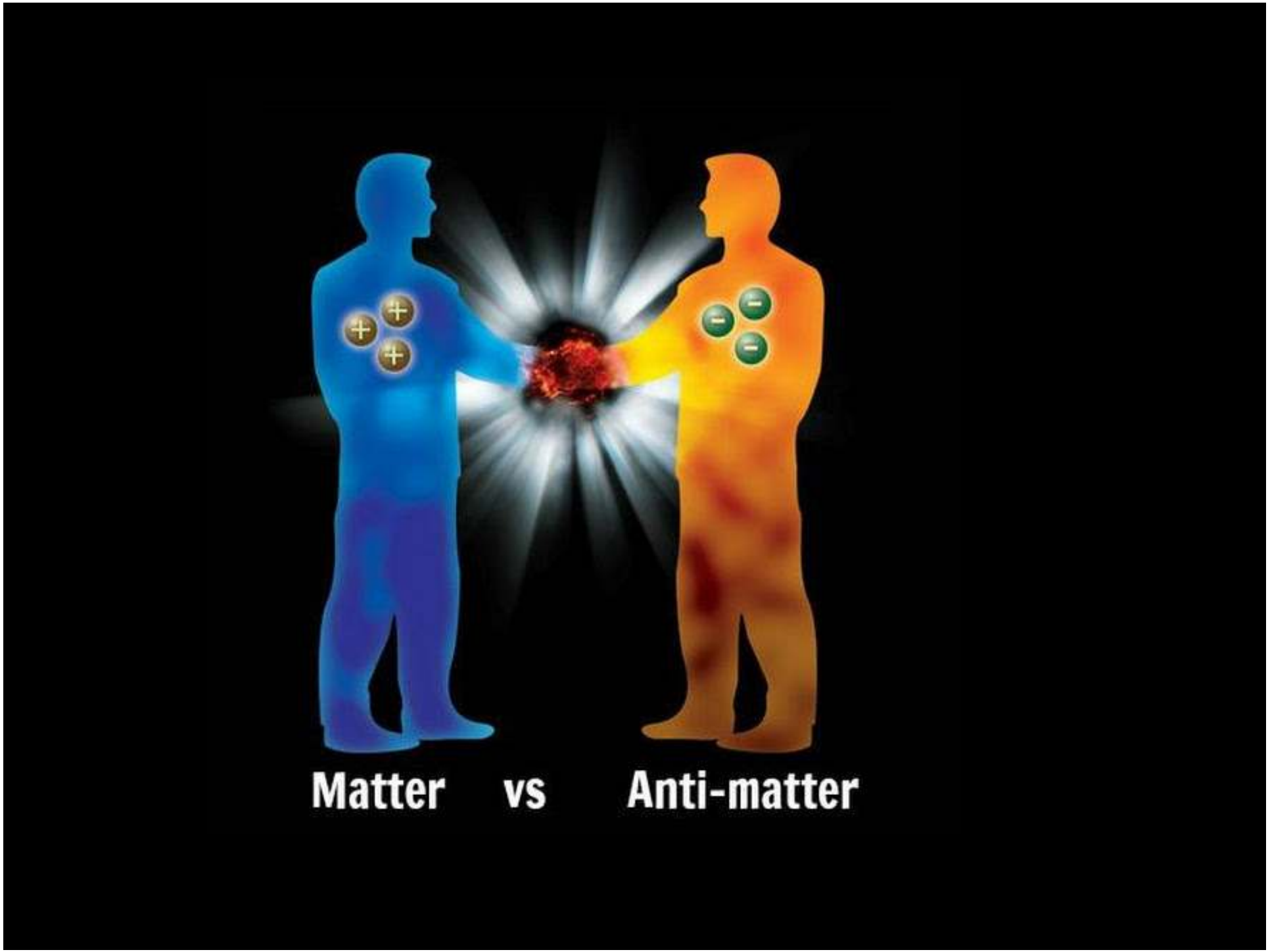
– where is the antimatter?
– what happens inside the black holes?
– what are dark matter and energy?
– the Schroedinger cat (collapse in quantum mechanics) – how we solve it?
– what is the structure of neutron stars?
– are there other Universes?
– where are....the extraterrestrials (aliens)?

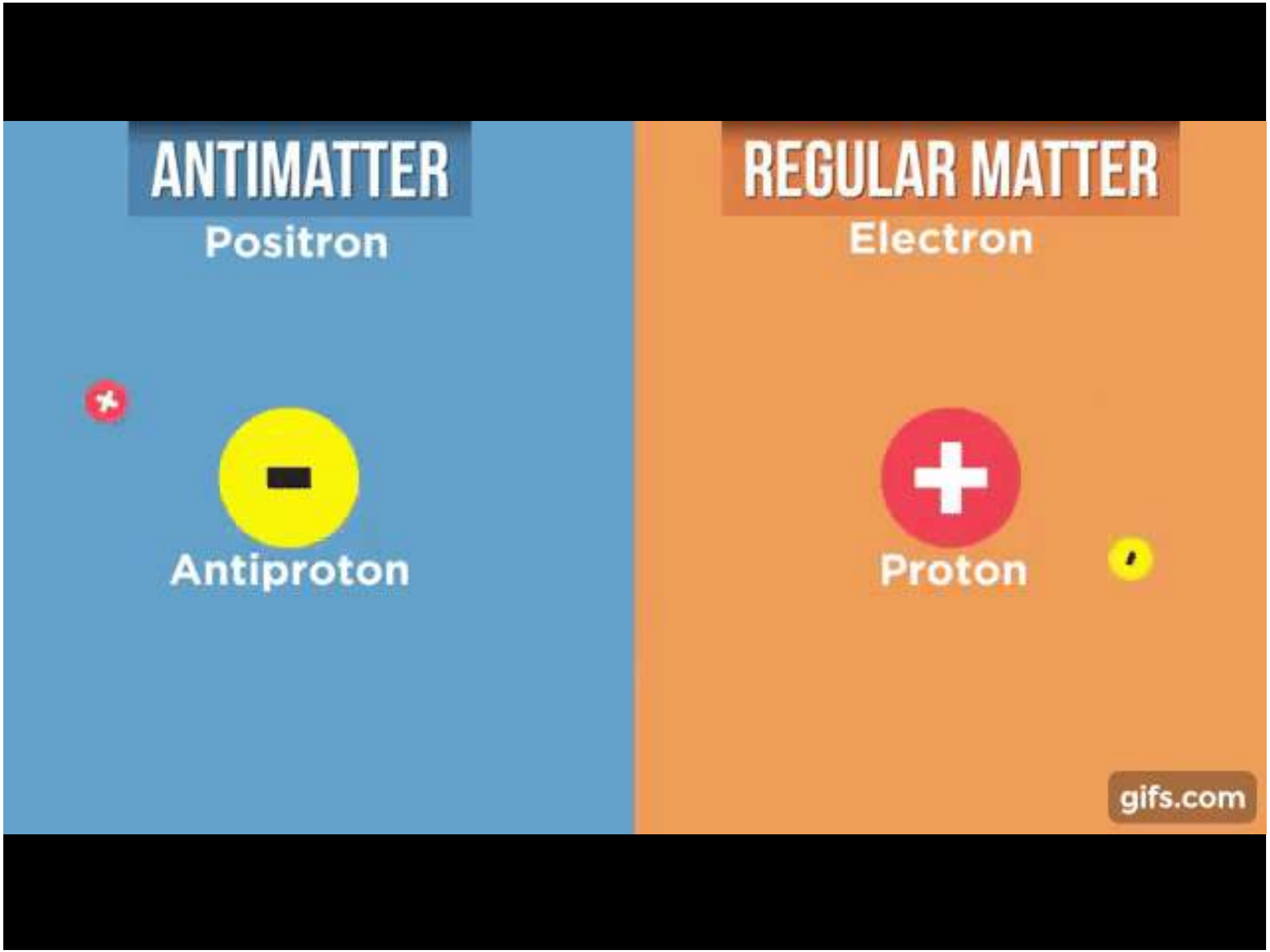
# 1) Where is the antimatter??



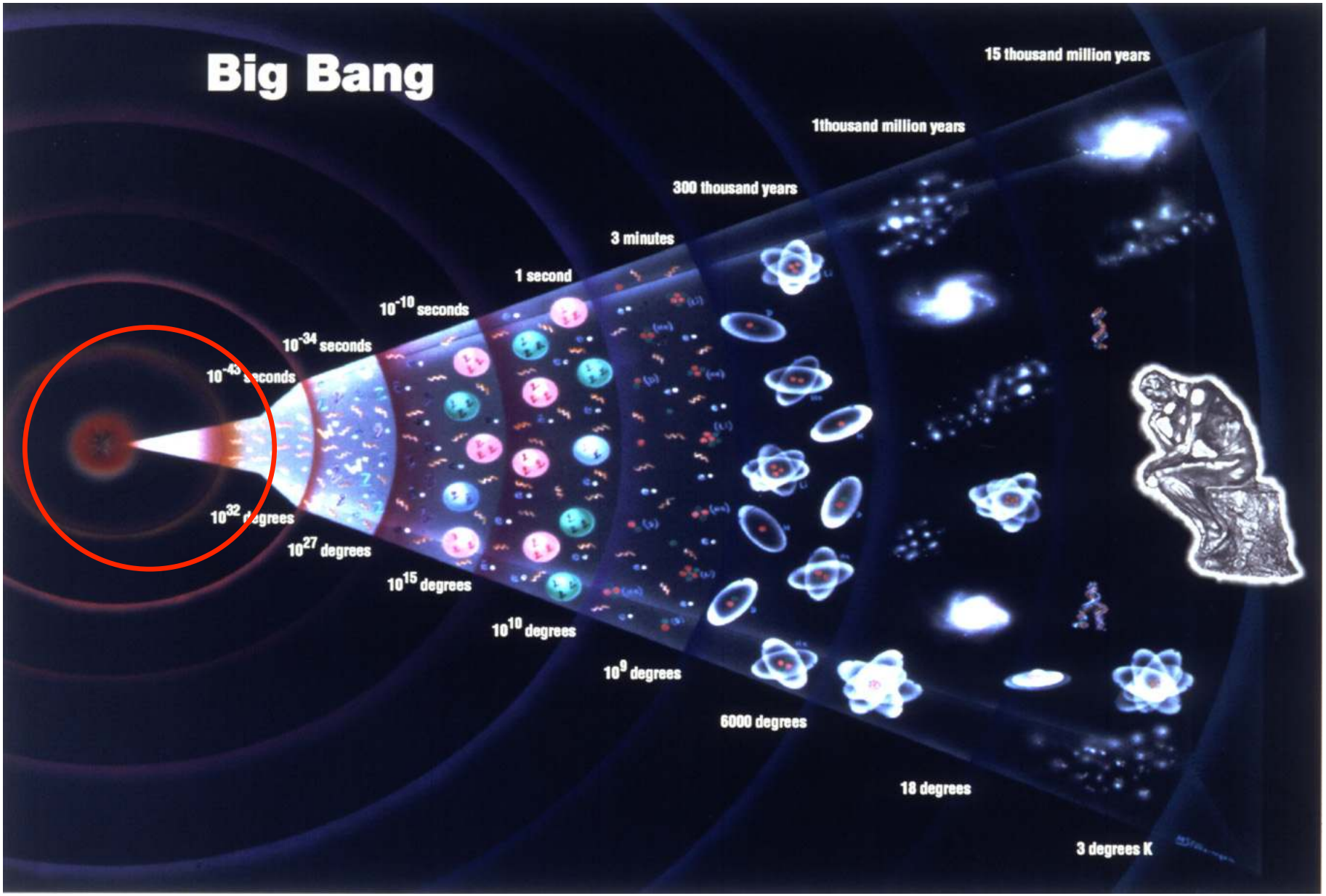

Quarks
u
up
c
charm
t
top
d
down
s
strange
b
bottom
$\nu_e$
electron neutrino
$\nu_\mu$
muon neutrino
$\nu_\tau$
tau neutrino
e
electron
μ
muon
τ
tau
Leptons
Antiquarks
$\bar{t}$
top
$\bar{c}$
charm
$\bar{u}$
up
$\bar{b}$
bottom
$\bar{s}$
strange
$\bar{d}$
down
$\bar{\nu}_\tau$
tau neutrino
$\bar{\nu}_\mu$
muon neutrino
$\bar{\nu}_e$
electron neutrino
$\bar{\tau}$
tau
$\bar{\mu}$
muon
$\bar{e}$
electron
Antileptons
Electron
Positron

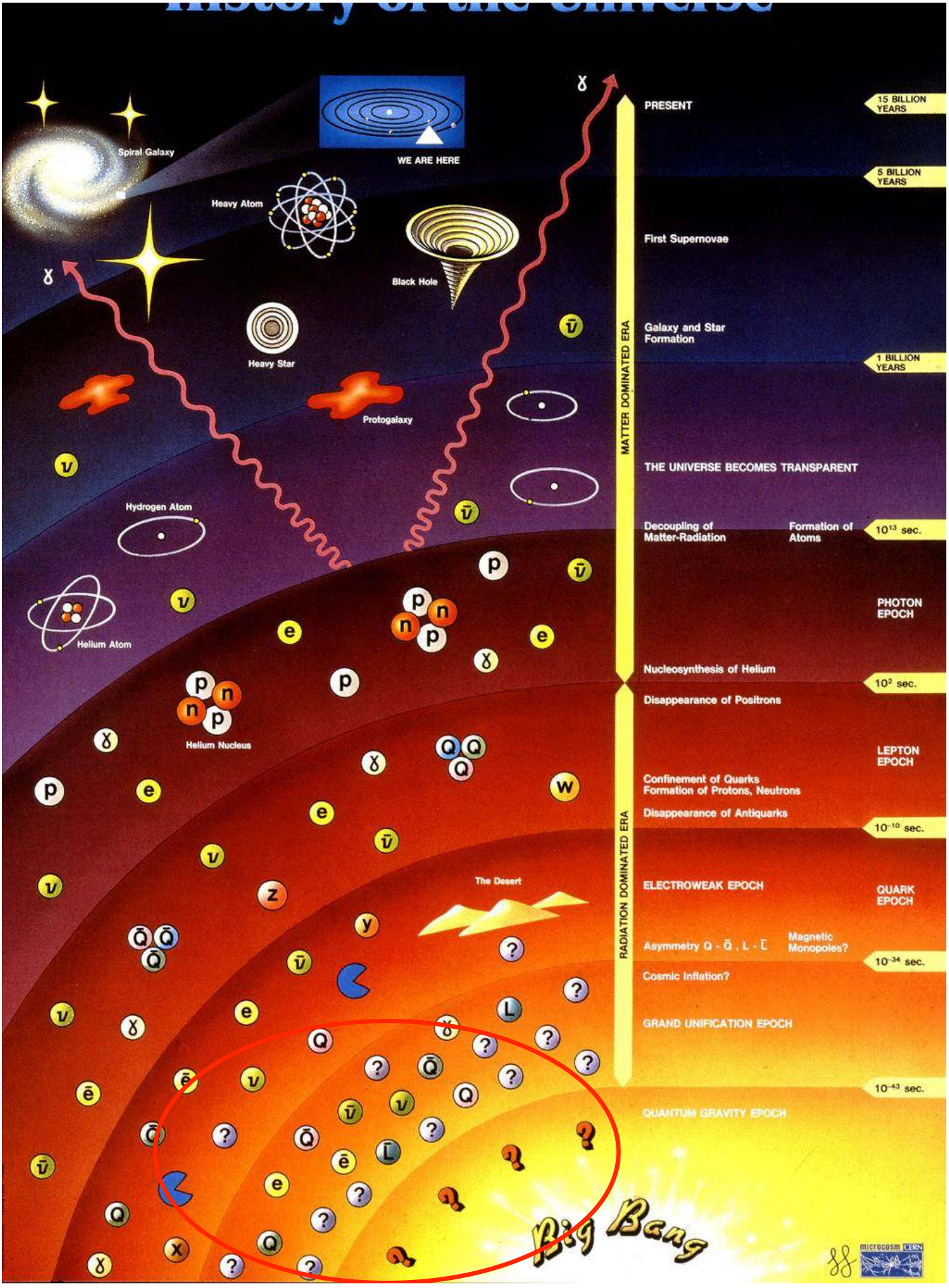

proton
electron
hydrogen
anti-proton
positron
anti-hydrogen


Matter vs Anti-matter


ANTIMATTER
Positron
Antiproton
REGULAR MATTER
Electron
Proton
gifs.com

# The Big Bang history

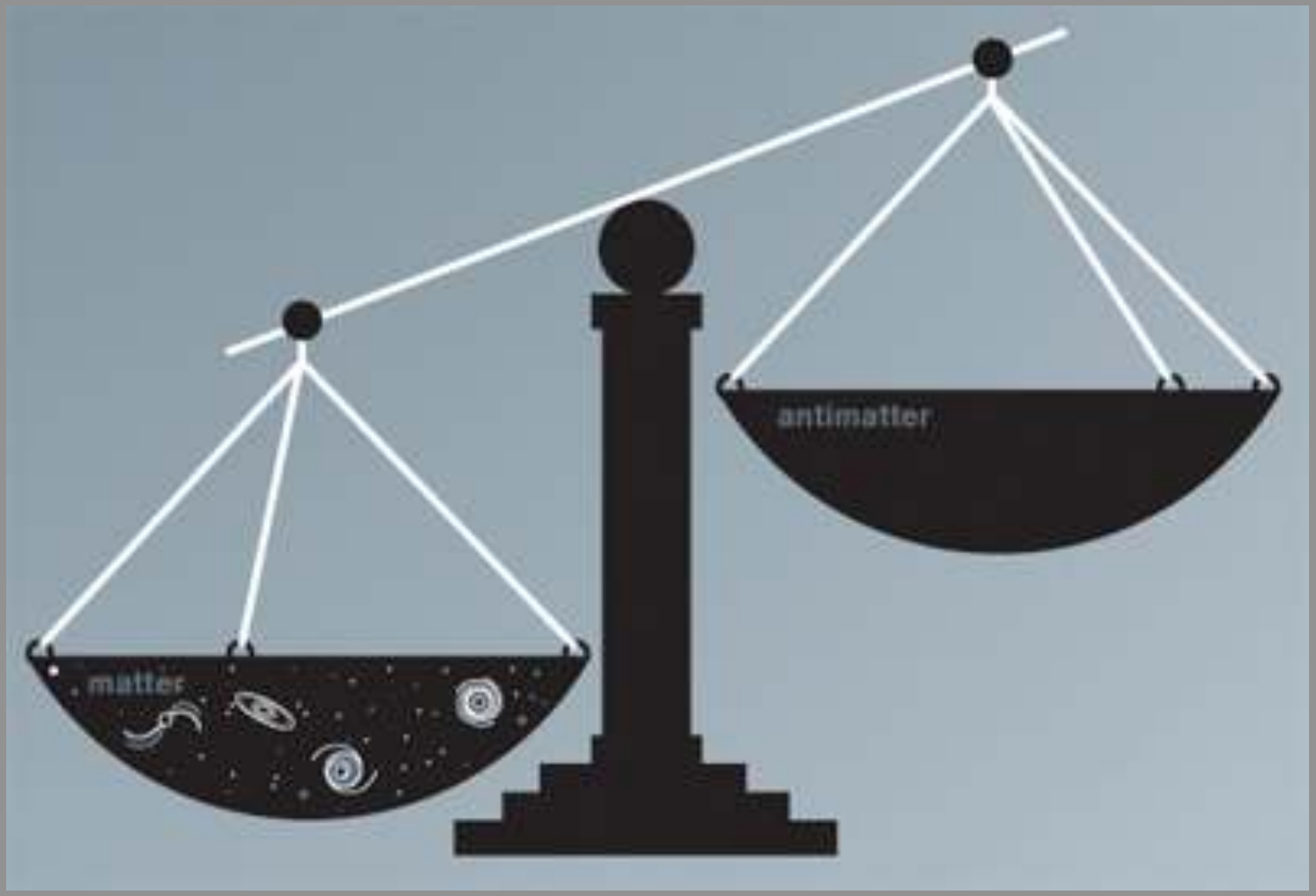



History of the Universe
Spiral Galaxy
WE ARE HERE
Heavy Atom
Black Hole
Heavy Star
Protogalaxy
Hydrogen Atom
Helium Atom
Helium Nucleus
The Desert
PRESENT
15 BILLION YEARS
5 BILLION YEARS
First Supernovae
Galaxy and Star Formation
1 BILLION YEARS
MATTER DOMINATED ERA
THE UNIVERSE BECOMES TRANSPARENT
Decoupling of Matter-Radiation
Formation of Atoms
10^13 sec.
PHOTON EPOCH
Nucleosynthesis of Helium
10^2 sec.
Disappearance of Positrons
LEPTON EPOCH
Confinement of Quarks
Formation of Protons, Neutrons
Disappearance of Antiquarks
10^-10 sec.
RADIATION DOMINATED ERA
ELECTROWEAK EPOCH
QUARK EPOCH
Asymmetry Q - Q̄ , L - L̄
Magnetic Monopoles?
10^-34 sec.
Cosmic Inflation?
GRAND UNIFICATION EPOCH
10^-43 sec.
QUANTUM GRAVITY EPOCH
Big Bang
microcosm CERN

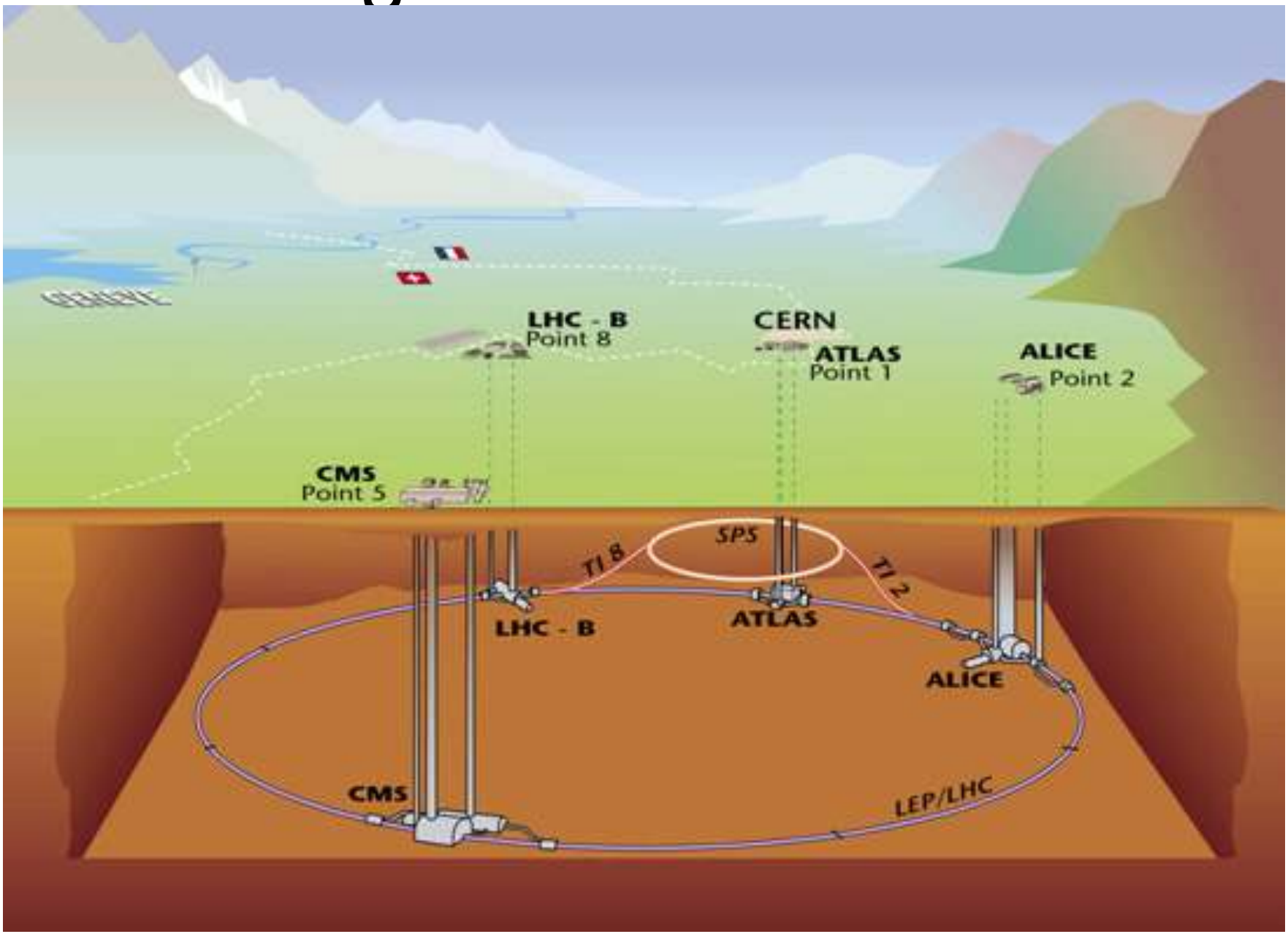

Where is
all the
antimatter?

CP violation (CPT)

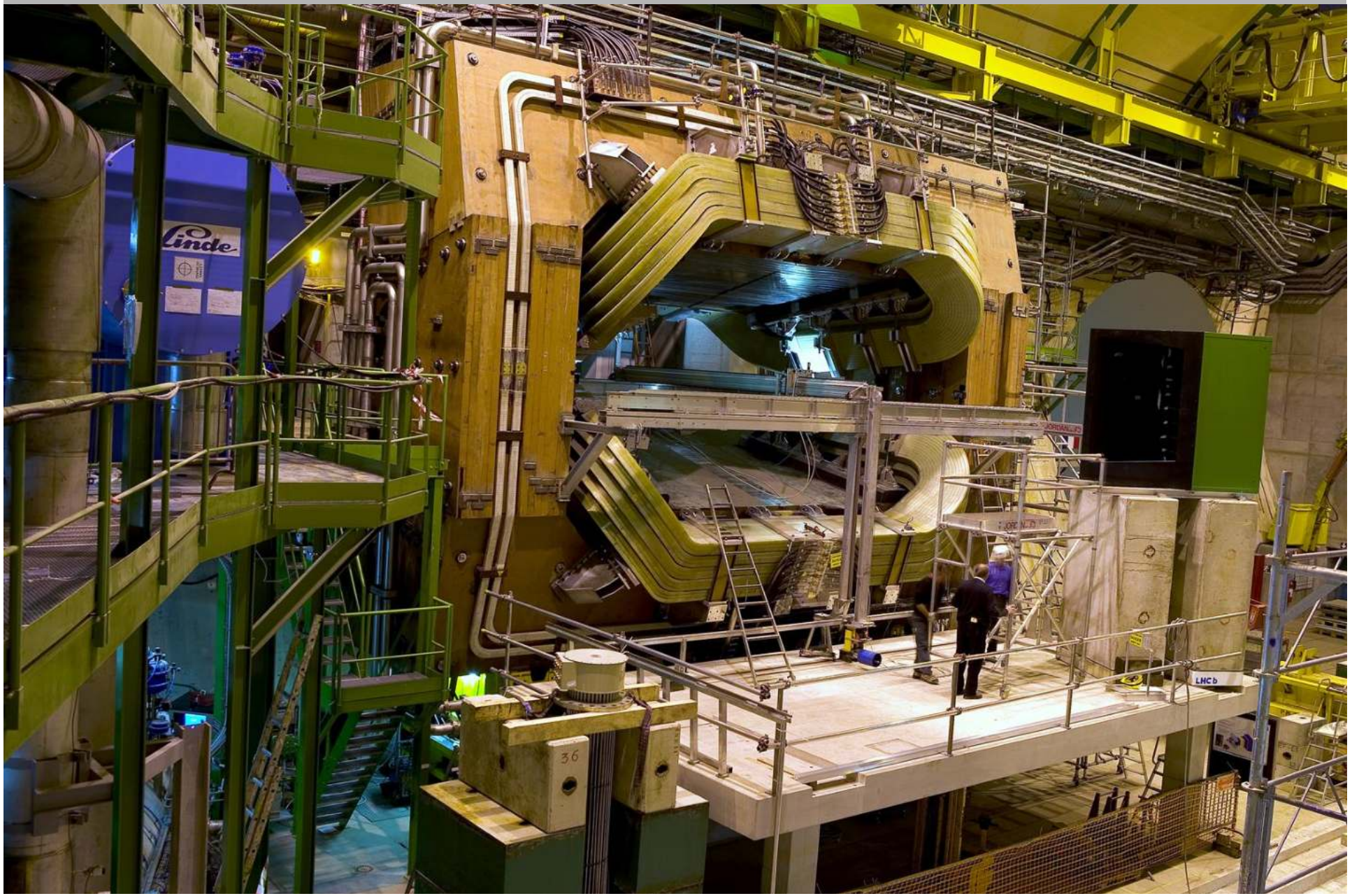
Assymetry between “laws of matter and laws of antimatter”

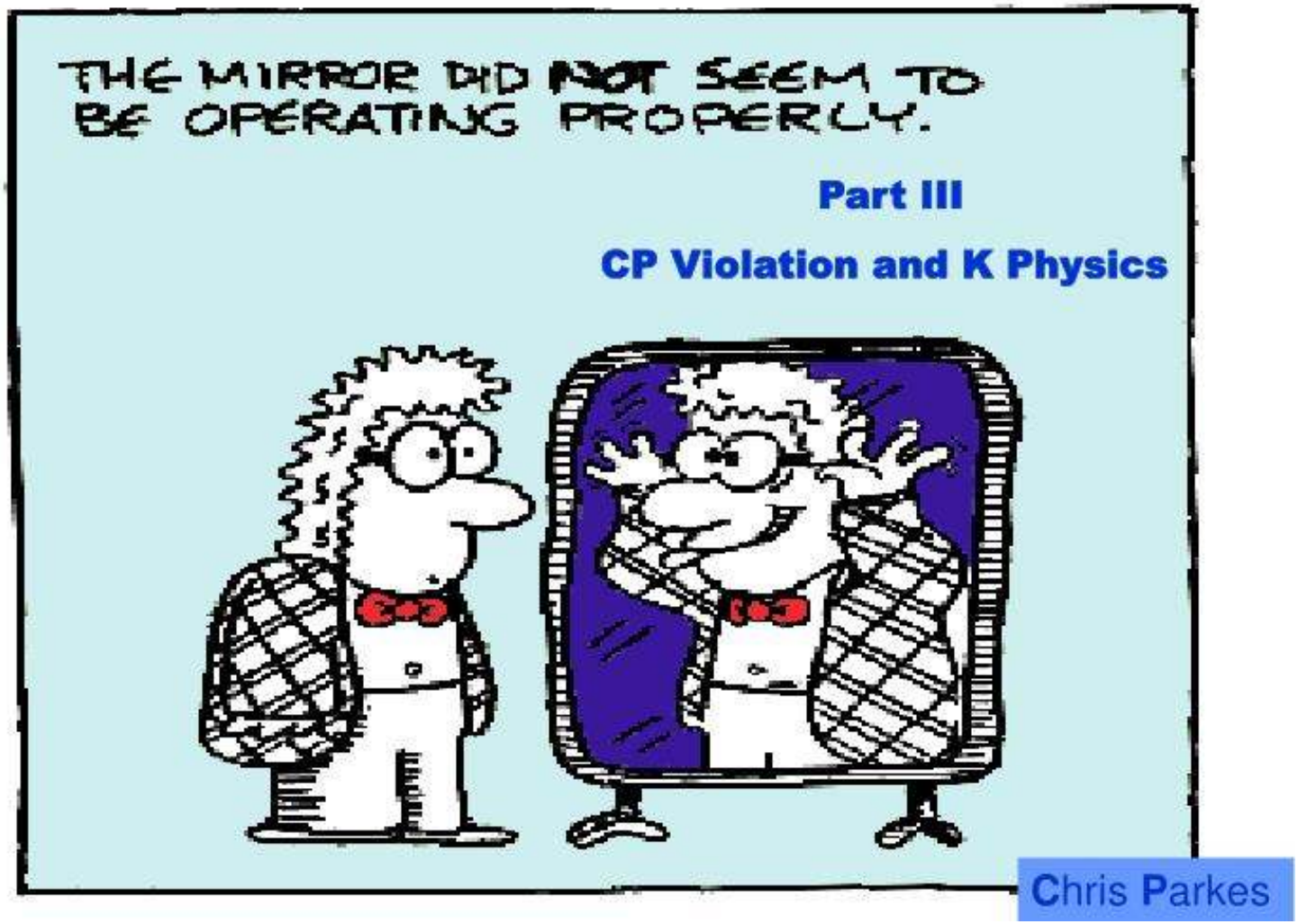

matter
antimatter

# Large Hadron Collider



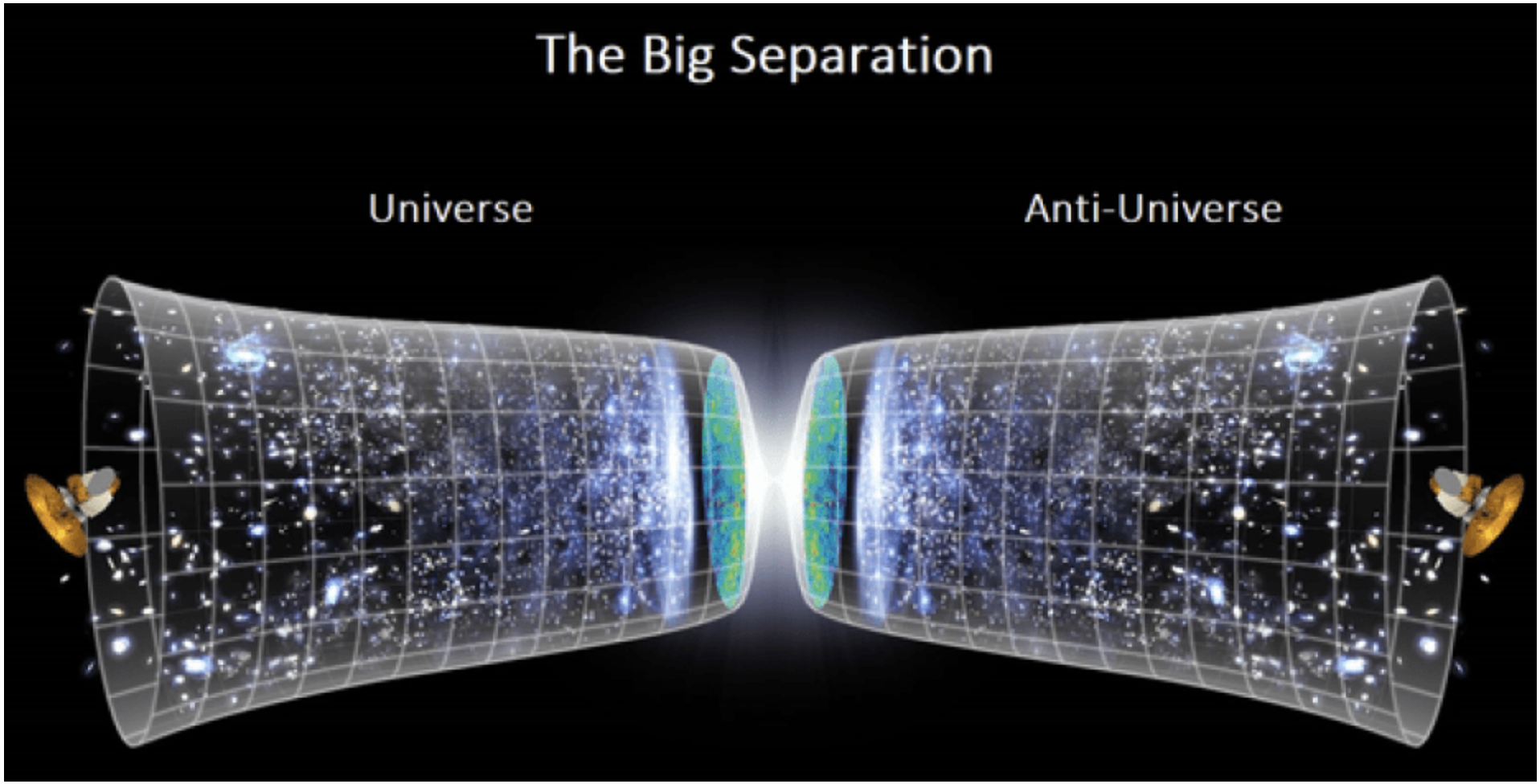
# LHCb





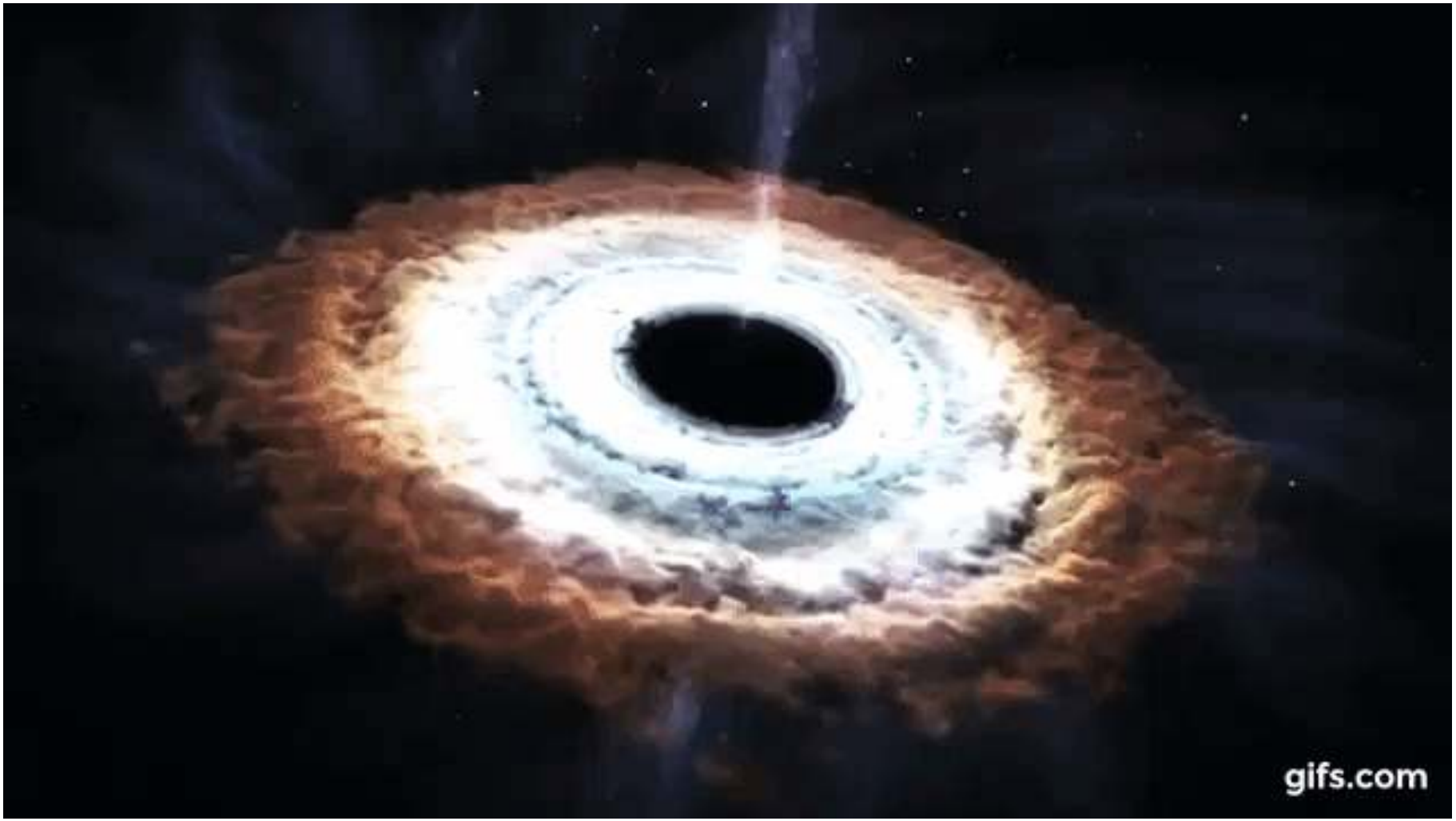

The measured assymetry does not (yet) explain why all antimatter «died»

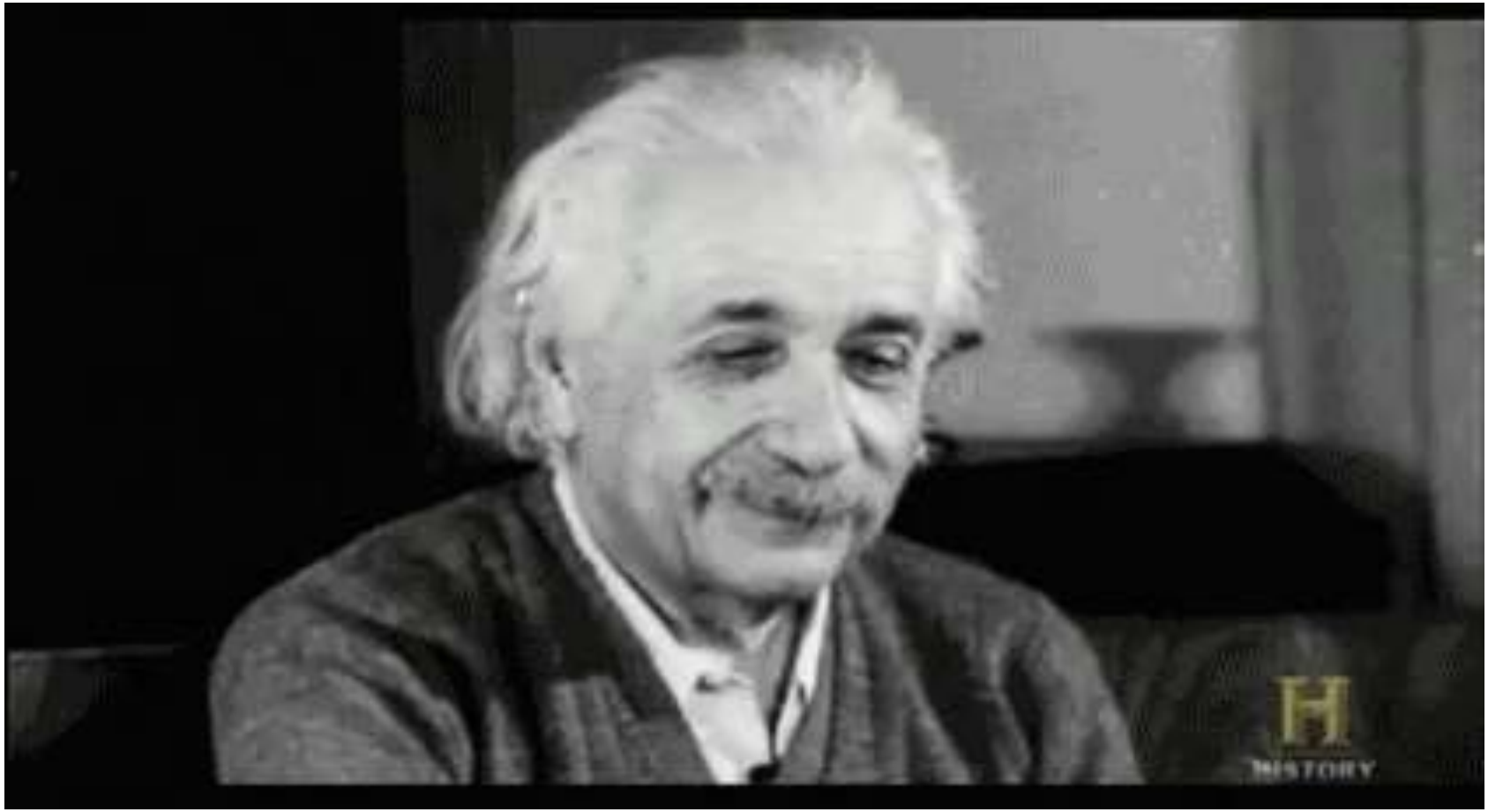
# New “theory”…another Univers (antimatter) on the other side (!) of the Big Bang



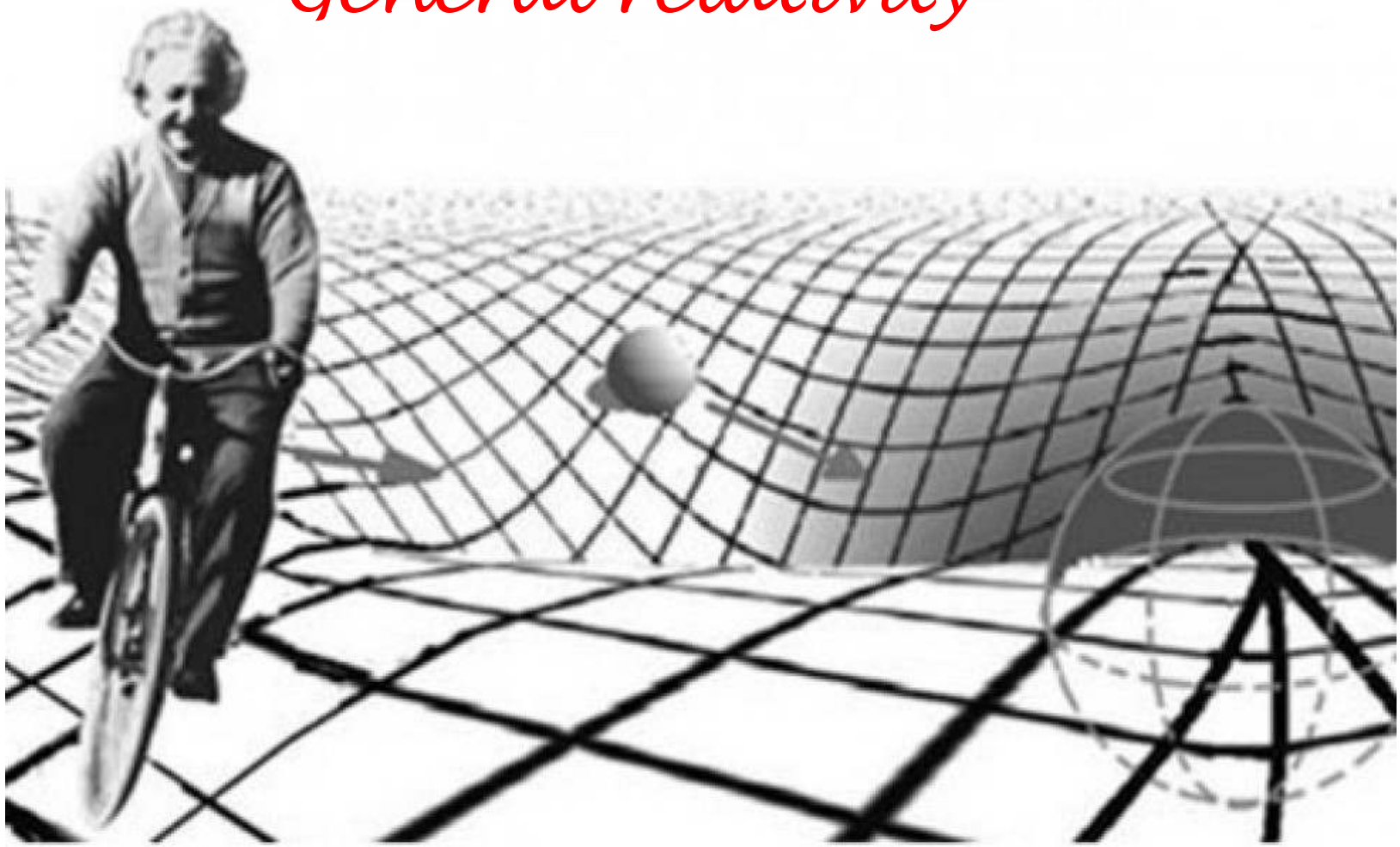
Sanford U
Research

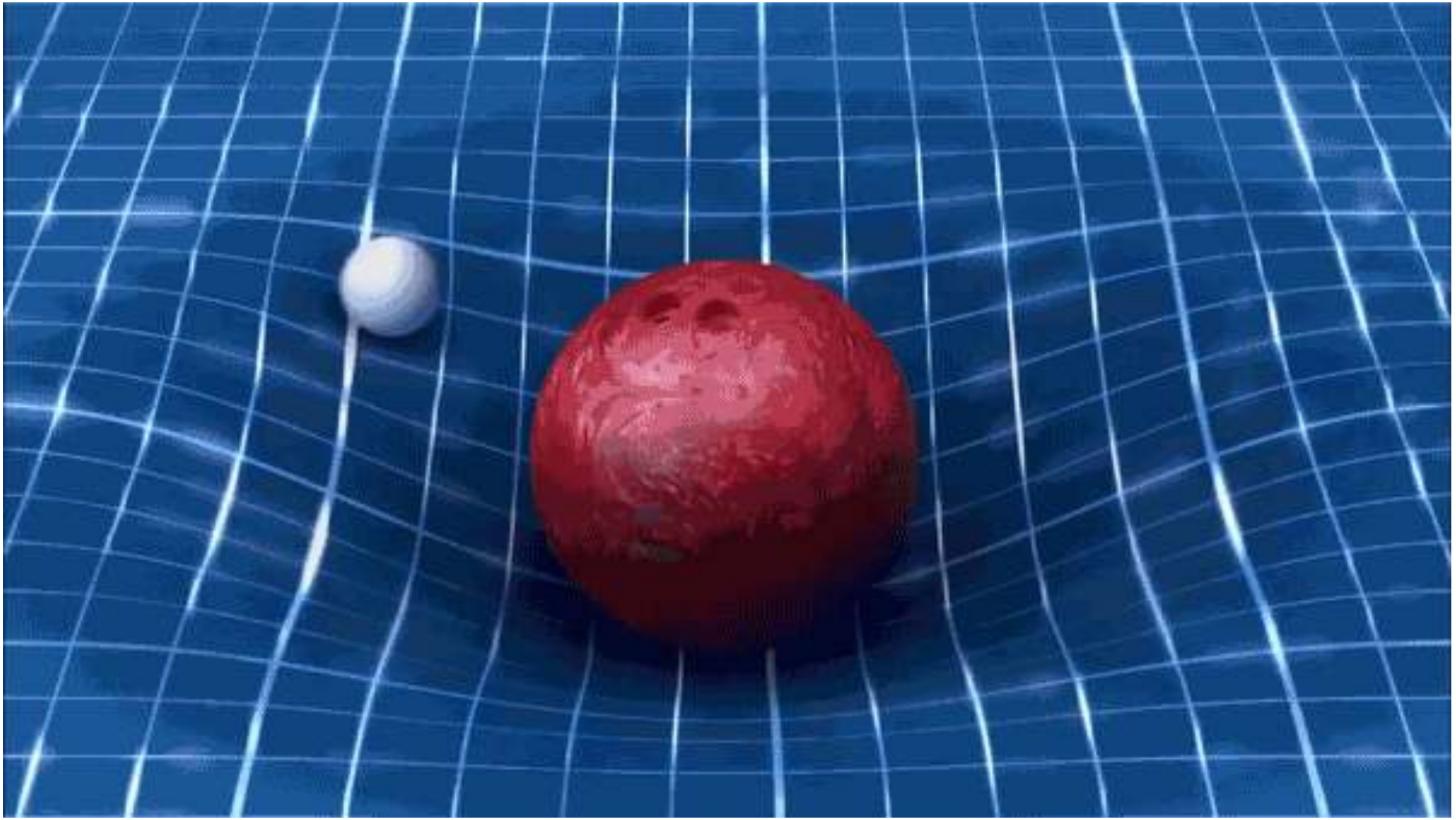
# 2) **Black holes**



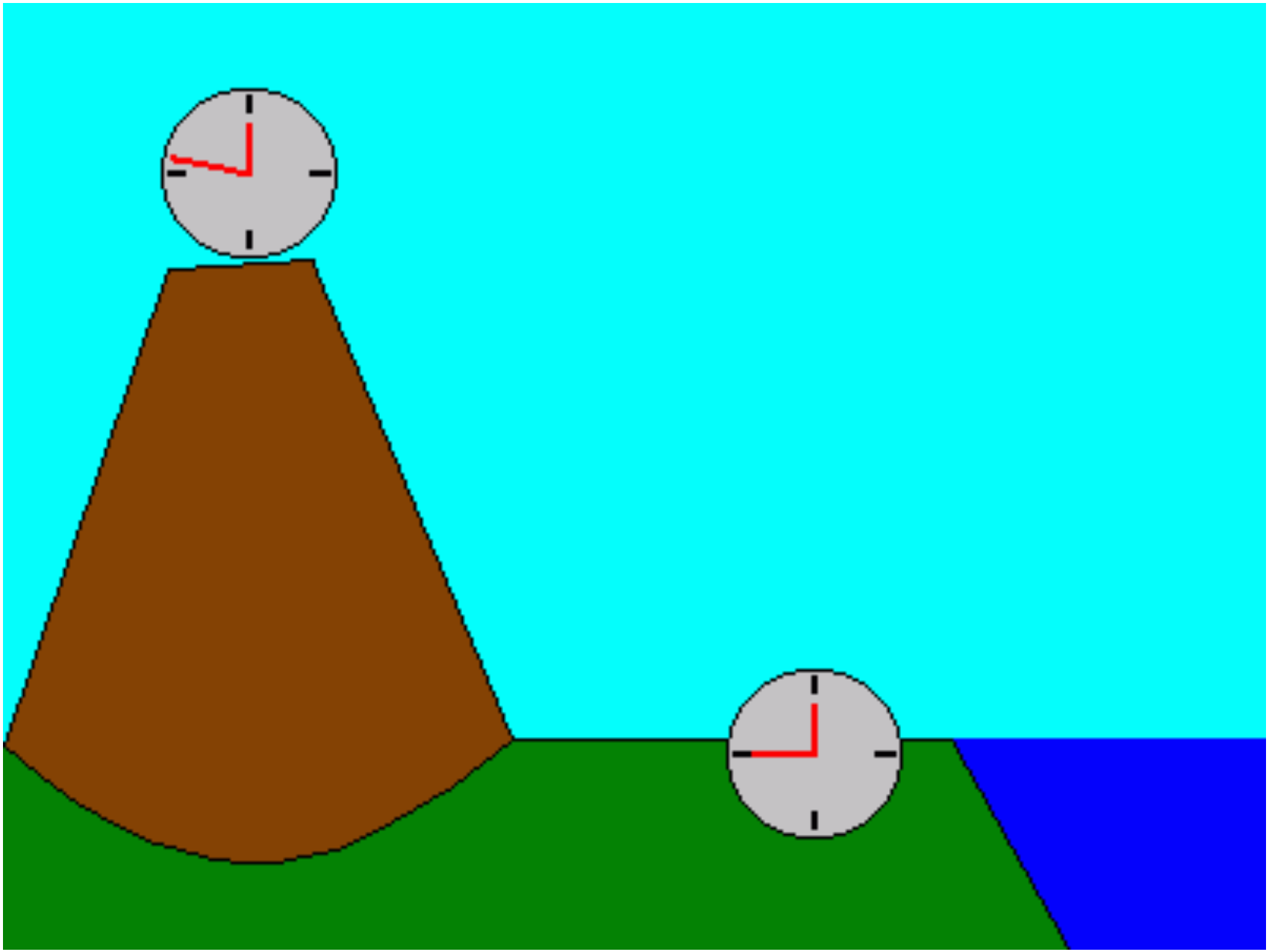

HISTORY

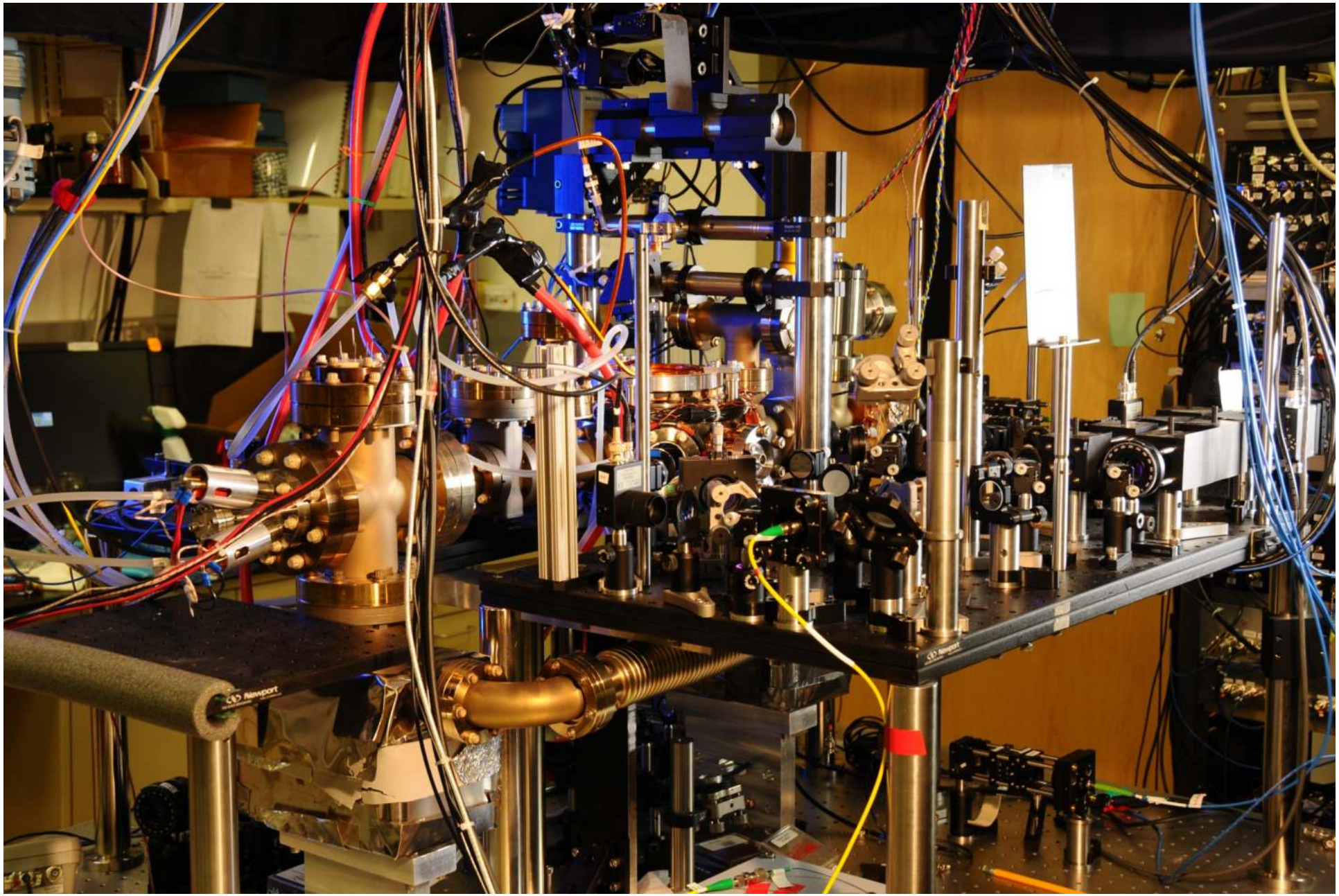
# General relativity

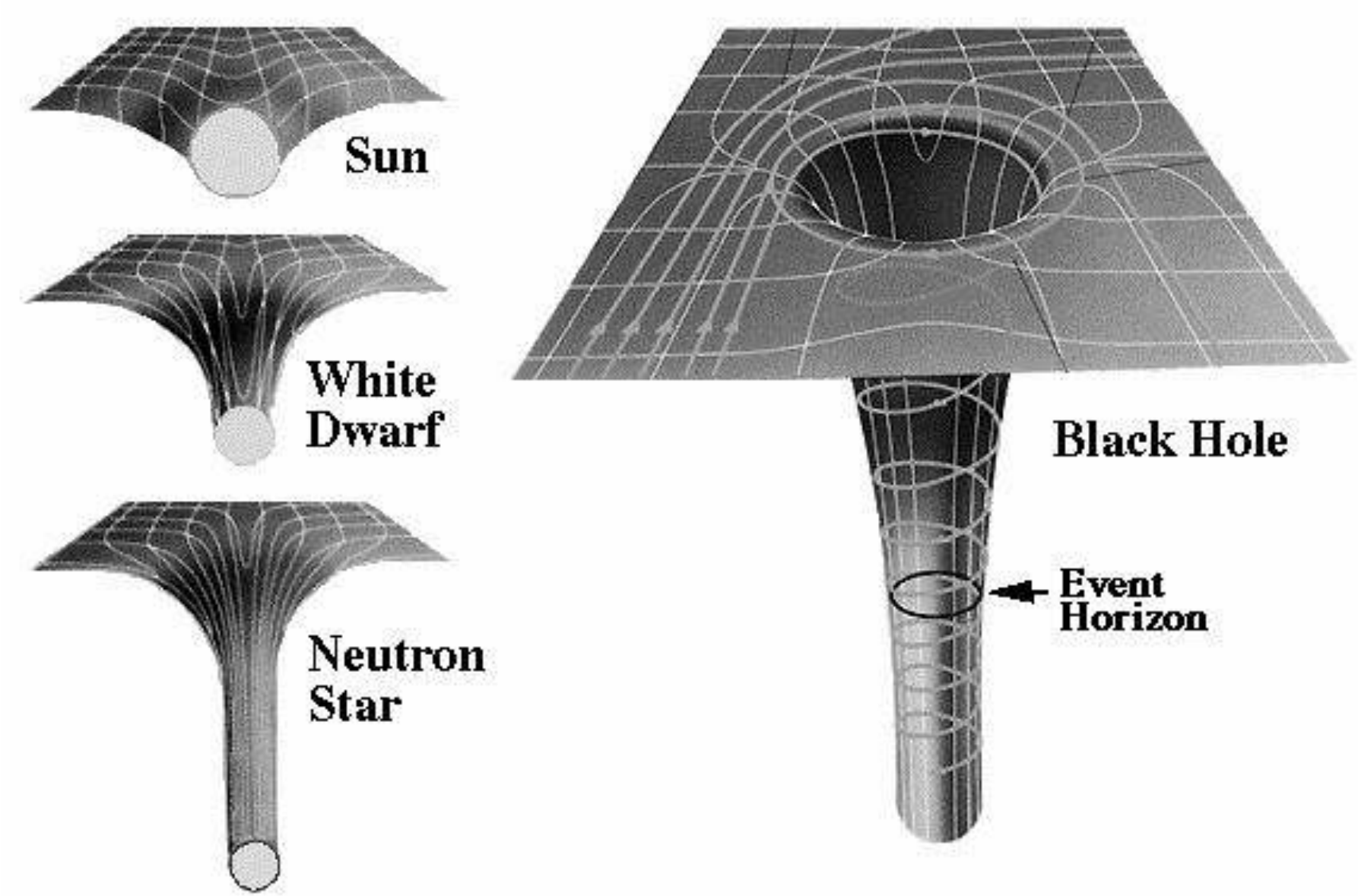




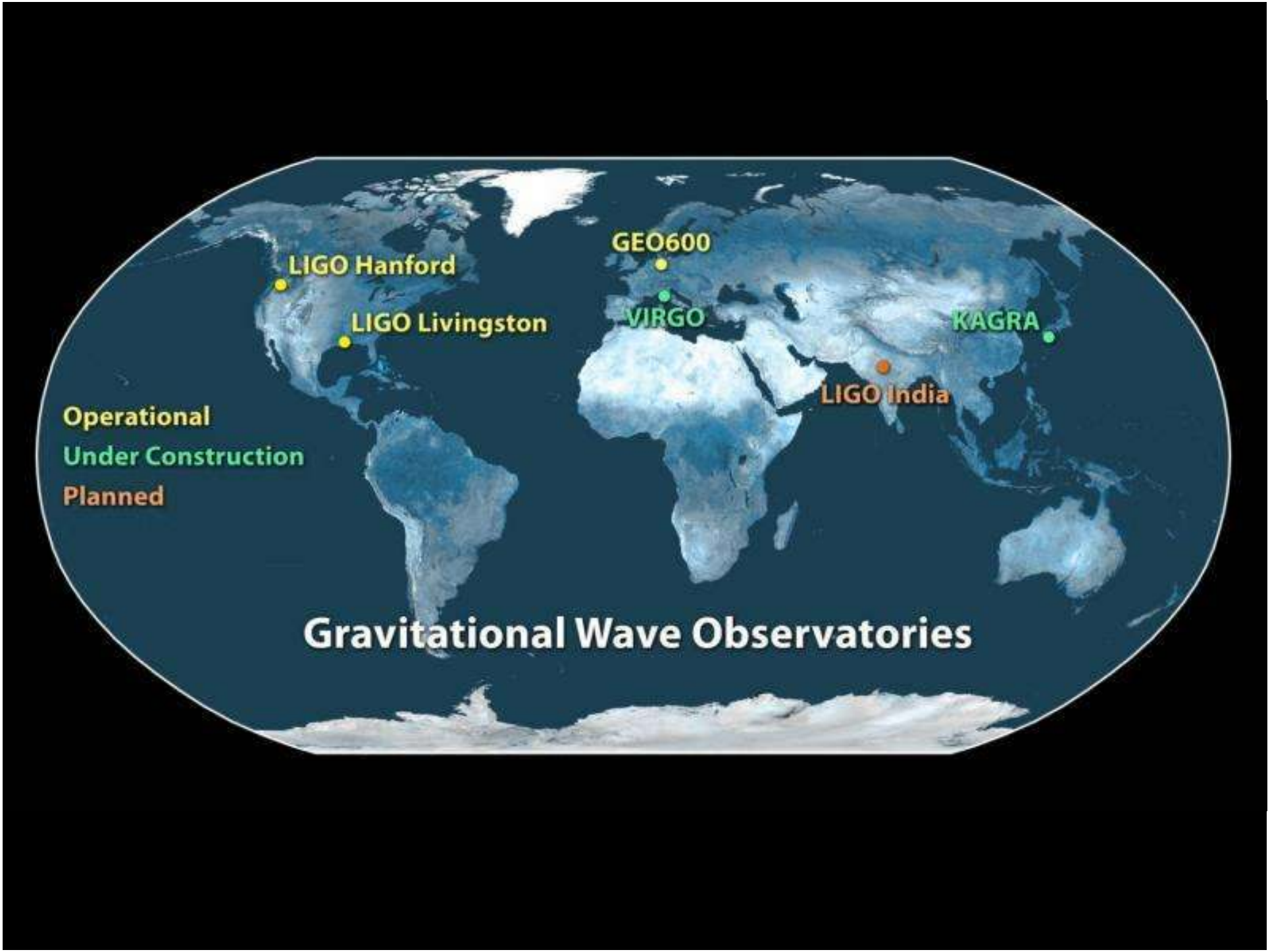

$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = \frac{8\pi G}{c^4} T_{\mu\nu}$
A. EINSTEIN

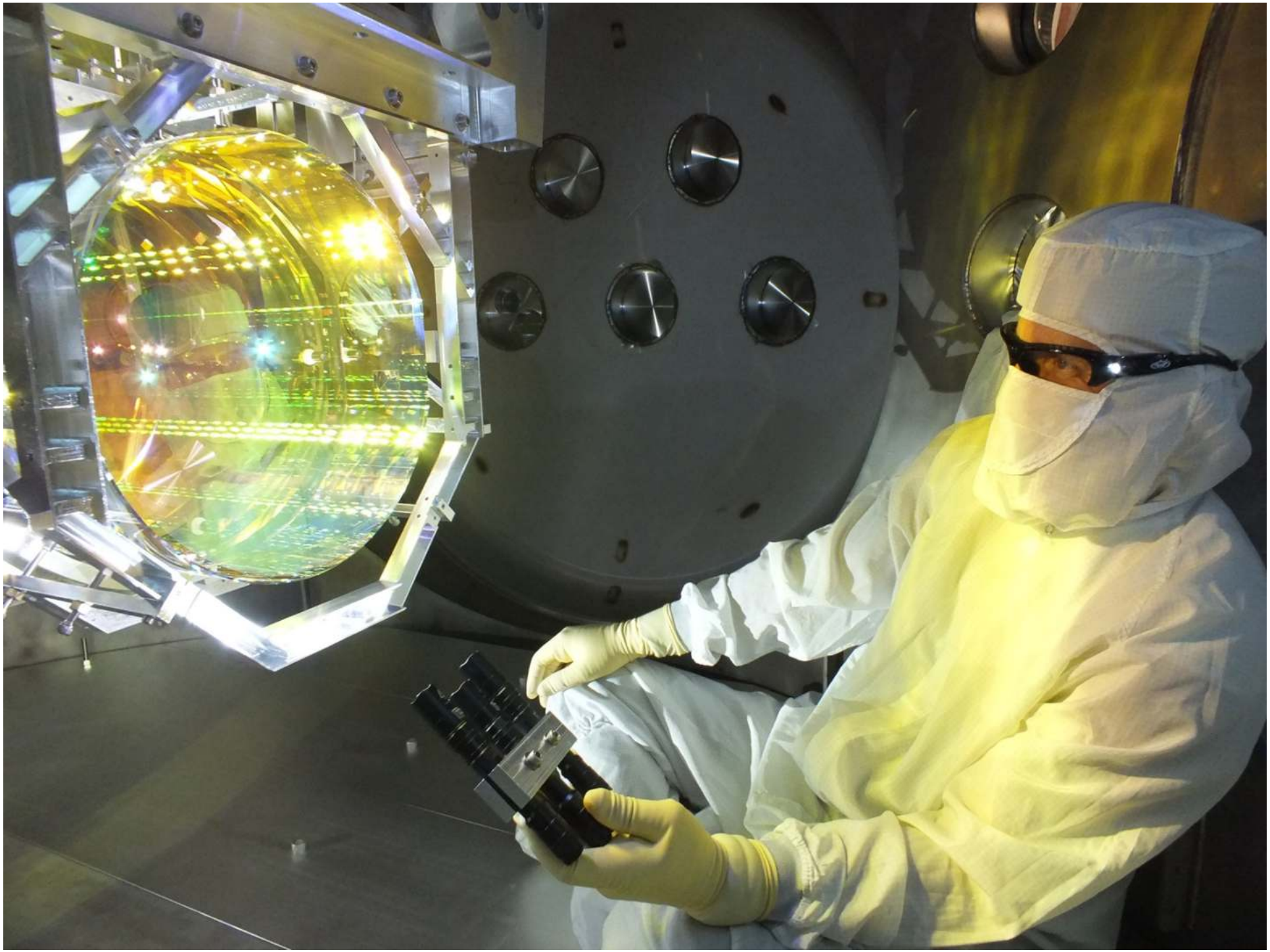


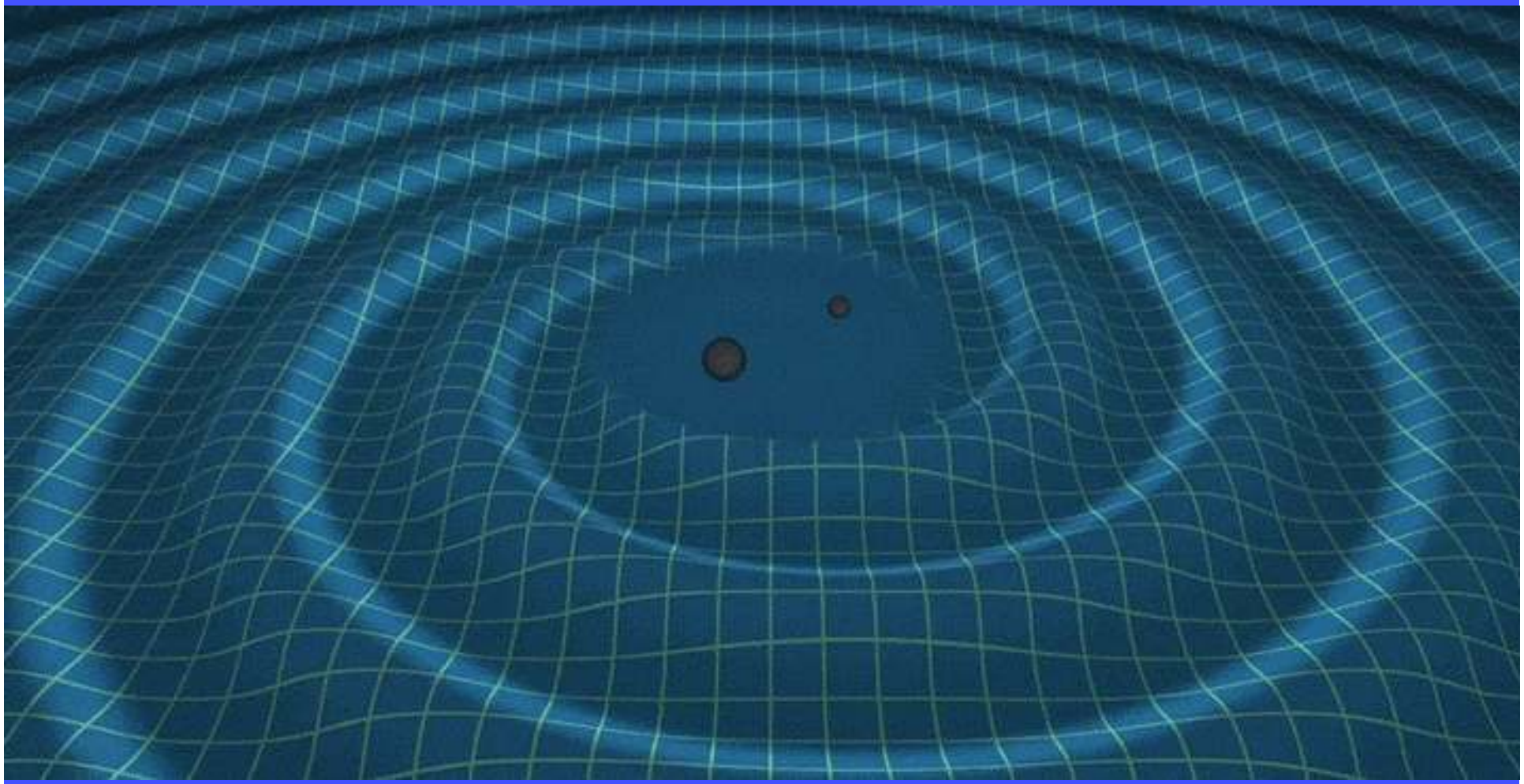

Newport
Newport

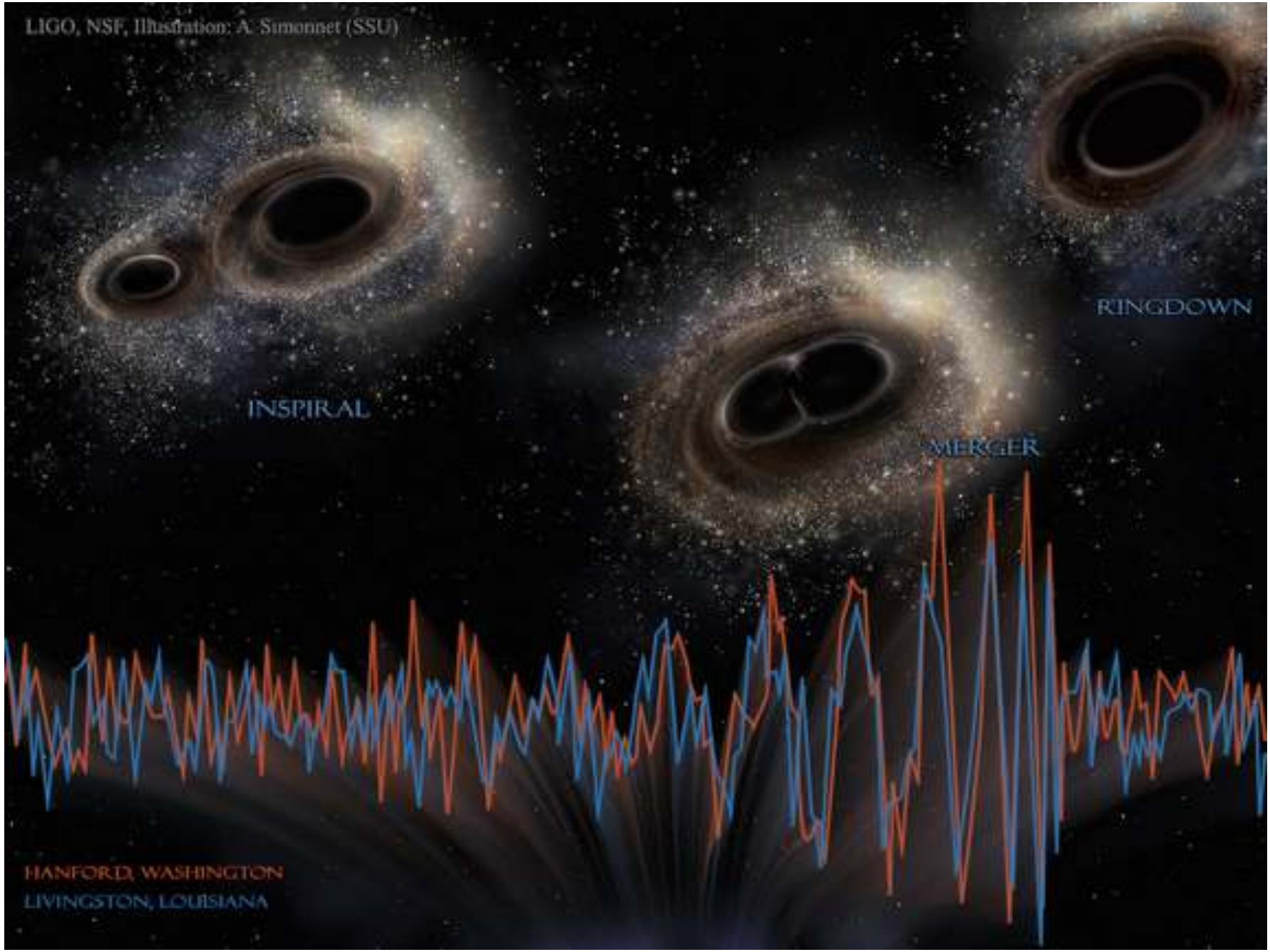


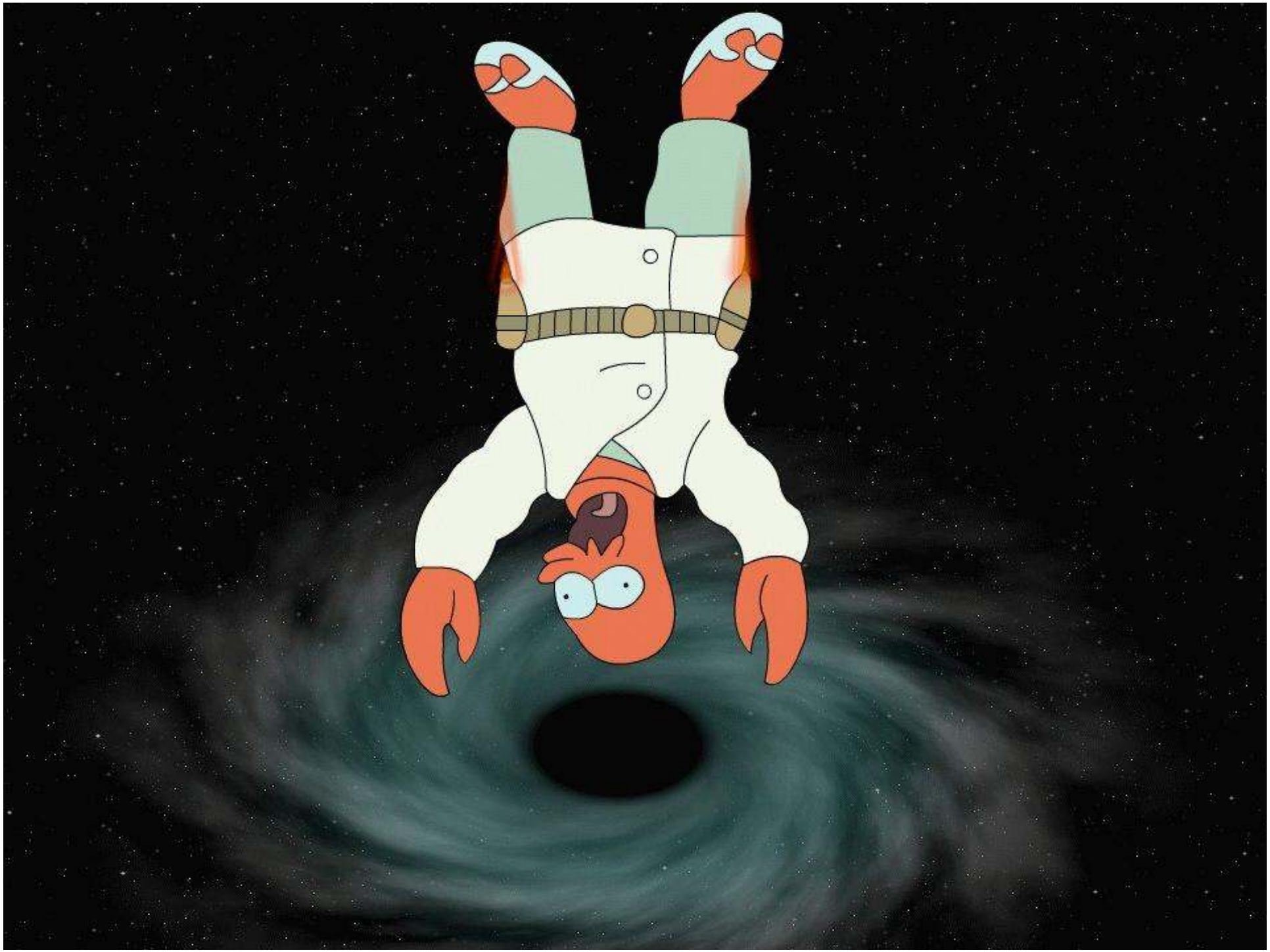

Credit: Adam Apollo

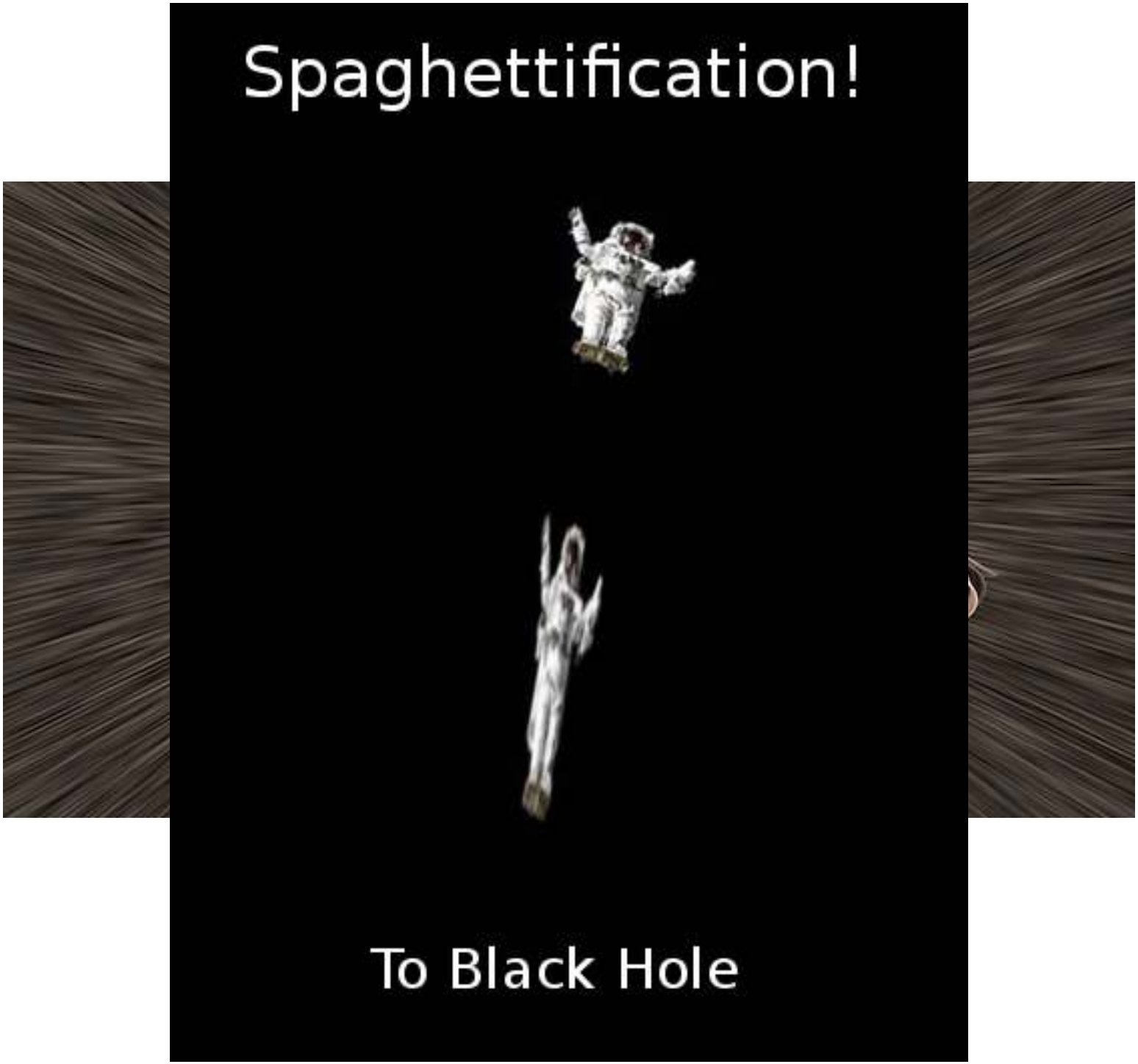

LIGO Hanford
GEO600
LIGO Livingston
VIRGO
KAGRA
LIGO India
Operational
Under Construction
Planned
Gravitational Wave Observatories



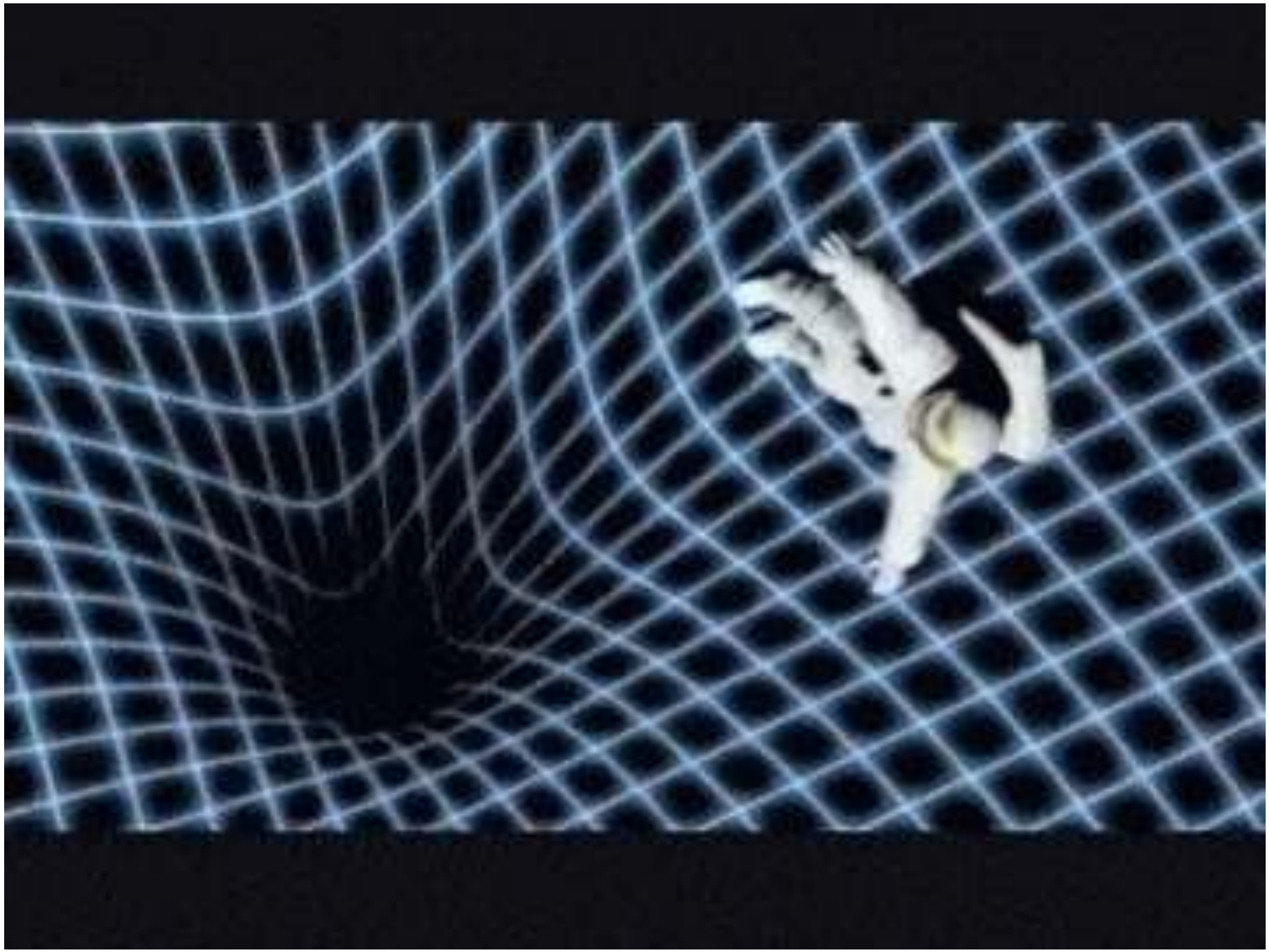



LIGO, NSF, Illustration: A. Simonnet (SSU)
INSPIRAL
MERGER
RINGDOWN
HANFORD, WASHINGTON
LIVINGSTON, LOUISIANA

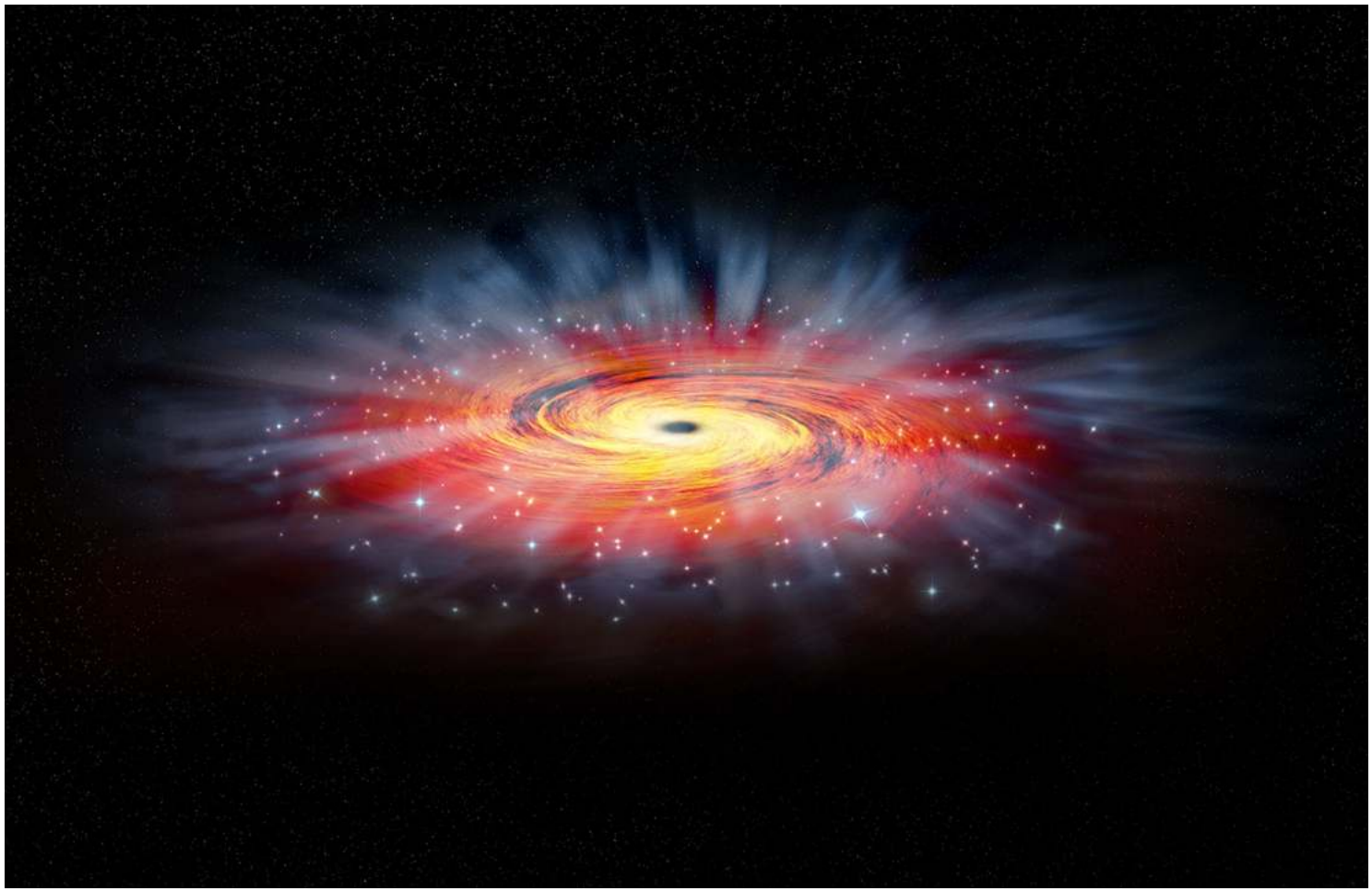



Spaghettification!
To Black Hole

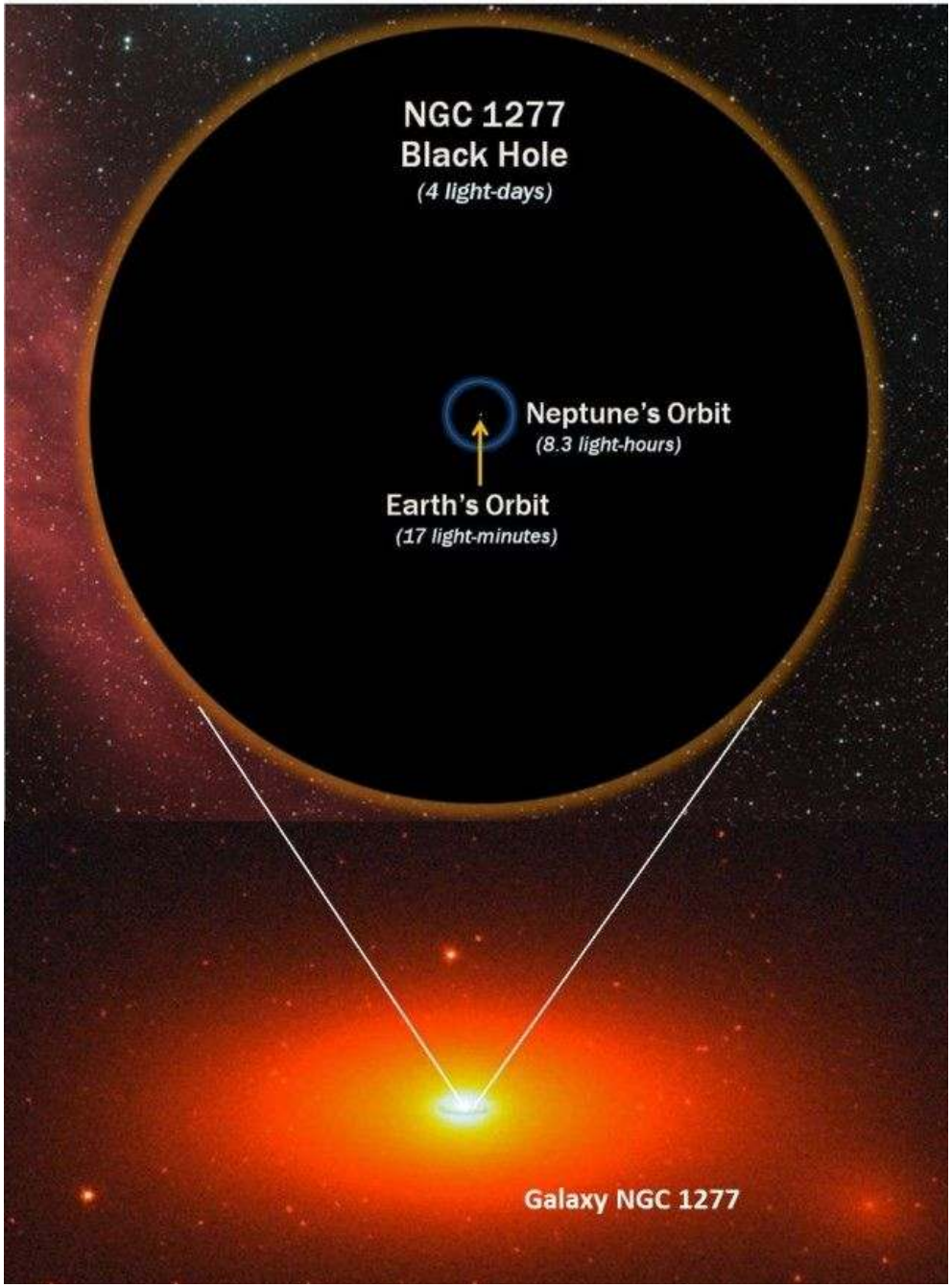
# Spaghettification



# Huge black holes
# no spaghetificaton



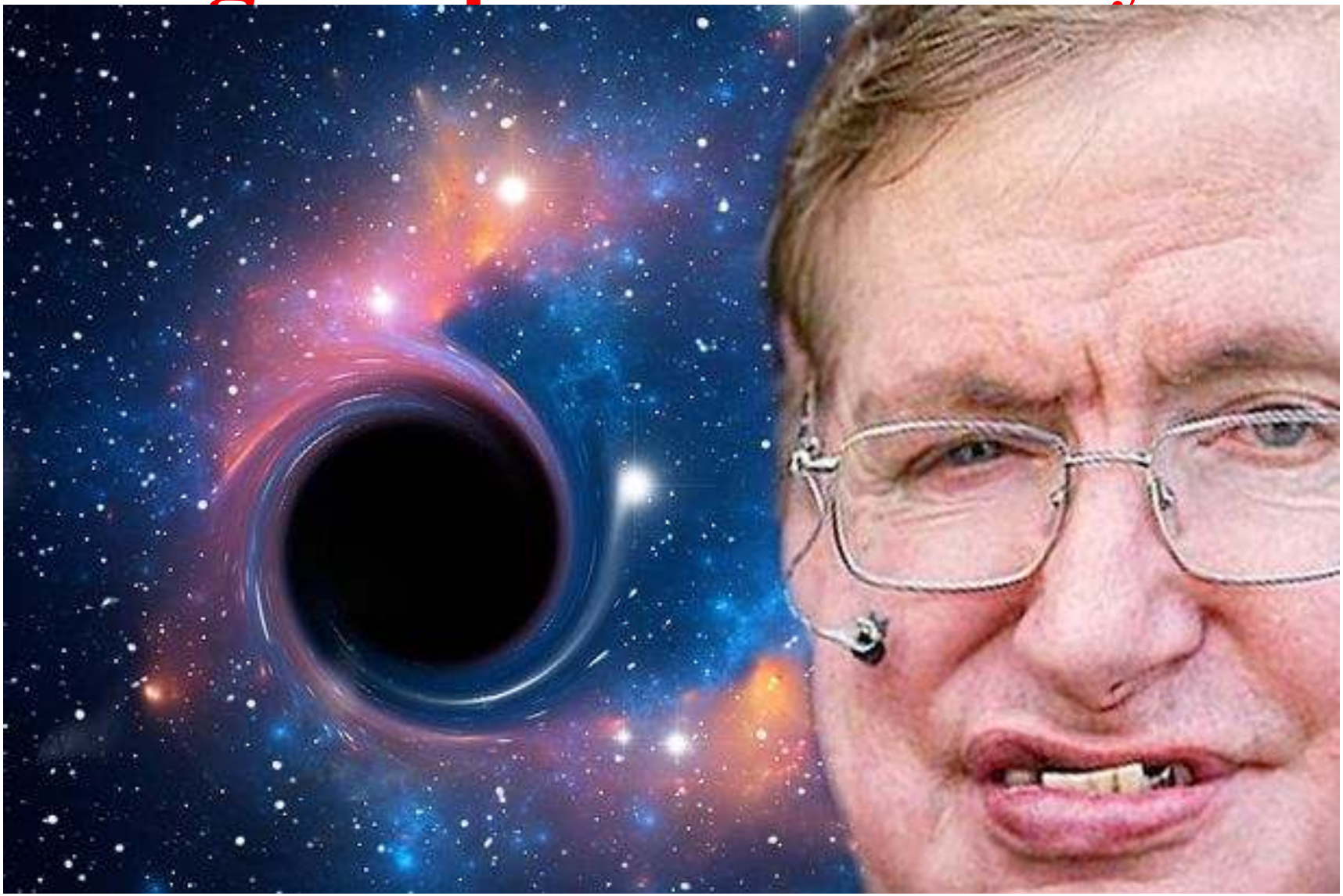
Black Hole – mass about 17 billion times Solar mass



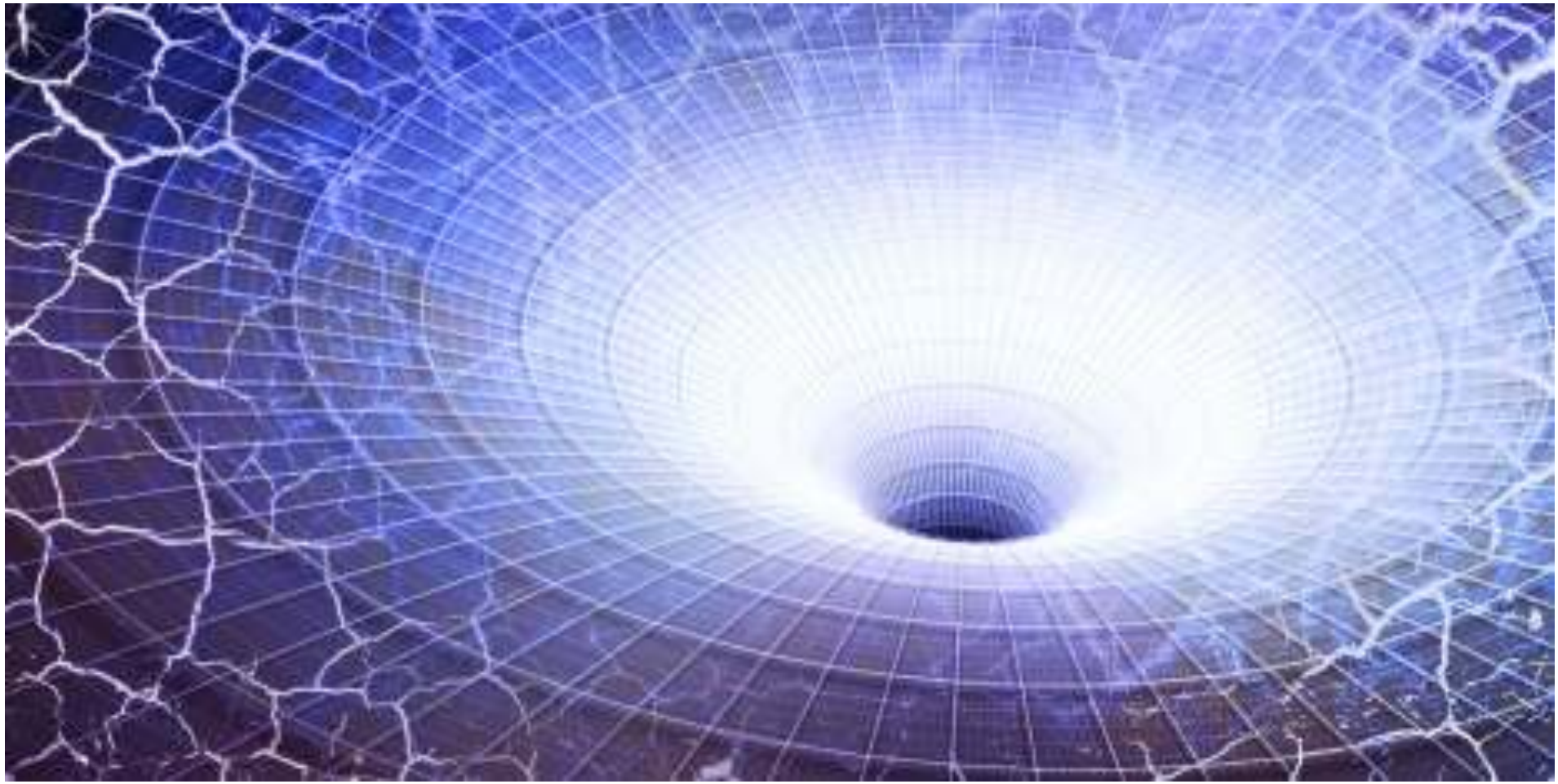

Interstellar??

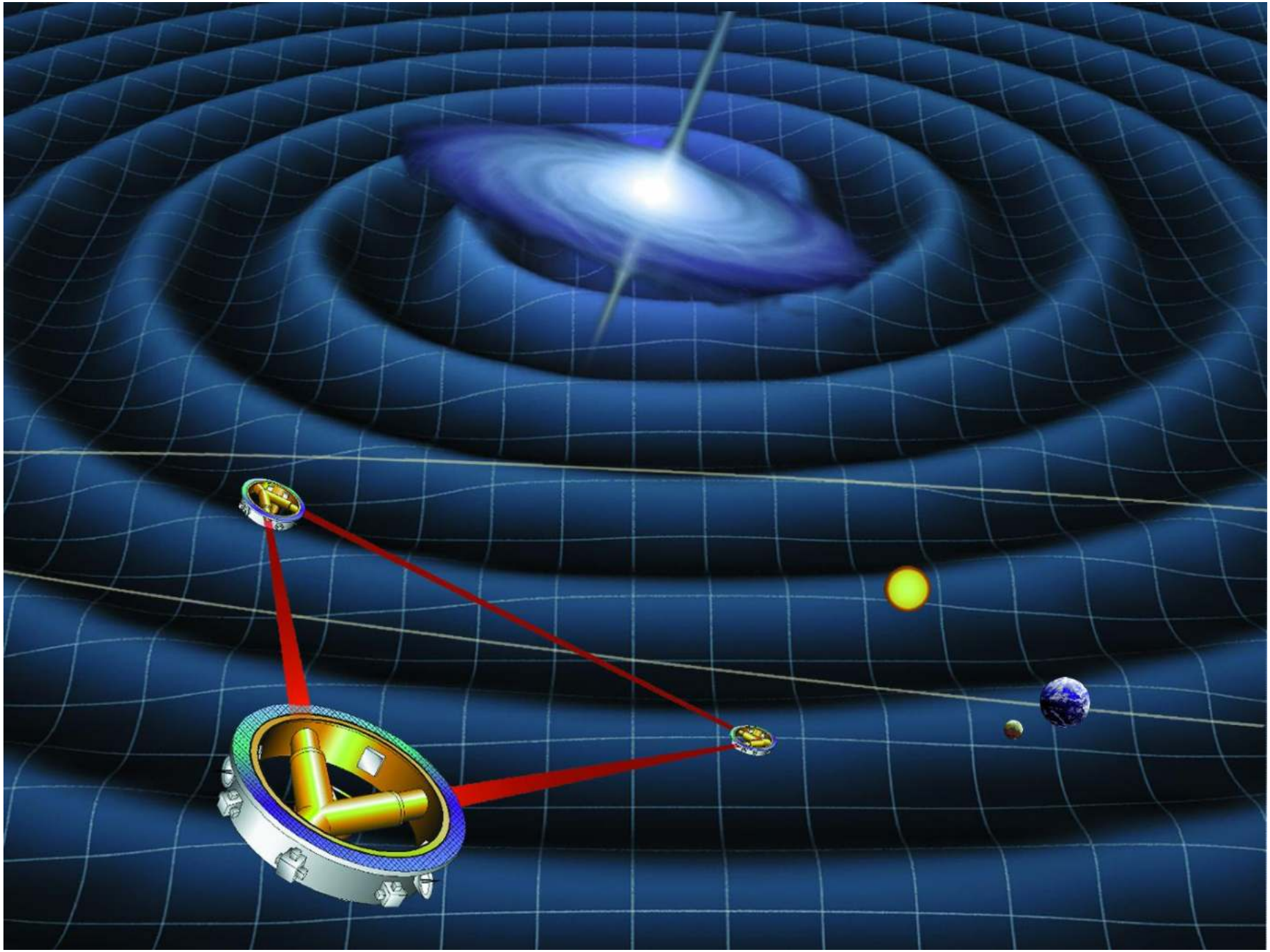
# Black Holes Are Passage To Another Universe

# If you feel you are in a black hole, don’t give up. There’s a way out

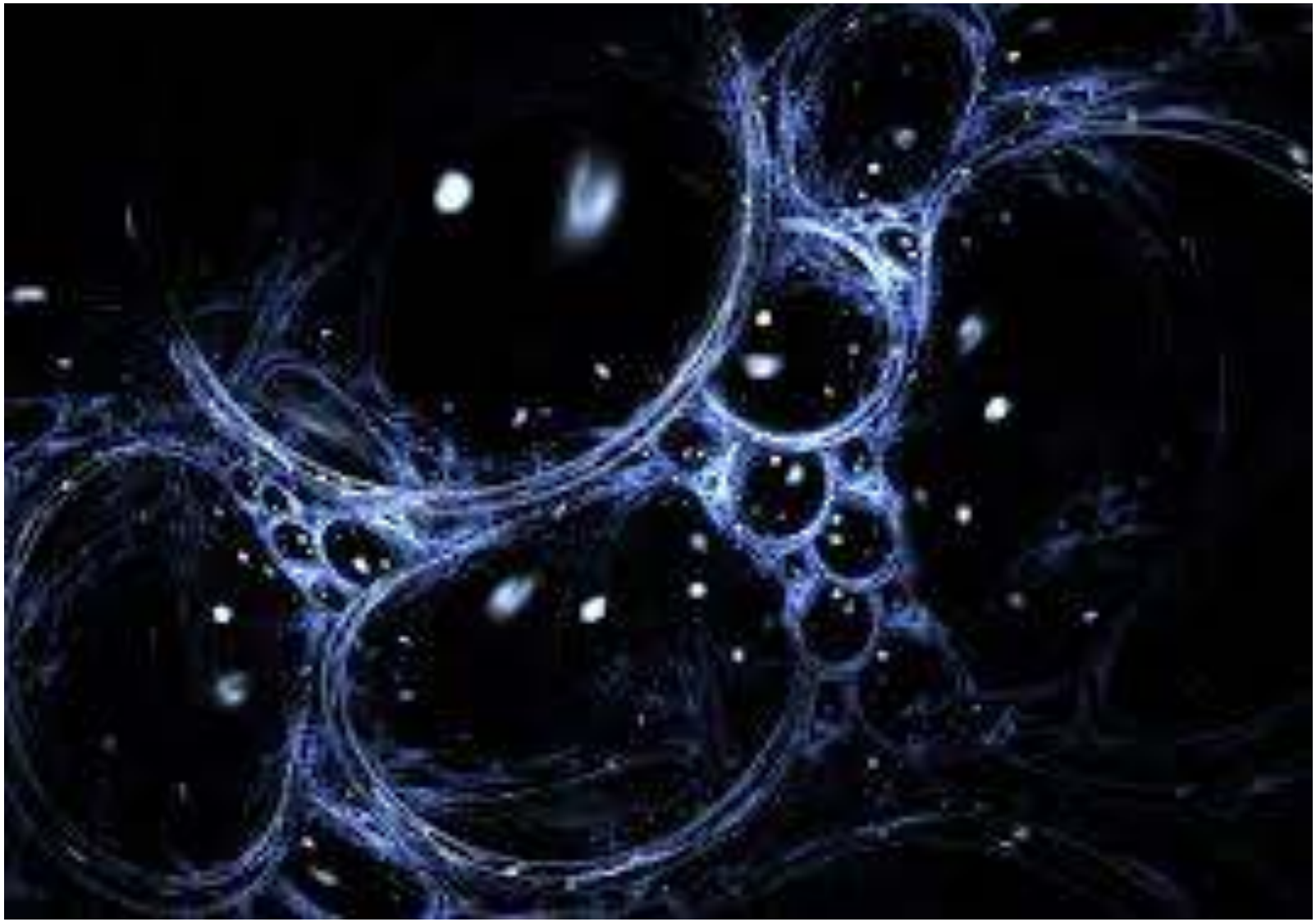


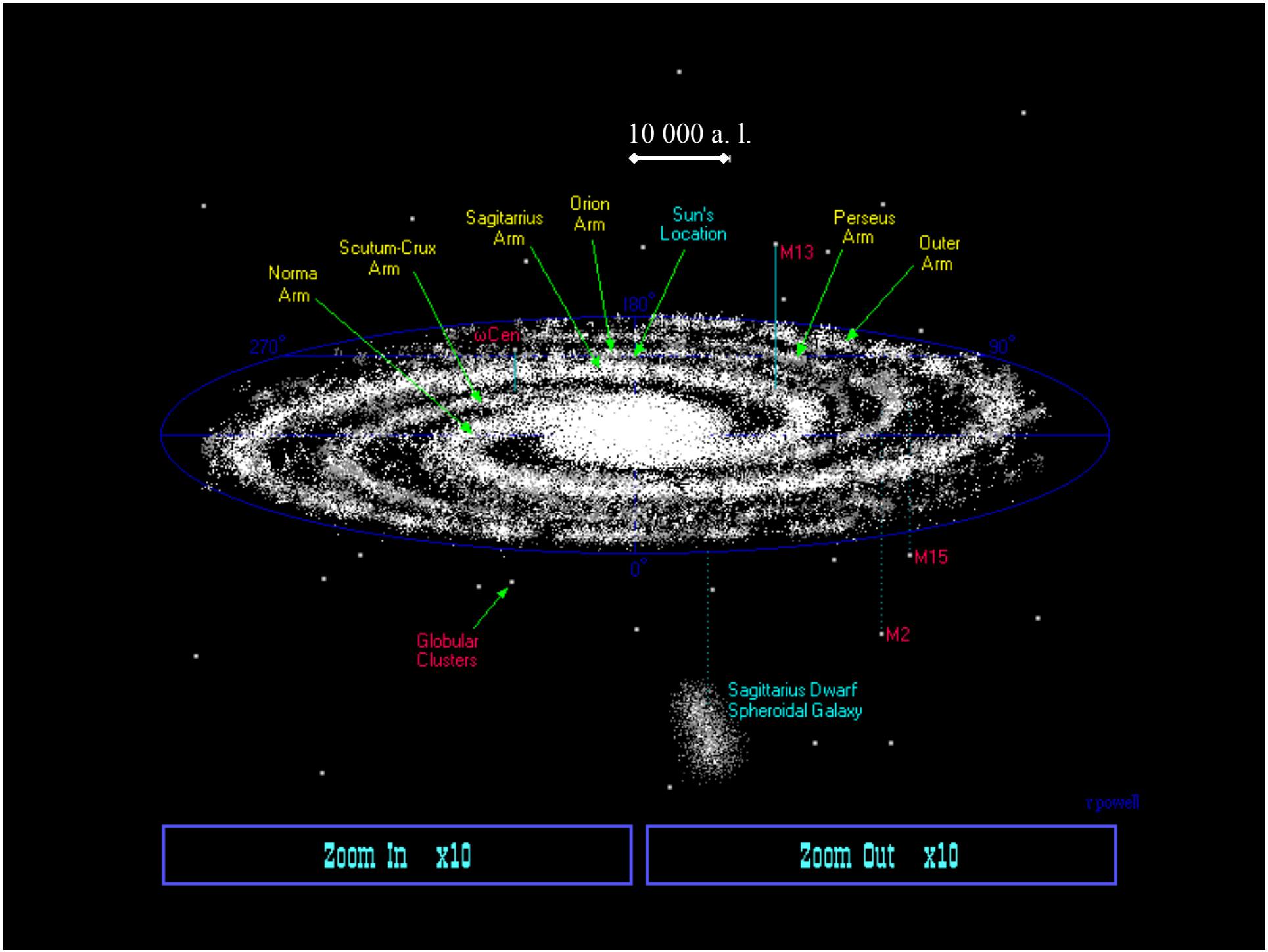
# Quantum gravity to explain BH ?

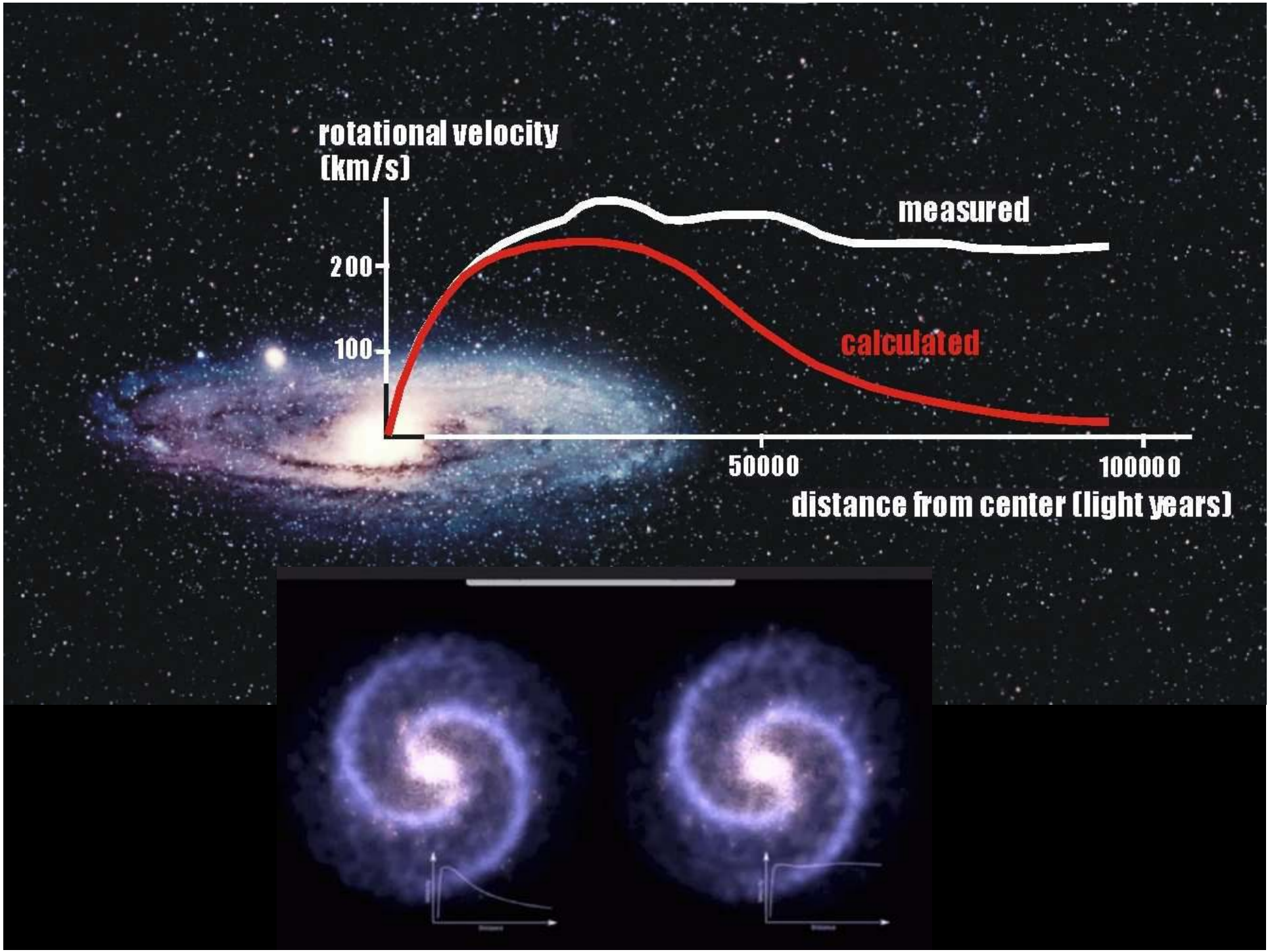


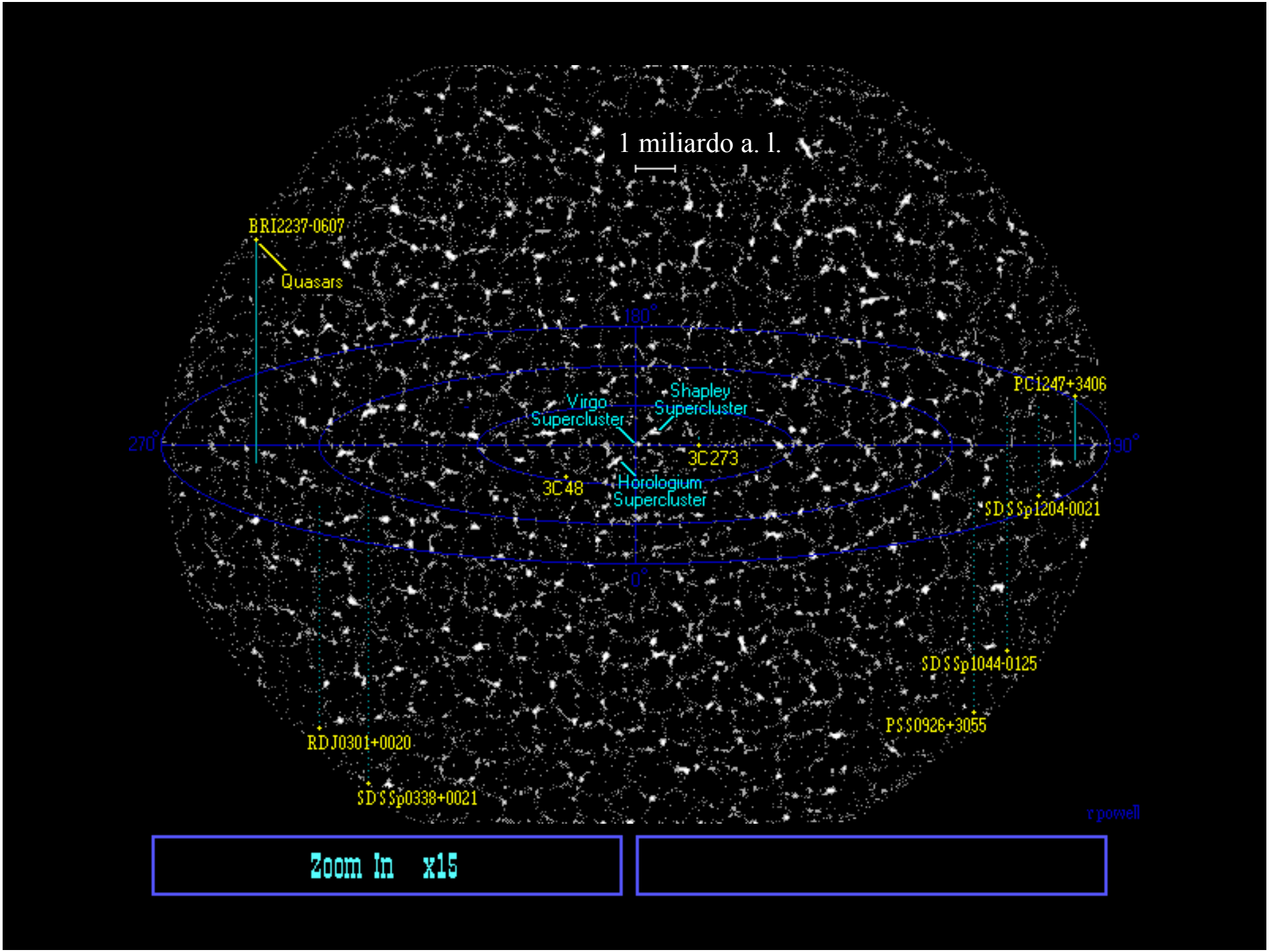


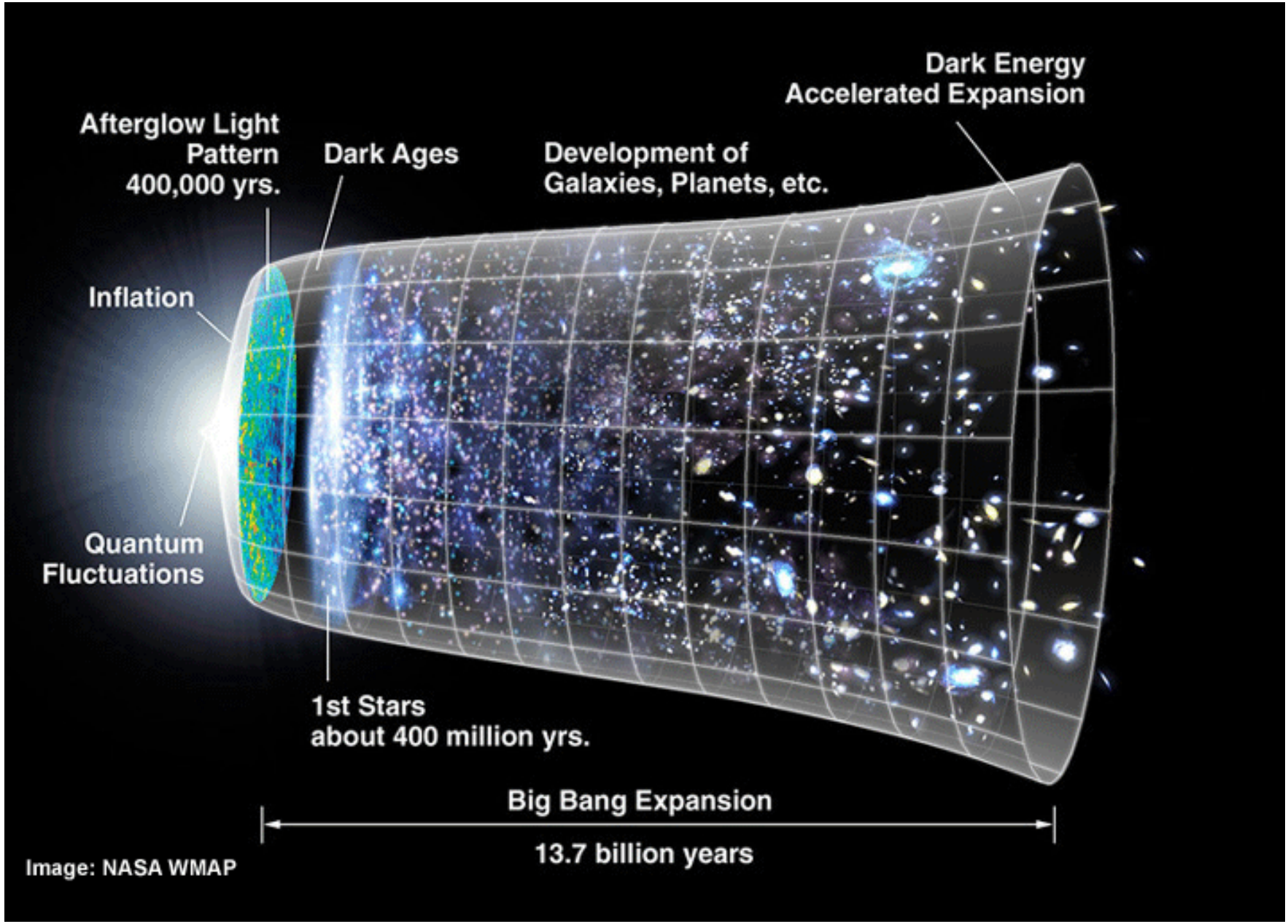
# 3) Dark matter and energy

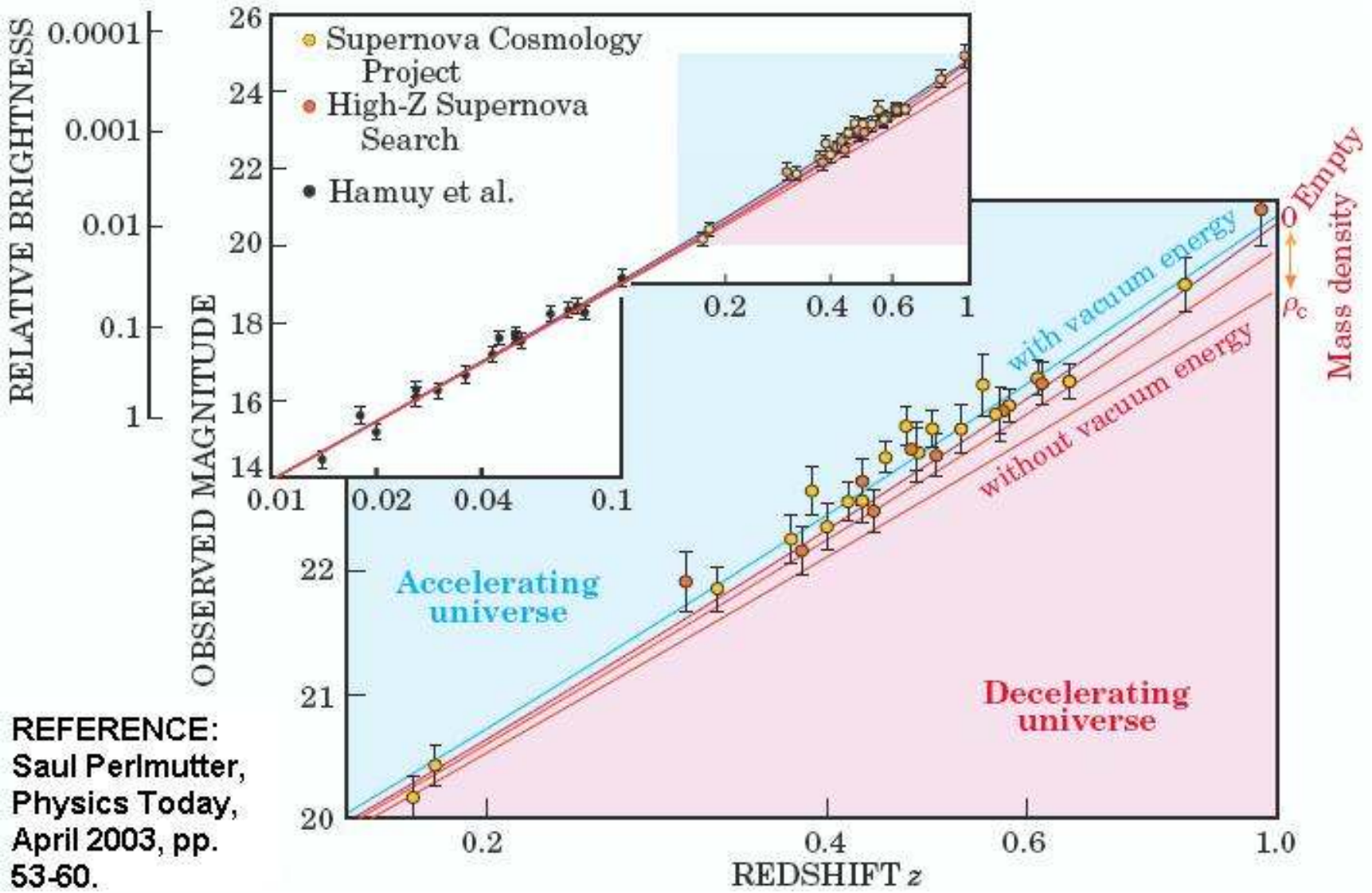



10 000 a. l.
Norma Arm
Scutum-Crux Arm
Sagitarrius Arm
Orion Arm
Sun's Location
M13
Perseus Arm
Outer Arm
180°
270°
ωCen
90°
0°
M15
M2
Globular Clusters
Sagittarius Dwarf Spheroidal Galaxy
r powell
Zoom In x10
Zoom Out x10

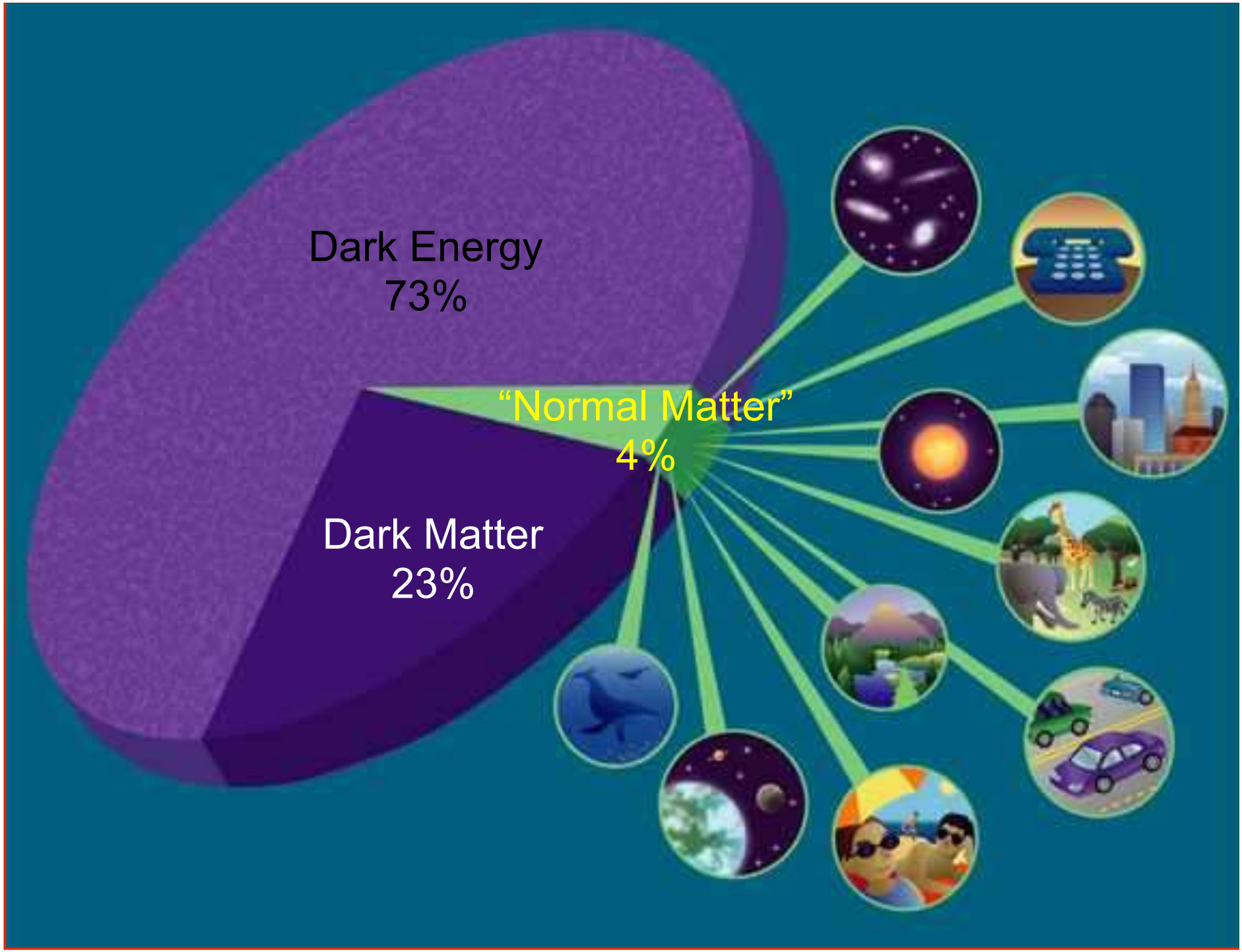

rotational velocity
(km/s)
200
100
measured
calculated
50000
100000
distance from center (light years)


1 miliardo a. l.
BRI2237-0607
Quasars
180°
270°
90°
0°
PC1247+3406
Virgo
Supercluster
Shapley
Supercluster
3C273
3C48
Horologium
Supercluster
SDSSp1204-0021
SDSSp1044-0125
PSS0926+3055
RDJ0301+0020
SDSSp0338+0021
r powell
Zoom In x15

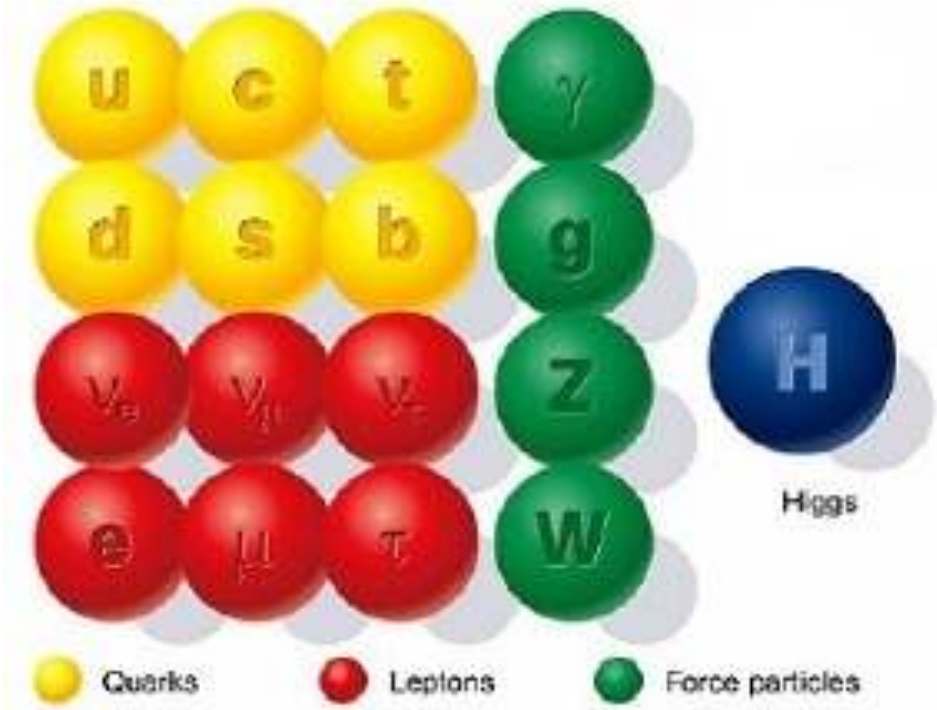

Dark Energy
Accelerated Expansion
Afterglow Light
Pattern
400,000 yrs.
Dark Ages
Development of
Galaxies, Planets, etc.
Inflation
Quantum
Fluctuations
1st Stars
about 400 million yrs.
Big Bang Expansion
13.7 billion years
Image: NASA WMAP



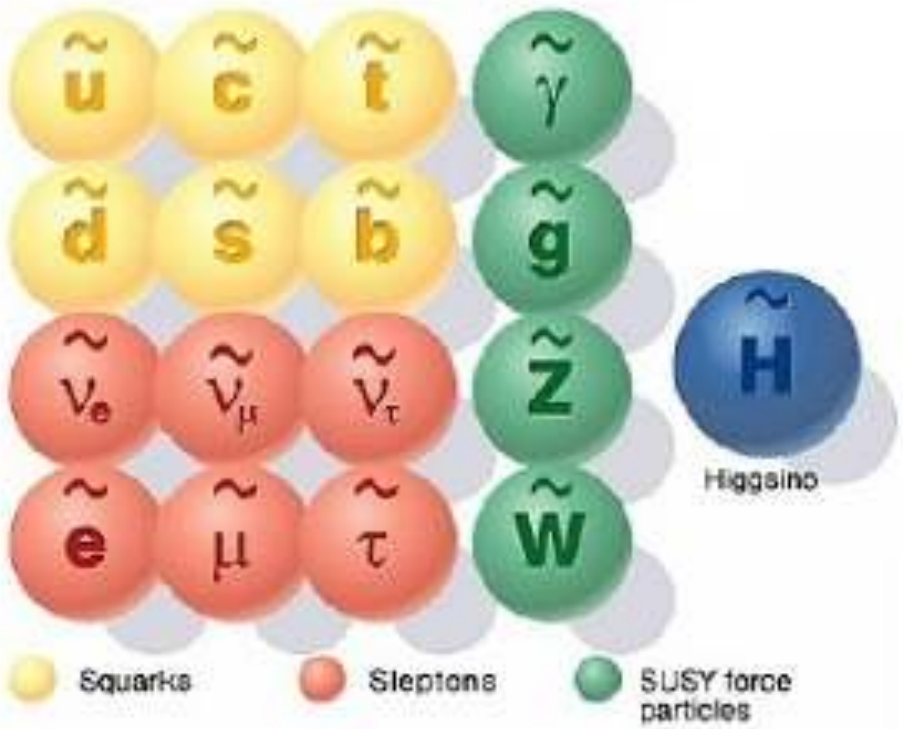

REFERENCE:
Saul Perlmutter, Physics Today, April 2003, pp. 53-60.


Dark Energy
73%
"Normal Matter"
4%
Dark Matter
23%

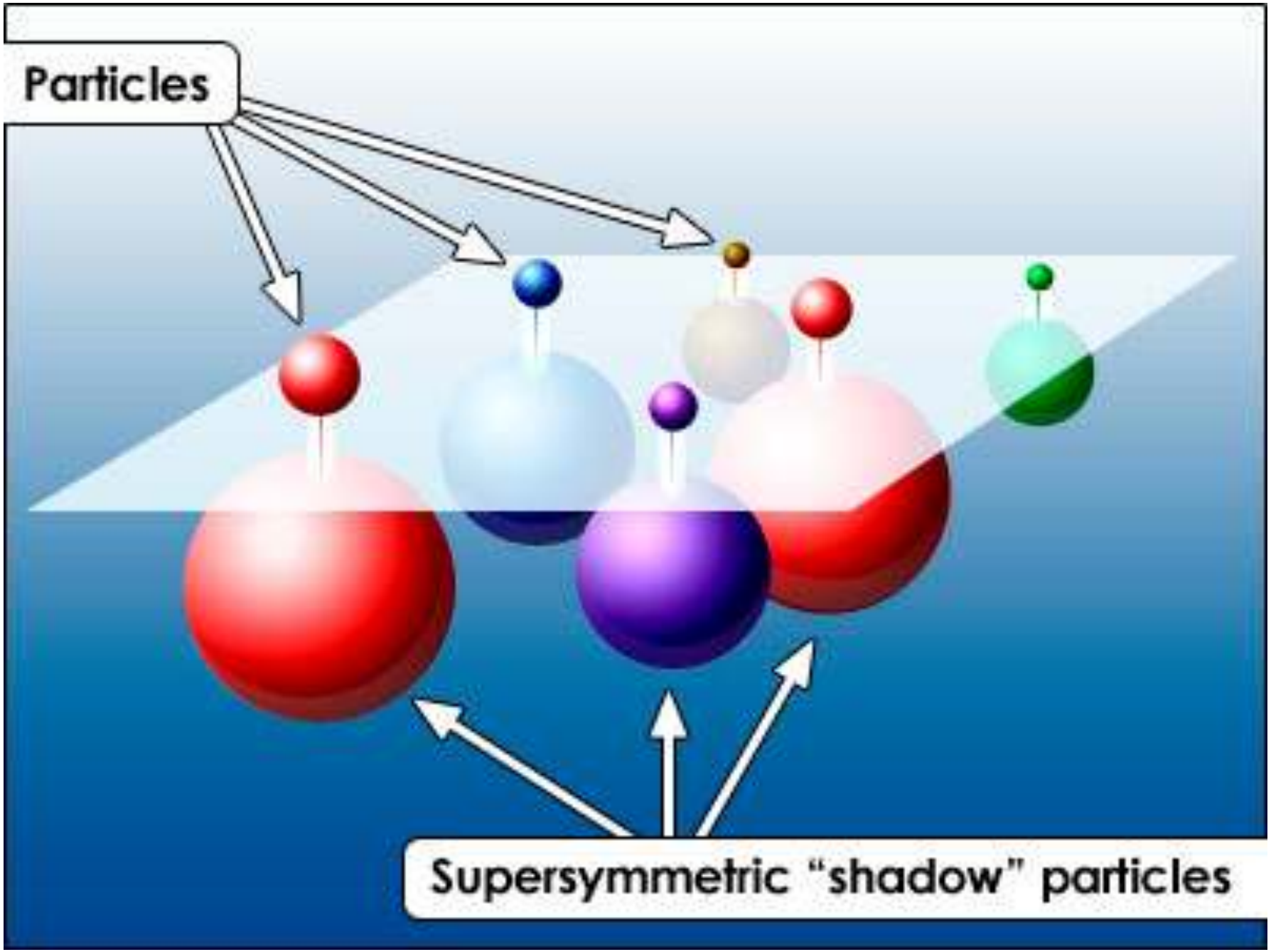
# SUPERSYMMETRY



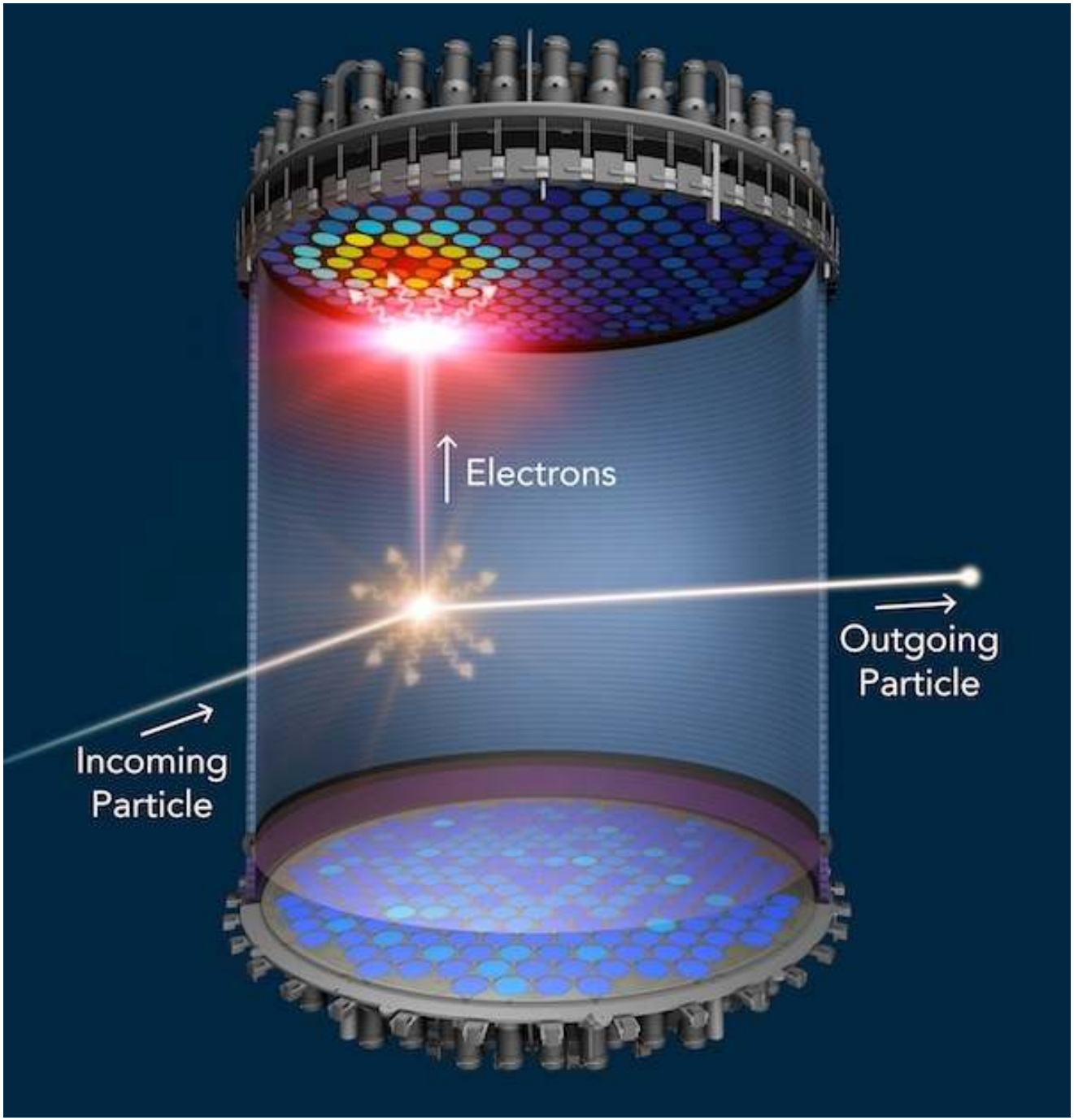

Standard particles

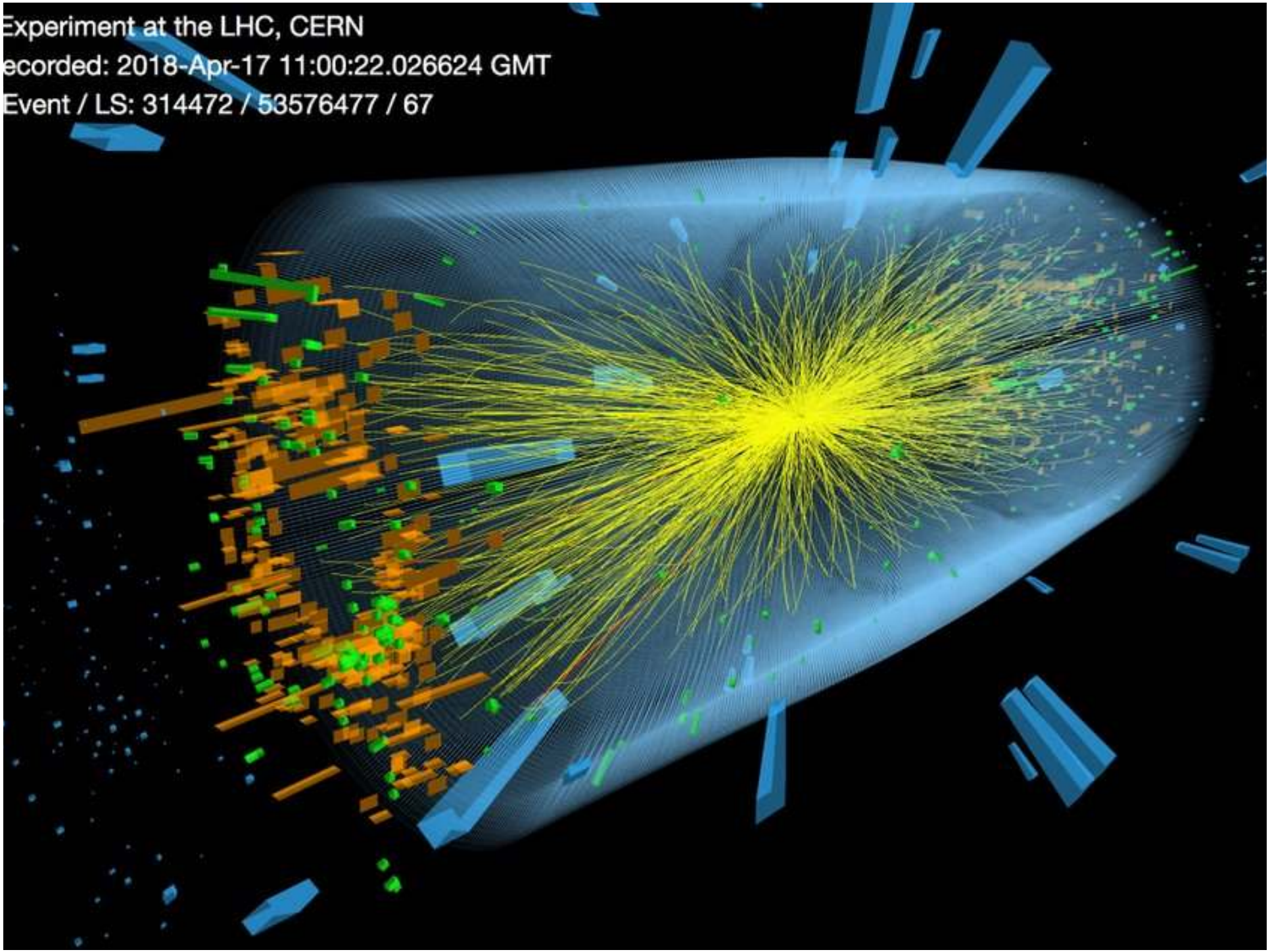



SUSY particles

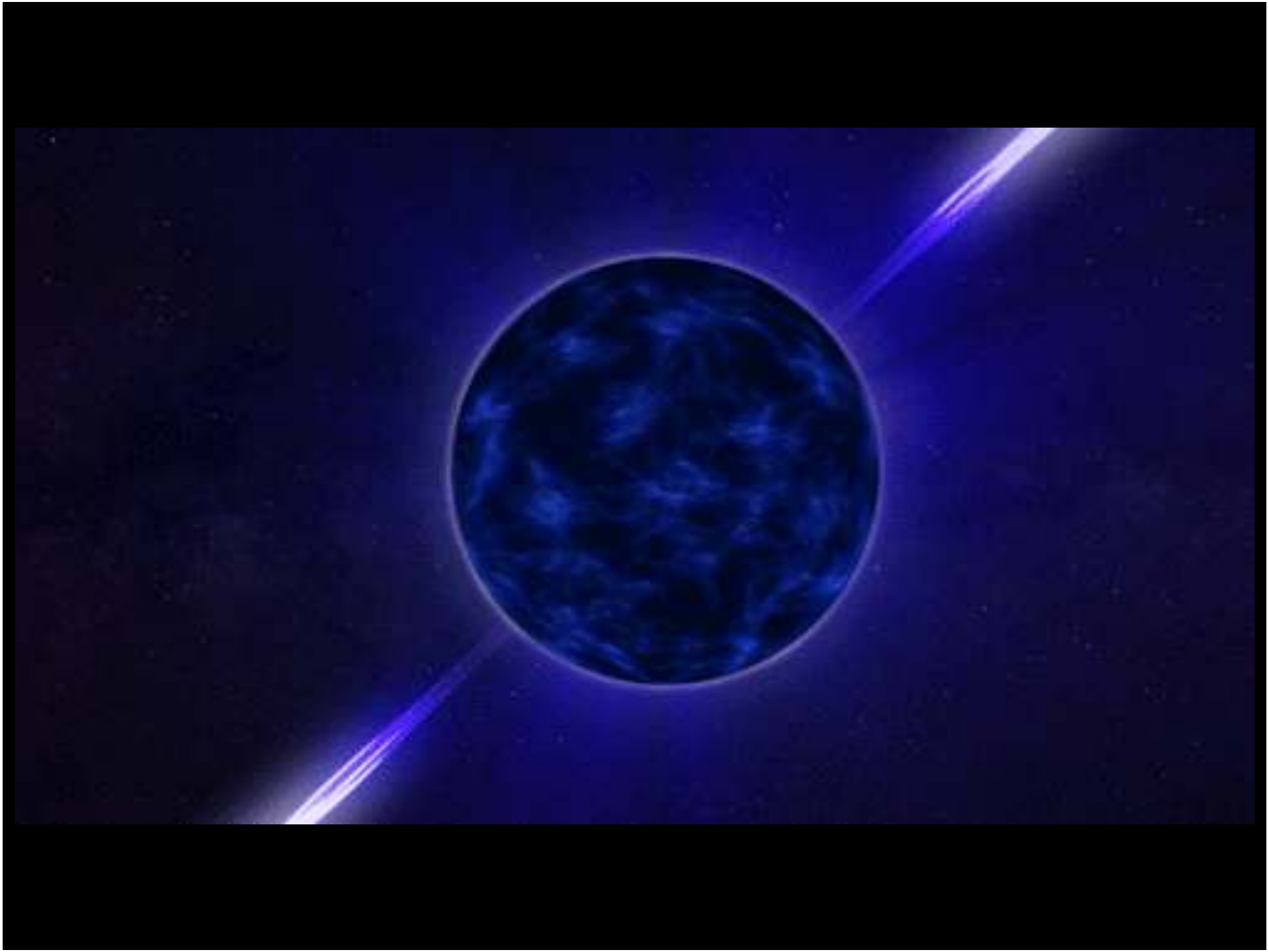

Particles
Supersymmetric "shadow" particles


XENON
XENON
enlightenir


Electrons
Outgoing Particle
Incoming Particle


Experiment at the LHC, CERN
ecorded: 2018-Apr-17 11:00:22.026624 GMT
Event / LS: 314472 / 53576477 / 67

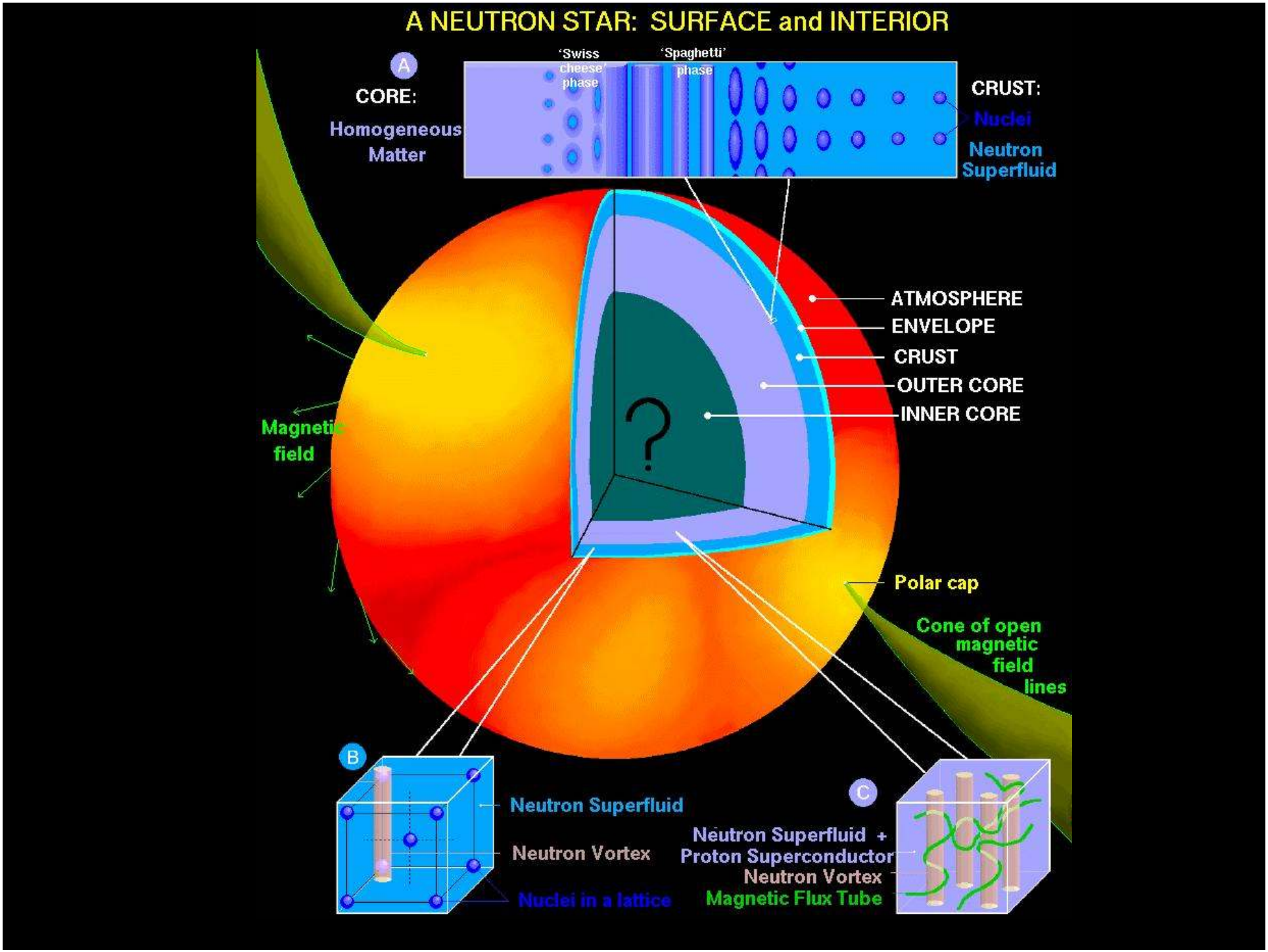
# 4) Structure of neutron stars



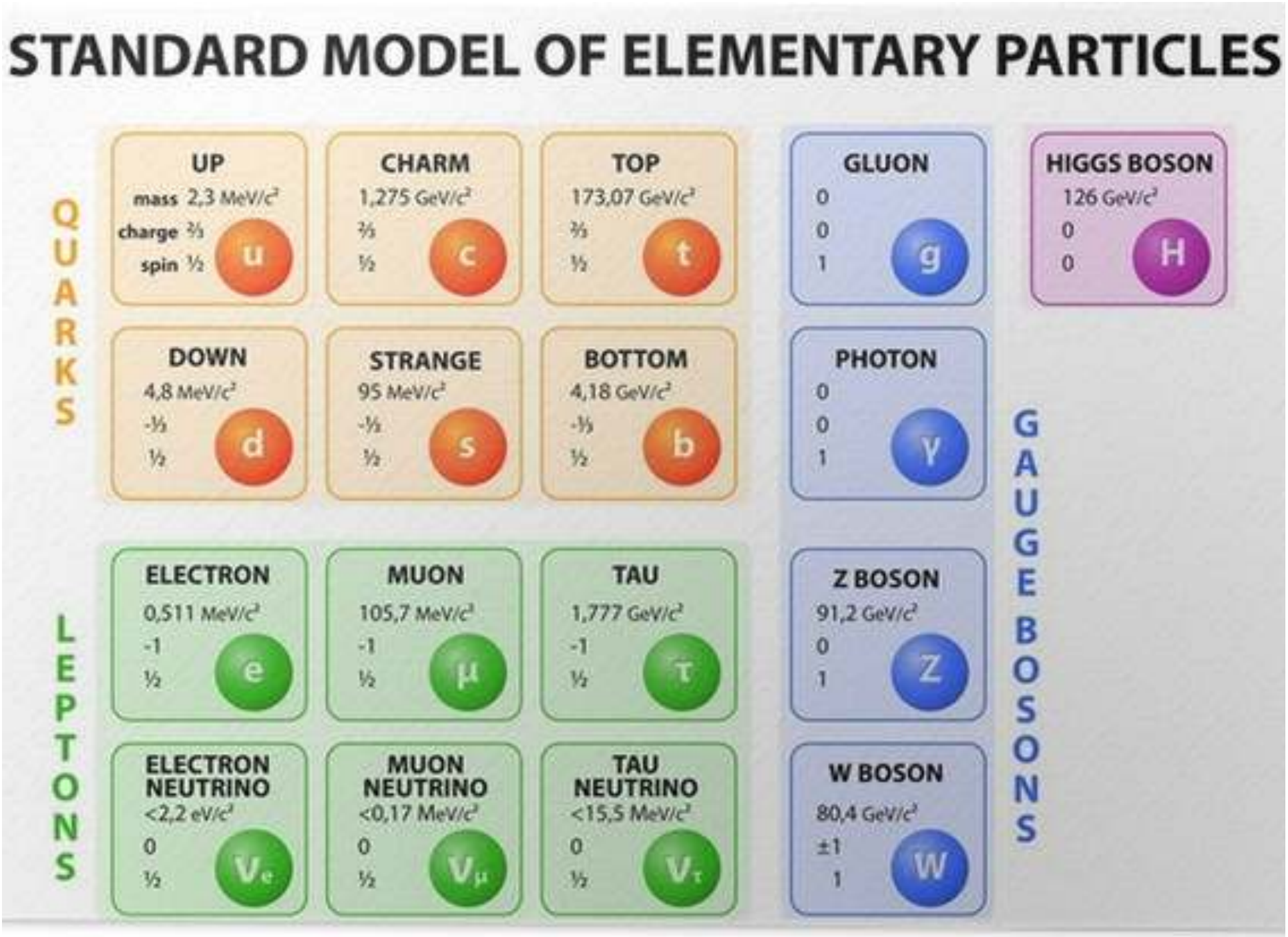

Neutron Star
Vancouver
www.kindaroomy.com

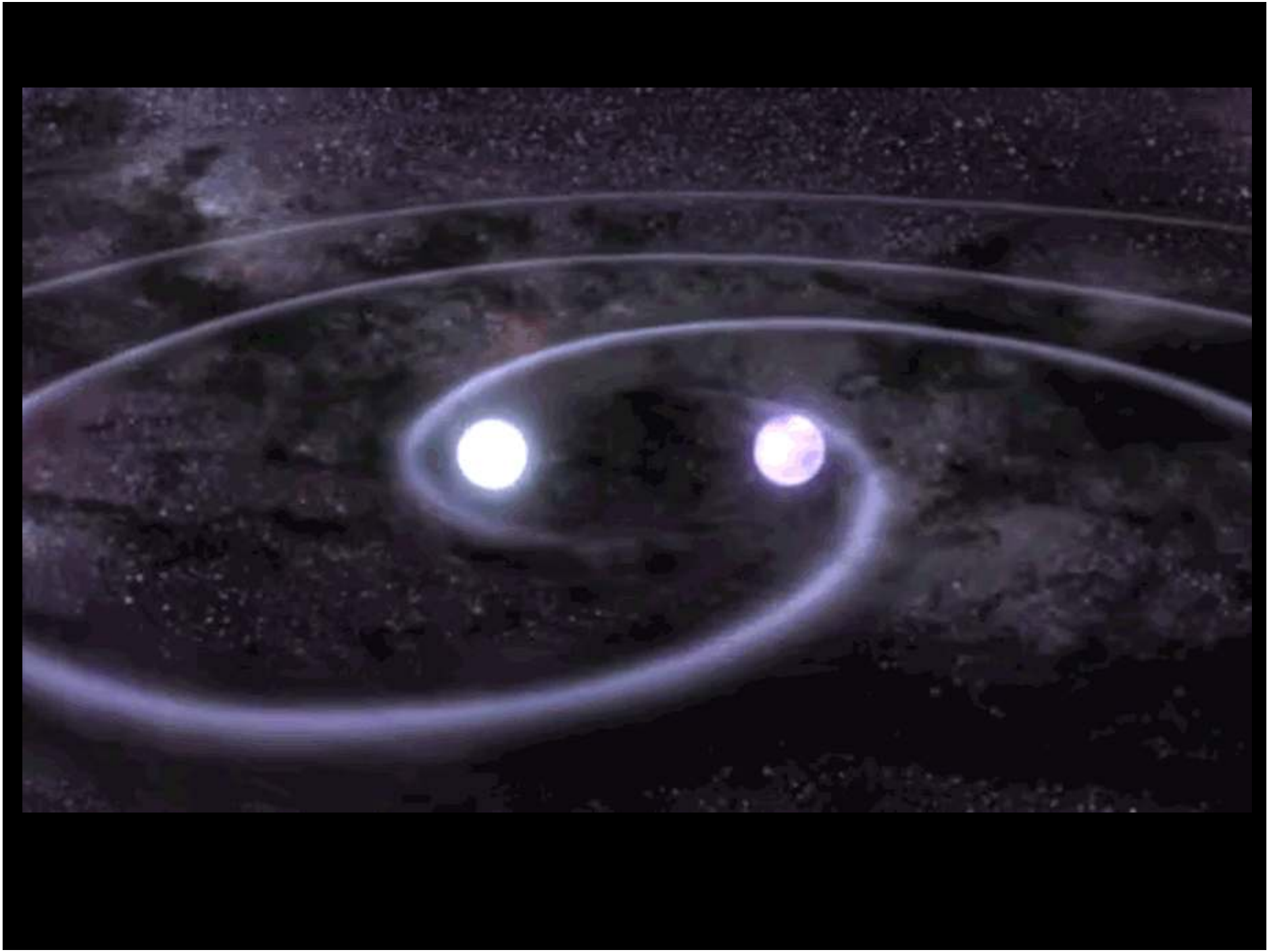
To achieve this density of a neutron star at home, just cram a herd of 50 million elephants into the volume of a thimble.

— Neil deGrasse Tyson —


A NEUTRON STAR: SURFACE and INTERIOR
A
CORE:
Homogeneous Matter
'Swiss cheese' phase
'Spaghetti' phase
CRUST:
Nuclei
Neutron Superfluid
ATMOSPHERE
ENVELOPE
CRUST
OUTER CORE
INNER CORE
?
Magnetic field
Polar cap
Cone of open magnetic field lines
B
Neutron Superfluid
Neutron Vortex
Nuclei in a lattice
C
Neutron Superfluid +
Proton Superconductor
Neutron Vortex
Magnetic Flux Tube

# STANDARD MODEL OF ELEMENTARY PARTICLES



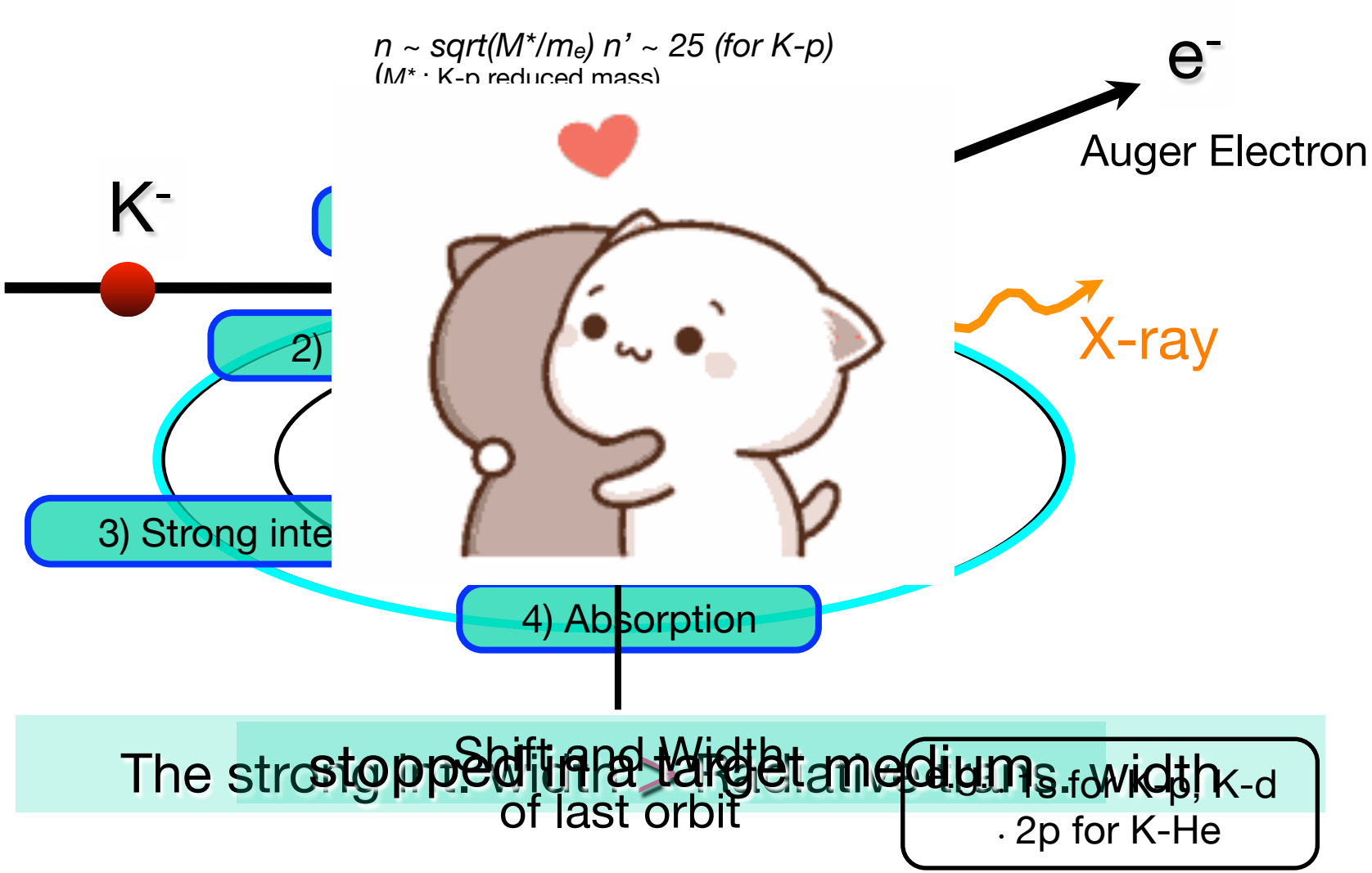


# DAΦNE a Frascati

# SIDDHARTA-2

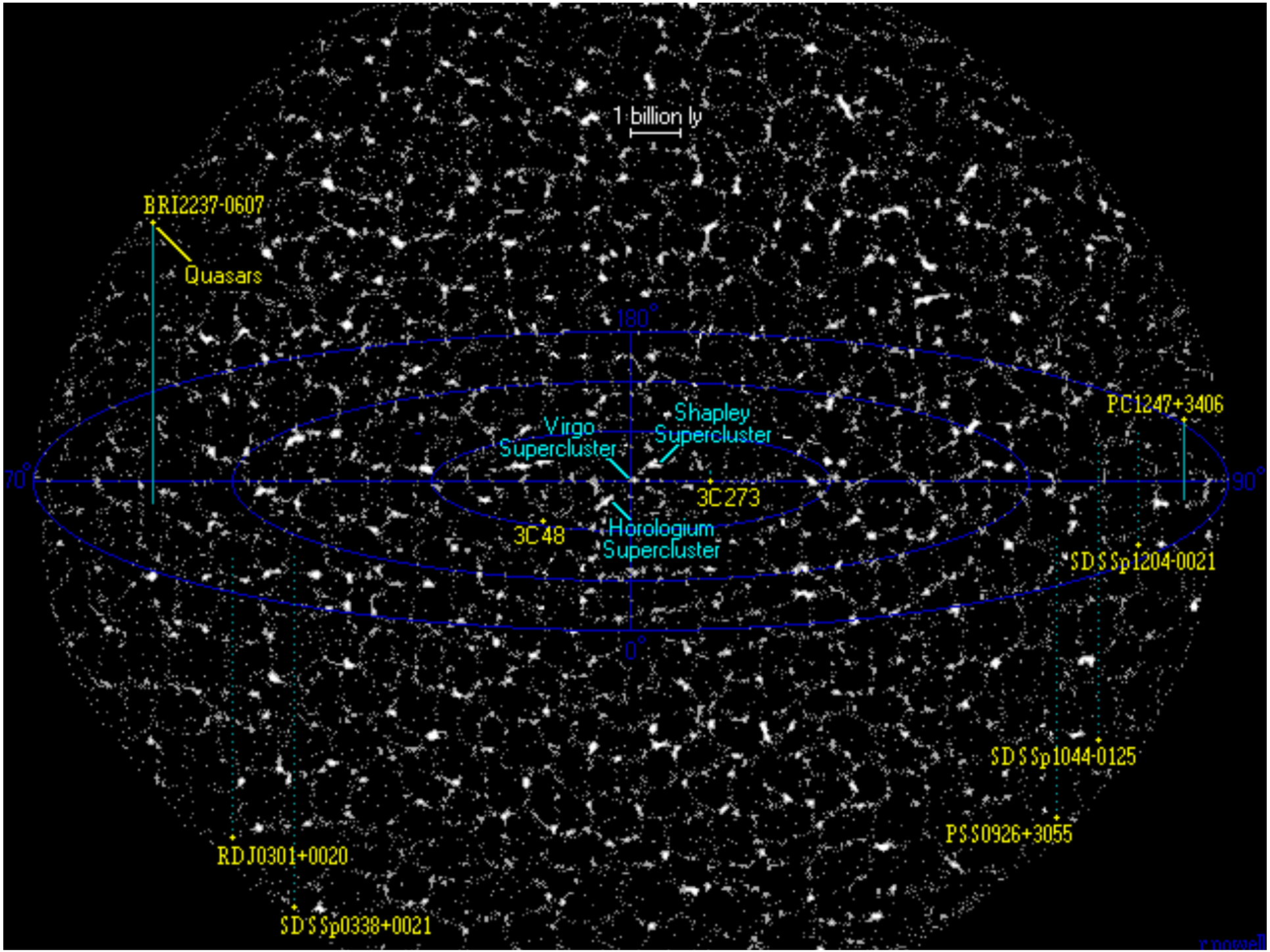
SIlicon Drift Detector for Hadronic Atom Research by Timing Applications

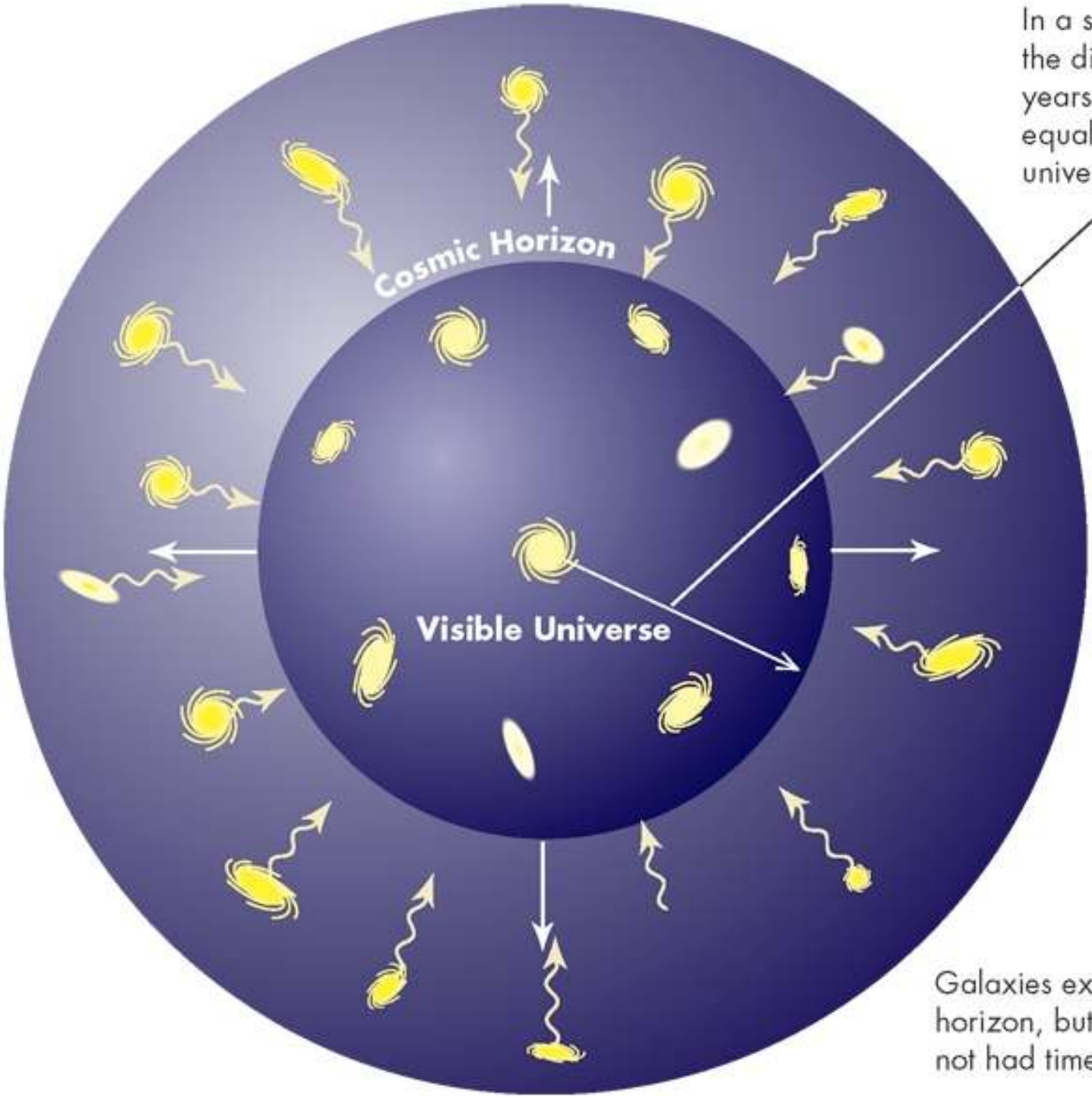
# Kaonic atom formation




The strong int. with relative beams. width

4) Parallel Universes
5) Schroedinger cat (quantum mechanics)

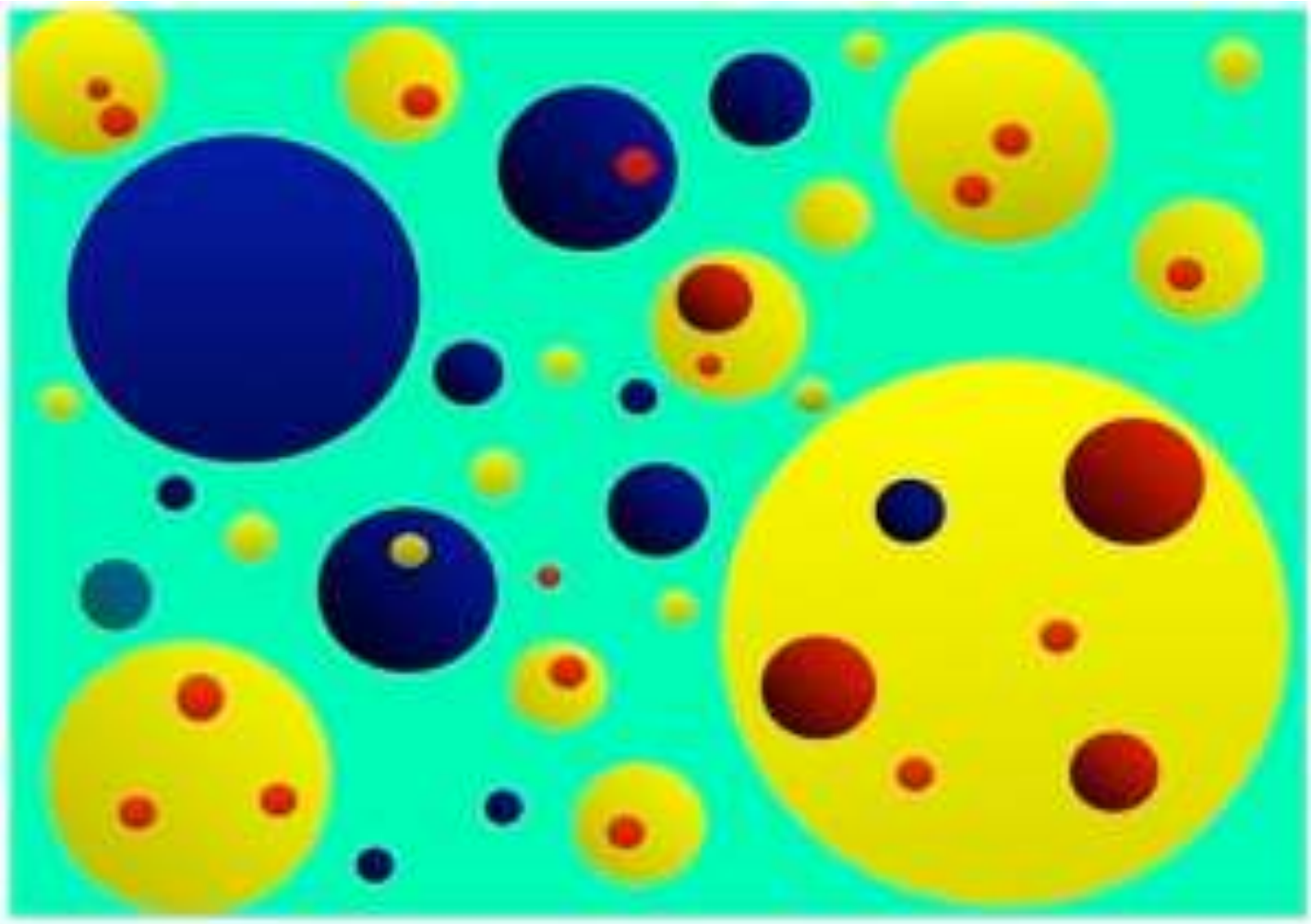

1 billion ly
BRI2237-0607
Quasars
180°
70°
90°
0°
Virgo
Supercluster
Shapley
Supercluster
3C273
3C48
Horologium
Supercluster
PC1247+3406
SDSSp1204-0021
SDSSp1044-0125
PSS0926+3055
RDJ0301+0020
SDSSp0338+0021

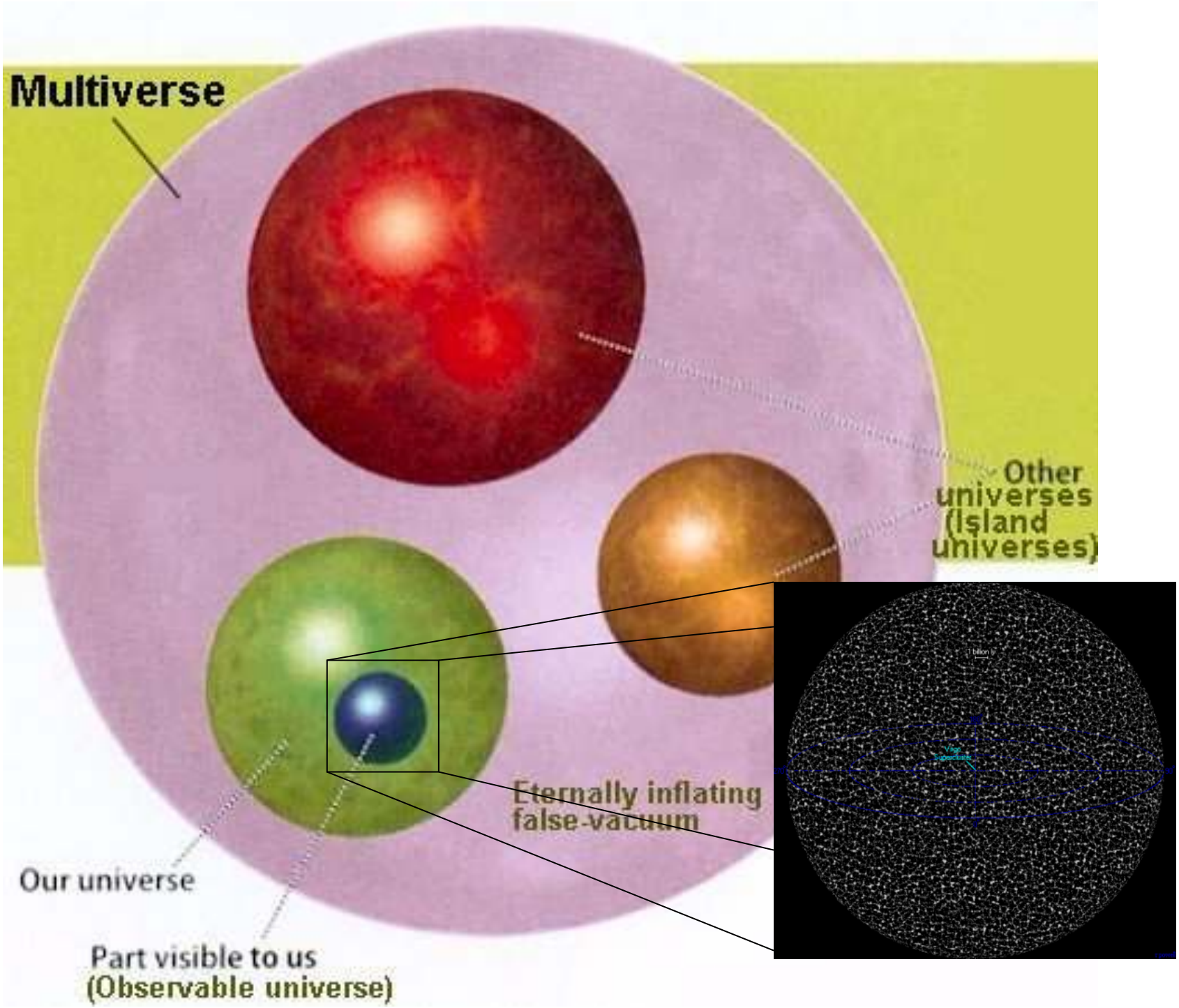



In a static universe, the distance in light-years to the horizon equals age of universe in years.

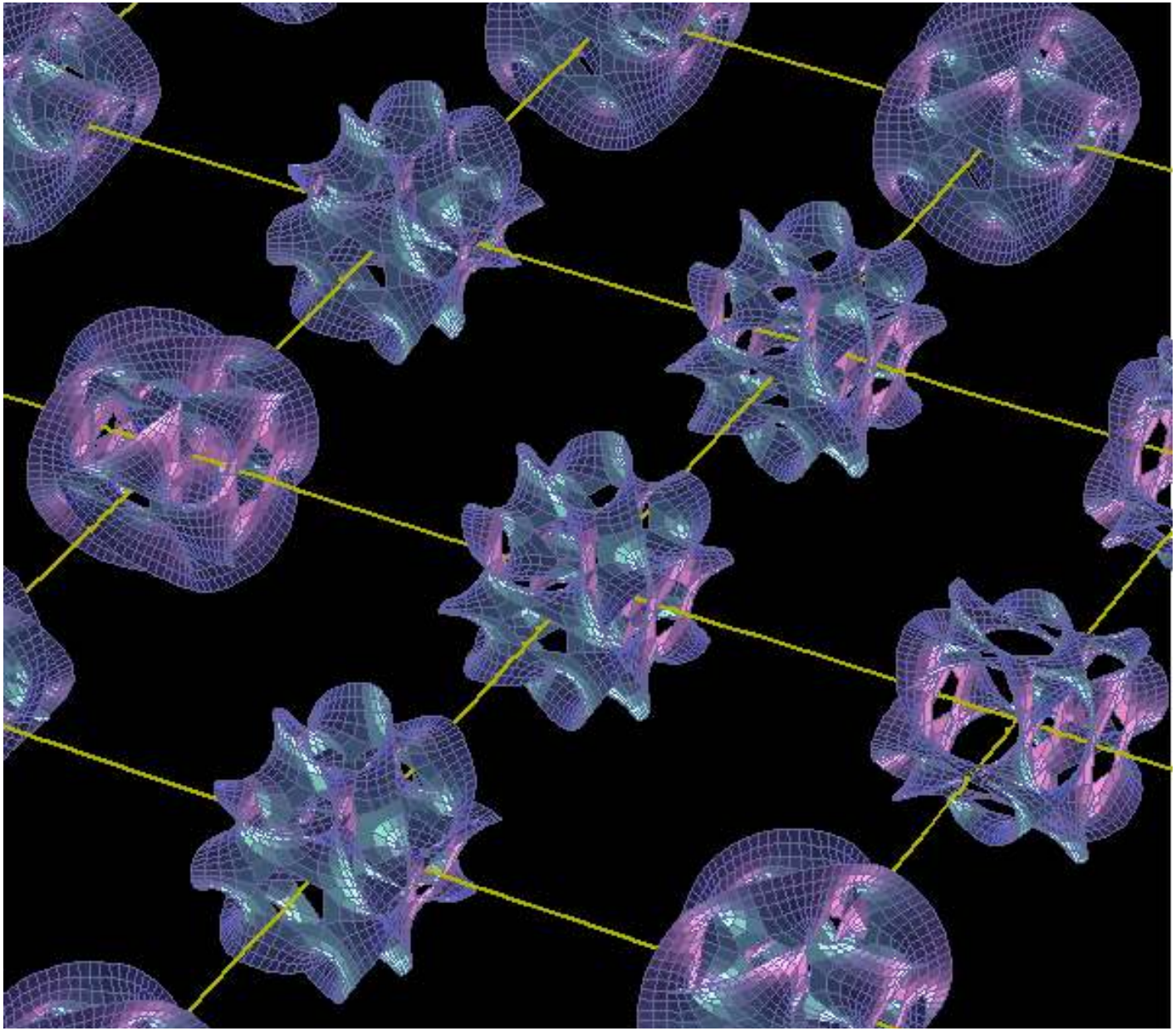
Galaxies exist beyond the horizon, but their light has not had time to reach us.

# More Universes with different physics

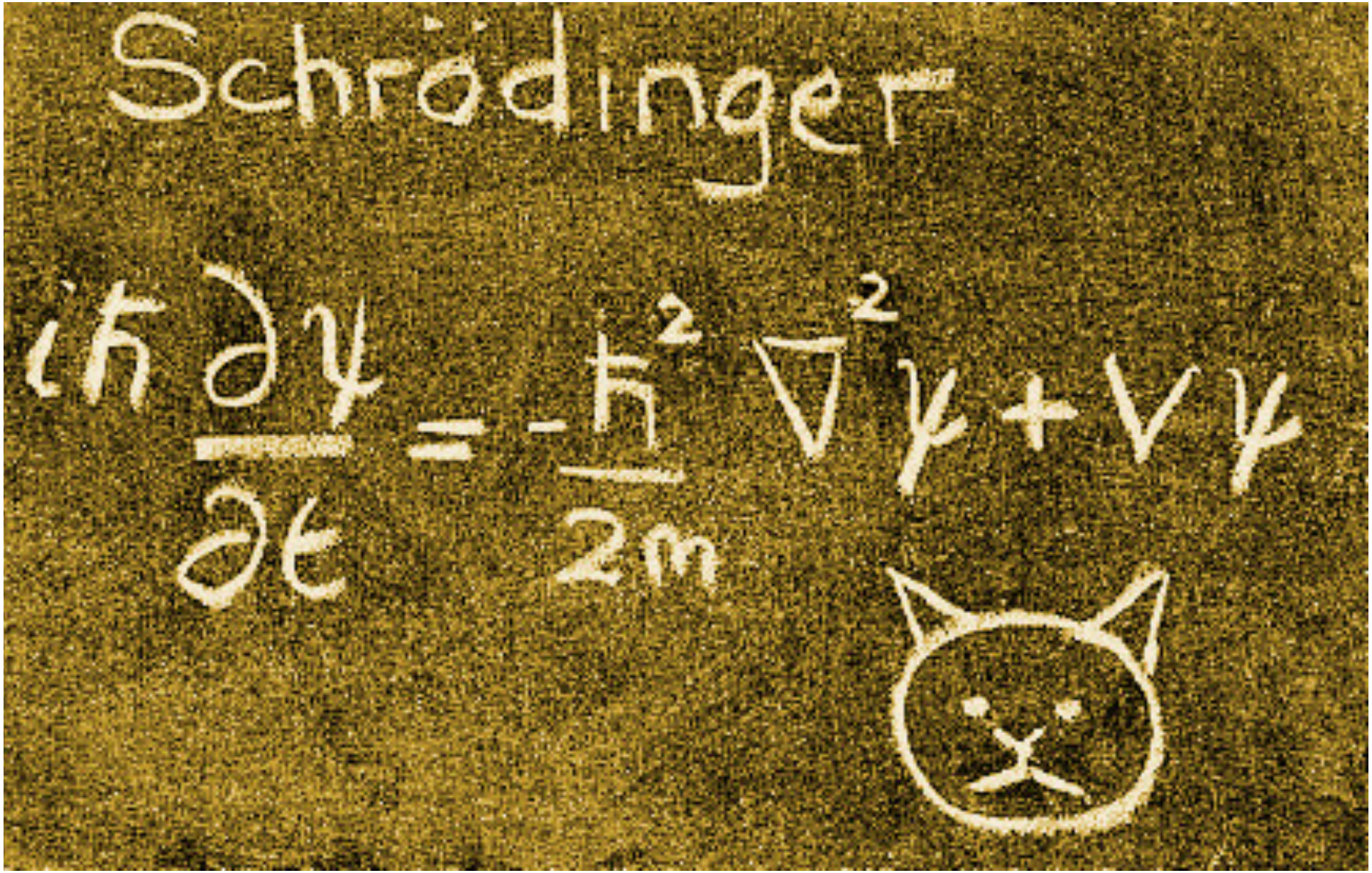



Multiverse
Other universes (Island universes)
Eternally inflating false-vacuum
Our universe
Part visible to us (Observable universe)

# String theory



# $10^{500}$ parallel universes


Schrödinger
$i\hbar \frac{\partial \psi}{\partial t} = -\frac{\hbar^2}{2m} \nabla^2 \psi + V\psi$

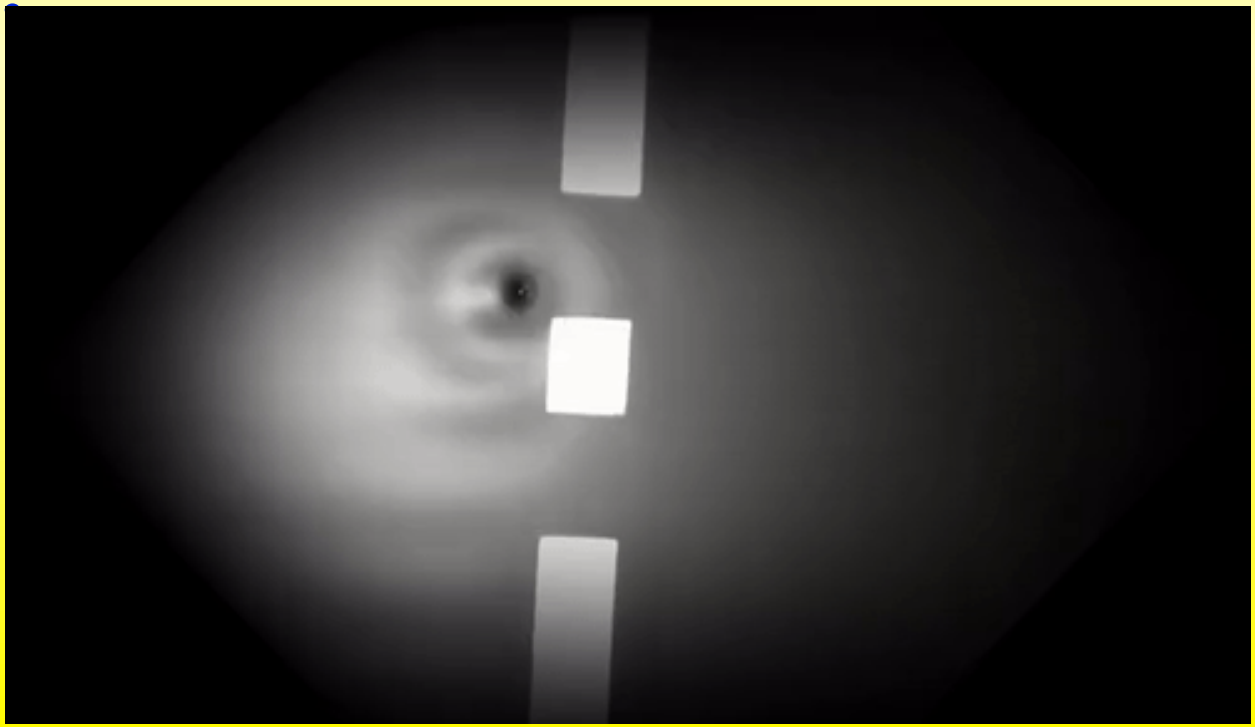
# Sovrapposizione Quantistica

$$\Psi = c_1 \psi_1 + c_2 \psi_2 + \ldots$$

# Possible solutions (Schroedinger cat)

-De Broglie – Bohm

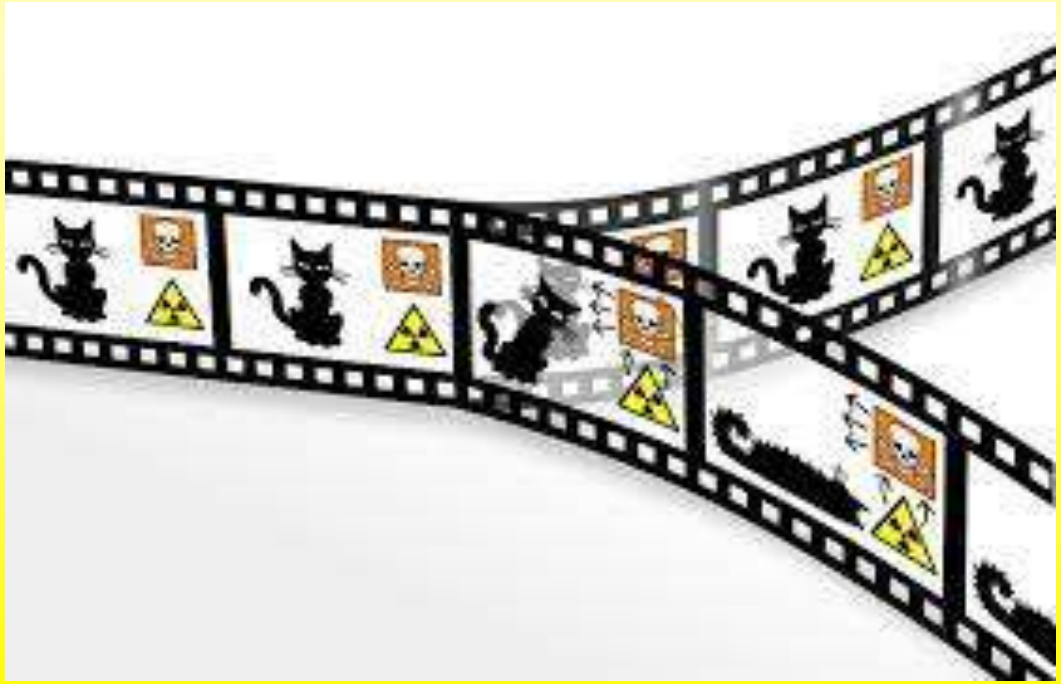
-.....



# Possible solutions (Schroedinger cat)

-Many worlds

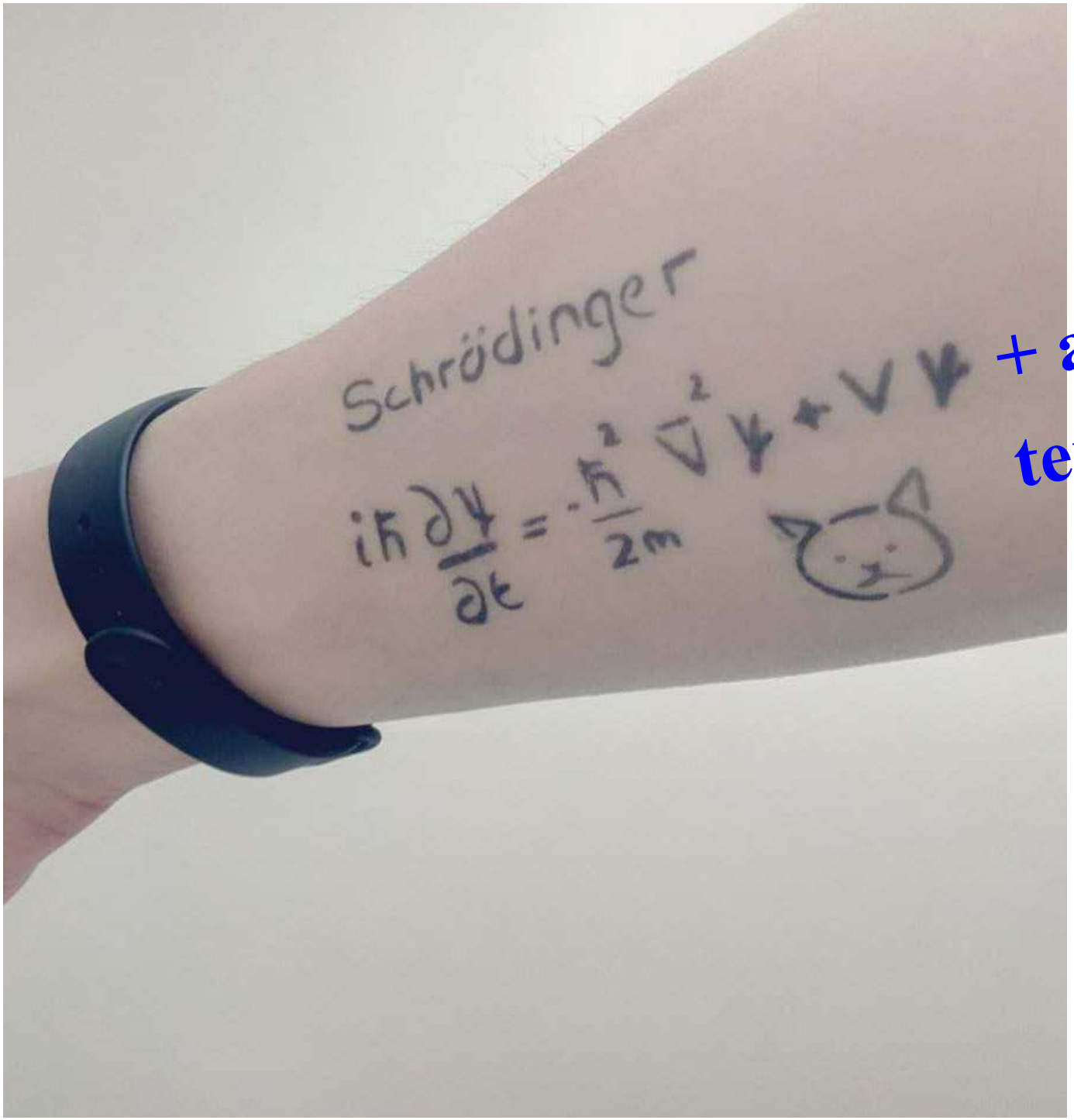
-.....



# Possible solutions (Schroedinger cat)

-Collapse of the wave function

-.....

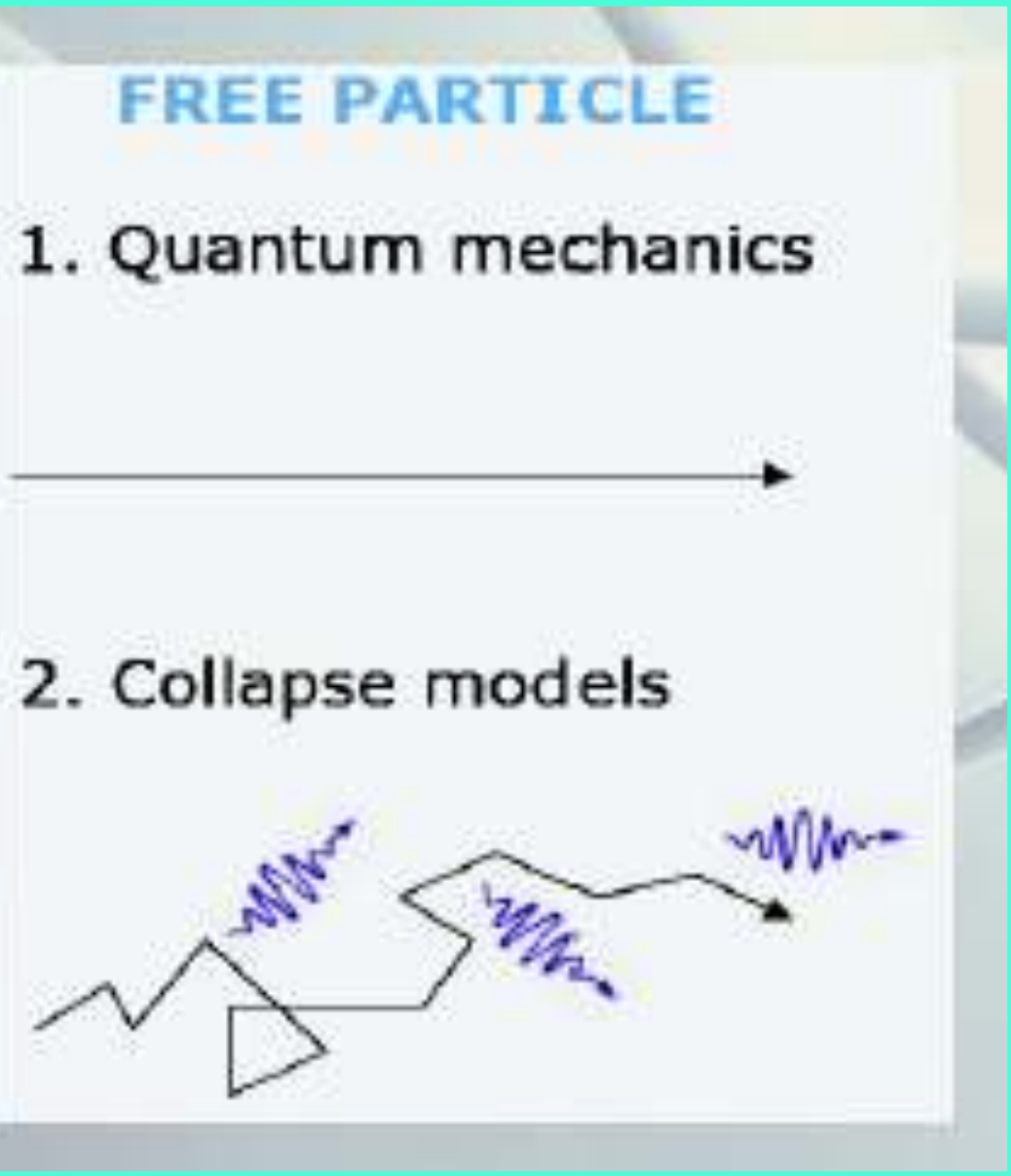



**+ additional terms**

Con Roger Penrose

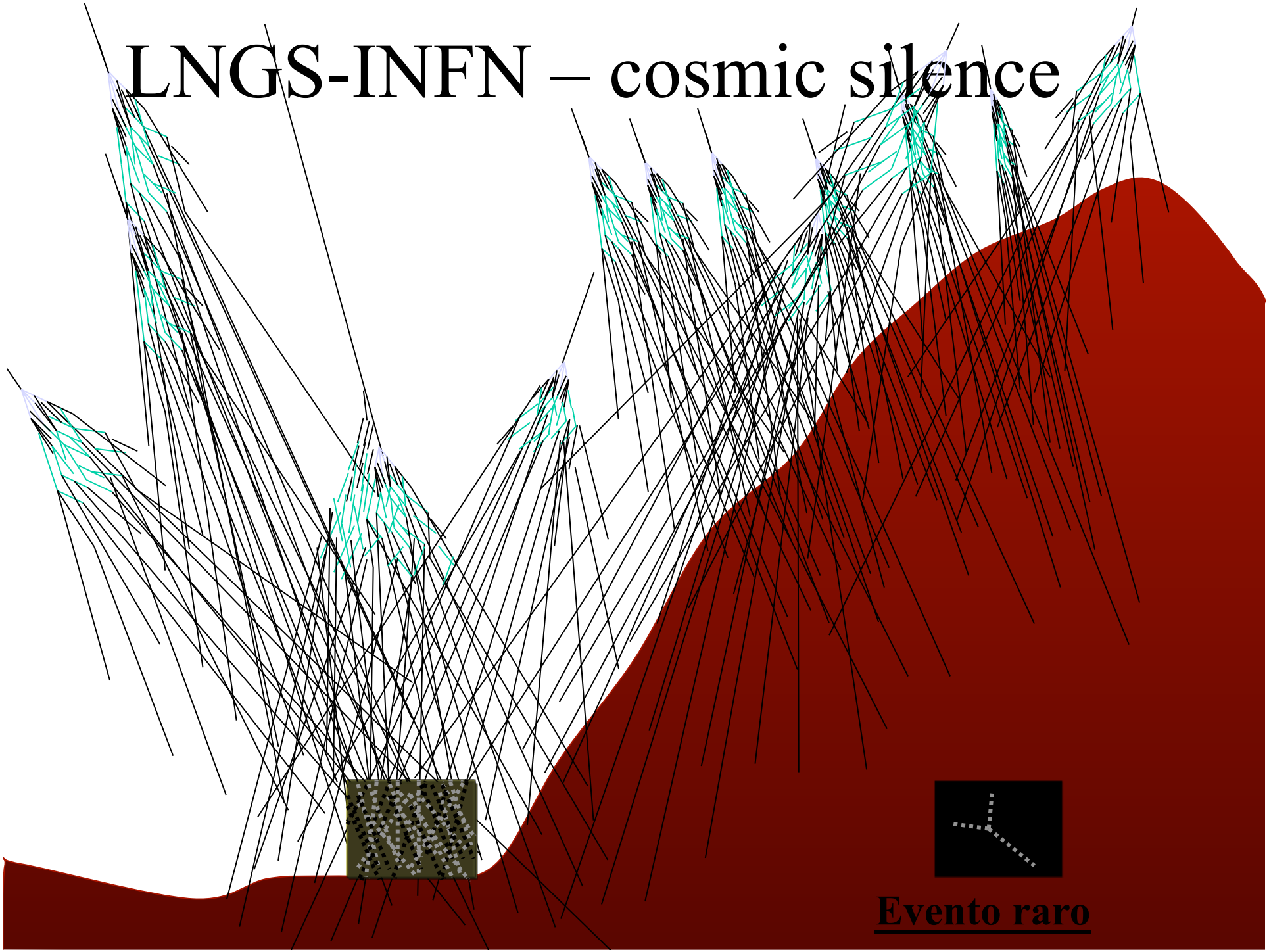
# FREE PARTICLE

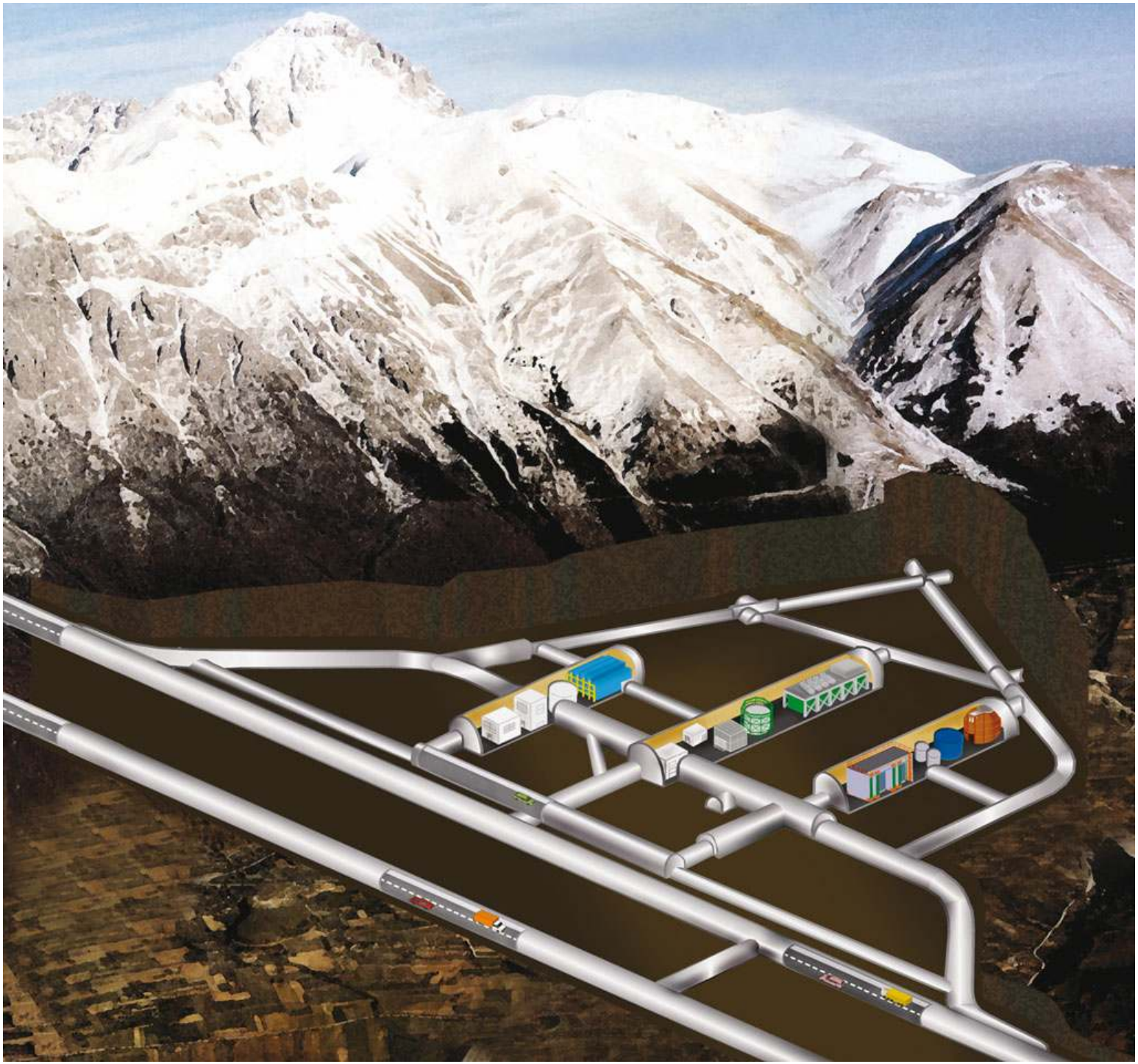
1. Quantum mechanics



2. Collapse models

# LNGS-INFN – cosmic silence



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Article | Published: 07 September 2020

# Underground test of gravity-related wave function collapse

Sandro Donadi ✉, Kristian Piscicchia ✉, Catalina Curceanu, Lajos Diósi, Matthias Laubenstein & Angelo Bassi ✉

*Nature Physics* **17**, 74–78(2021) | Cite this article



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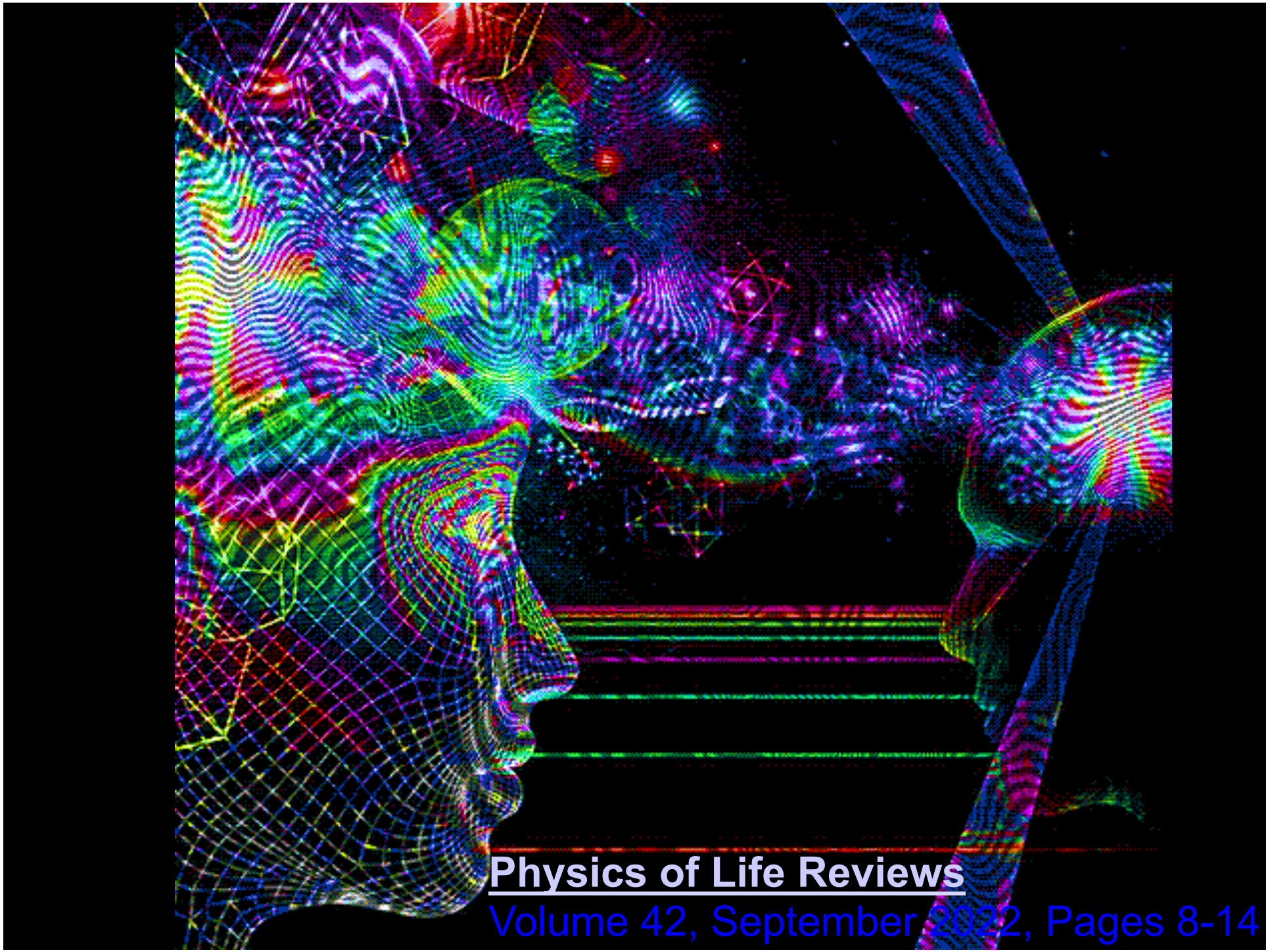


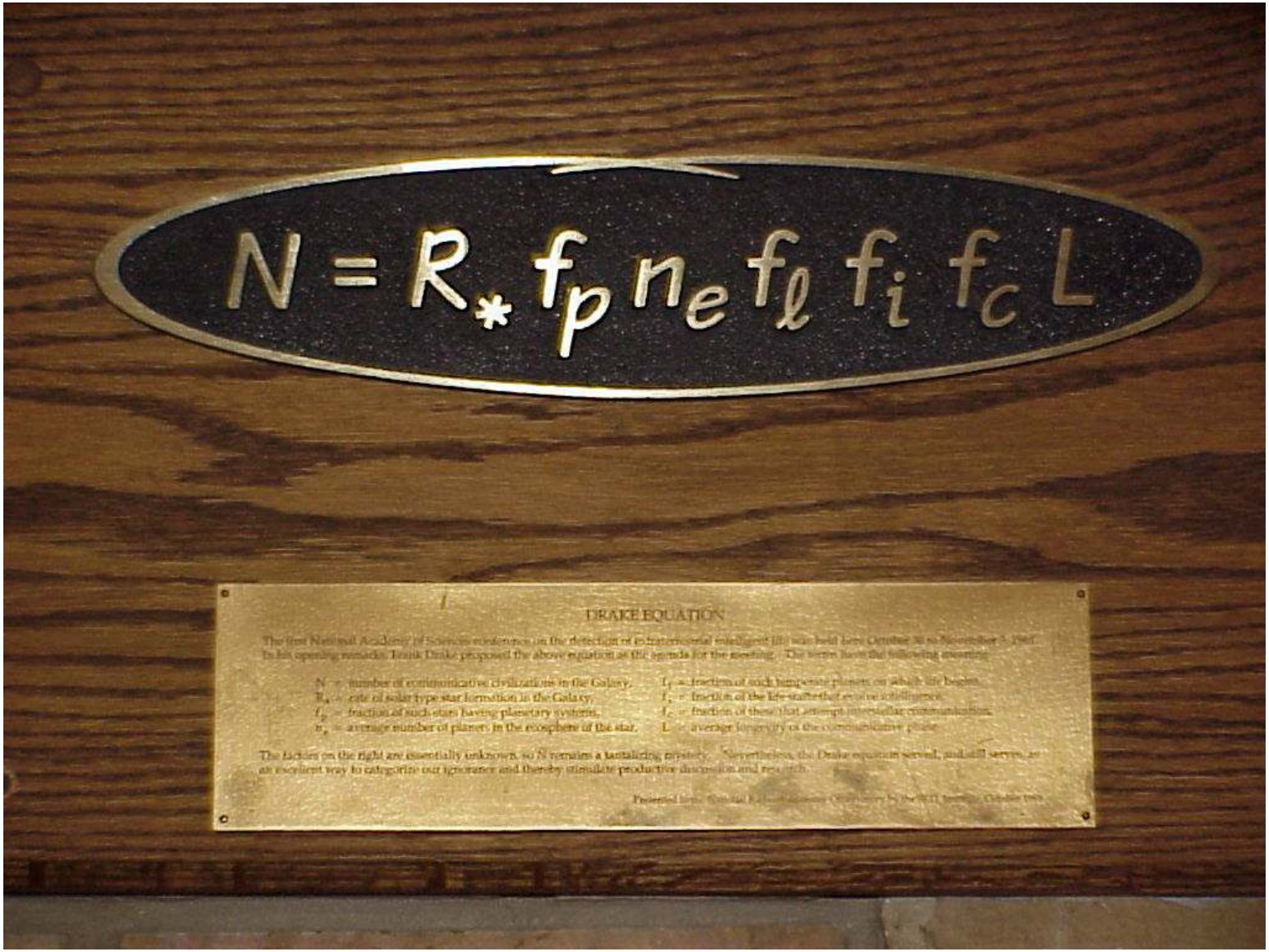
Physics of Life Reviews
Volume 42, September 2022, Pages 8-14

# 7) Where are «the others» (aliens)?

# Where are the others?

## Fermi paradox: if there are many alien civilizations where are they?

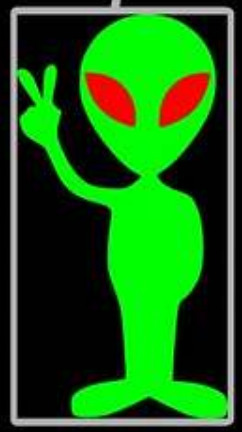
# Drake's equation:

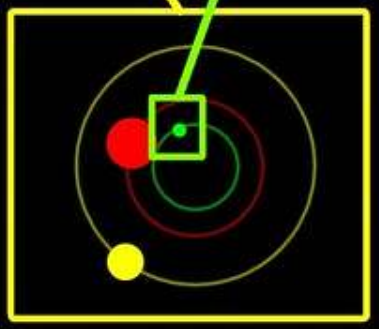


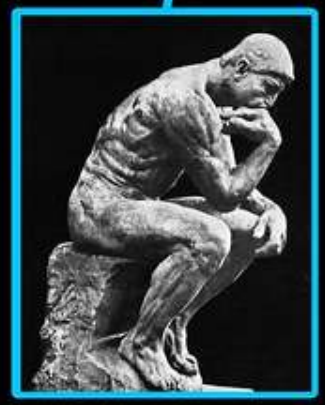
# Are we alone?

*The Drake equation*

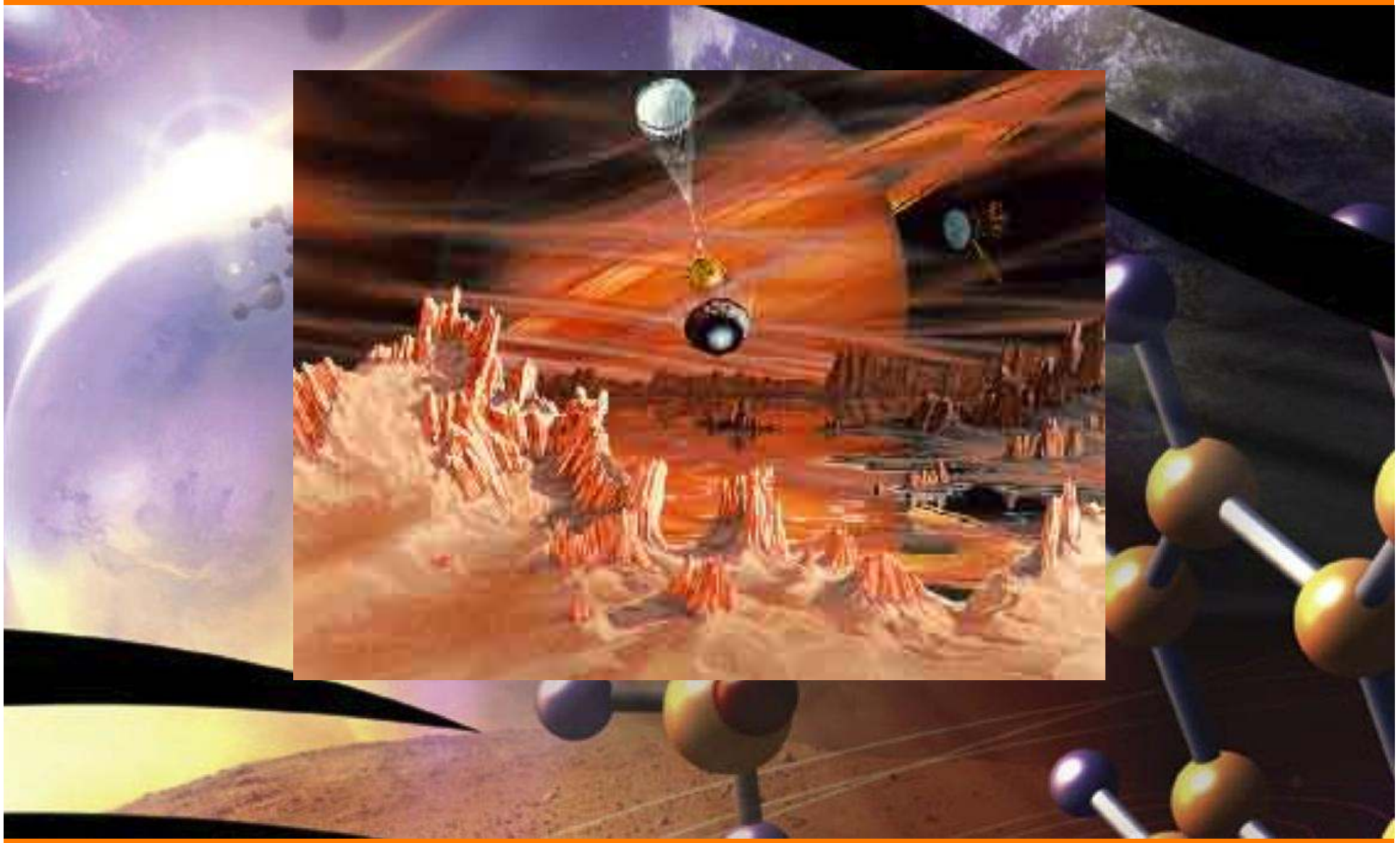
$$N = R^* \times f_p \times n_e \times f_l \times f_i \times f_c \times L$$



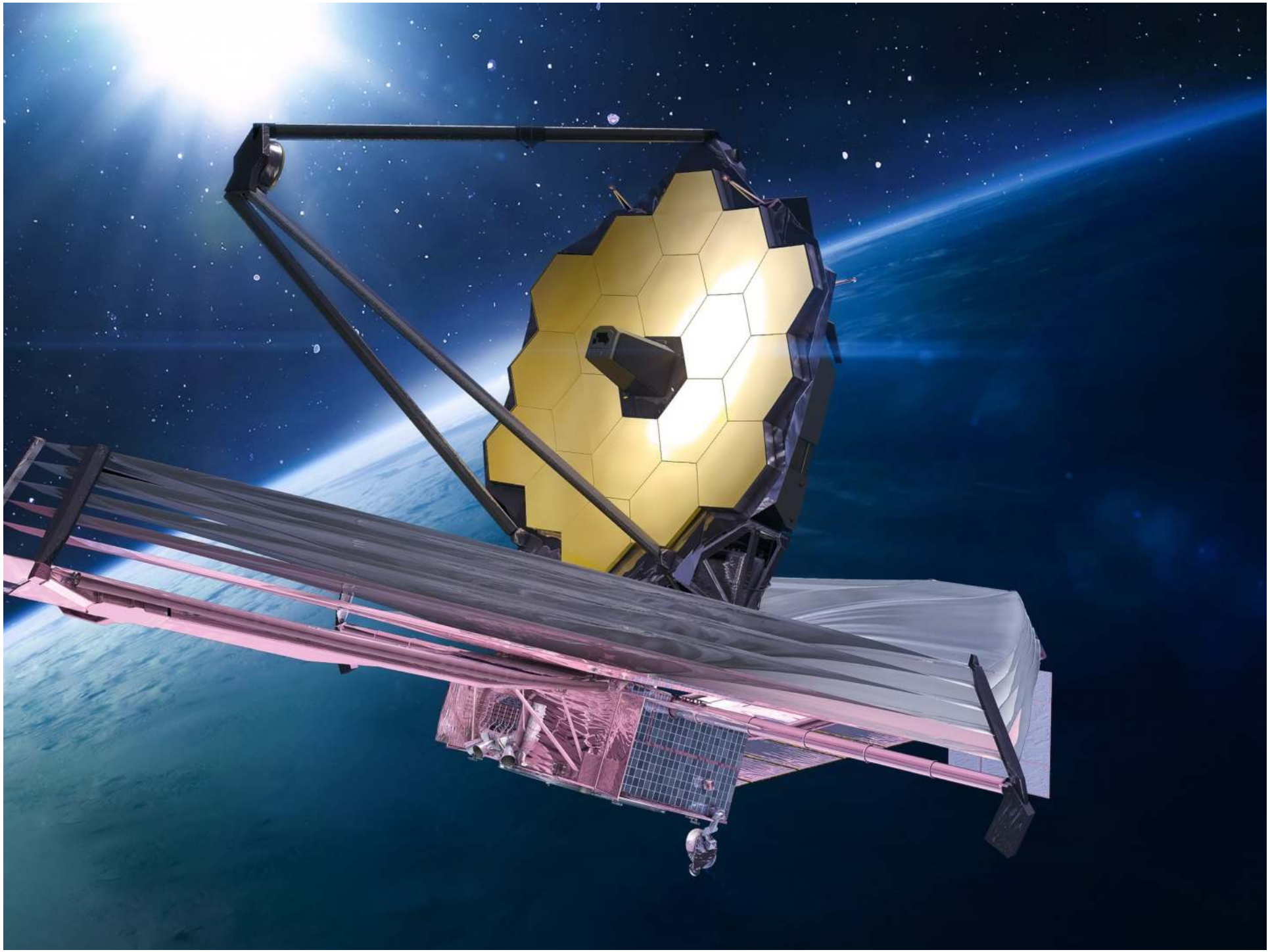




# They are here



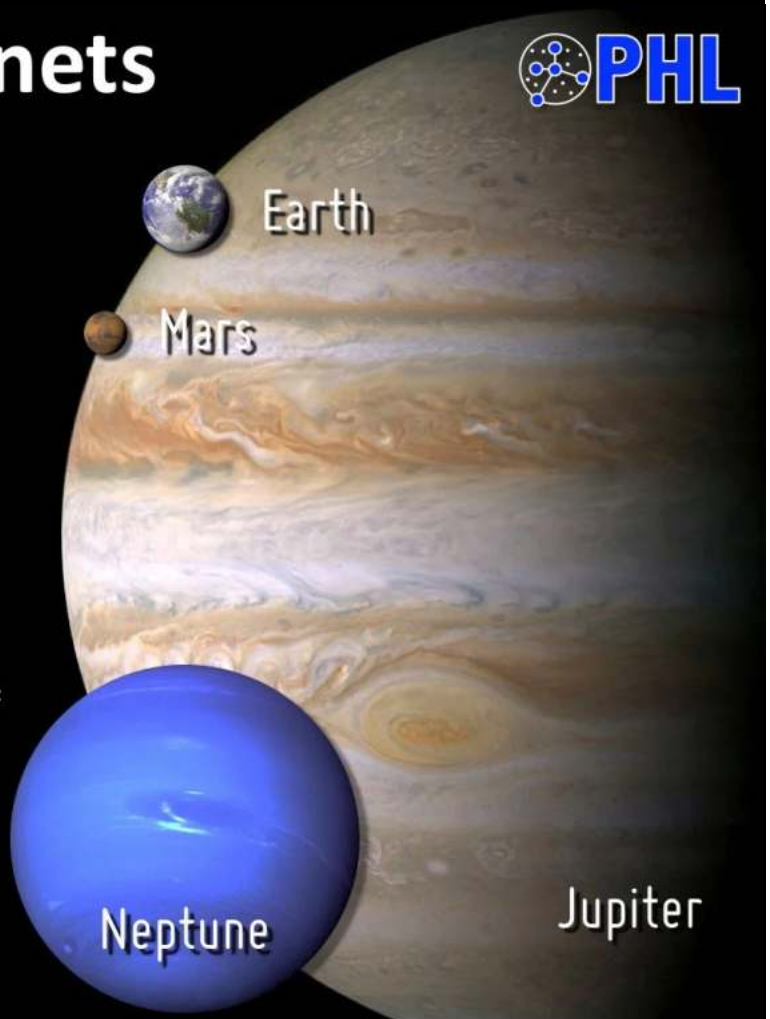
# FAST (China), 500m



# Potentially Habitable Exoplanets

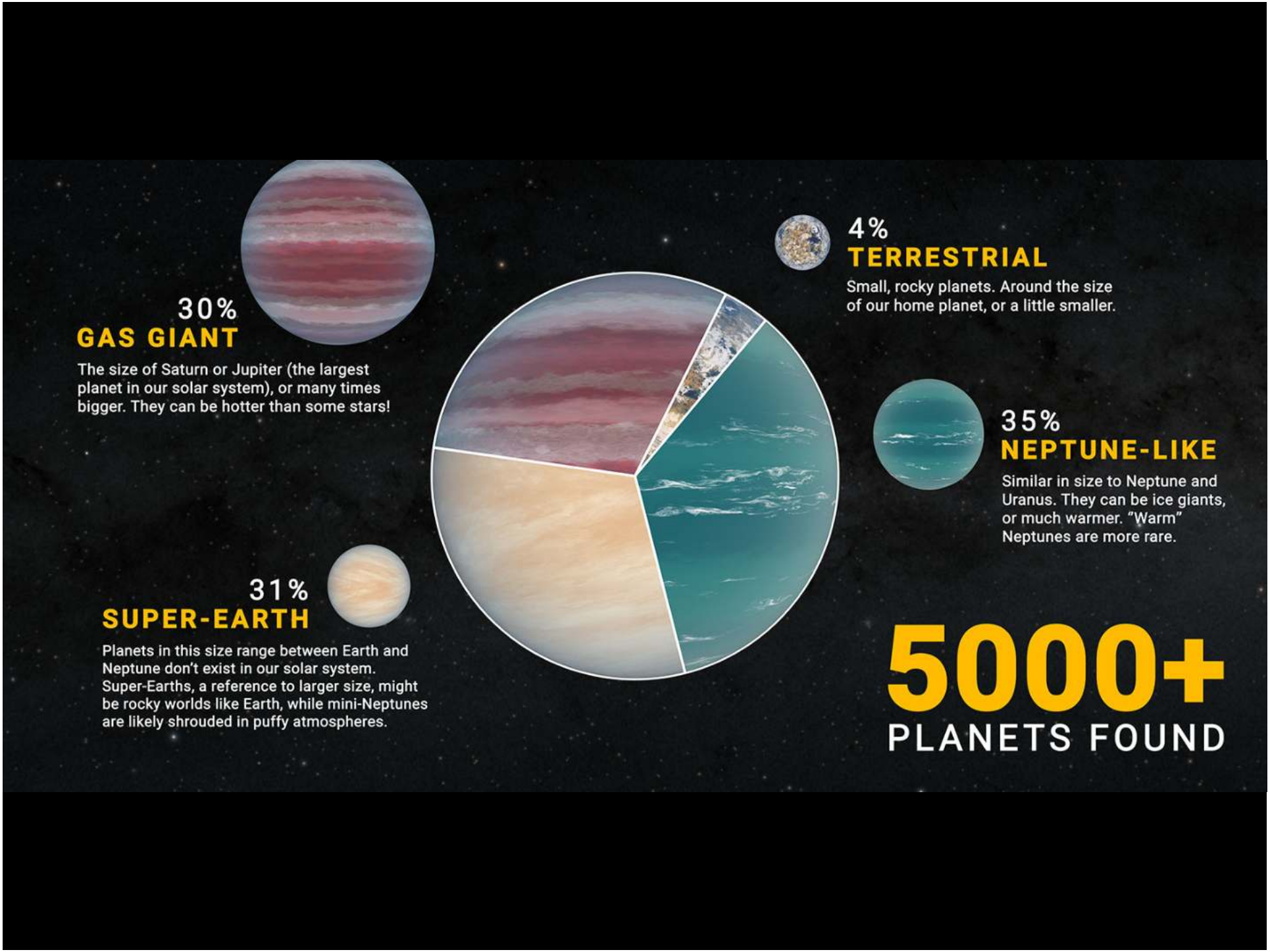
Ranked by Distance from Earth (light years)

PHL

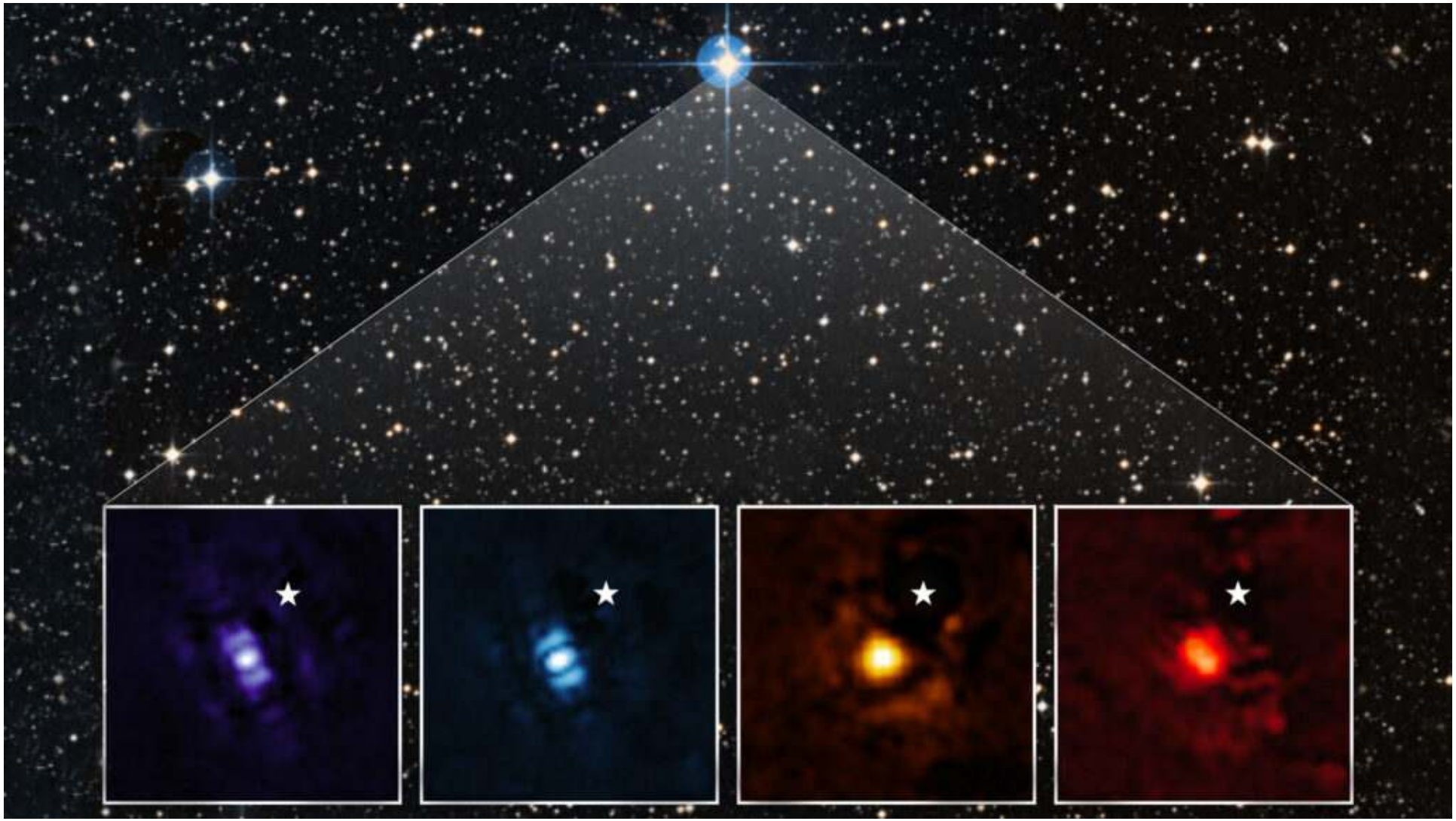




Artistic representations. Earth, Mars, Jupiter, and Neptune for scale. Distance from Earth is between brackets. Planet candidates indicated with asterisks.

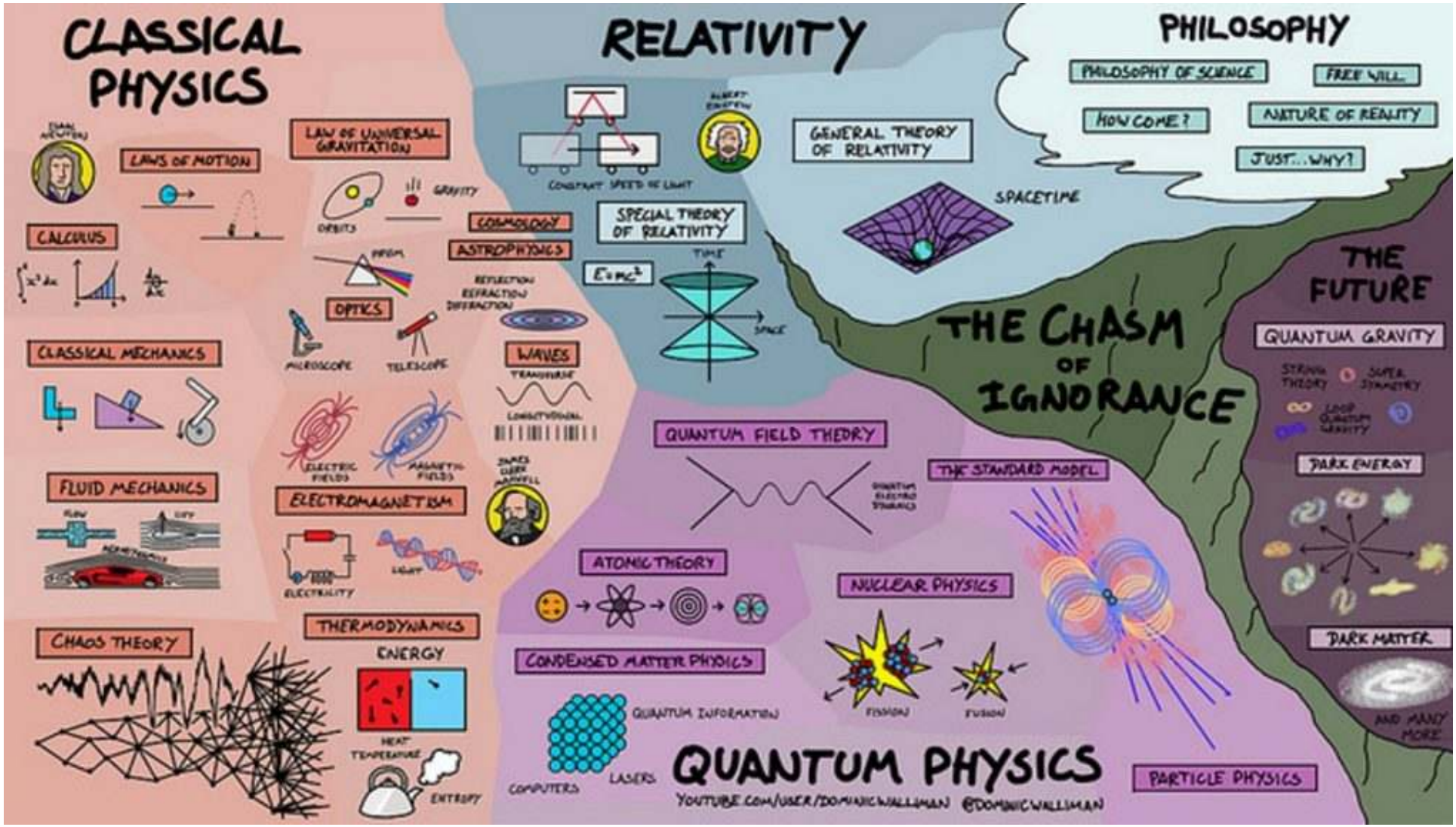
CREDIT: PHL @ UPR Arecibo (phl.upr.edu) Jul 2, 2018


30%
GAS GIANT
The size of Saturn or Jupiter (the largest planet in our solar system), or many times bigger. They can be hotter than some stars!
4%
TERRESTRIAL
Small, rocky planets. Around the size of our home planet, or a little smaller.
35%
NEPTUNE-LIKE
Similar in size to Neptune and Uranus. They can be ice giants, or much warmer. "Warm" Neptunes are more rare.
31%
SUPER-EARTH
Planets in this size range between Earth and Neptune don't exist in our solar system. Super-Earths, a reference to larger size, might be rocky worlds like Earth, while mini-Neptunes are likely shrouded in puffy atmospheres.
5000+
PLANETS FOUND

# James Web telescope (atmosphere...)




AlaTeRRy
InGenesis creations


CLASSICAL PHYSICS
LAWS OF MOTION
LAW OF UNIVERSAL GRAVITATION
GRAVITY
ORBITS
CALCULUS
COSMOLOGY
ASTROPHYSICS
PRISM
OPTICS
REFLECTION
REFRACTION
DIFFRACTION
MICROSCOPE
TELESCOPE
WAVES
TRANSVERSE
LONGITUDINAL
CLASSICAL MECHANICS
ELECTRIC FIELDS
MAGNETIC FIELDS
FLUID MECHANICS
ELECTROMAGNETISM
ELECTRICITY
LIGHT
CHAOS THEORY
THERMODYNAMICS
ENERGY
HEAT
TEMPERATURE
ENTROPY
RELATIVITY
CONSTANT SPEED OF LIGHT
GENERAL THEORY OF RELATIVITY
SPACETIME
SPECIAL THEORY OF RELATIVITY
E=mc²
TIME
SPACE
PHILOSOPHY
PHILOSOPHY OF SCIENCE
FREE WILL
HOW COME?
NATURE OF REALITY
JUST... WHY?
THE CHASM OF IGNORANCE
THE FUTURE
QUANTUM GRAVITY
STRING THEORY
SUPER SYMMETRY
LOOP QUANTUM GRAVITY
DARK ENERGY
DARK MATTER
AND MANY MORE
QUANTUM FIELD THEORY
THE STANDARD MODEL
ATOMIC THEORY
NUCLEAR PHYSICS
FISSION
FUSION
CONDENSED MATTER PHYSICS
QUANTUM INFORMATION
COMPUTERS
LASERS
QUANTUM PHYSICS
PARTICLE PHYSICS
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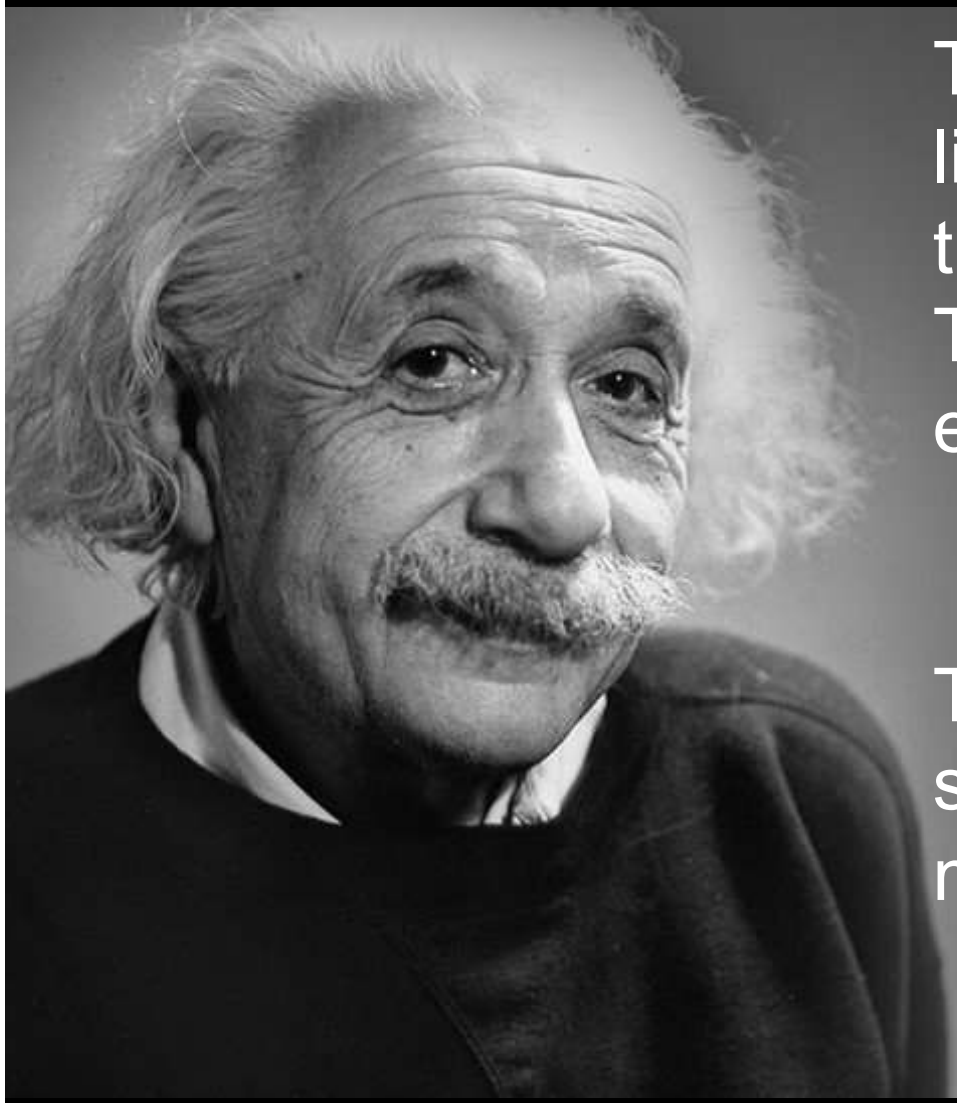
# *Feynman – The value of science*

Out of the cradle
onto dry land
here it is
standing:
atoms with consciousness;
matter with curiosity.

Stands at the sea,
wonders at wondering: I
a universe of atoms
an atom in the universe.

# *The next Einstein could be you!*



There are only two ways to live your life. One is as though nothing is a miracle. The other is as though everything is a miracle.

Try not to become a man of success. Rather become a man of value.

— Albert Einstein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FROM QUARKS TO BLACK HOLES:
LET'S GET INSPYRED!
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Foundational Questions Institute

TEQ


# Post-questionnaire