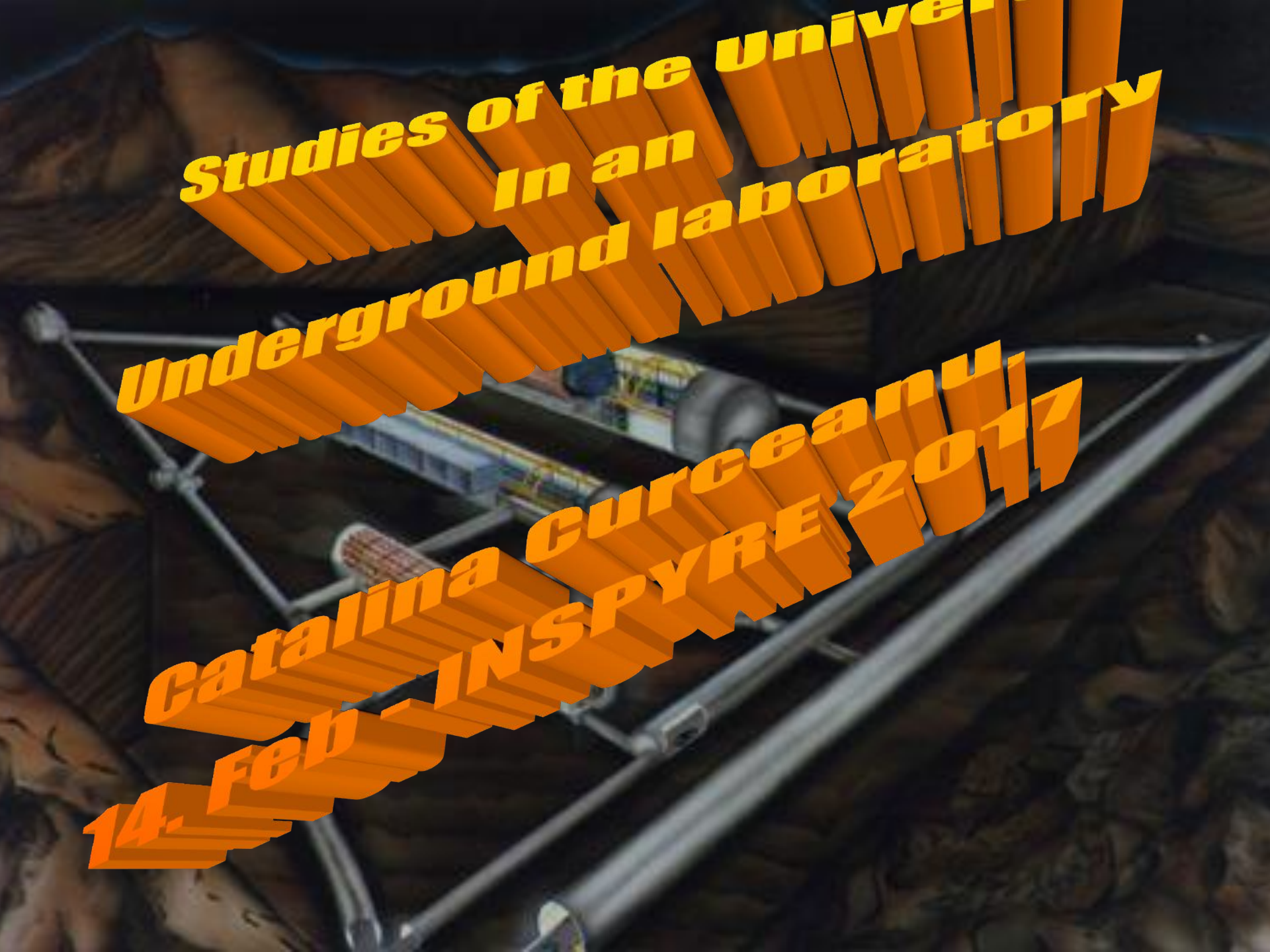
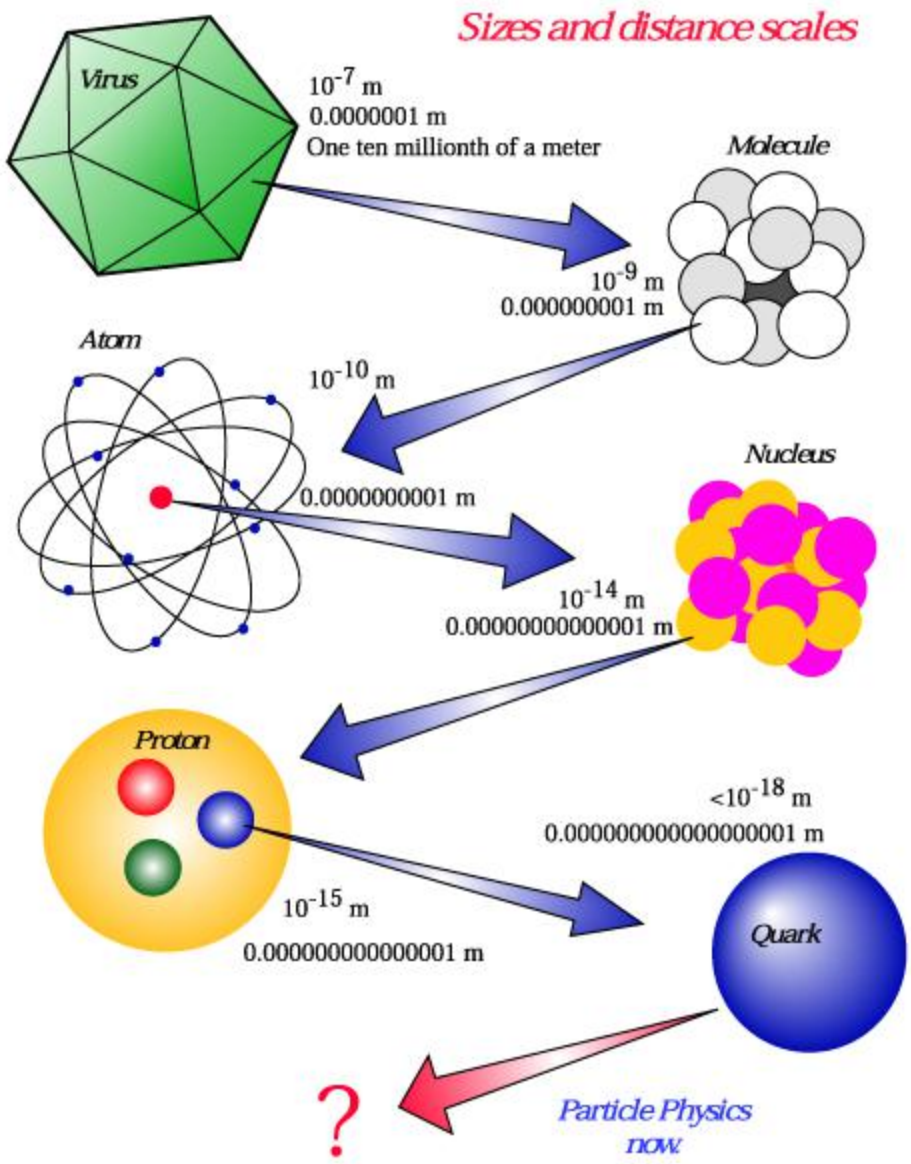
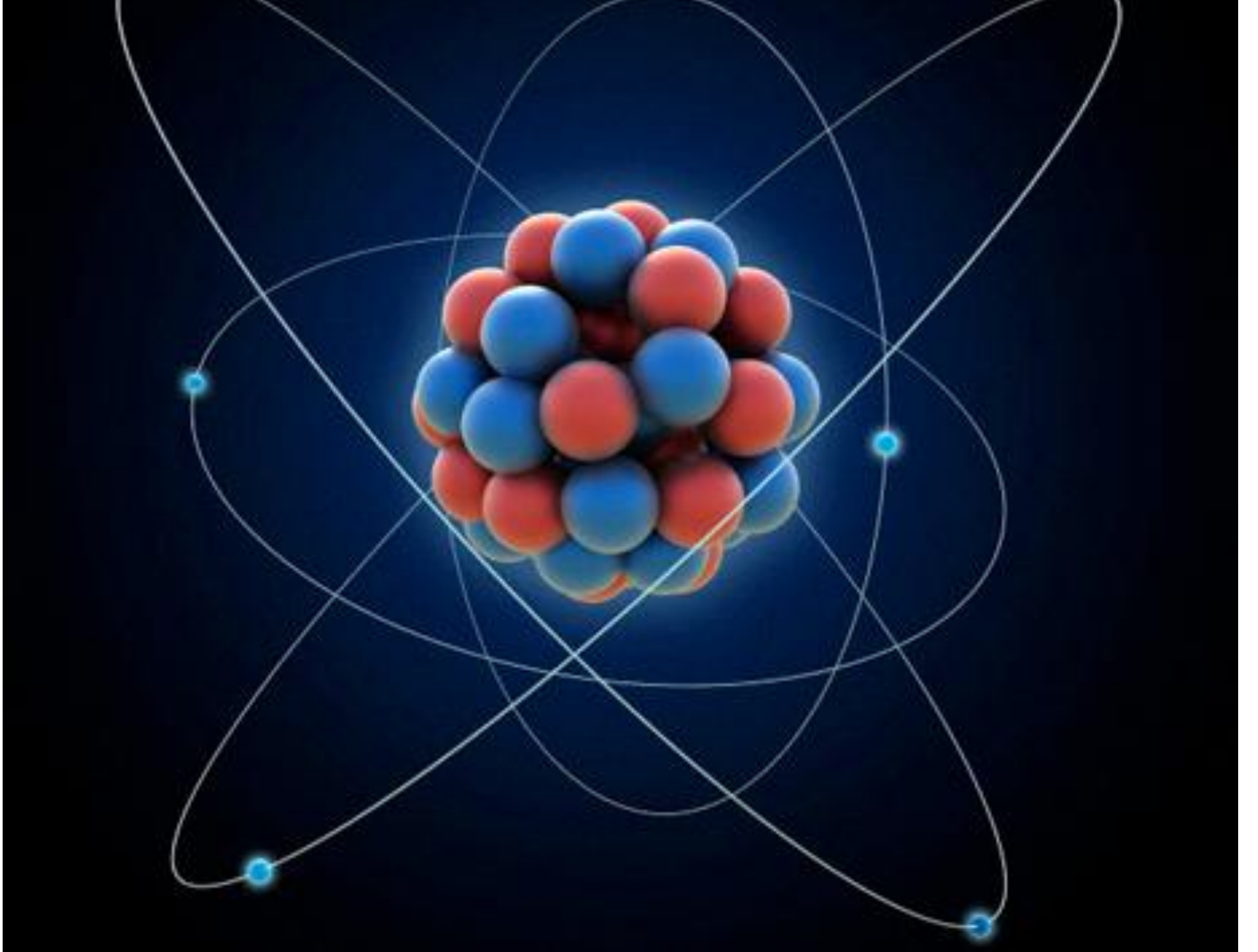
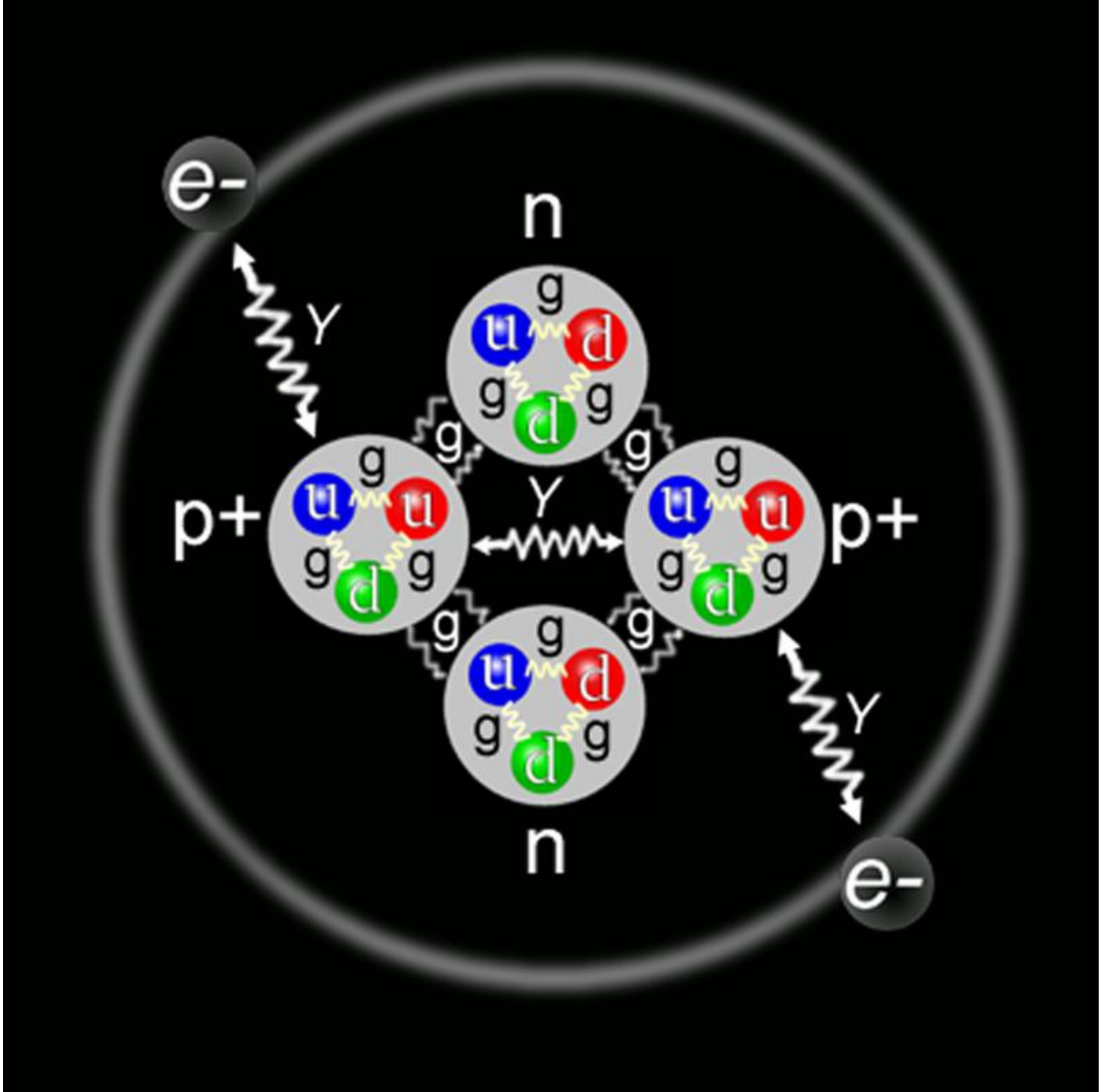

Studies of the Universe
In an
Underground laboratory
Catalina Curceanu
14. Feb - INSPYRE 2017



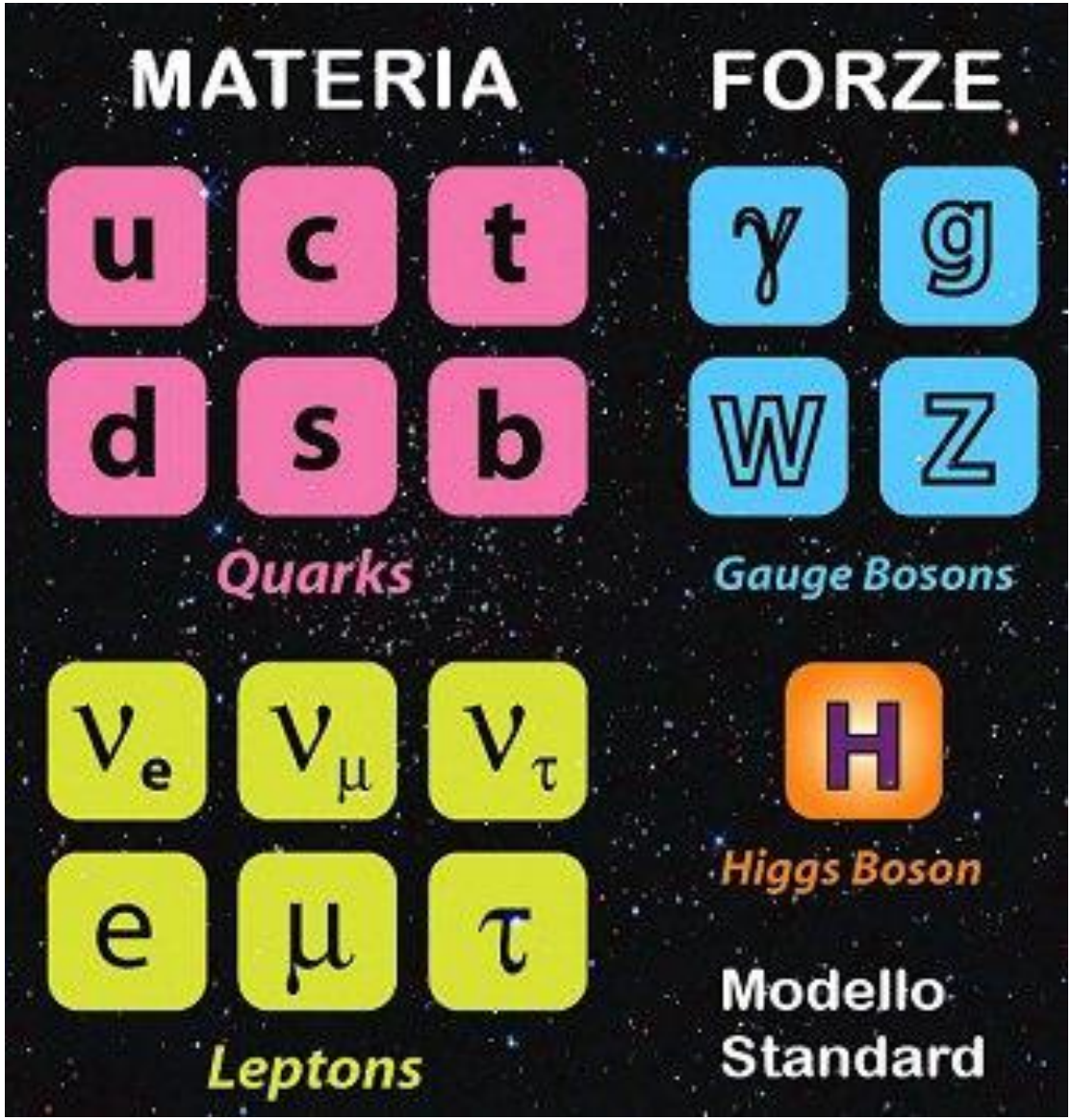
In the Standard Model there are the neutrinos!

~10^9 ν/proton!!



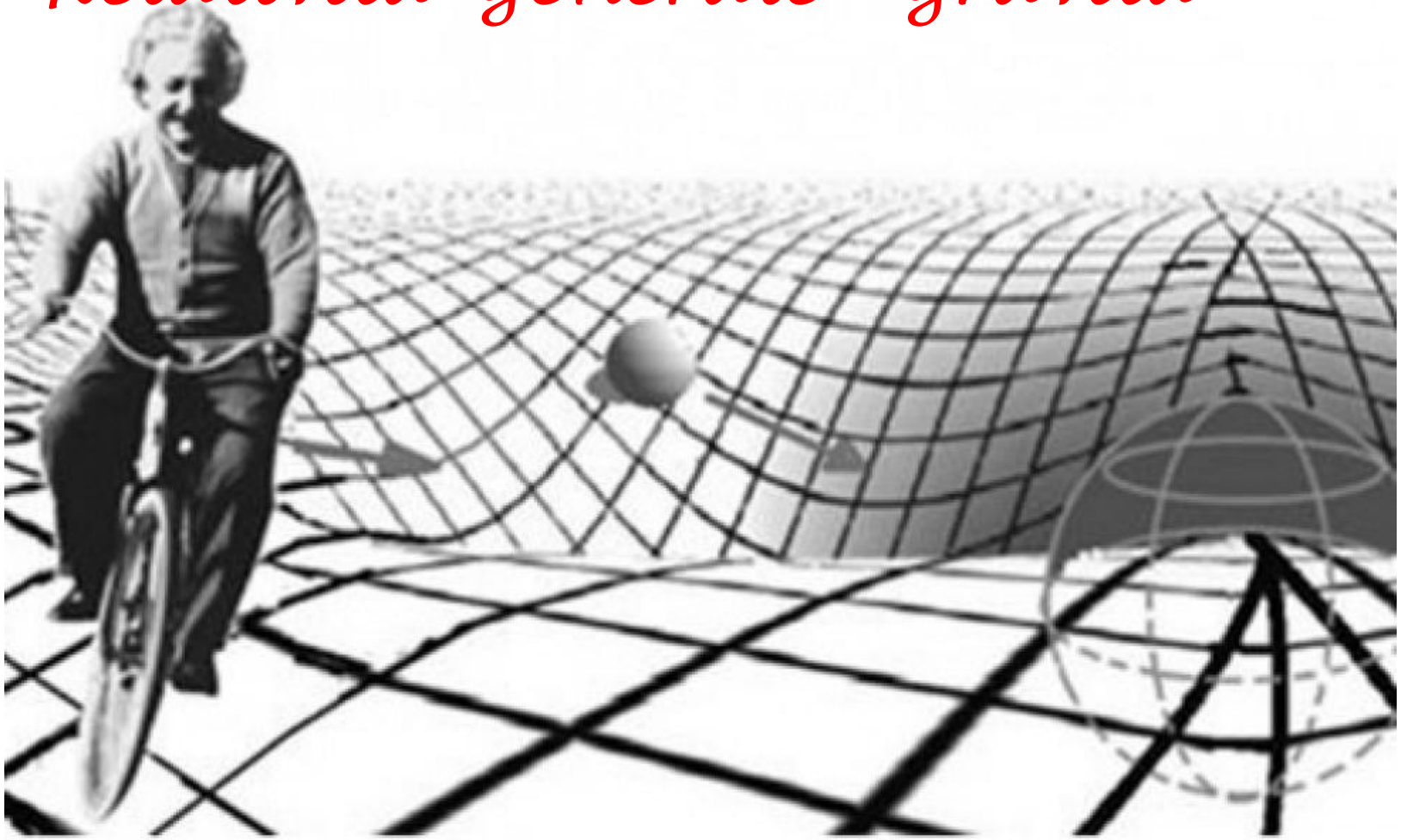

e-
n
γ
g
u
d
p+
γ
p+
g
n
γ
e-

Modello standard della fisica della particelle



NON include la gravita'!

Relativita' generale - gravita'

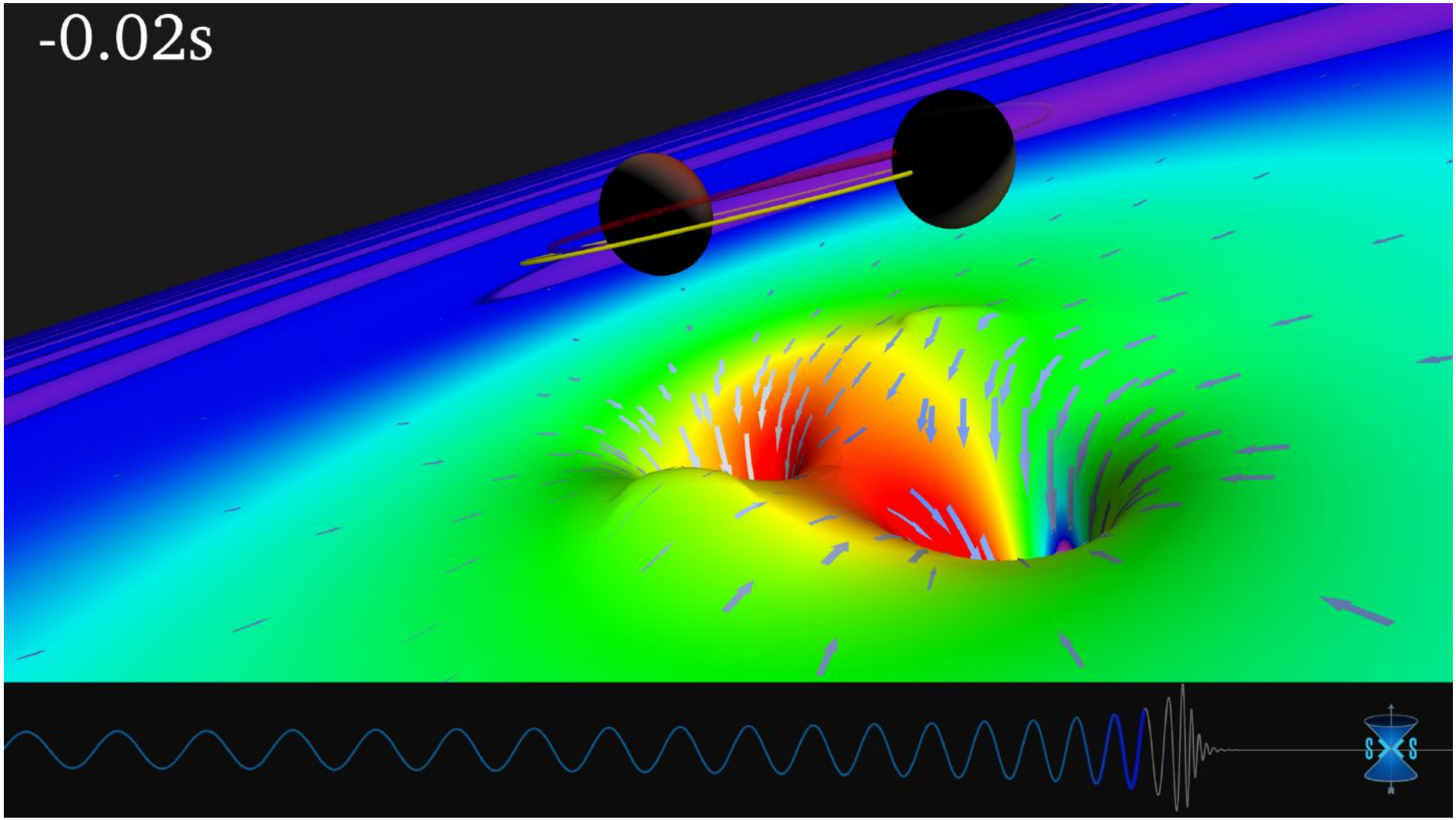


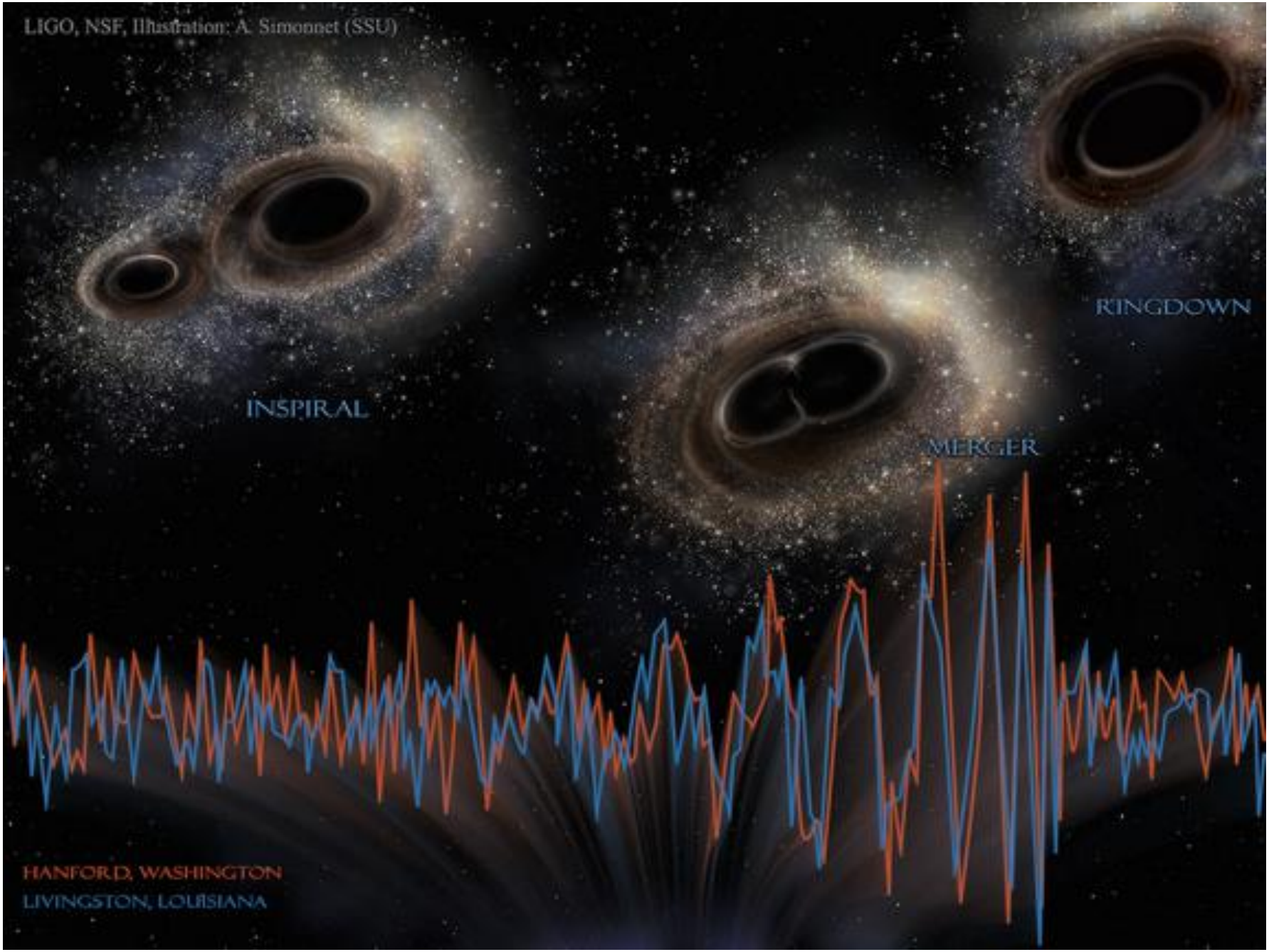
Einstein's Equation (GR)

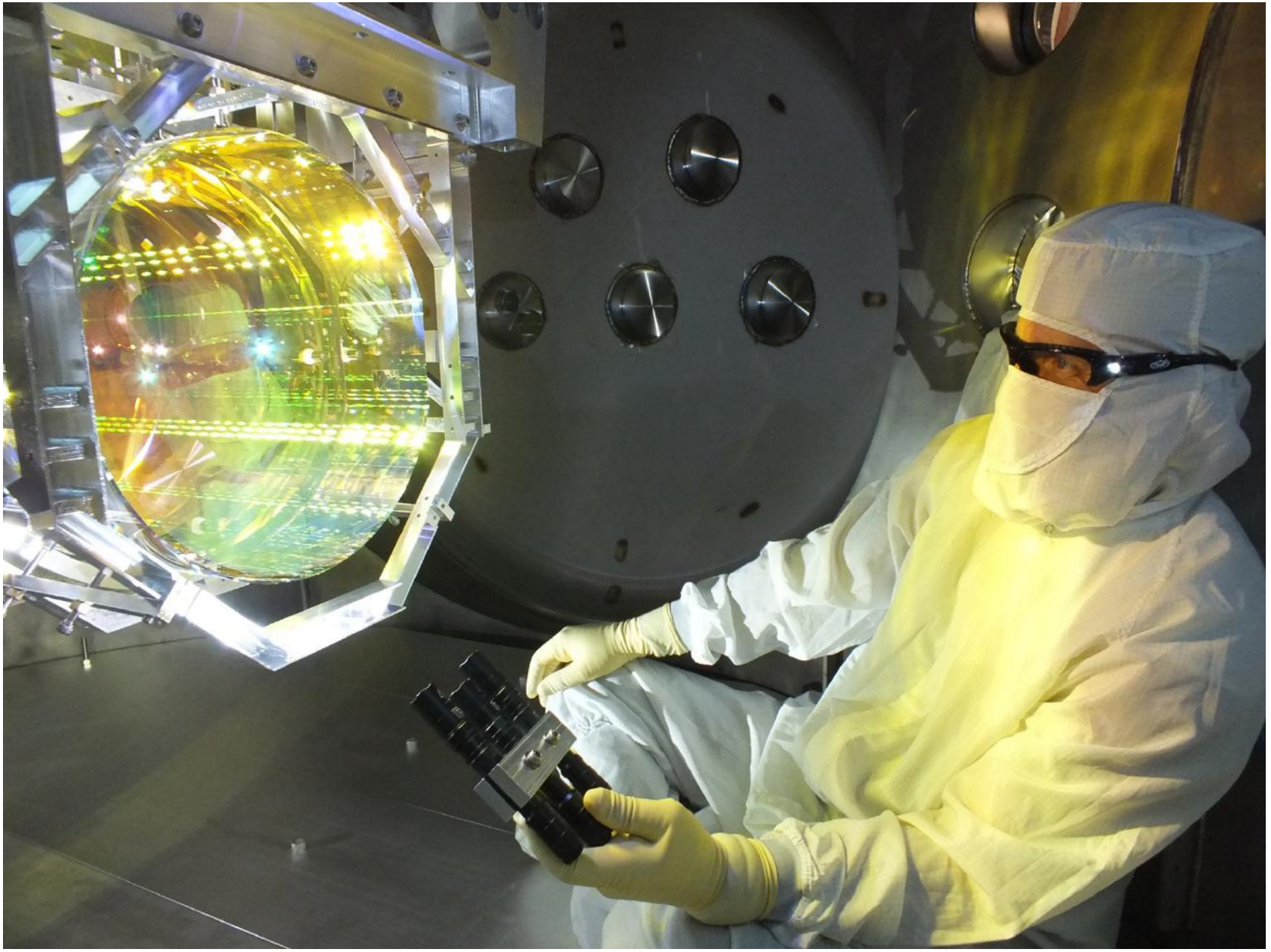
$$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = \frac{8\pi G}{c^4} T_{\mu\nu}$$

Geometry Space-time	=	Mass-energy distribution

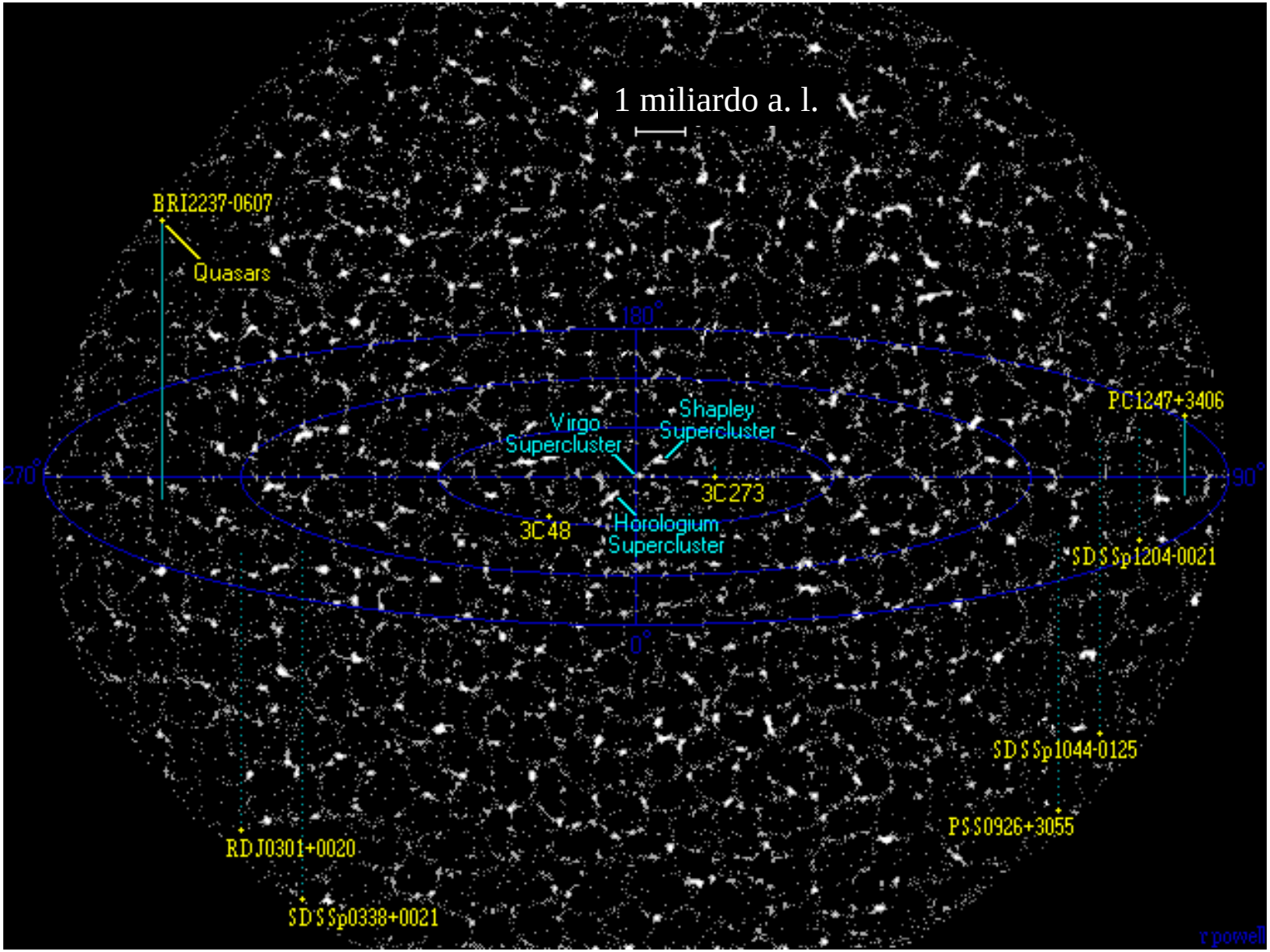
Spacetime tells matter how to move; matter tells spacetime how to curve


-0.02s


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

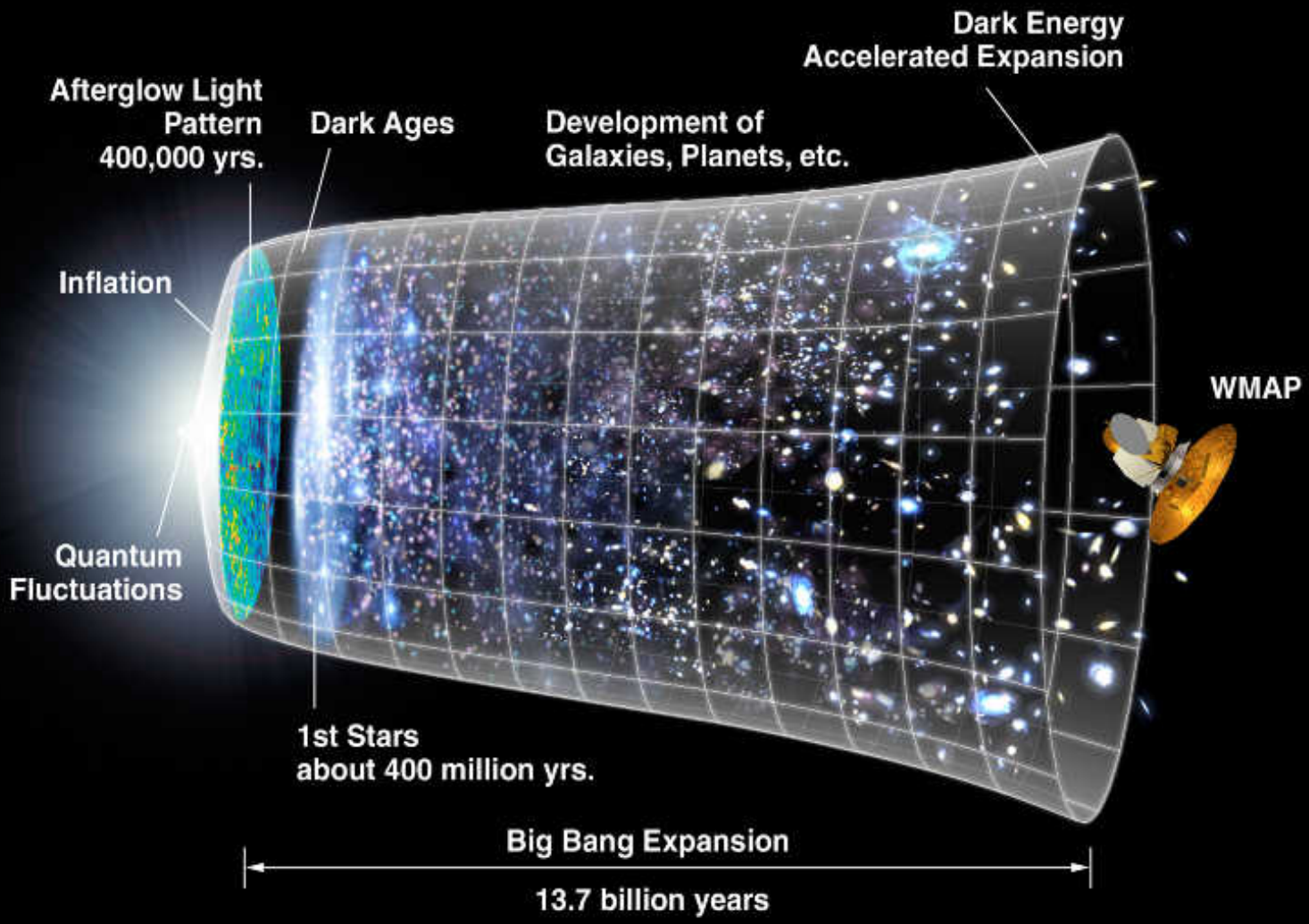


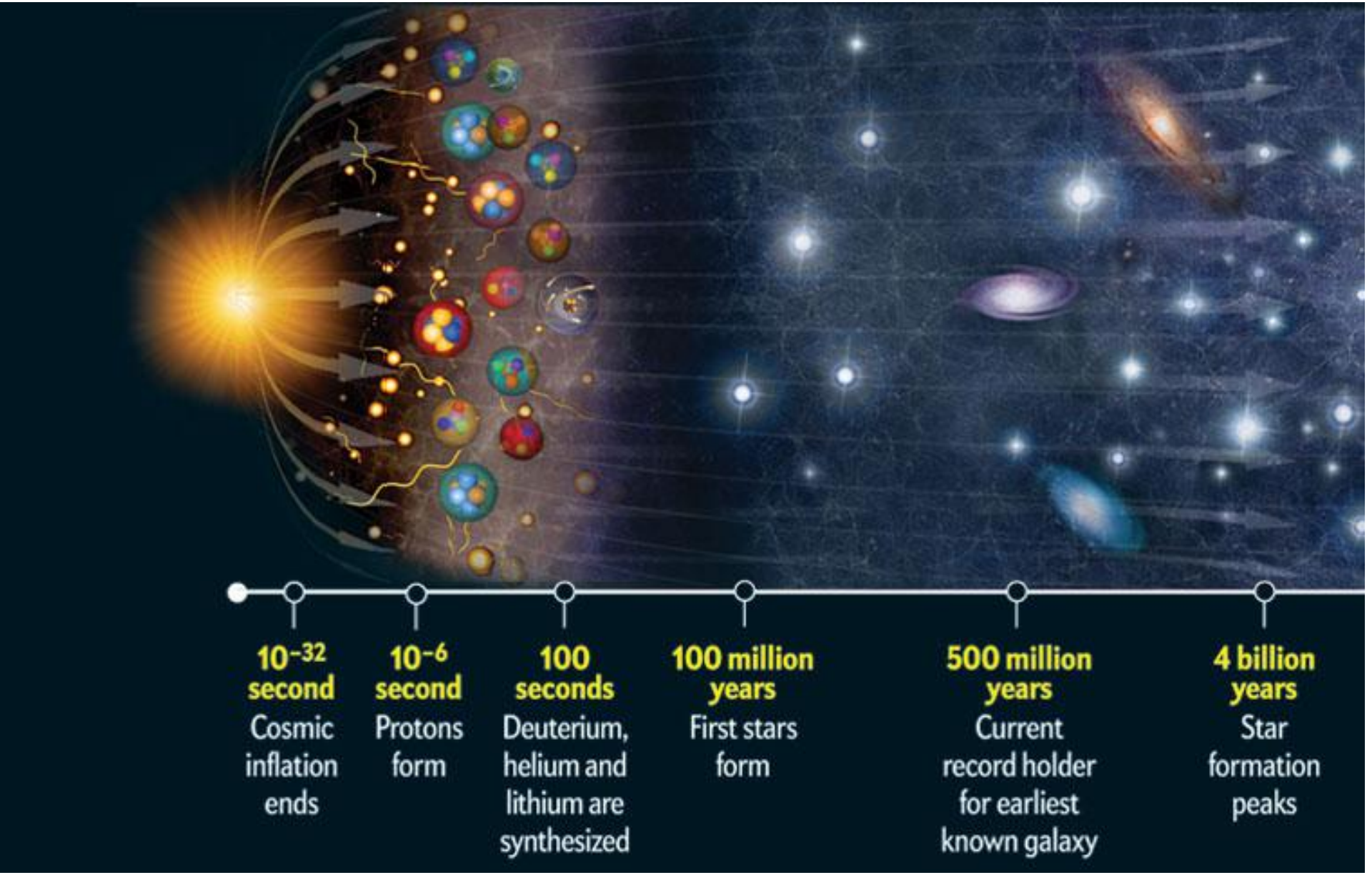

ESA
esa


1 miliardo a. l.
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

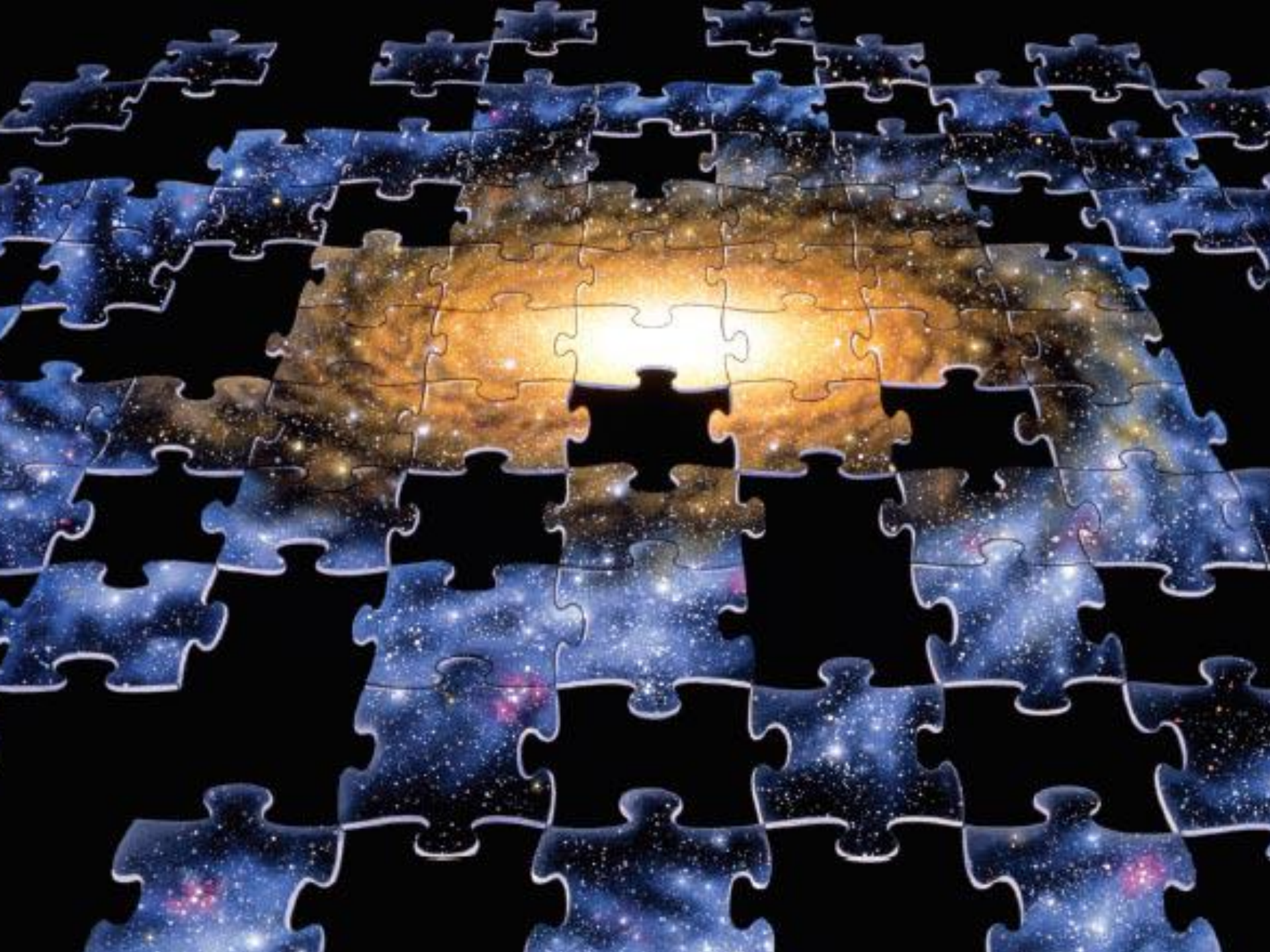
The Big Bang Model



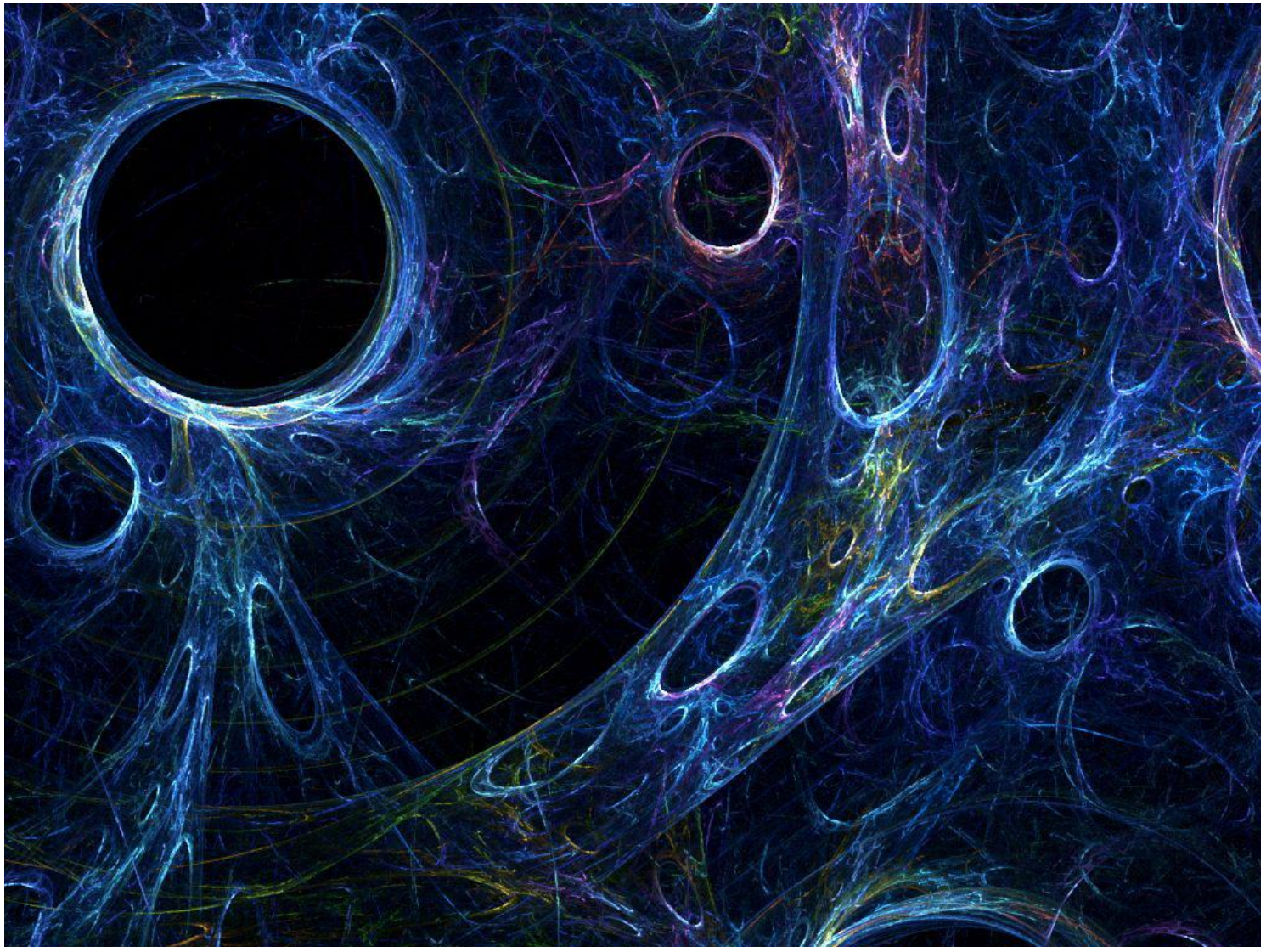

10^{-32} second
Cosmic inflation ends
10^{-6} second
Protons form
100 seconds
Deuterium, helium and lithium are synthesized
100 million years
First stars form
500 million years
Current record holder for earliest known galaxy
4 billion years
Star formation peaks

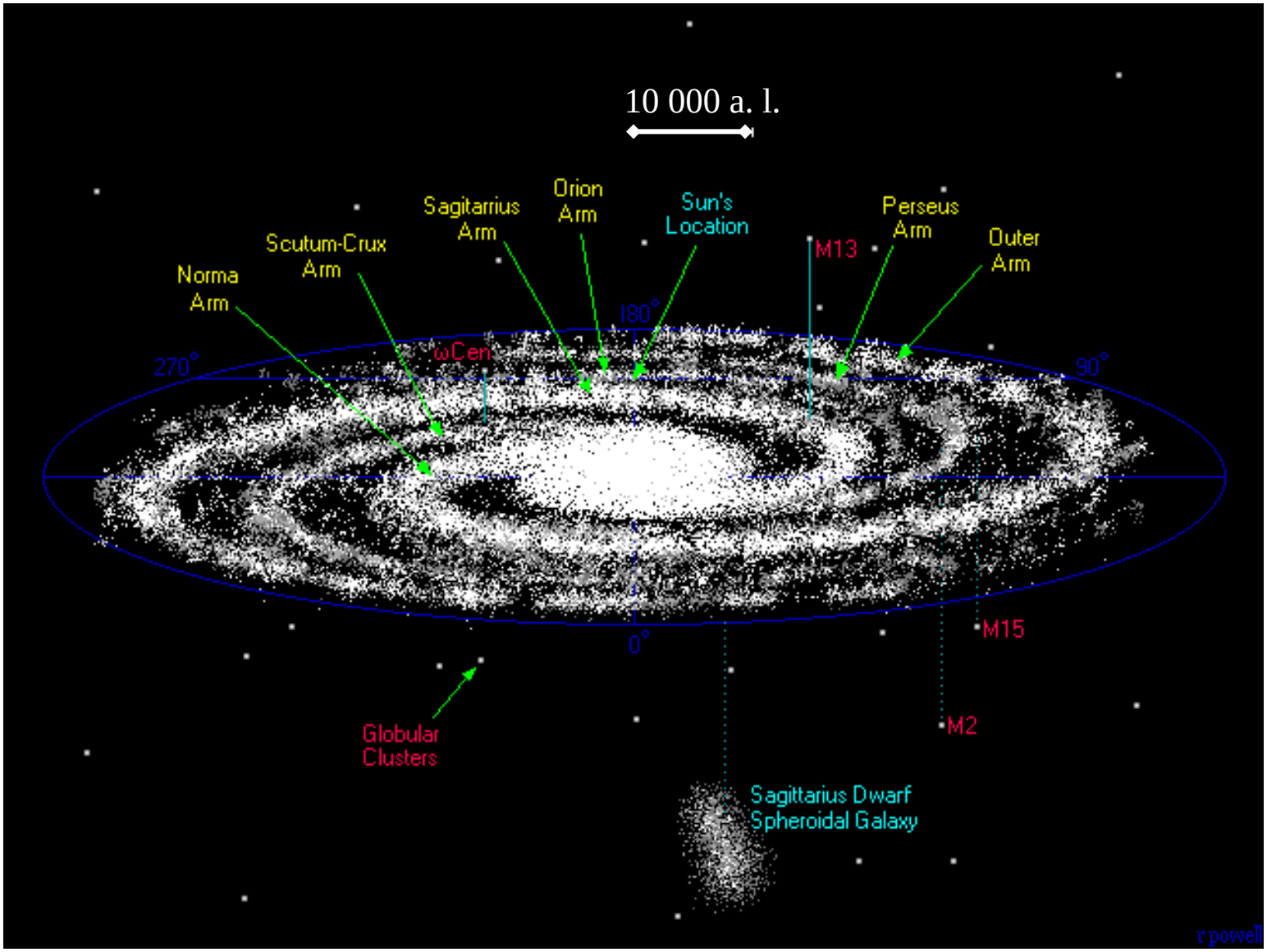
Have we understood the Universe?

Terra Incognita



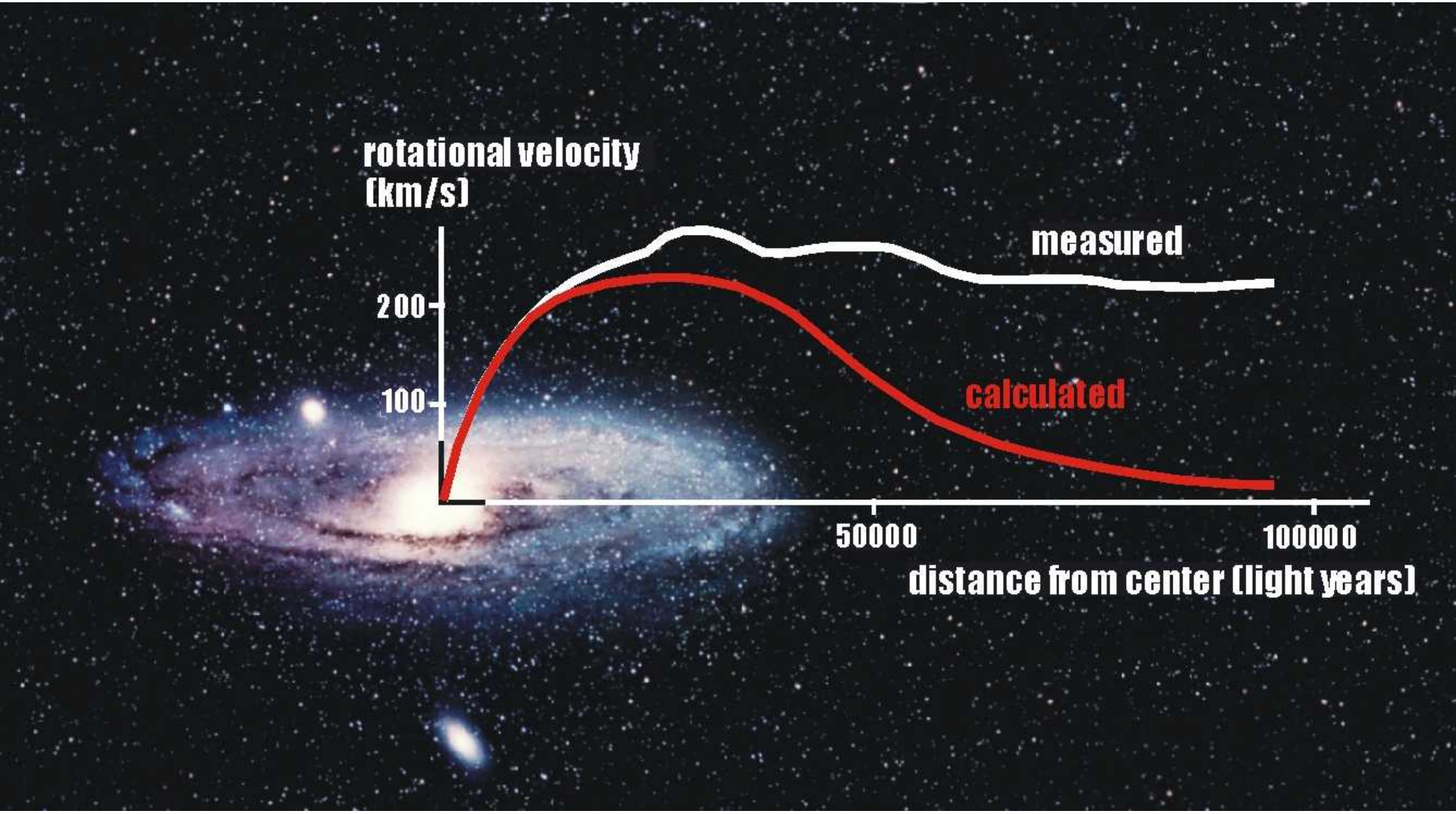
Dark matter and

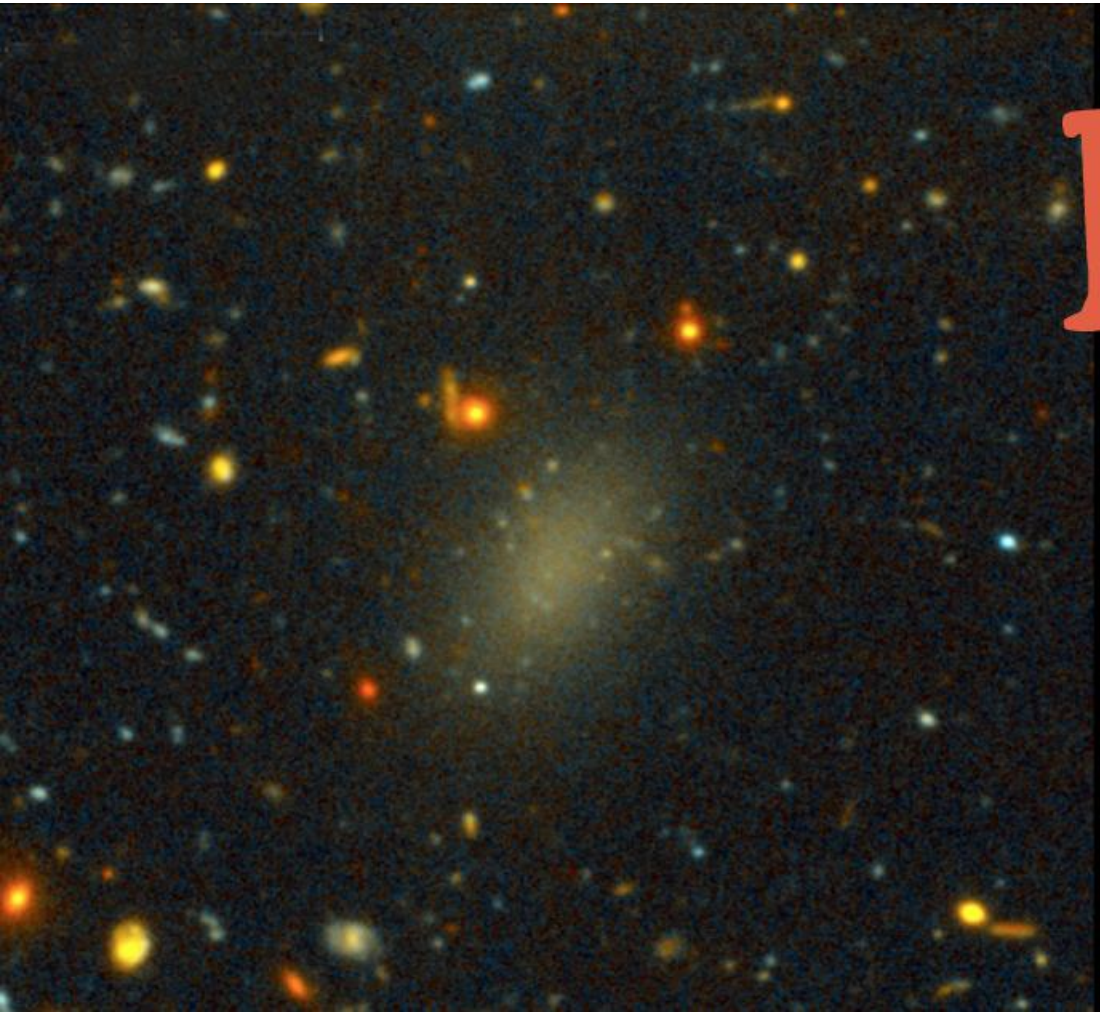




Zoom In x10

Zoom Out x10

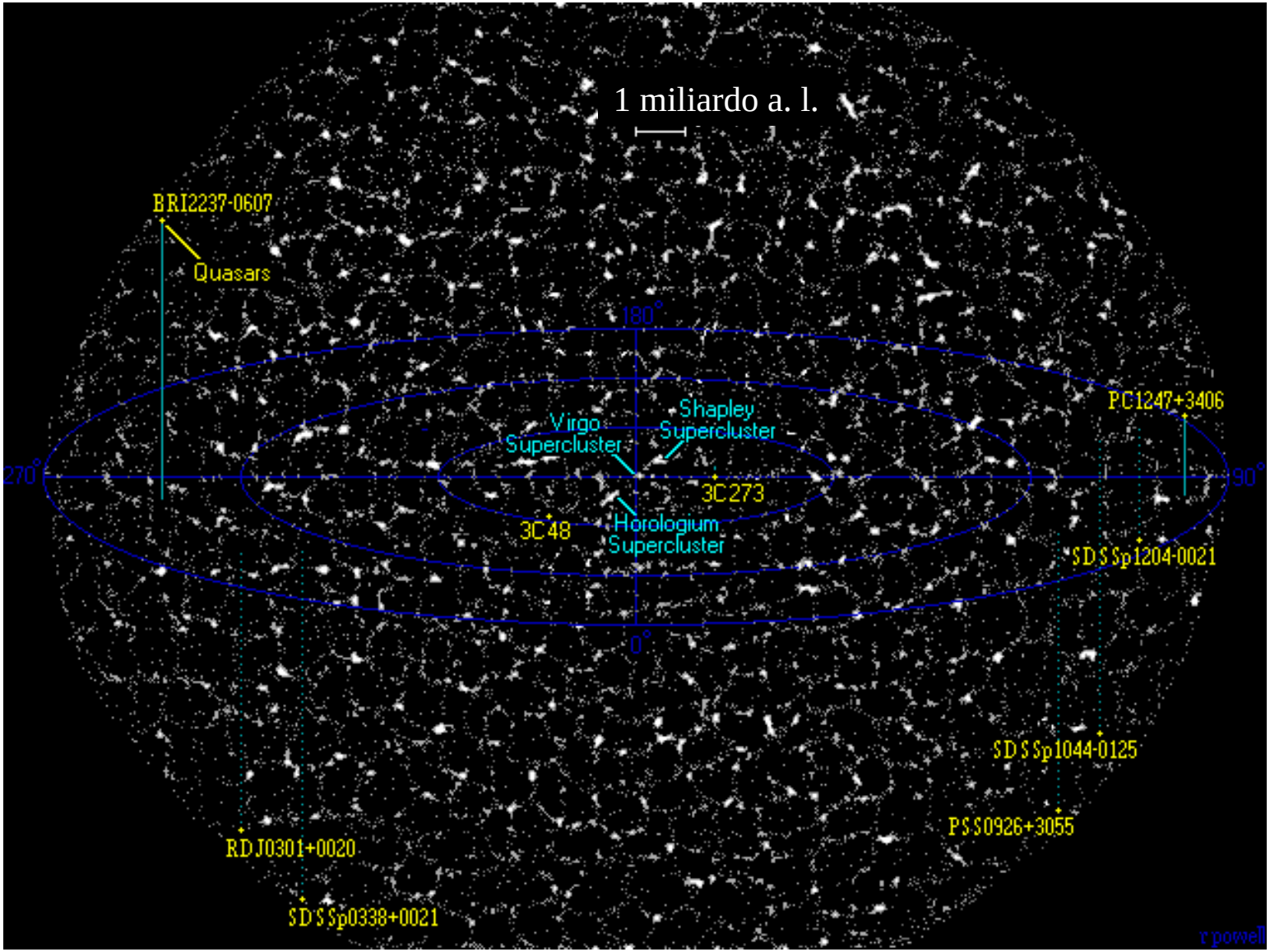

rotational velocity
(km/s)
200
100
measured
calculated
50000
100000
distance from center (light years)



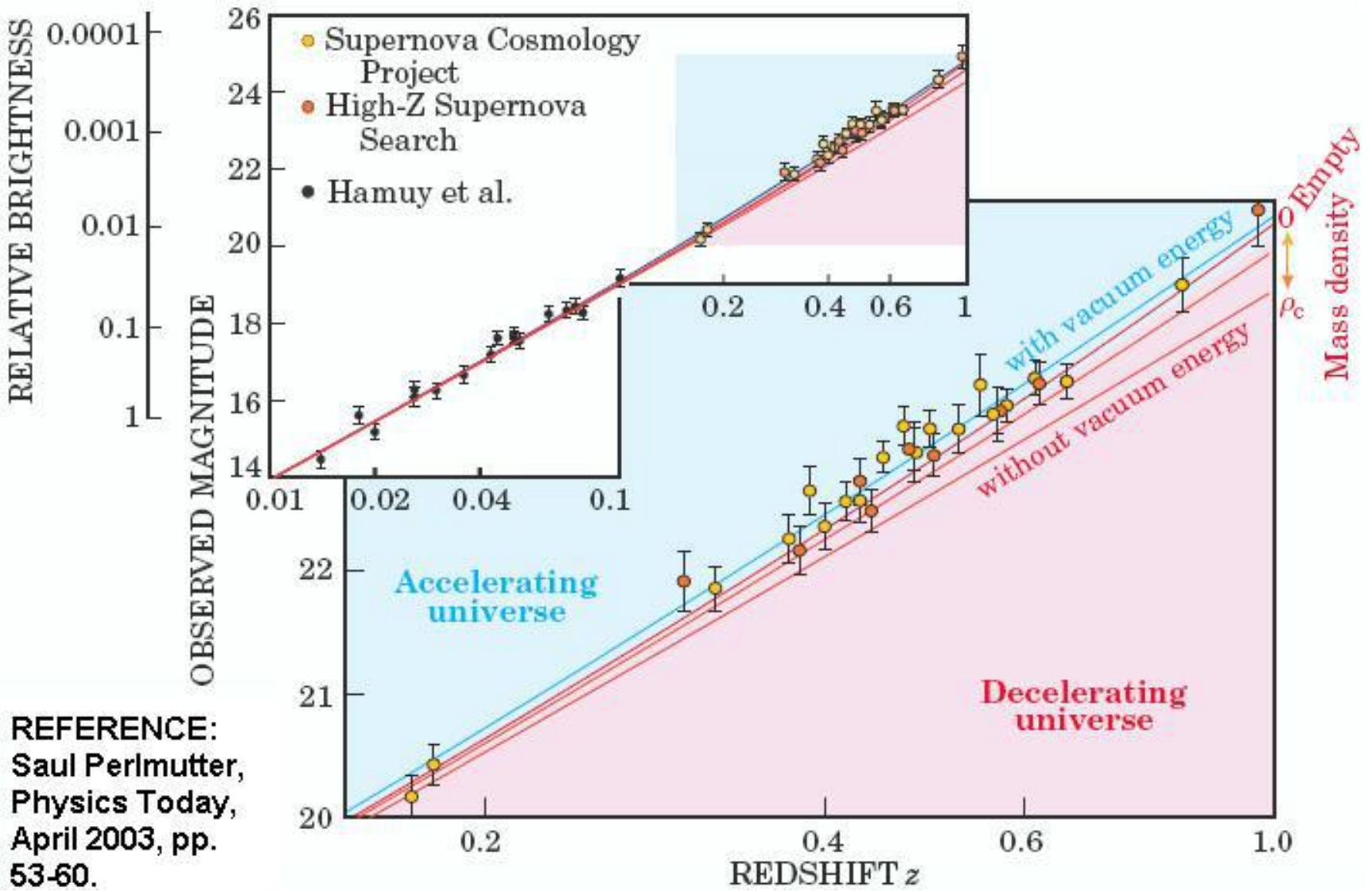
FOUND

99.9%

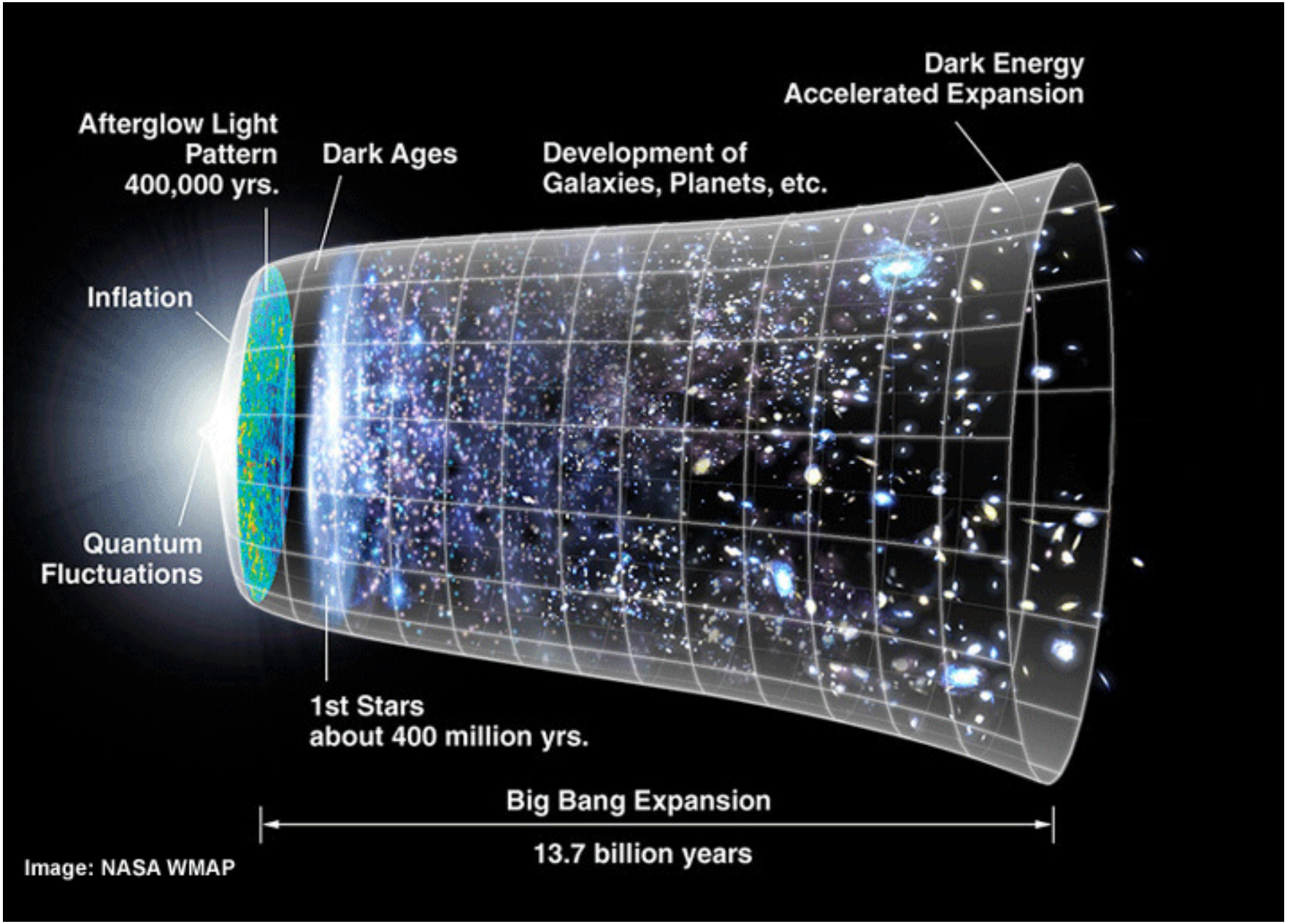
DARK MATTER GALAXY

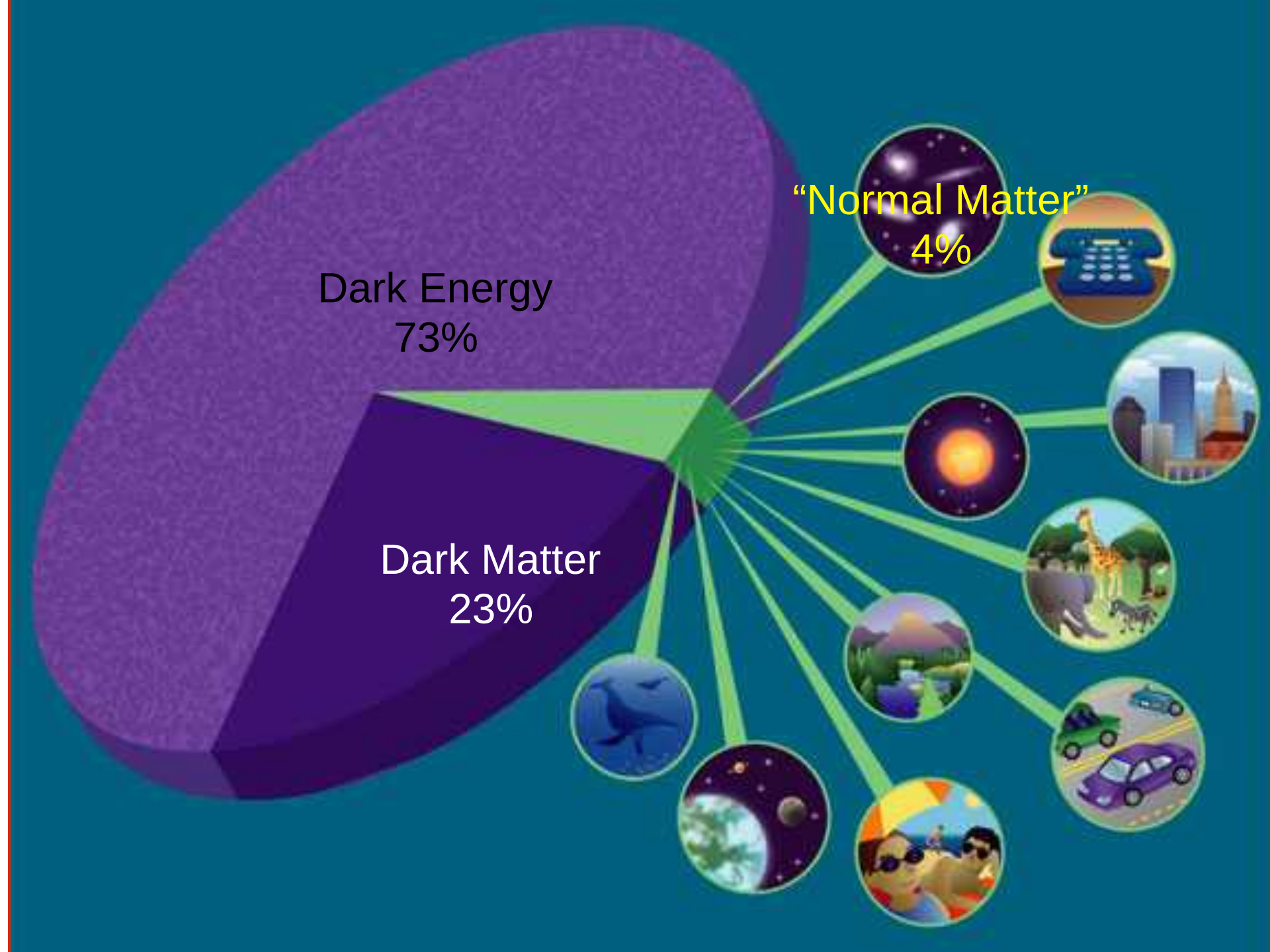

1 miliardo a. l.
BRI2237-0607
Quasars
180°
270°
90°
0°
Virgo
Supercluster
Shapley
Supercluster
3C273
3C48
Horologium
Supercluster
PC1247+3406
SDSSp1204-0021
SDSSp1044-0125
PSS0926+3055
RDJ0301+0020
SDSSp0338+0021
r powell

Zoom In x15

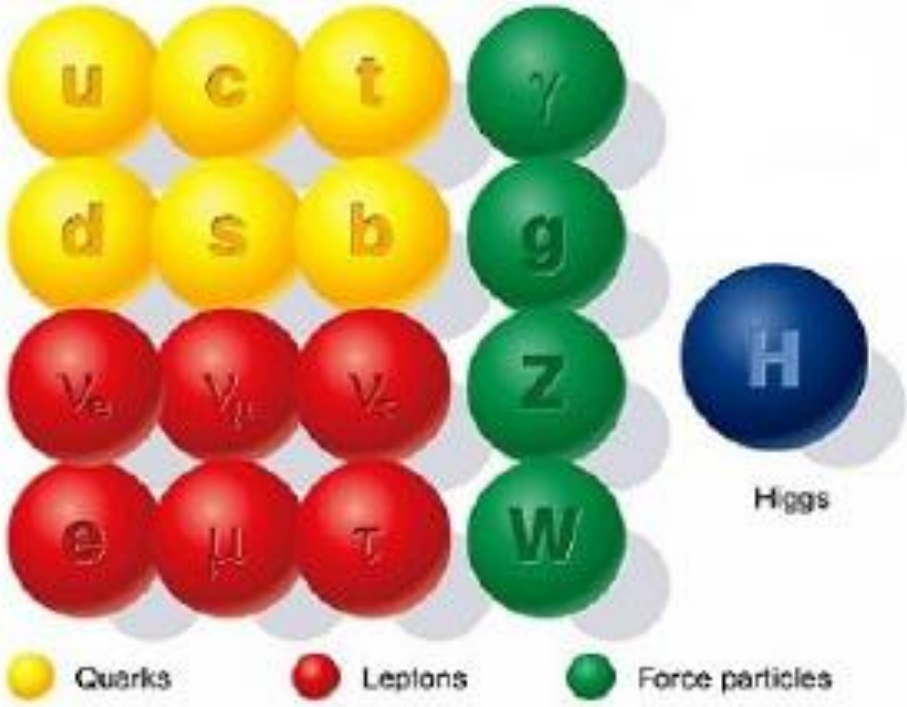


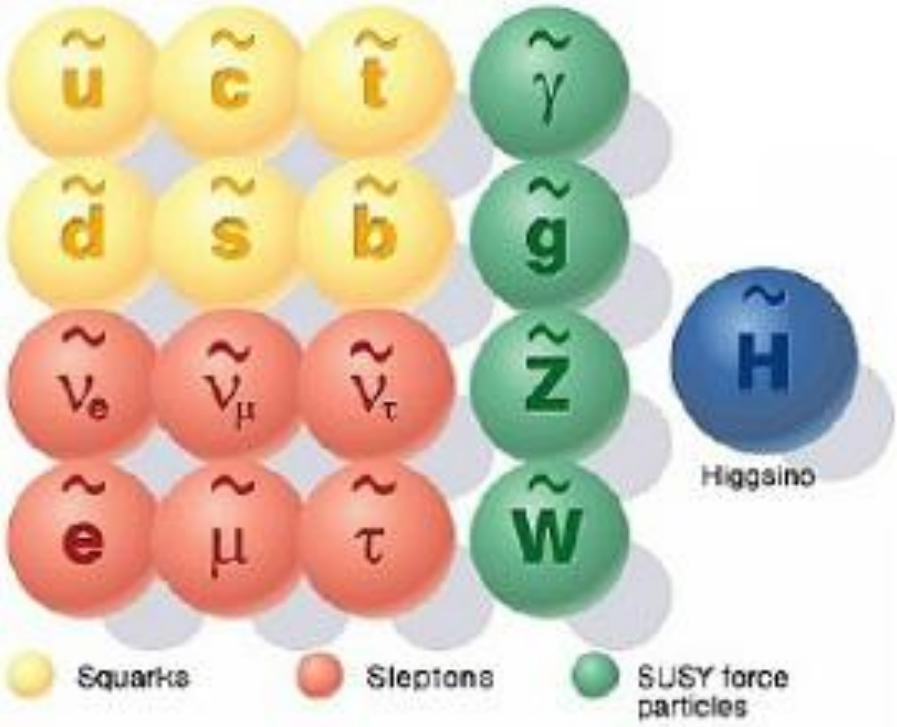
REFERENCE:
Saul Perlmutter, Physics Today, April 2003, pp. 53-60.


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


Dark Energy
73%
Dark Matter
23%
“Normal Matter”
4%

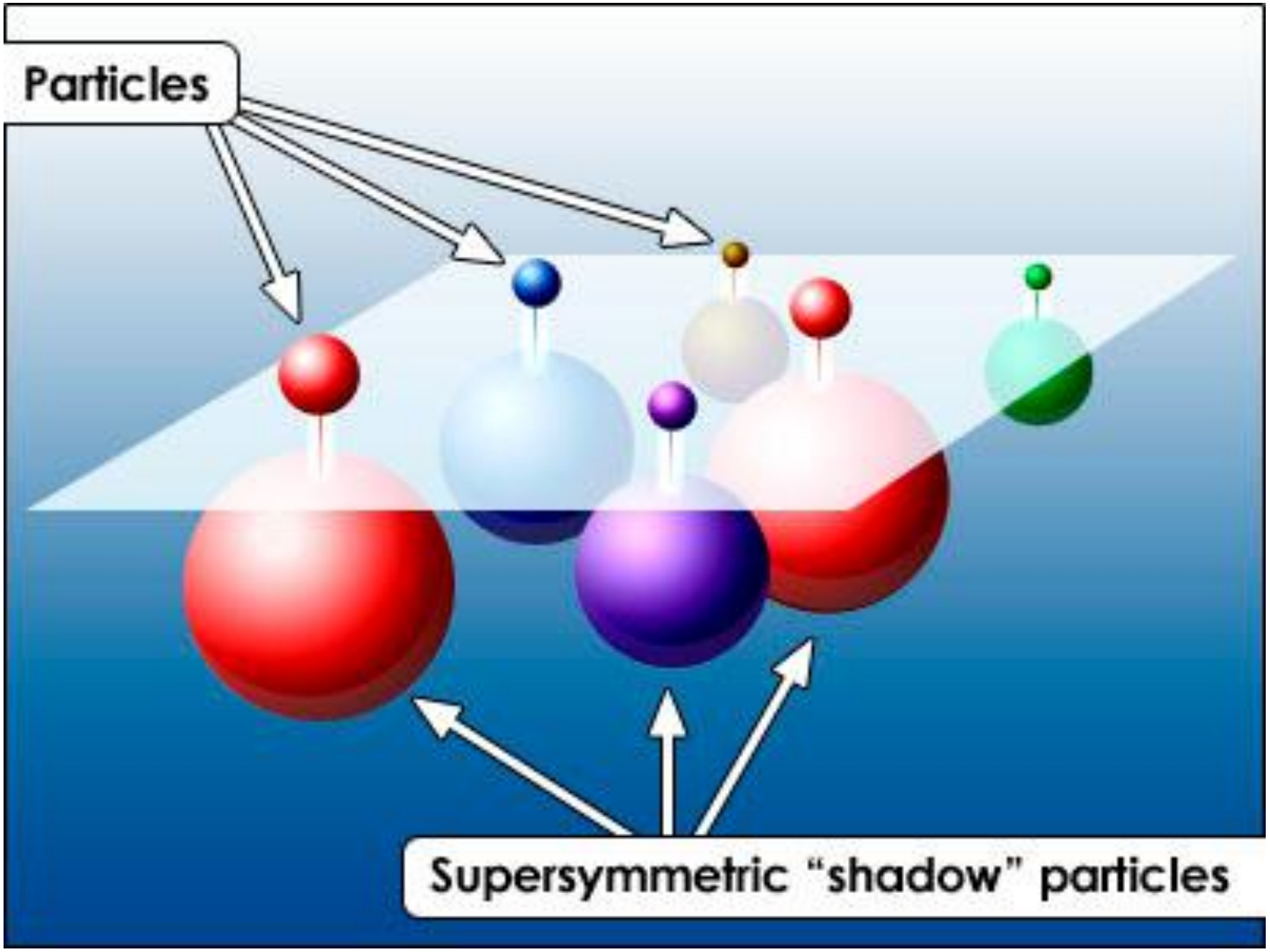
SUPERSYMMETRY





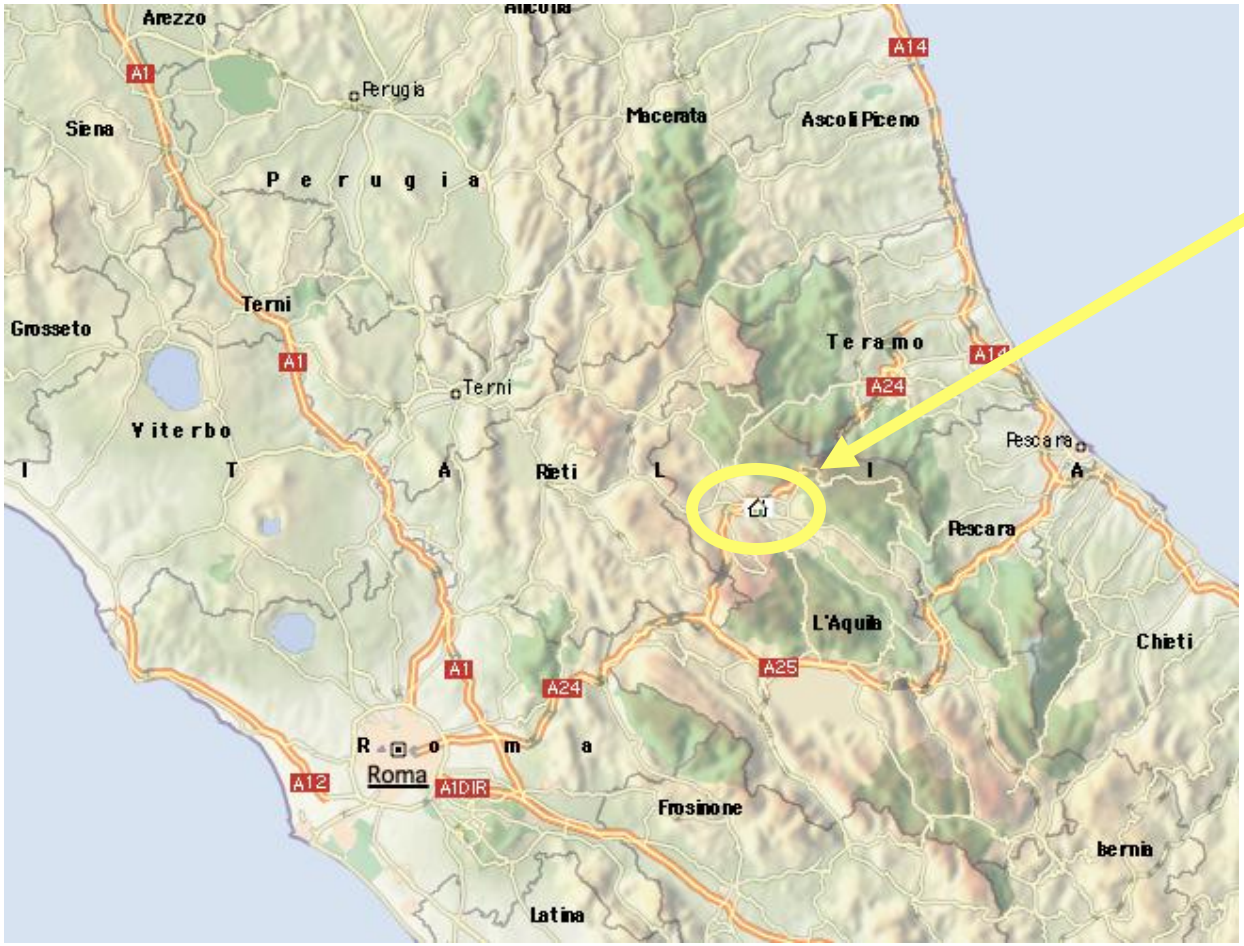
Standard particles

SUSY particles

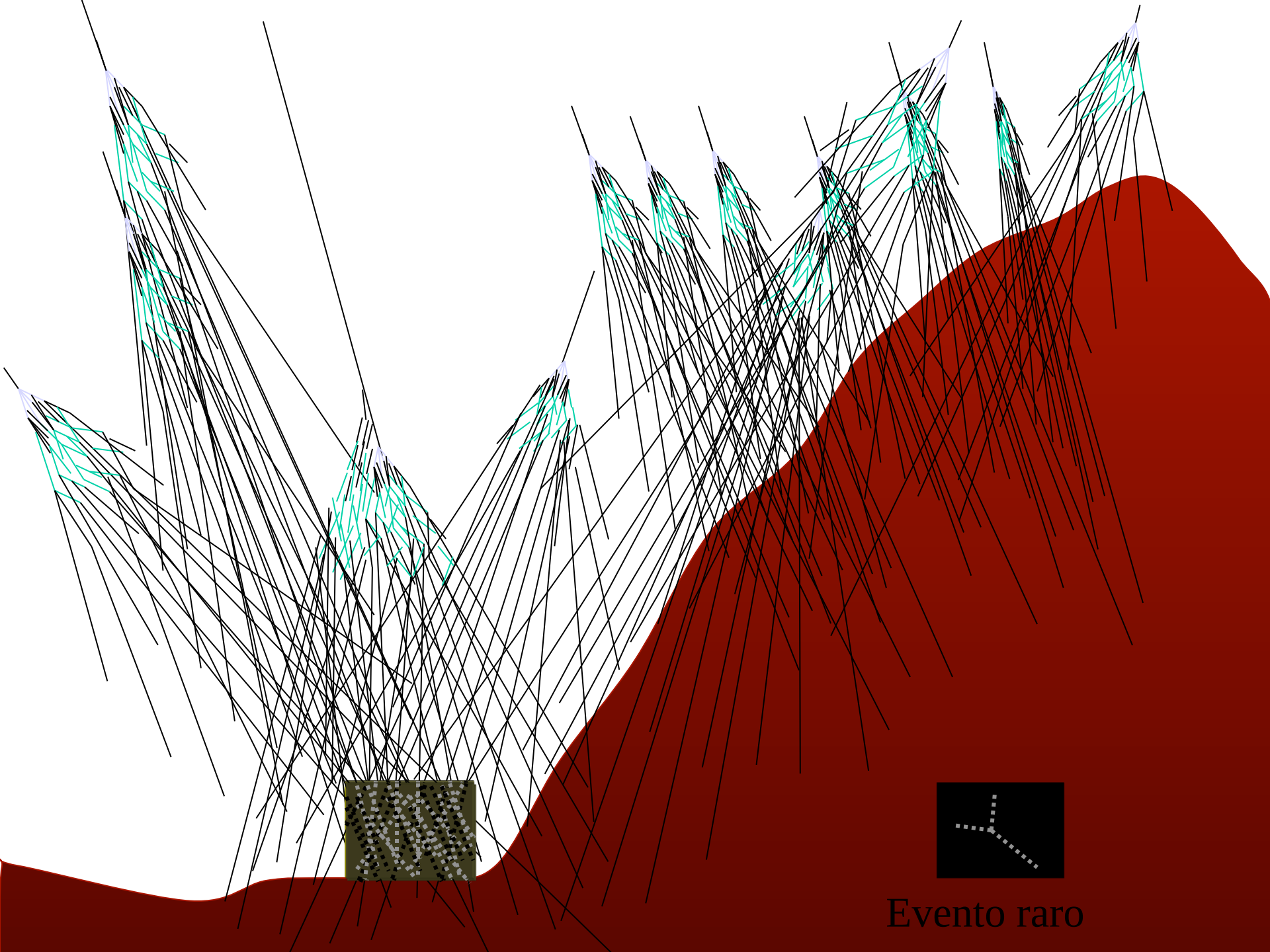

Particles
Supersymmetric "shadow" particles

A caccia di particelle di materia oscura

Laboratori Nazionali del Gran Sasso, Istituto Nazionale di Fisica Nucleare

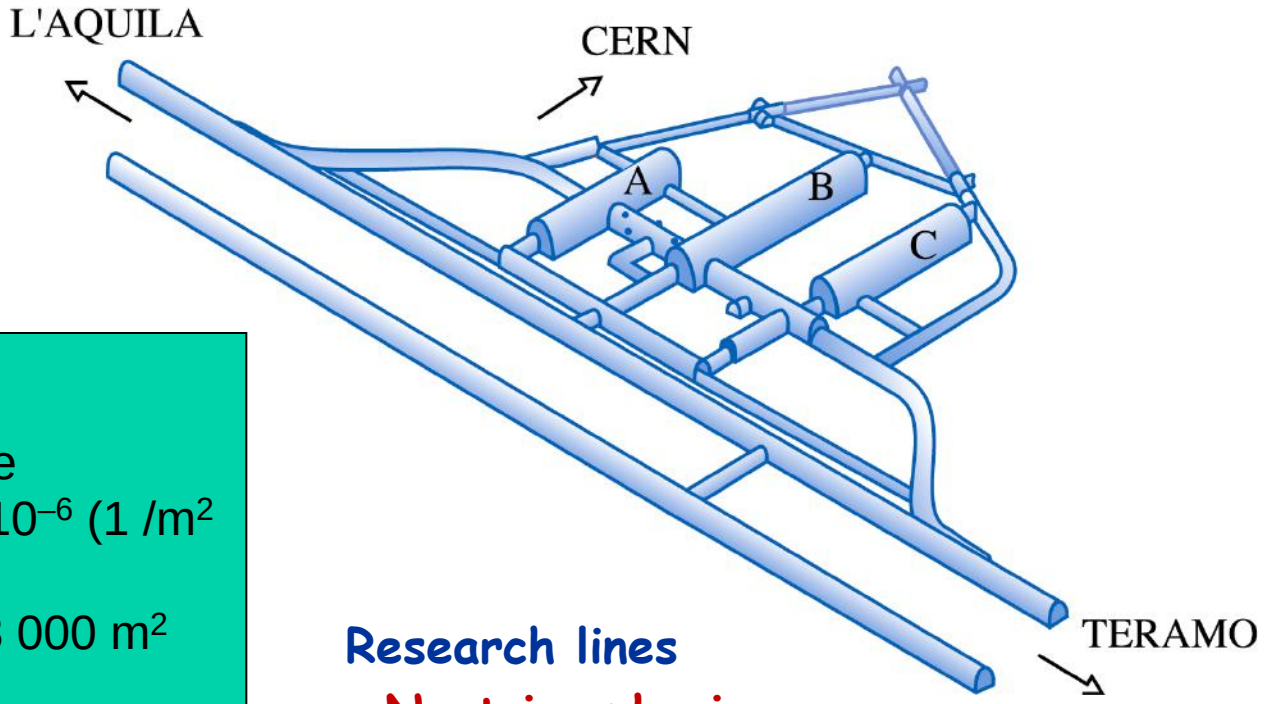



via Galilei
P


Evento raro

LABORATORI NAZIONALI DEL GRAN SASSO - INFN

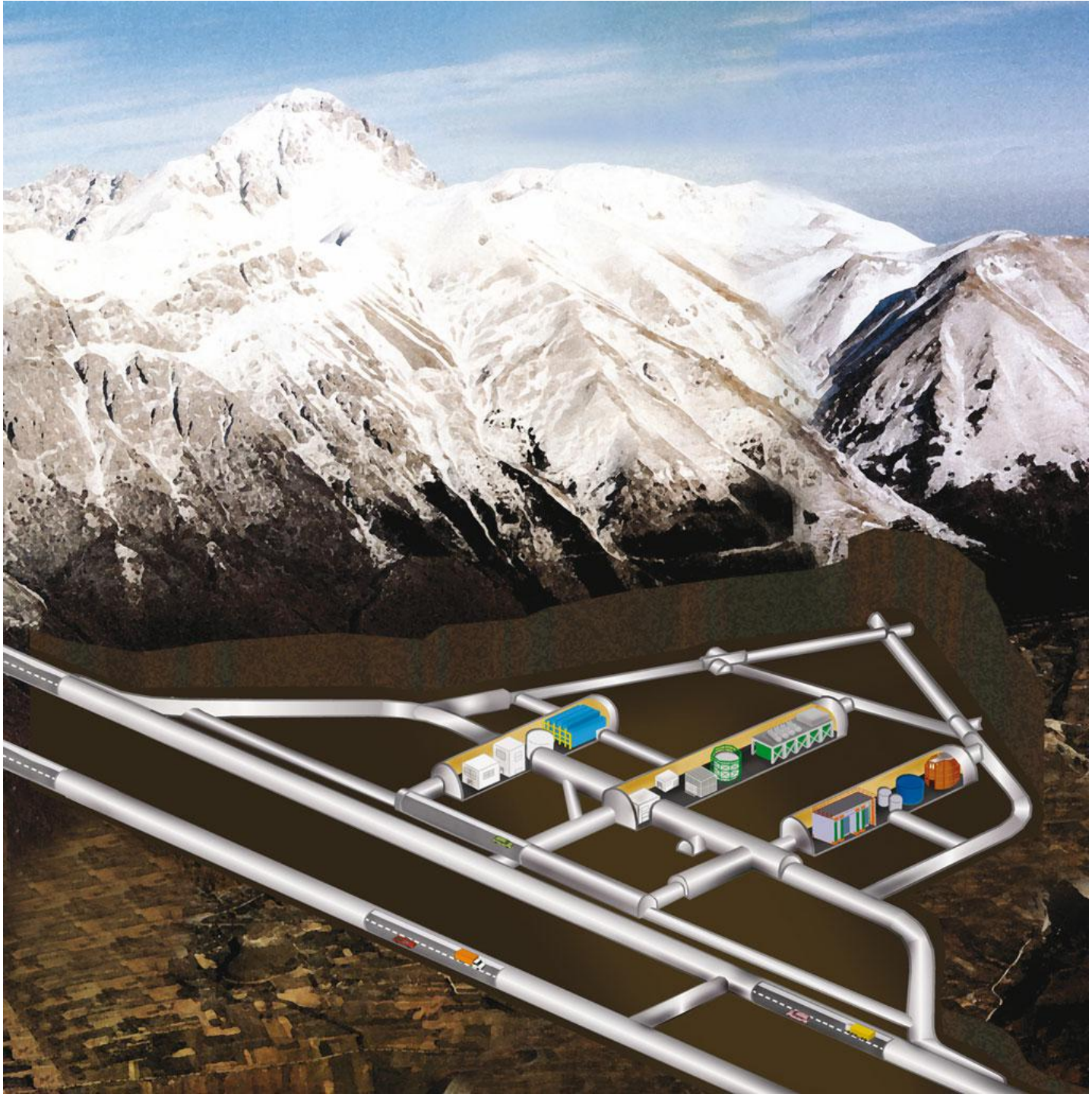
Largest underground laboratory for astroparticle physics

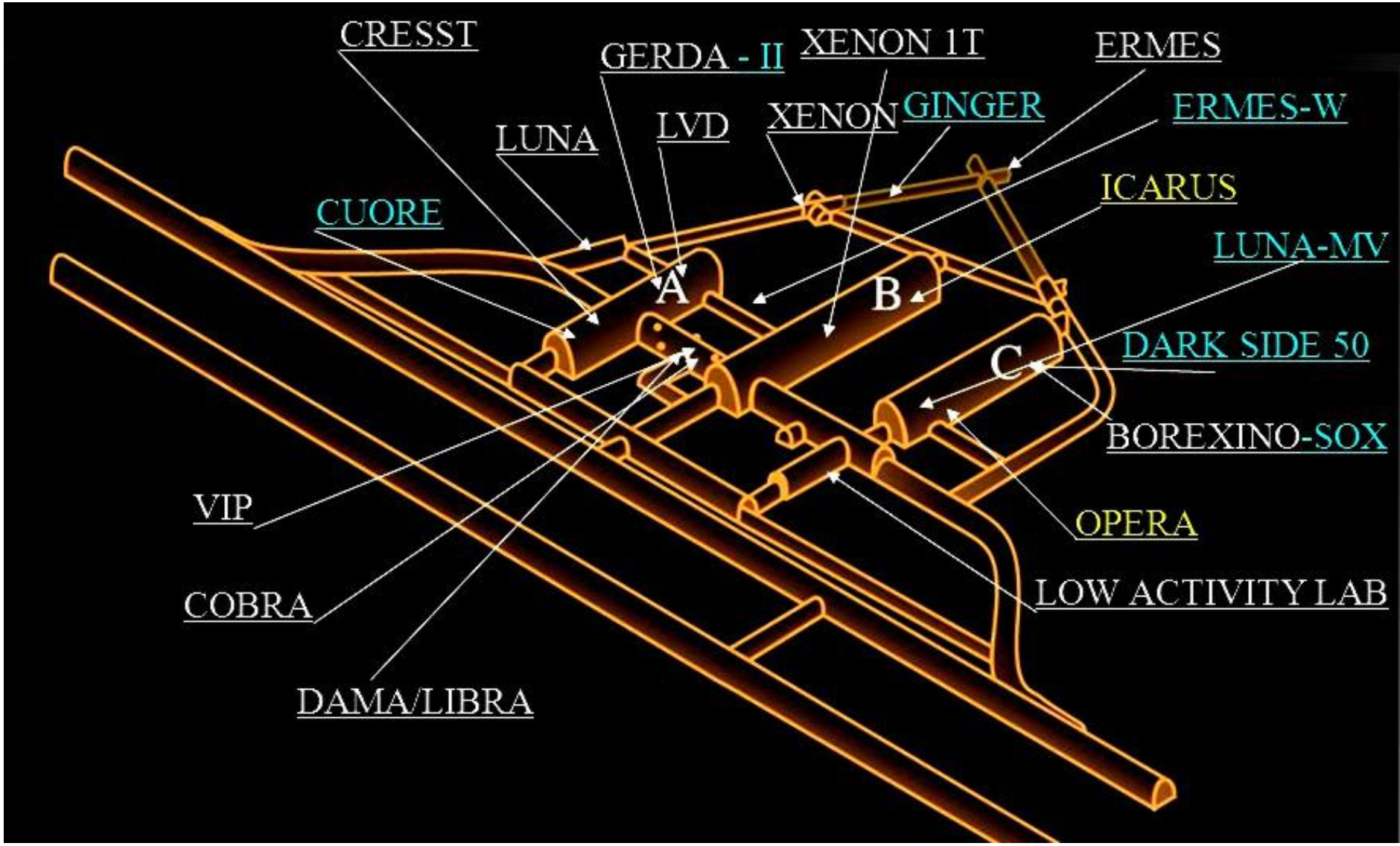


1400 m rock coverage
cosmic μ reduction= 10^{-6} (1 /m^2 h)
underground area: 18 000 m^2
external facilities
easy access

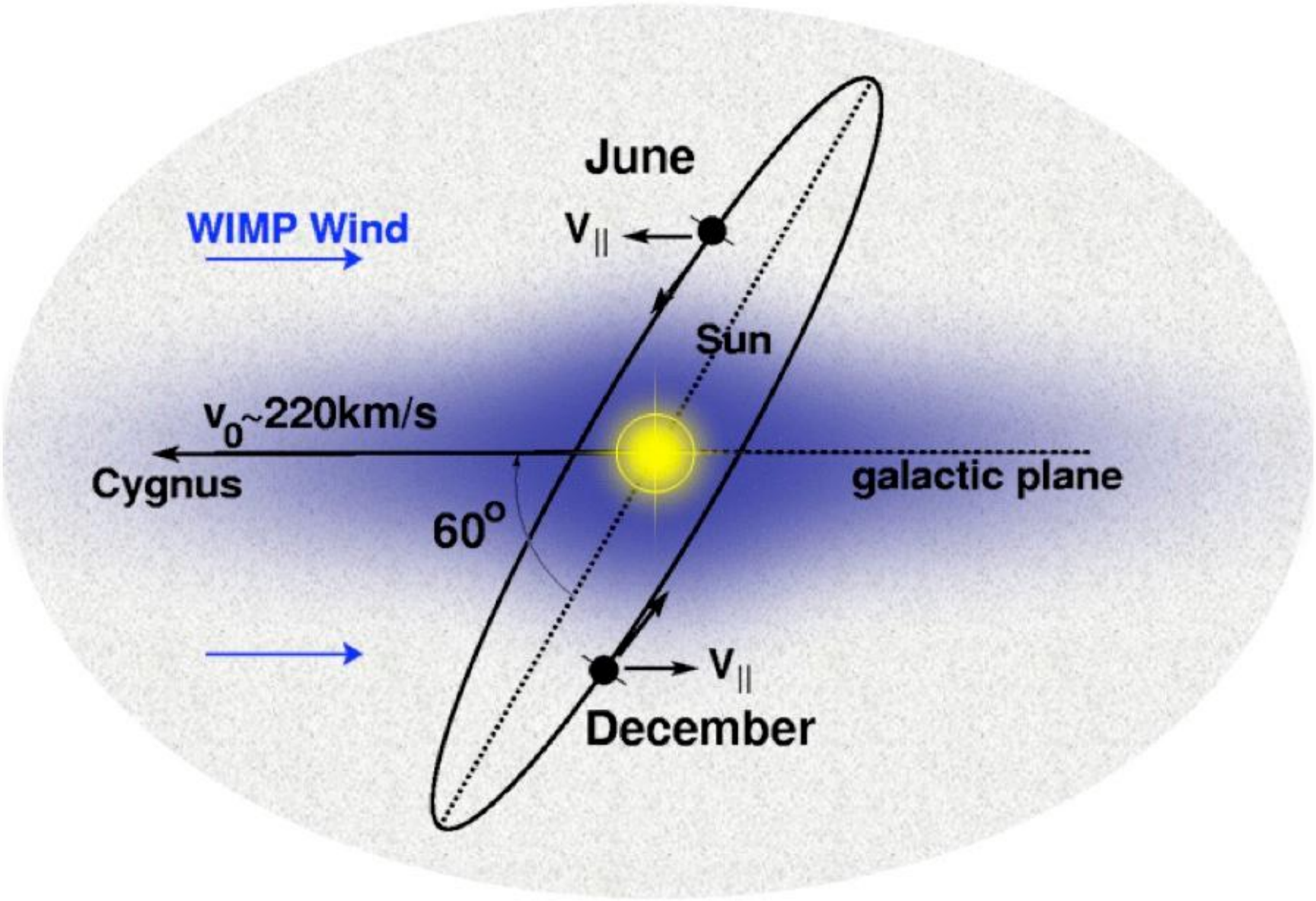
Research lines

- **Neutrino physics**
  (mass, oscillations, stellar physics)
- **Dark matter**
- **Nuclear reactions of astrophysics interest**
- **Geophysics**
- **Biology**




CRESST
GERDA - II
XENON 1T
ERMES
LUNA
LVD
XENON
GINGER
ERMES-W
CUORE
ICARUS
LUNA-MV
A
B
C
DARK SIDE 50
BOREXINO-SOX
VIP
OPERA
COBRA
LOW ACTIVITY LAB
DAMA/LIBRA

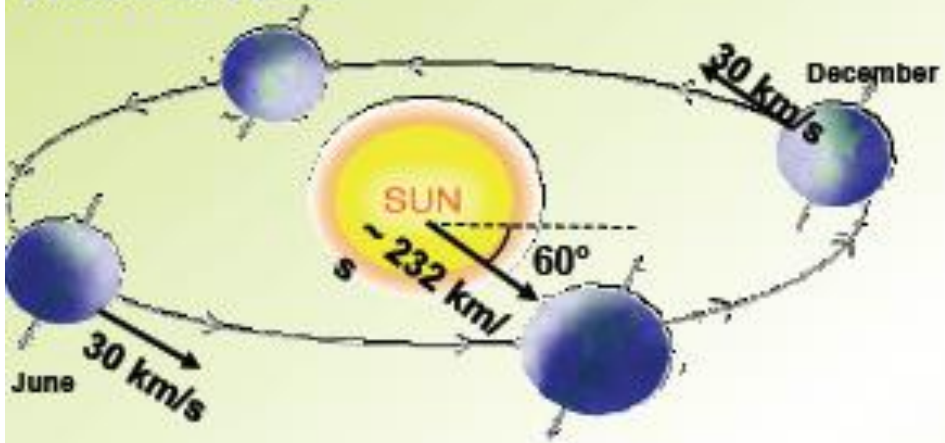
Annual modulation induced by Dark Matter



The annual modulation: a model independent signature for the investigation of Dark Matter particles component in the galactic halo

With the present technology, the annual modulation is the main model independent signature for the DM signal. Although the modulation effect is expected to be relatively small a suitable large-mass, low-radioactive set-up with an efficient control of the running conditions would point out its presence.

Drukier, Freese, Spergel PRD86
Freese et al. PRD88



- $v_{sun} \sim 232$ km/s (Sun velocity in the halo)
- $v_{orb} = 30$ km/s (Earth velocity around the Sun)
- $\gamma = \pi/3$, $\omega = 2\pi/T$, $T = 1$ year
- $t_0 = 2^{nd}$ June (when $v_\oplus$ is maximum)

$$v_\oplus(t) = v_{sun} + v_{orb}\cos\gamma\cos[\omega(t-t_0)]$$

$$S_k[\eta(t)] = \int_{\Delta E_k} \frac{dR}{dE_R} dE_R \cong S_{0,k} + S_{m,k}\cos[\omega(t-t_0)]$$

Expected rate in given energy bin changes because the annual motion of the Earth around the Sun moving in the Galaxy

Requirements of the annual modulation

1) Modulated rate according cosine
2) In a definite low energy range
3) With a proper period (1 year)
4) With proper phase (about 2 June)
5) Just for single hit events in a multi-detector set-up
6) With modulation amplitude in the region of maximal sensitivity must be <7% for usually adopted halo distributions, but it can be larger in case of some possible scenarios

To mimic this signature, spurious effects and side reactions must not only - obviously - be able to account for the whole observed modulation amplitude, but also to satisfy contemporaneously all the requirements

The DM annual modulation signature has a different origin and, thus, different peculiarities (e.g. the phase) with respect to those effects connected with the seasons instead

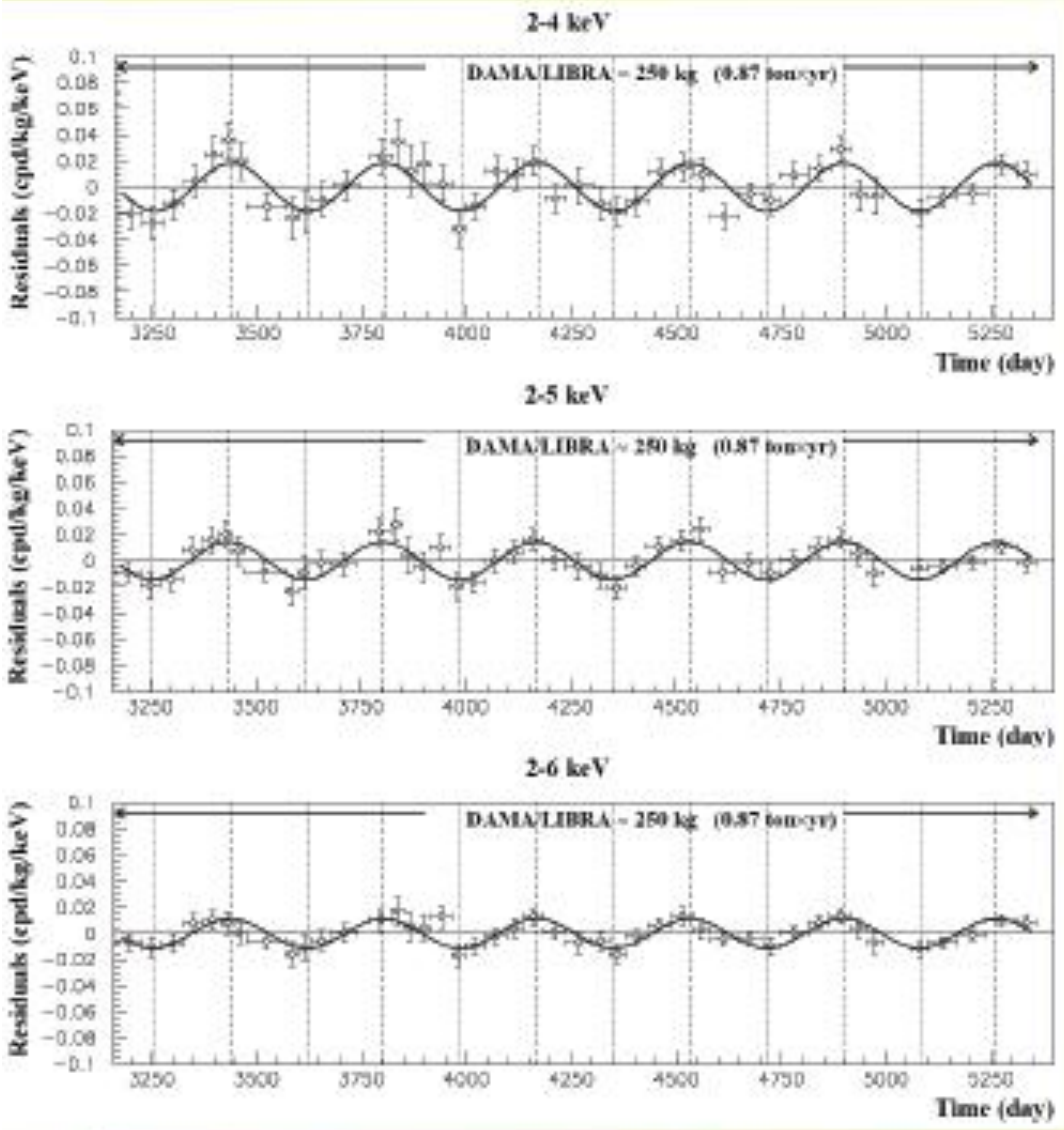
DAMA/LIBRA

Model Independent Annual Modulation Result

experimental single-hit residuals rate vs time and energy

DAMA/LIBRA 1-6 (0.87 ton×yr)

$A\cos[\omega(t-t_0)]$; continuous lines: $t_0 = 152.5$ d, $T = 1.00$ y



The fit has been done on the DAMA/NaI & DAMA/LIBRA data (1.17 ton × yr)

2-4 keV

A=(0.0183±0.0022) cpd/kg/keV

χ^2/dof = 75.7/79 **8.3 σ C.L.**

Absence of modulation? No

χ^2/dof=147/80 ⇒ P(A=0) = 7×10^{-6}

2-5 keV

A=(0.0144±0.0016) cpd/kg/keV

χ^2/dof = 56.6/79 **9.0 σ C.L.**

Absence of modulation? No

χ^2/dof=135/80 ⇒ P(A=0) = 1.1×10^{-4}

2-6 keV

A=(0.0114±0.0013) cpd/kg/keV

χ^2/dof = 64.7/79 **8.8 σ C.L.**

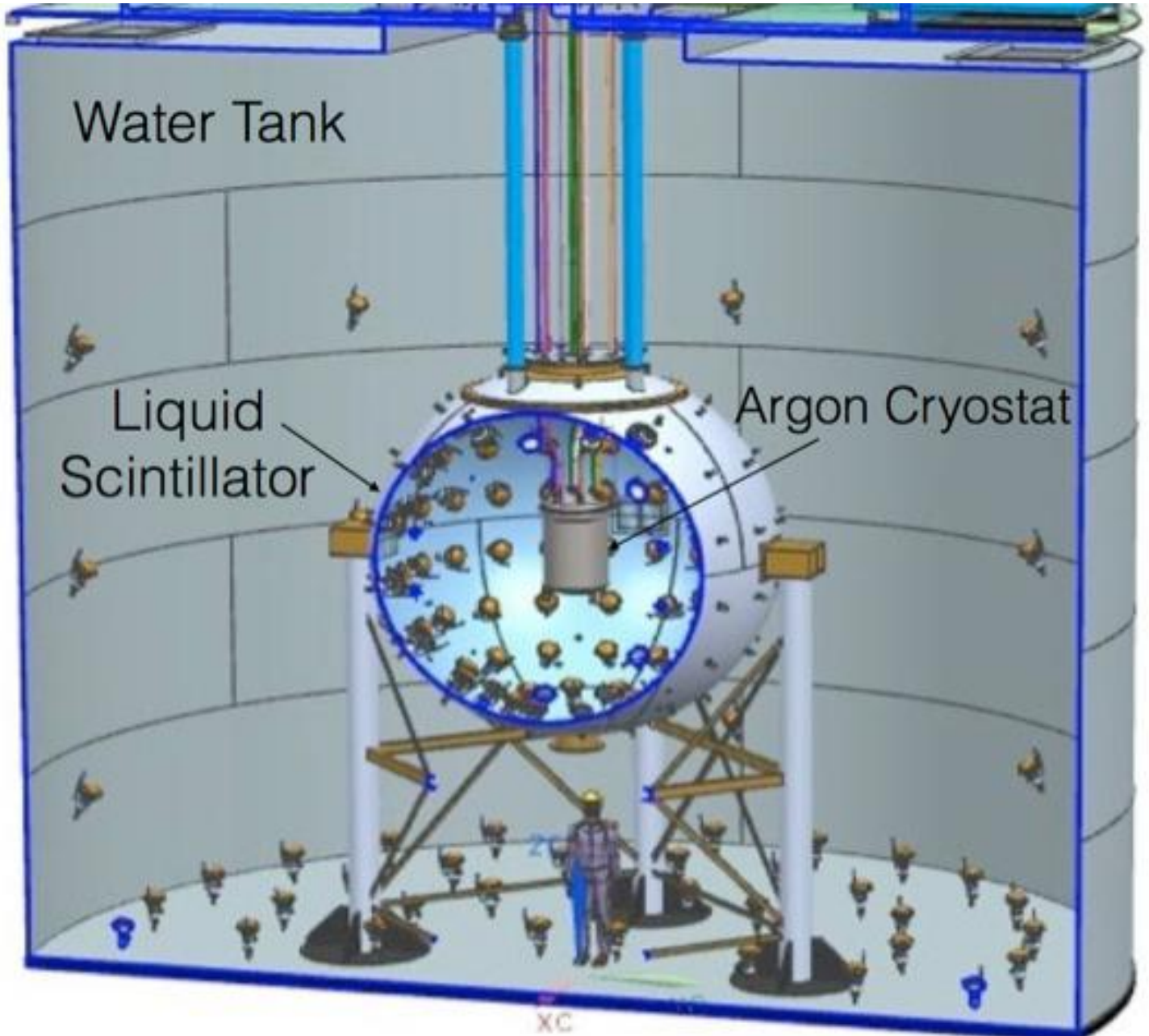
Absence of modulation? No

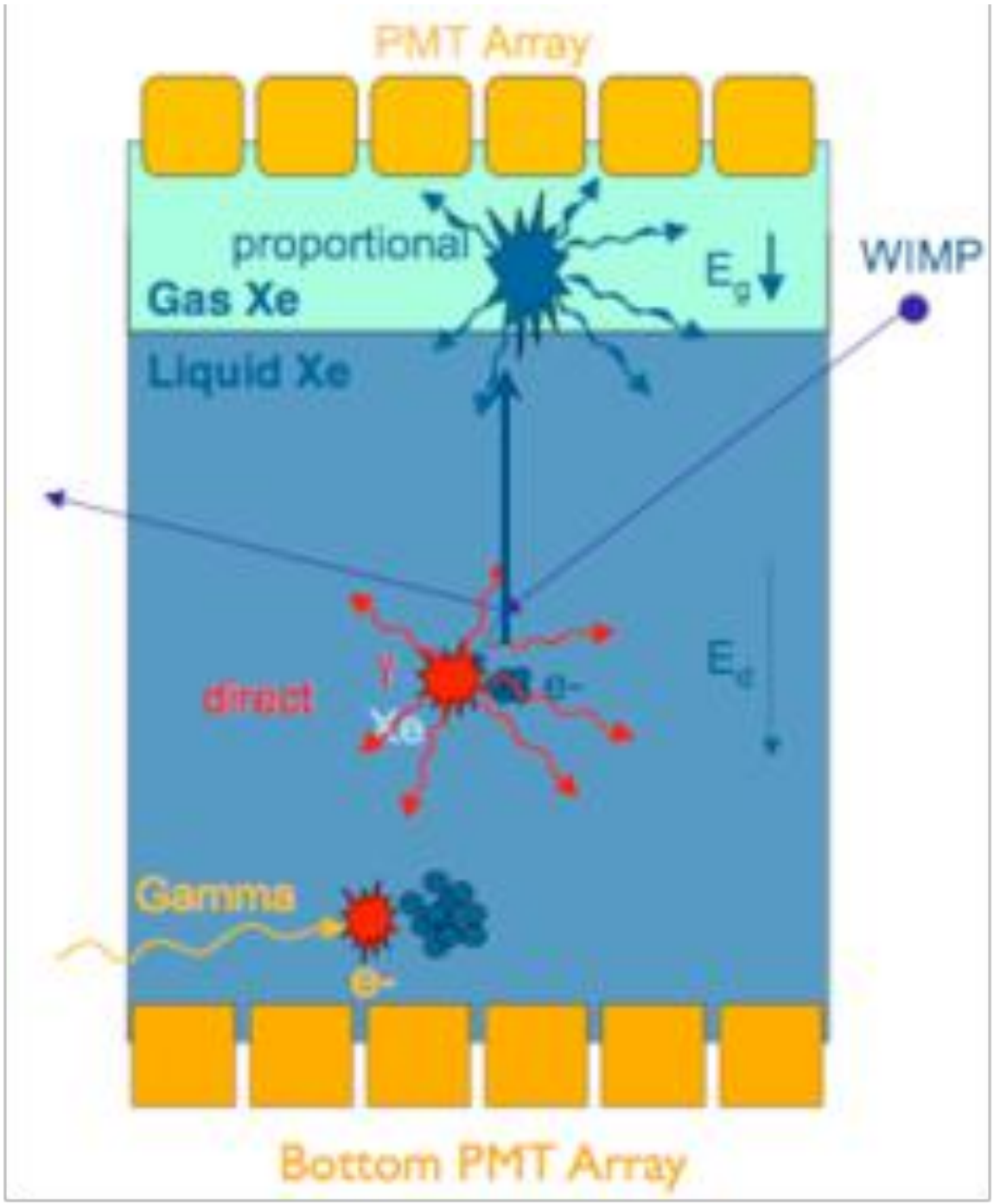
χ^2/dof=140/80 ⇒ P(A=0) = 4.3×10^{-5}

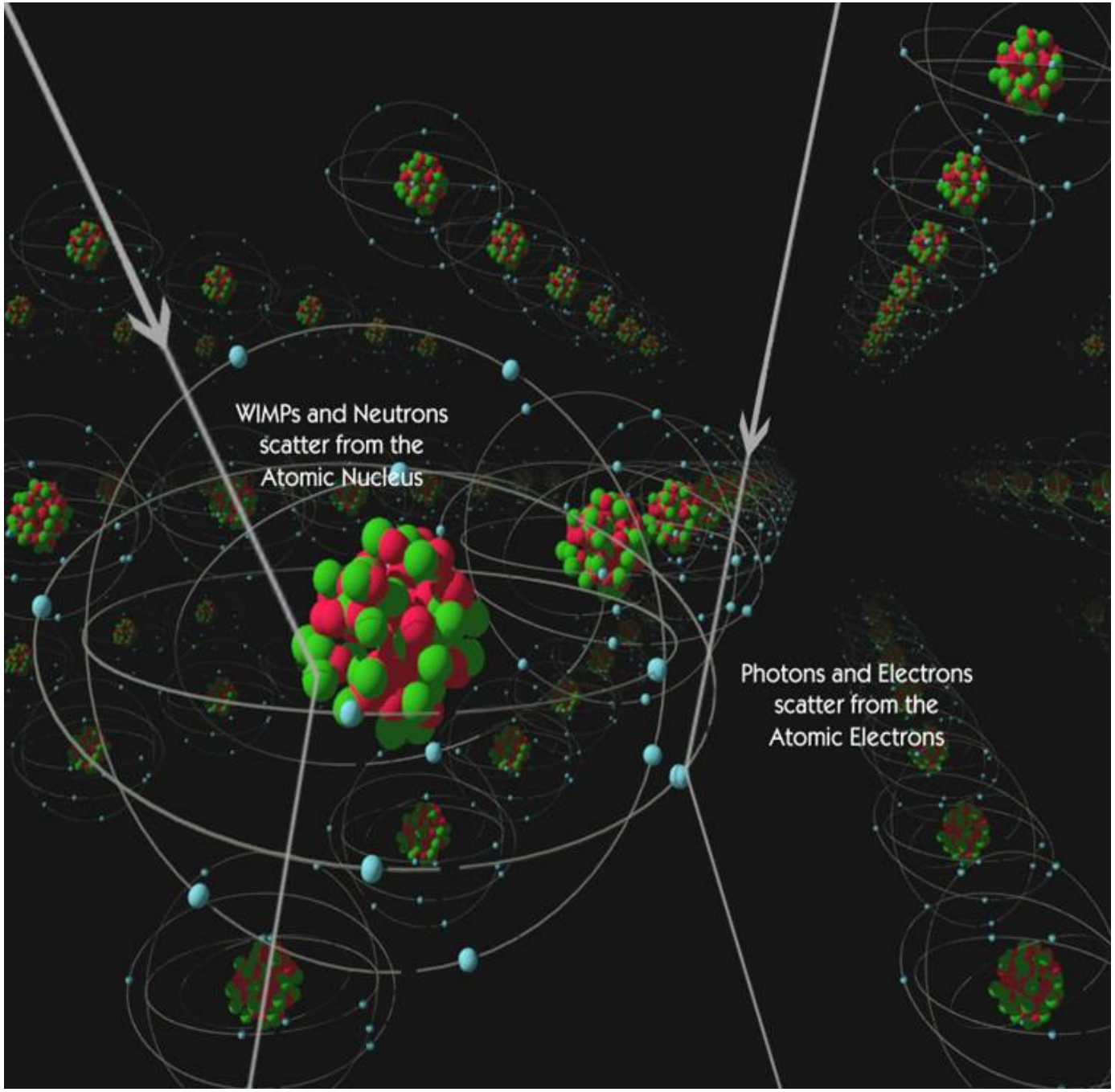
The data favor the presence of a modulated behavior with proper features at 8.8σ C.L.

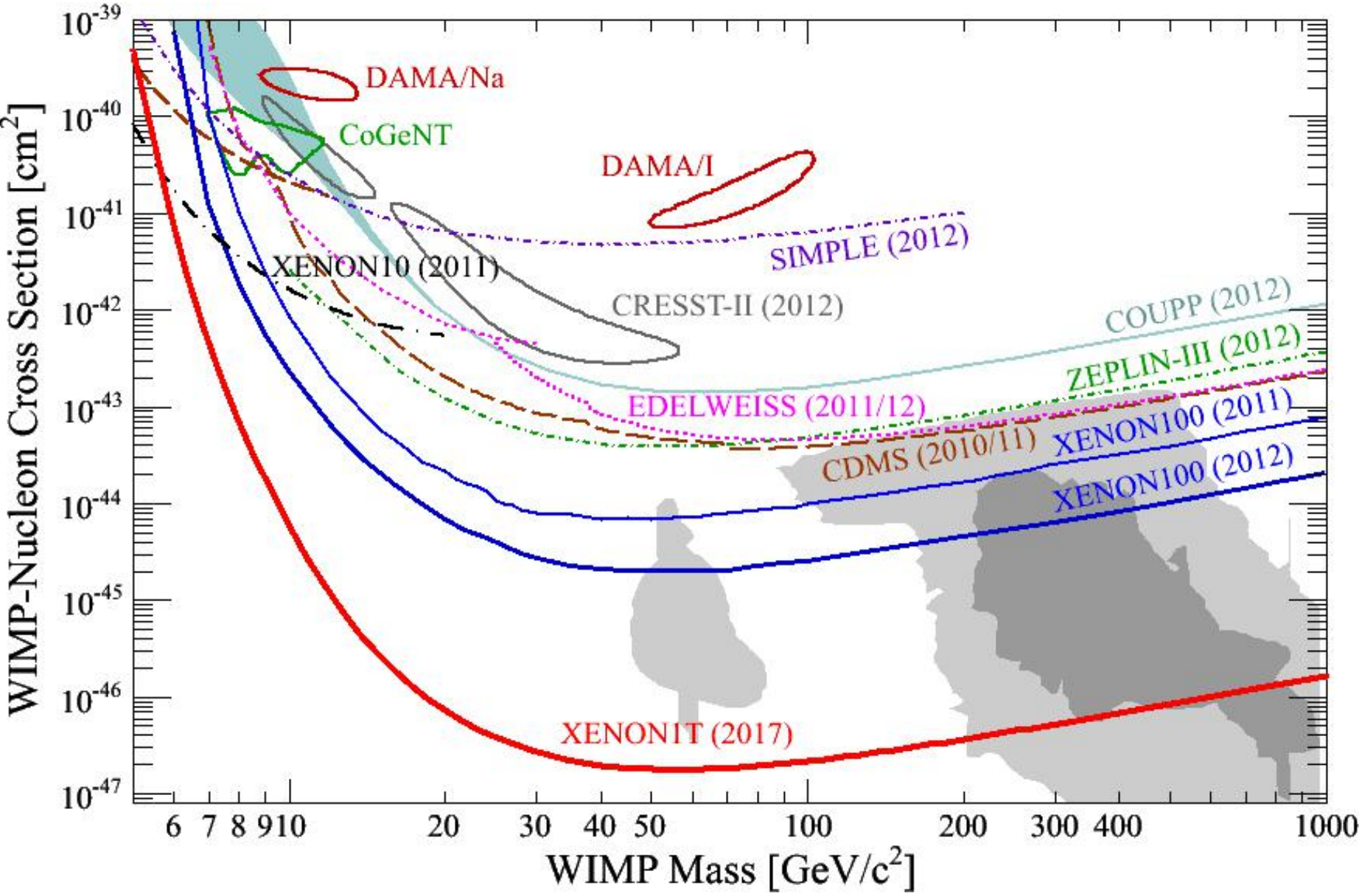
XENON 1T

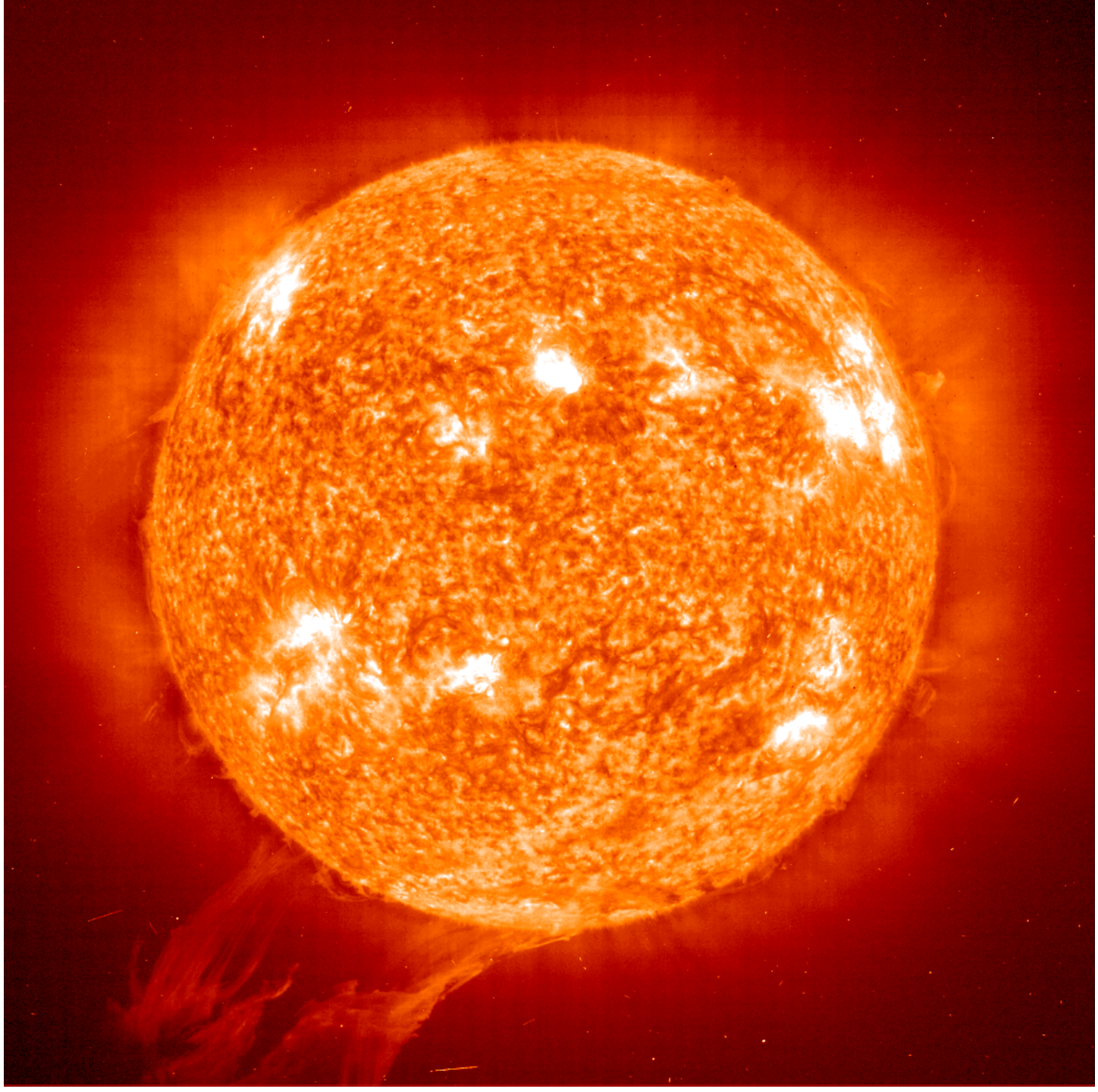
DarkSide



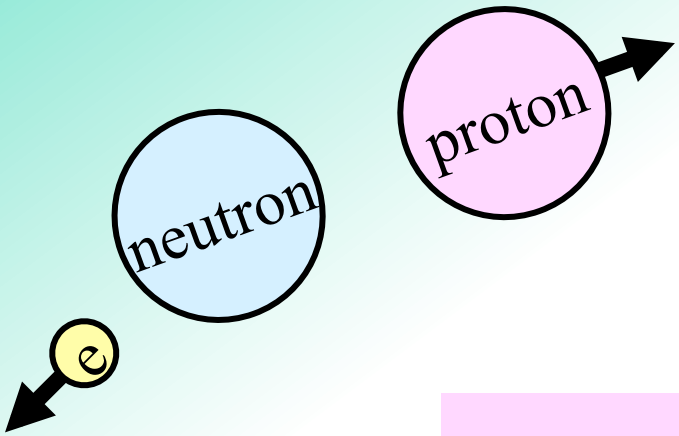

PMT Array
proportional
Gas Xe
Liquid Xe
WIMP
E_g
E_e
direct
γ
Xe
e-
Gamma
e-
Bottom PMT Array


WIMPs and Neutrons
scatter from the
Atomic Nucleus
Photons and Electrons
scatter from the
Atomic Electrons


DAMA/Na
CoGeNT
DAMA/I
SIMPLE (2012)
XENON10 (2011)
CRESST-II (2012)
COUPP (2012)
ZEPLIN-III (2012)
EDELWEISS (2011/12)
CDMS (2010/11)
XENON100 (2011)
XENON100 (2012)
XENON1T (2017)
WIMP-Nucleon Cross Section [cm^2]
WIMP Mass [GeV/c^2]
10^{-39}
10^{-40}
10^{-41}
10^{-42}
10^{-43}
10^{-44}
10^{-45}
10^{-46}
10^{-47}
6 7 8 9 10 20 30 40 50 100 200 300 400 1000

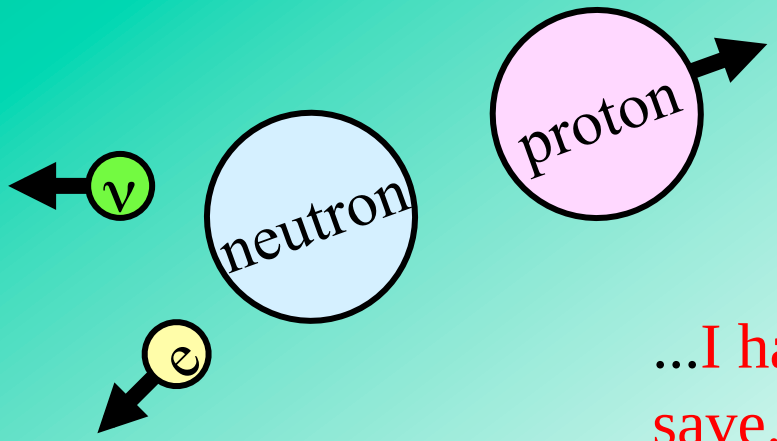


β decay



Non-conservation of energy???

β decay



December 4, 1930

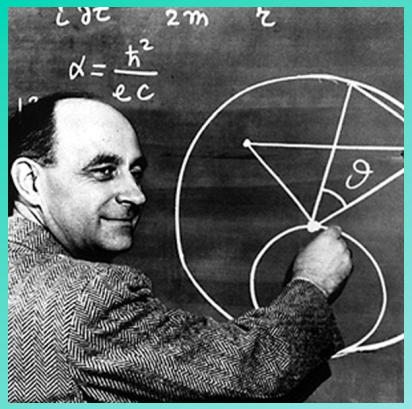
Dear radioactive ladies and gentlemen,

...I have hit upon a 'desperate remedy' to save...the law of conservation of energy. Namely the possibility that there exists in the nuclei electrically neutral particles, that I call neutrons...I agree that my remedy could seem incredible...but **only the one who dare can win**...

Unfortunately I cannot appear in person, since I am indispensable at a ball here in Zurich.

Your humble servant
W. Pauli

Neutrino Facts

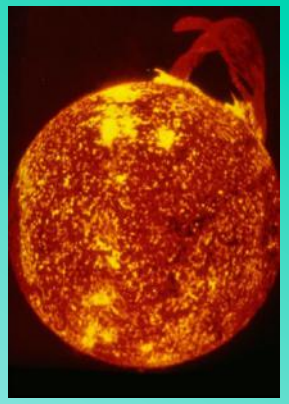


Neutrino from Enrico Fermi for “Little neutral one”

ν flux on Earth from Sun

$6.5 \times 10^{14}/(m^2\ s)$

<E> ~ 0.3 MeV



Neutrino from sun will pass through 5 LY of solid lead, with 50% chance of interacting

Average number of solar neutrinos interacting in a person per year

≤ 30!

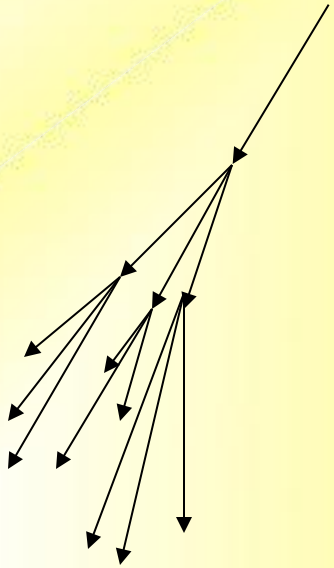
≤ 1 with ‘real energy’

Sun:

$p + p \rightarrow d + e^+ + \nu_e$

$^8B \rightarrow {}^8Be + e^+ + \nu_e$

$2\times10^{38}\ s^{-1}$



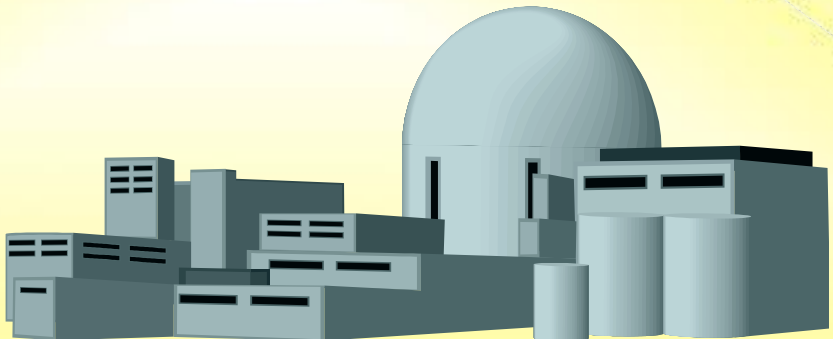
Uranium & Thorium
from Earth crust

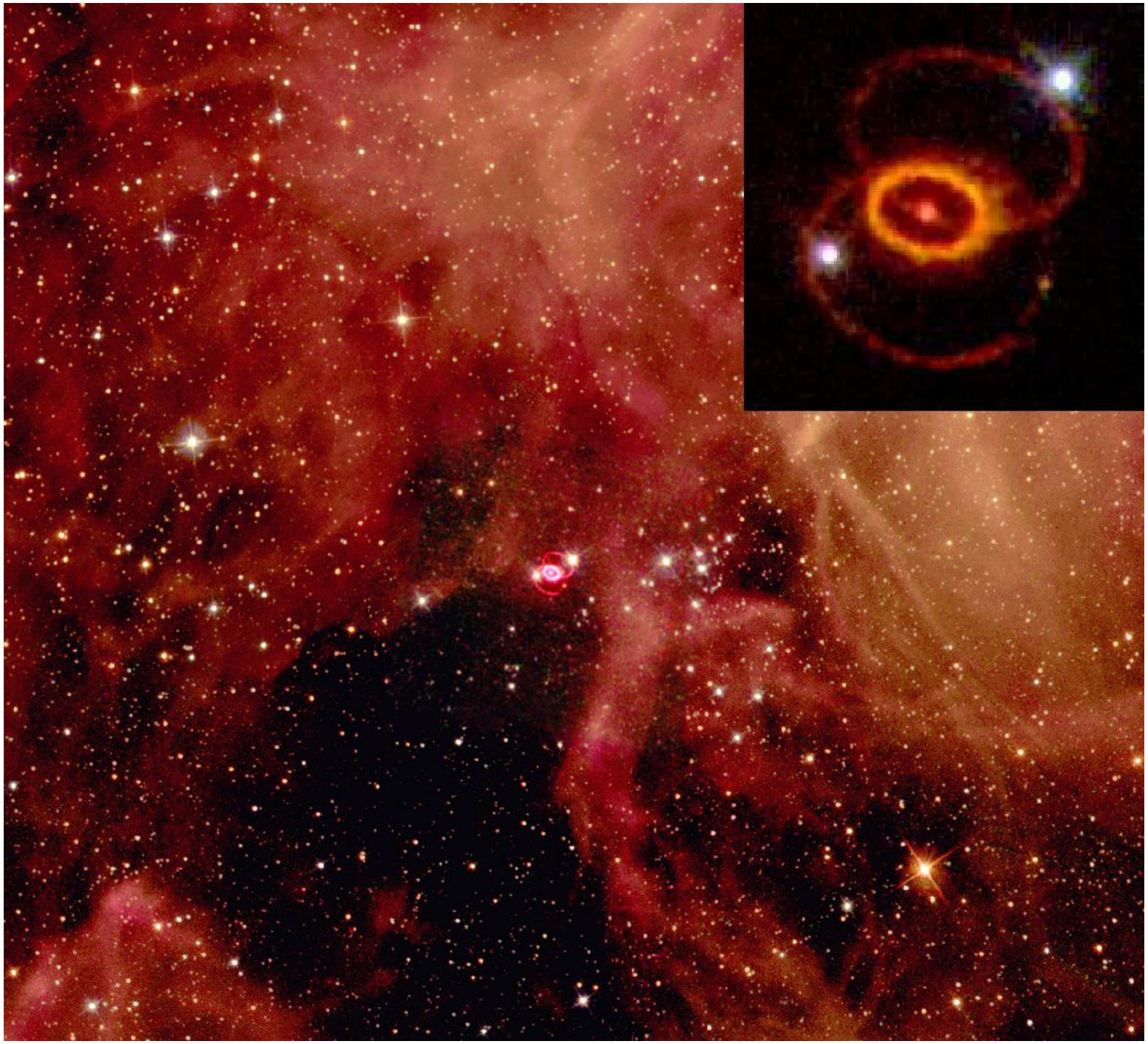
$\sim 5\times10^{10}\ s^{-1}\ m^{-2}$

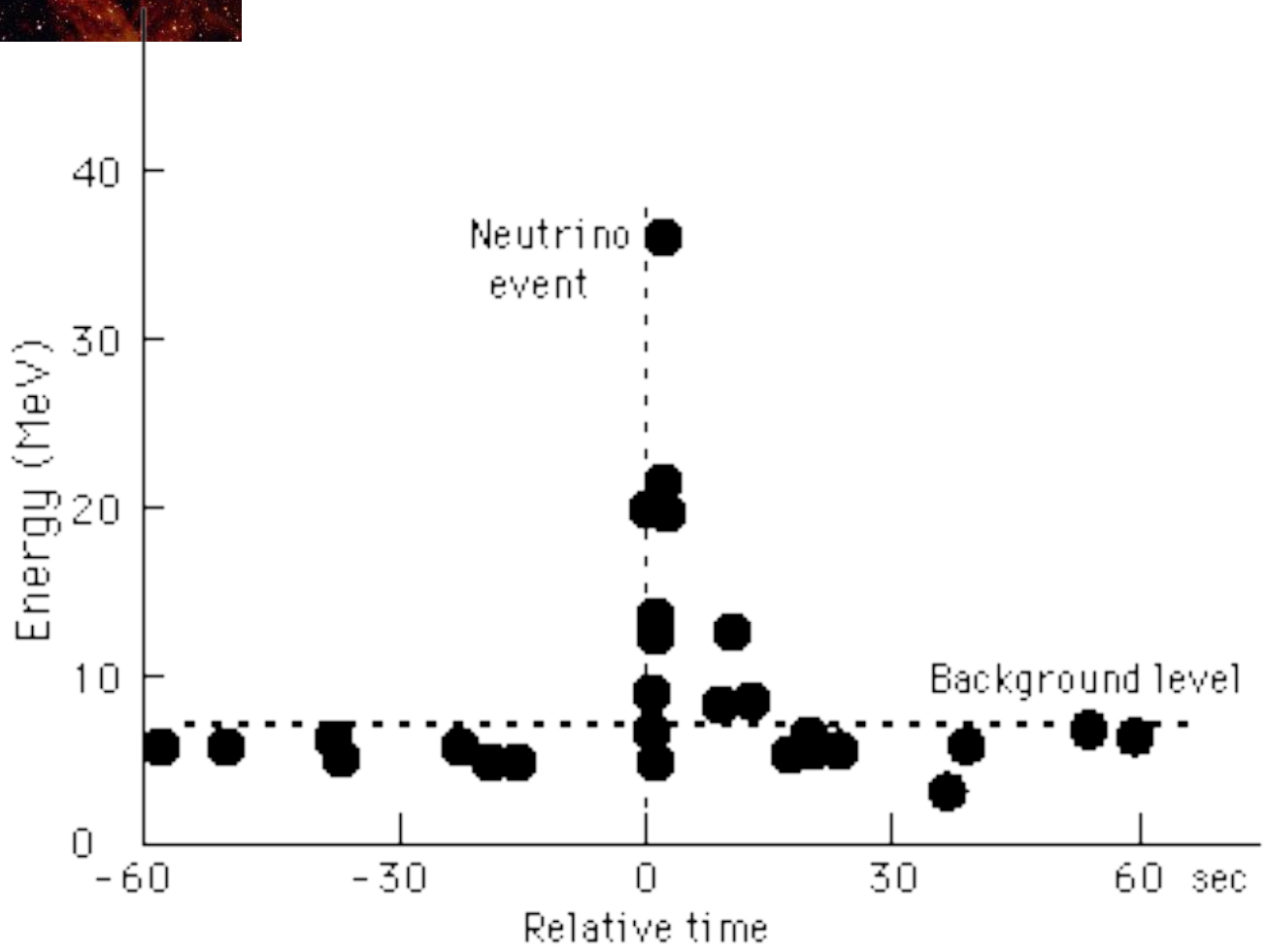
Neutrino sources

Cosmic Rays
$\sim100\ m^{-2}\ s^{-1}$

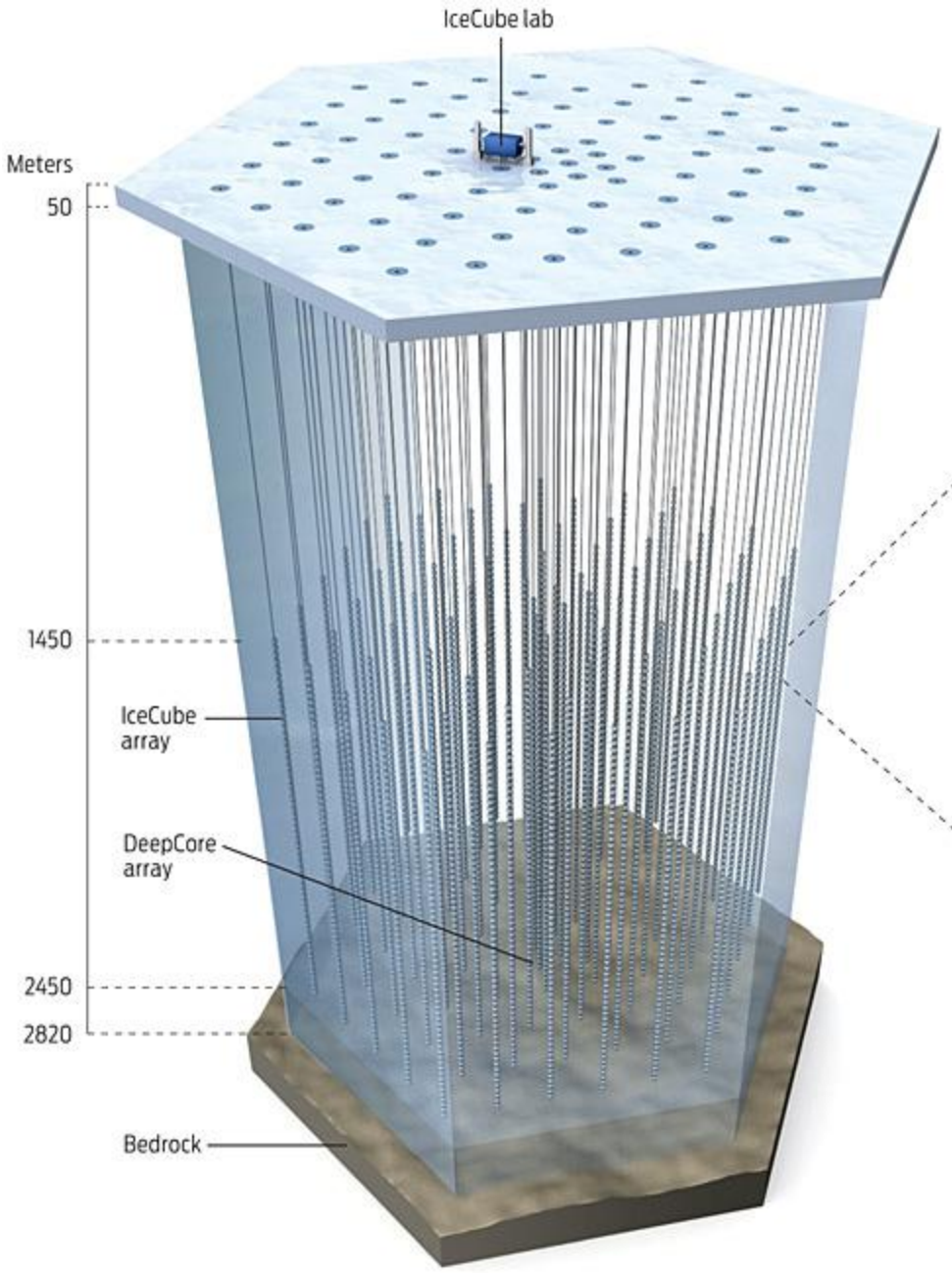
Nuclear power reactors
$\sim10^{20}\ s^{-1}$



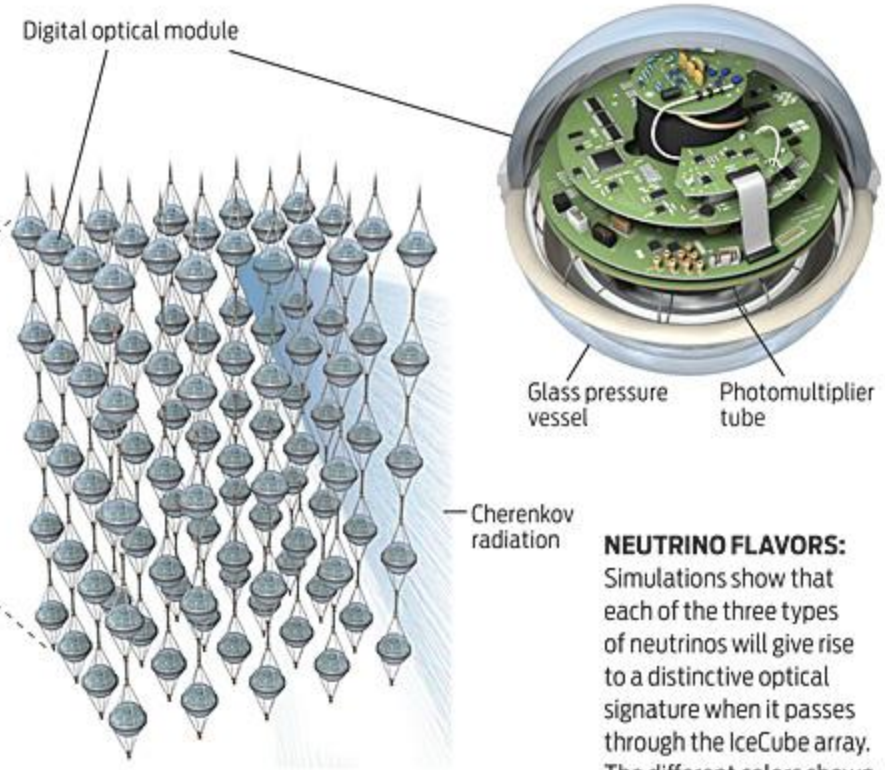



40
30
20
10
0
Energy (MeV)
Neutrino
event
Background level
-60
-30
0
30
60
sec
Relative time

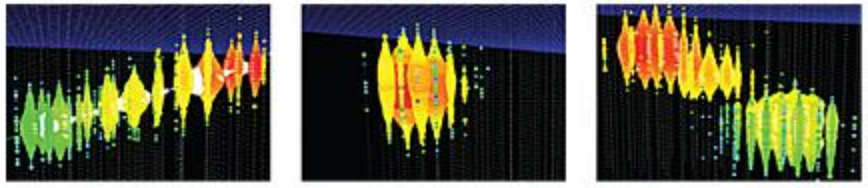
Ice Cube, the "eye" inside Ice at South Pole to measure neutrinos ("underground")

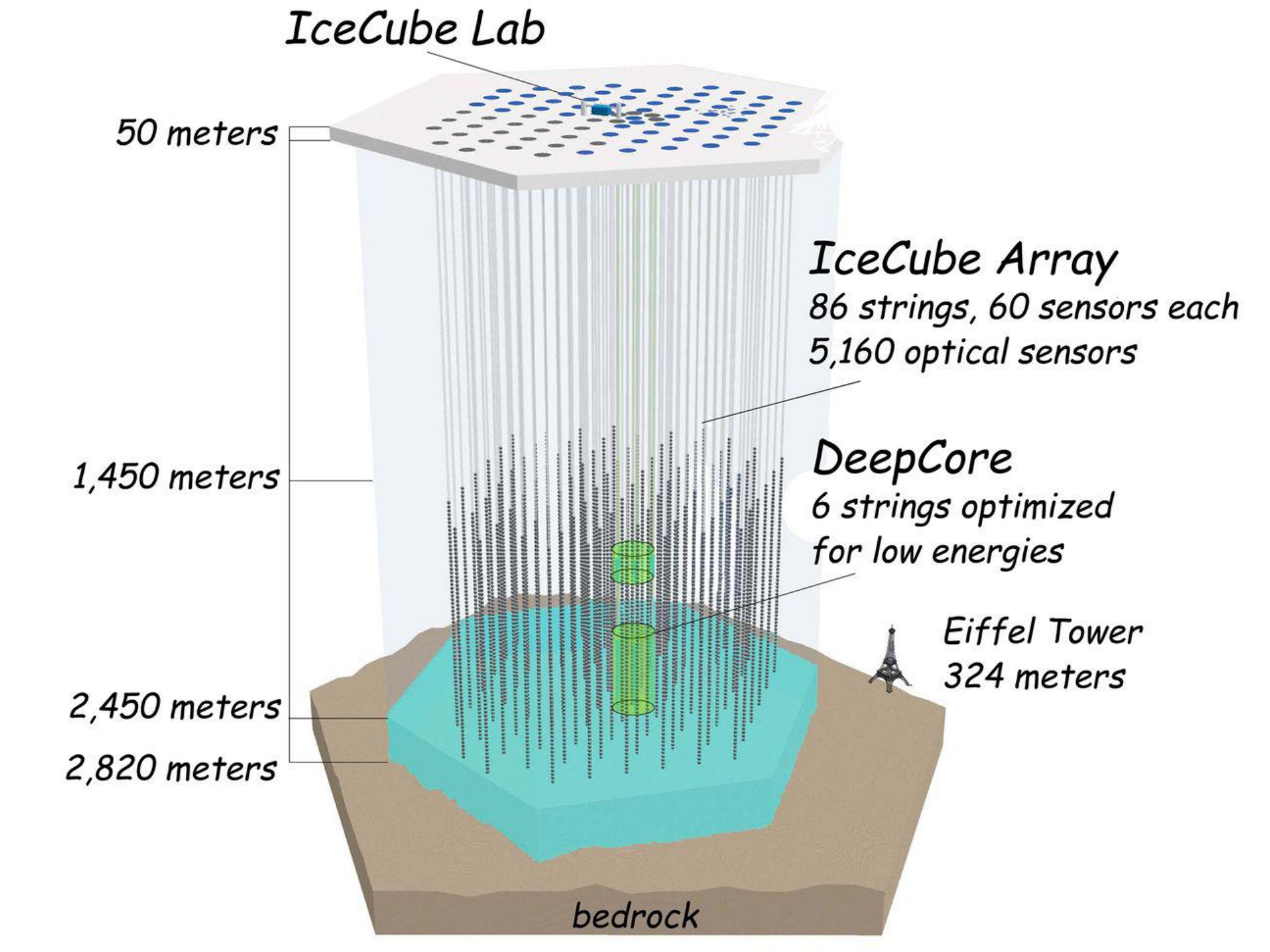


ELECTRONIC PEARLS: The digital optical modules used to sense the passage of neutrinos through the ice are encased in spherical pressure vessels made of borosilicate glass. They are attached to their suspending cables at 17-meter vertical intervals, from 1450 to 2450 meters' depth. After a string has been deployed and tested, the surrounding water (left over from drilling the hole) freezes the detectors in place.



NEUTRINO FLAVORS: Simulations show that each of the three types of neutrinos will give rise to a distinctive optical signature when it passes through the IceCube array. The different colors shown here represent detections taking place at slightly different times.




IceCube Lab
50 meters
IceCube Array
86 strings, 60 sensors each
5,160 optical sensors
1,450 meters
DeepCore
6 strings optimized
for low energies
Eiffel Tower
324 meters
2,450 meters
2,820 meters
bedrock

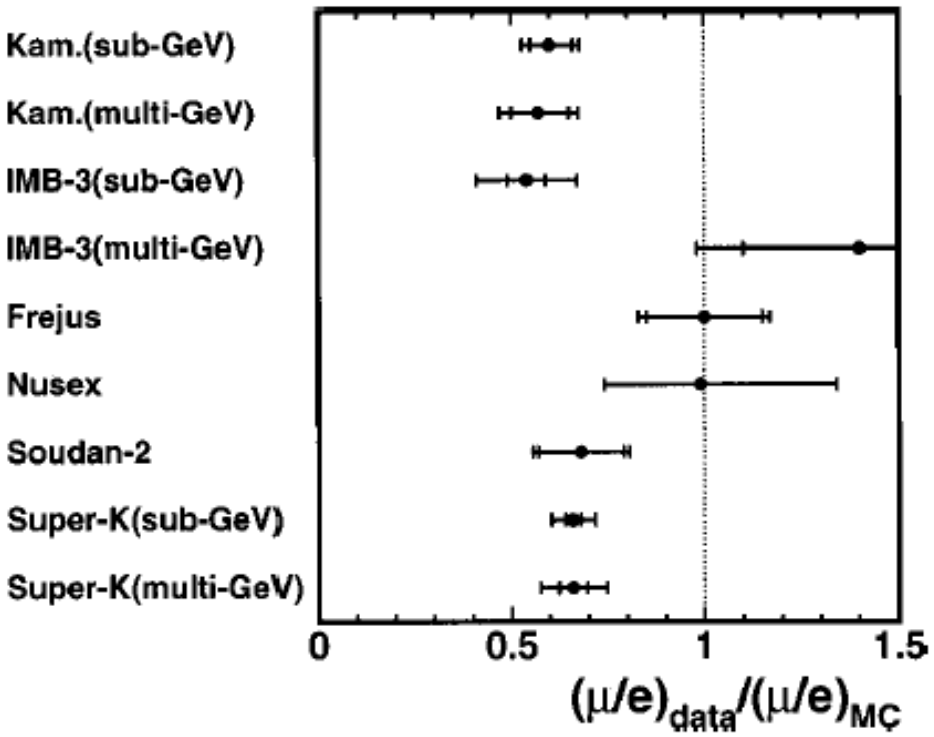
Neutrino masses

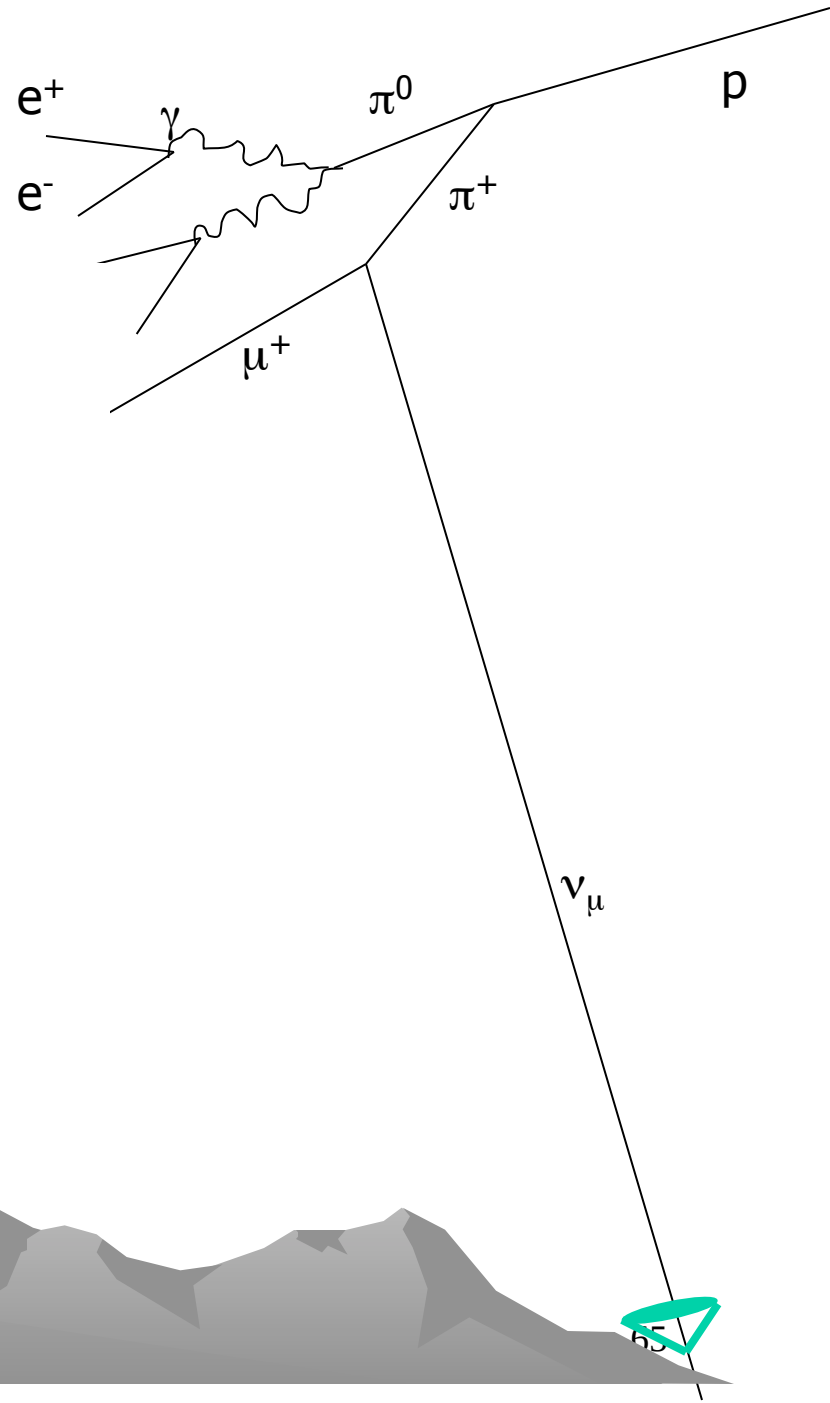
One of the most fascinating mysteries of Modern Physics

Was believed to be zero!

Presently we know they are not zero, but we do not know how small they are!

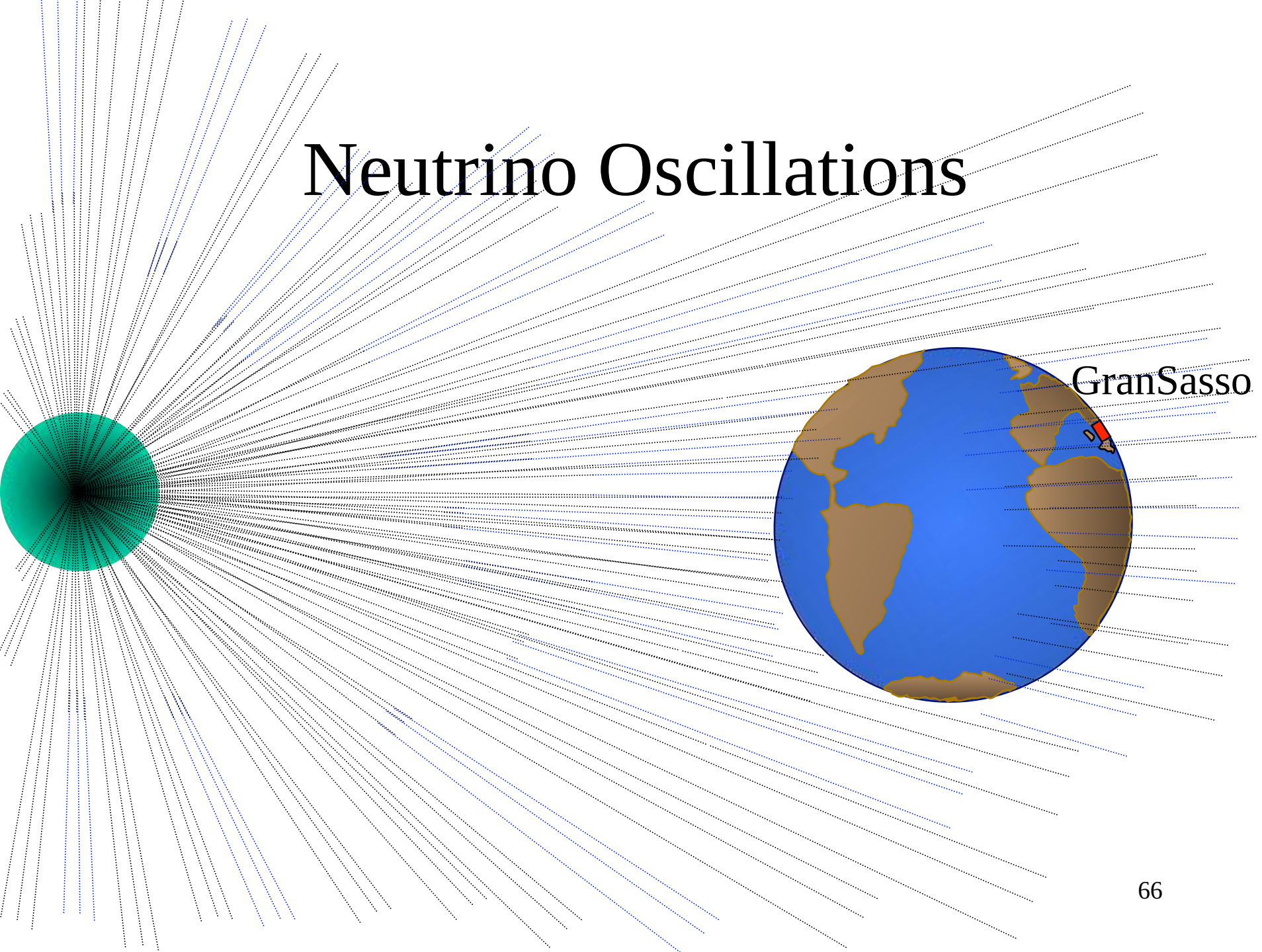
Neutrinos produced in atmosphere





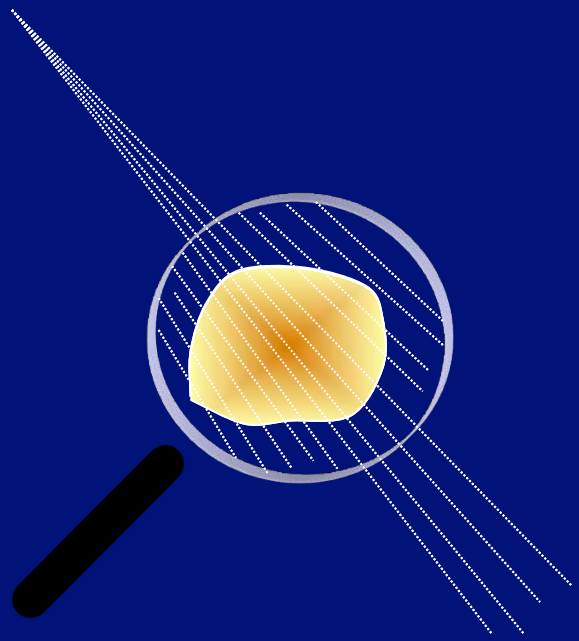
Crisis lasted about... 20 anni!

Neutrino Oscillations



Neutrinos oscillations

u up	c charm	t top	g gluone
d down	s strange	b bottom	γ fotone
ν_e e-neutrino	ν_μ μ-neutrino	ν_τ τ-neutrino	W bosone
e elettrone	μ muone	τ tau	Z bosone



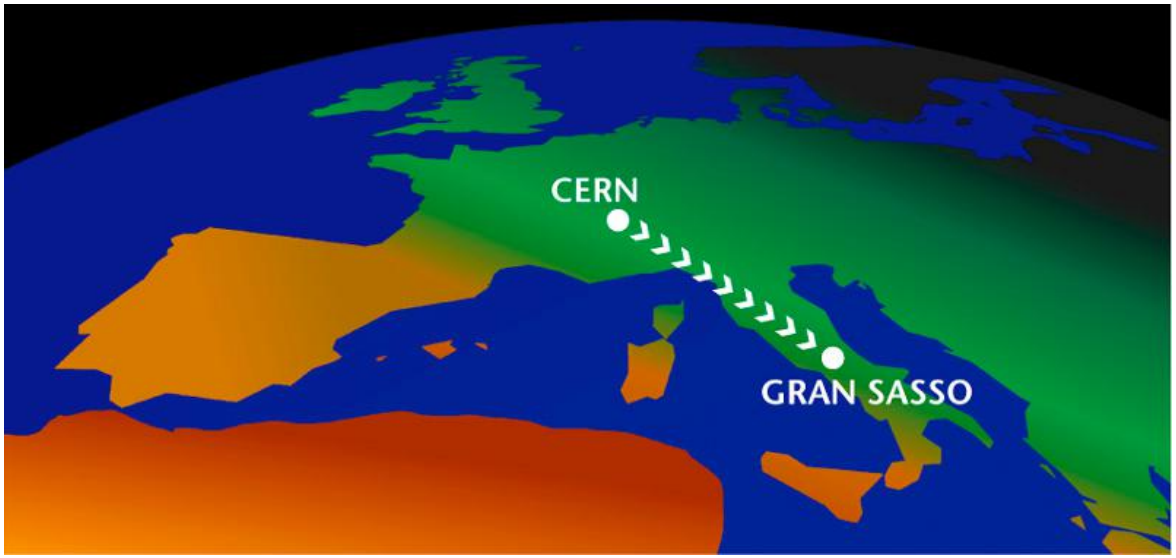
Milioni di neutrini al secondo attraverso un granello di sabbia

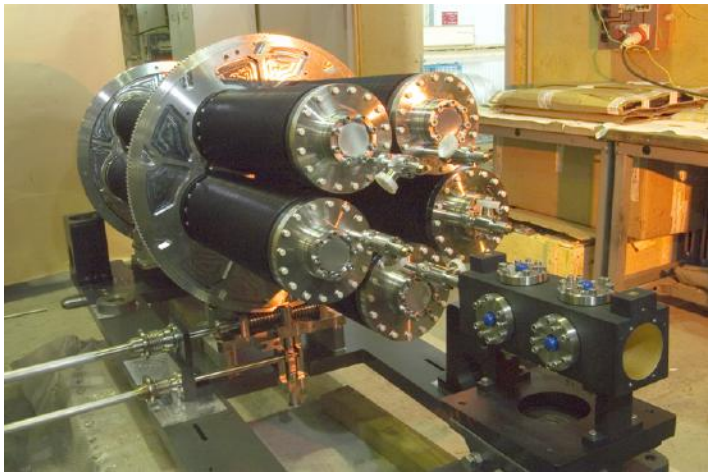
The most direct test:

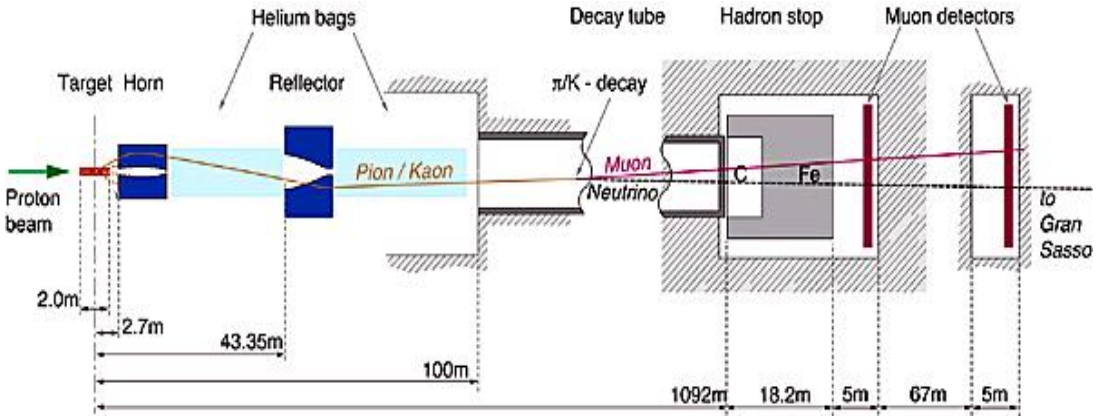
$$P(\nu_\mu \rightarrow \nu_\tau) \approx \cos^4 \vartheta_{13} \sin^2 2\vartheta_{23} \sin^2 [1.27 \Delta m^2_{23} L(km)/E(GeV)]$$

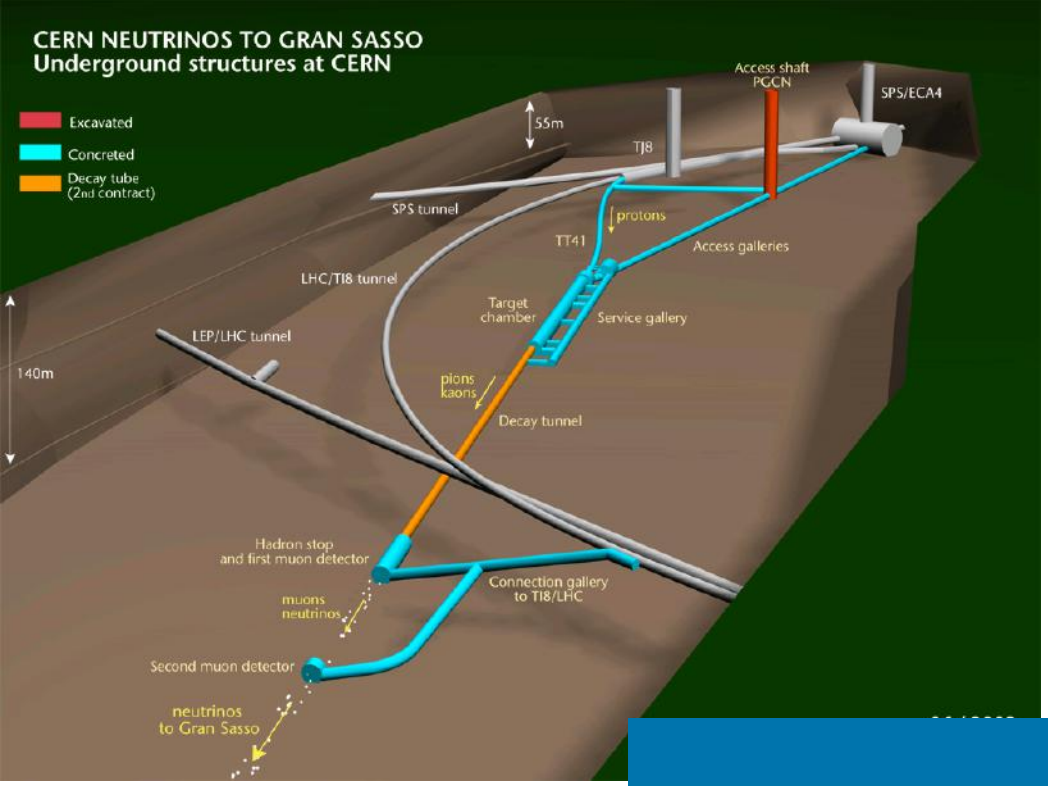
LNGS

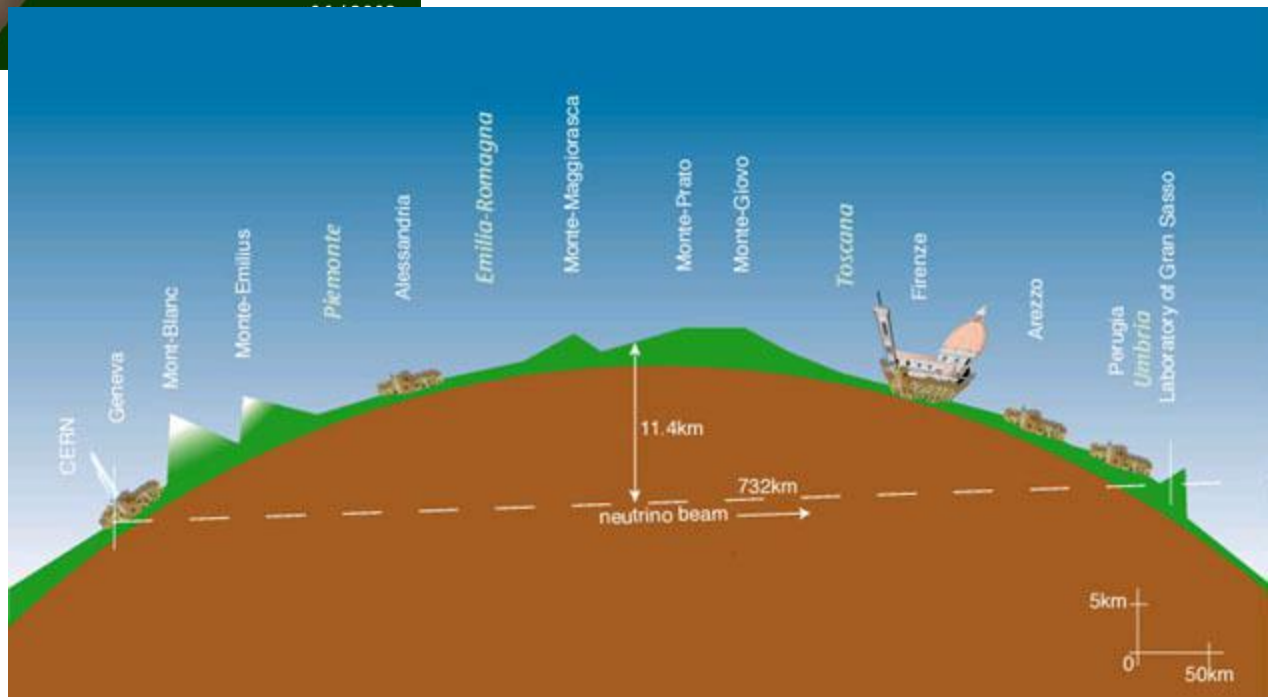
Cern Neutrinos to Gran Sasso (CNGS)








CERN NEUTRINOS TO GRAN SASSO
Underground structures at CERN
Excavated
Concreted
Decay tube
(2nd contract)
55m
Access shaft
PGCN
SPS/ECA4
TI8
SPS tunnel
protons
TT41
Access galleries
LHC/TI8 tunnel
Target
chamber
Service gallery
LEP/LHC tunnel
140m
pions
kaons
Decay tunnel
Hadron stop
and first muon detector
Connection gallery
to TI8/LHC
muons
neutrinos
Second muon detector
neutrinos
to Gran Sasso

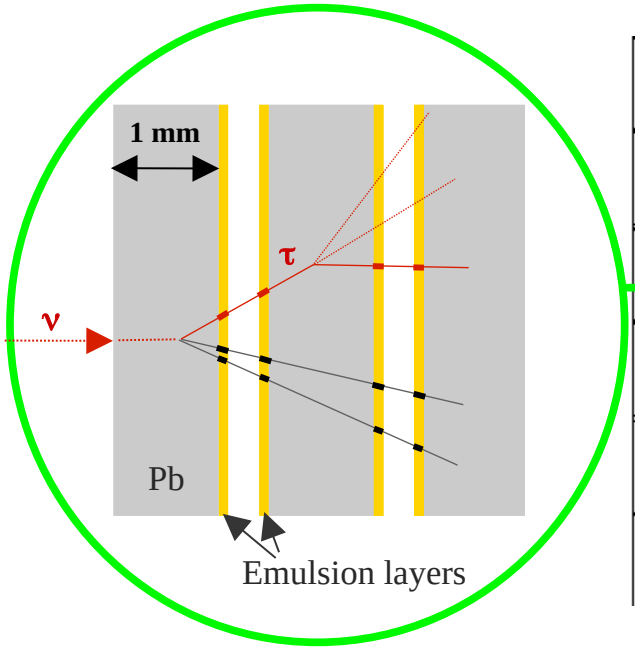

CERN
Geneva
Mont-Blanc
Monte-Emilius
Piemonte
Alessandria
Emilia-Romagna
Monte-Maggiorasca
Monte-Prato
Monte-Giovo
Toscana
Firenze
Arezzo
Perugia
Umbria
Laboratory of Gran Sasso
11.4km
732km
neutrino beam
5km
0
50km

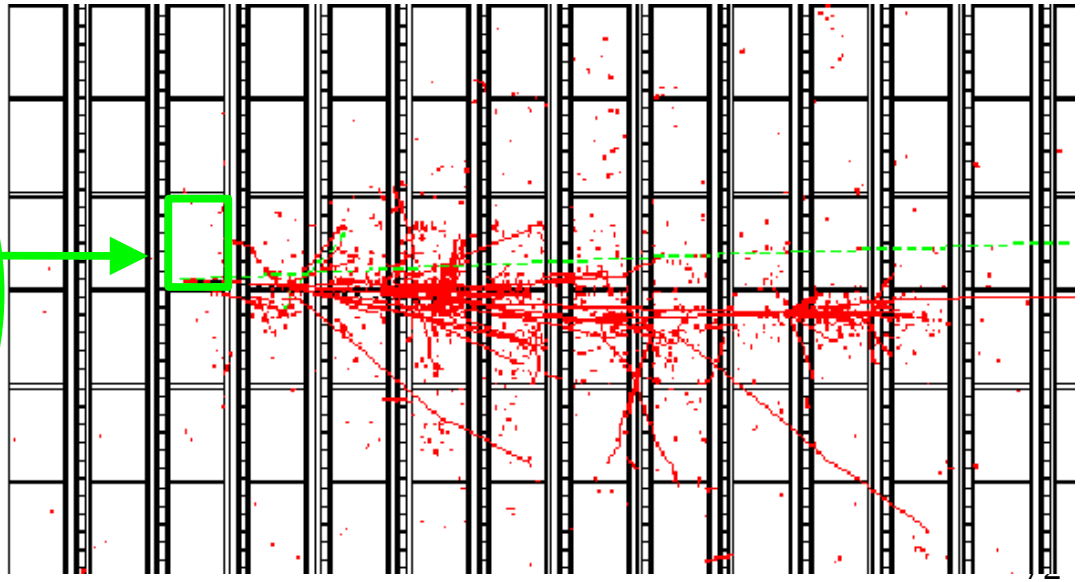
OPERA experiment

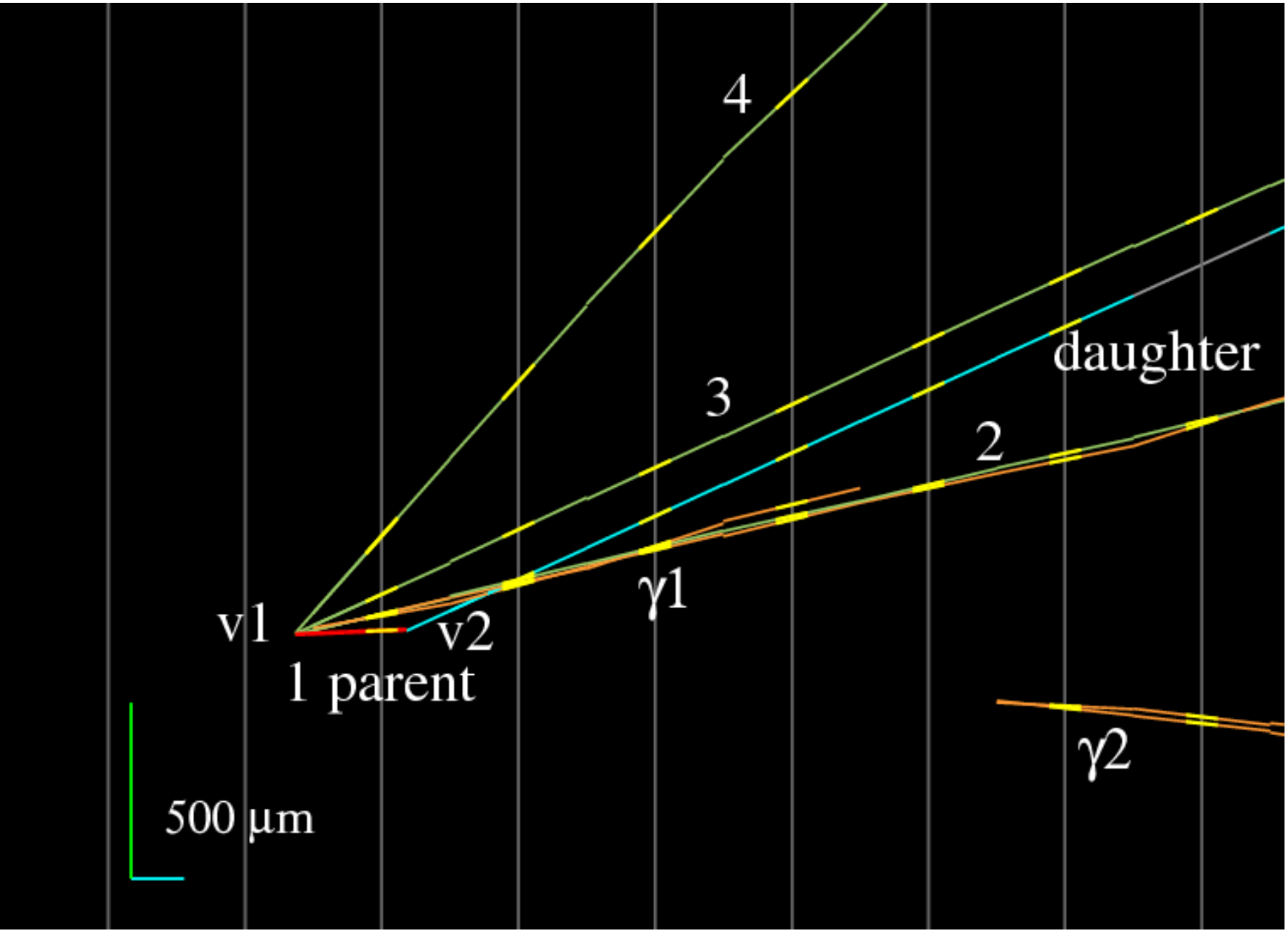
OPERA ha scelto il canale più diretto e pulito per dimostrare l'oscillazione $\nu_\mu \Rightarrow \nu_\tau$
il prezzo da pagare:

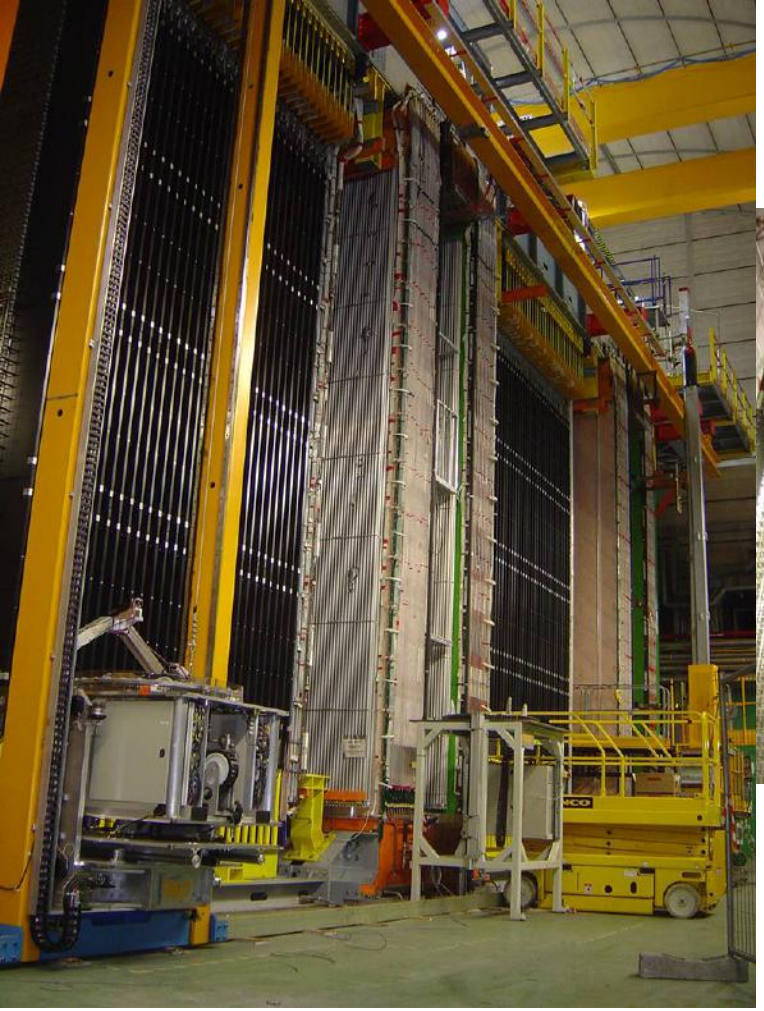
ν oscillation → masse enormi **AND** τ decay → risoluzioni al μm

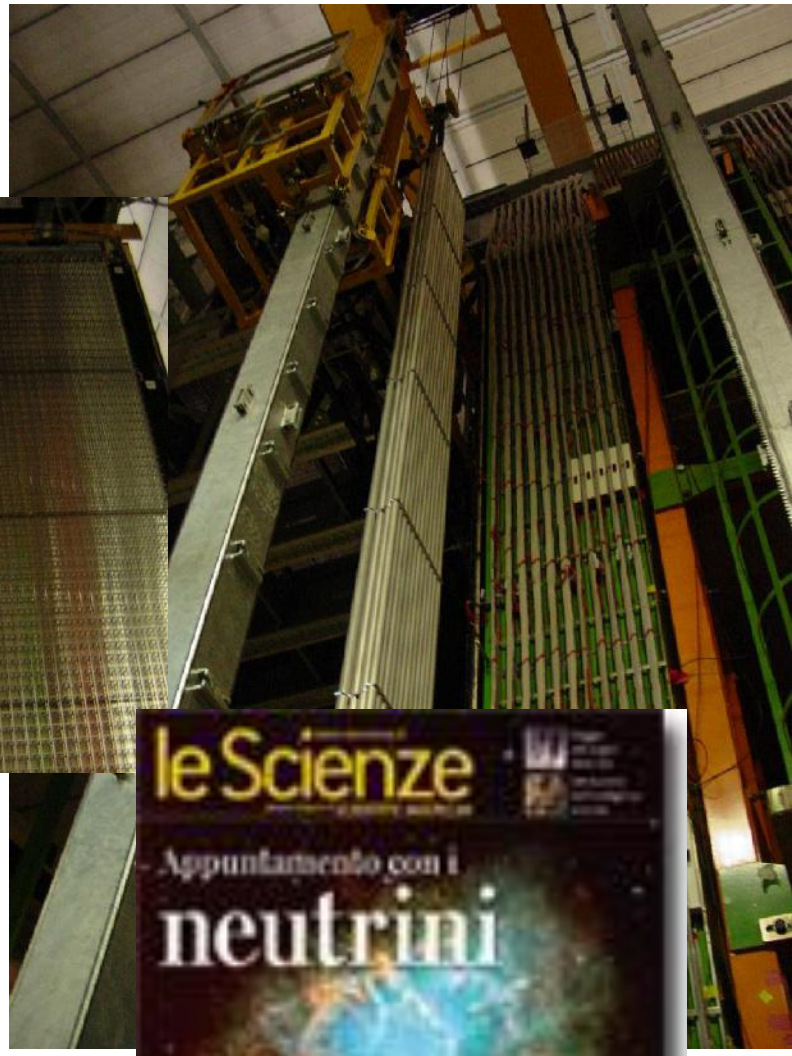
Lead – nuclear emulsion sandwich






4
3
2
daughter
γ1
v1
v2
1 parent
γ2
500 µm

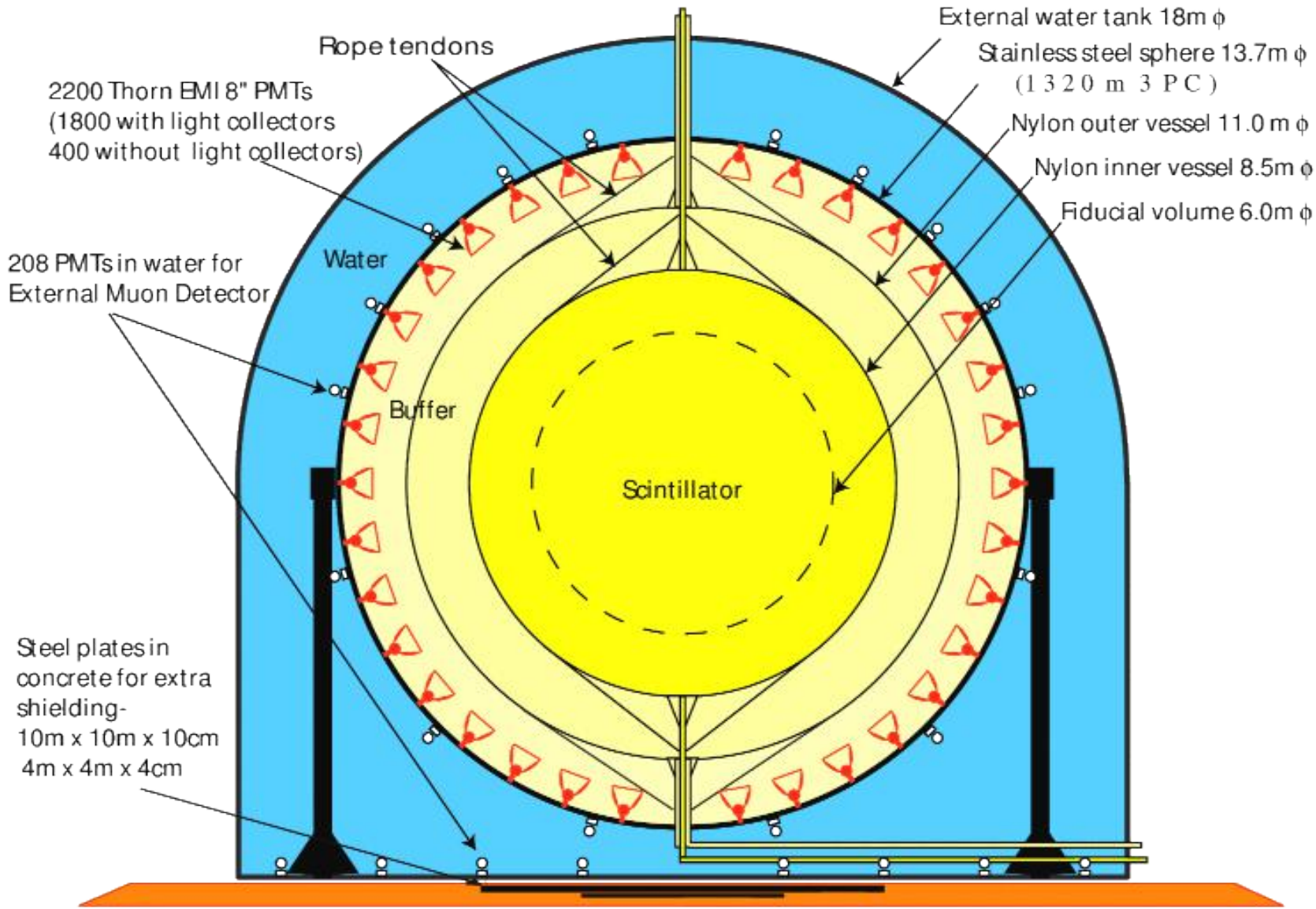


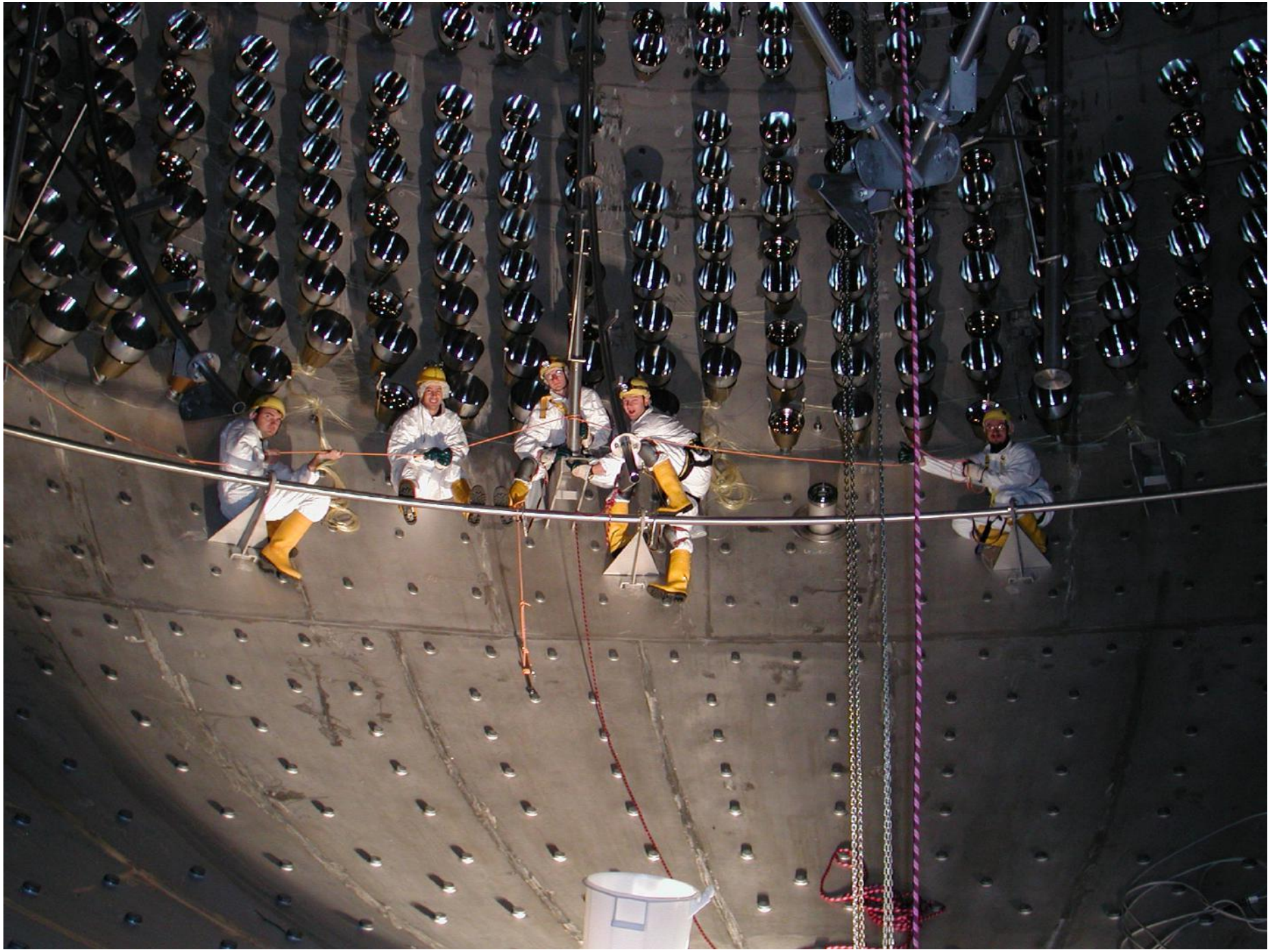



le Scienze
Appuntamento con i
neutrini

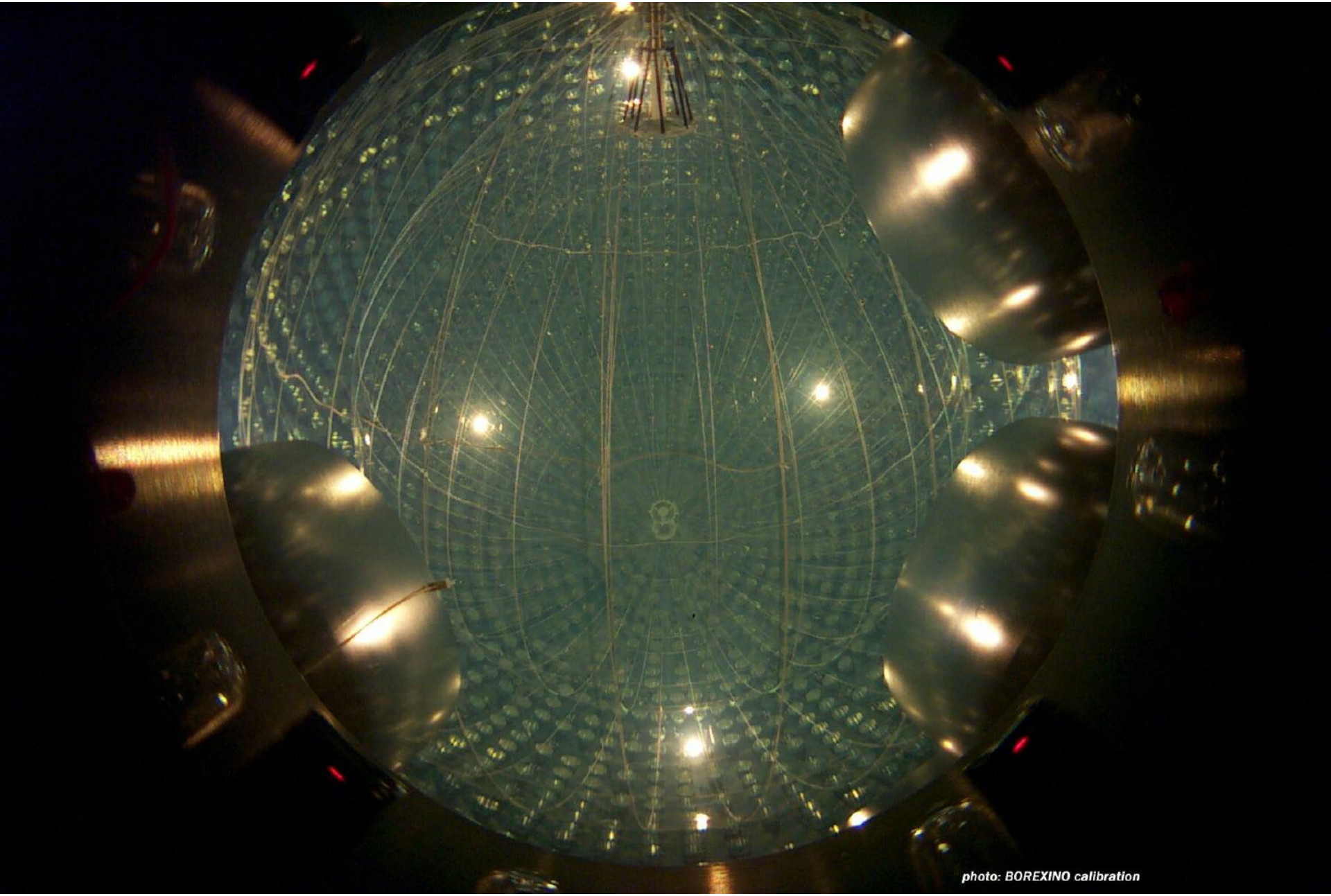
BOREXINO at LNGS

Borexino Experiment



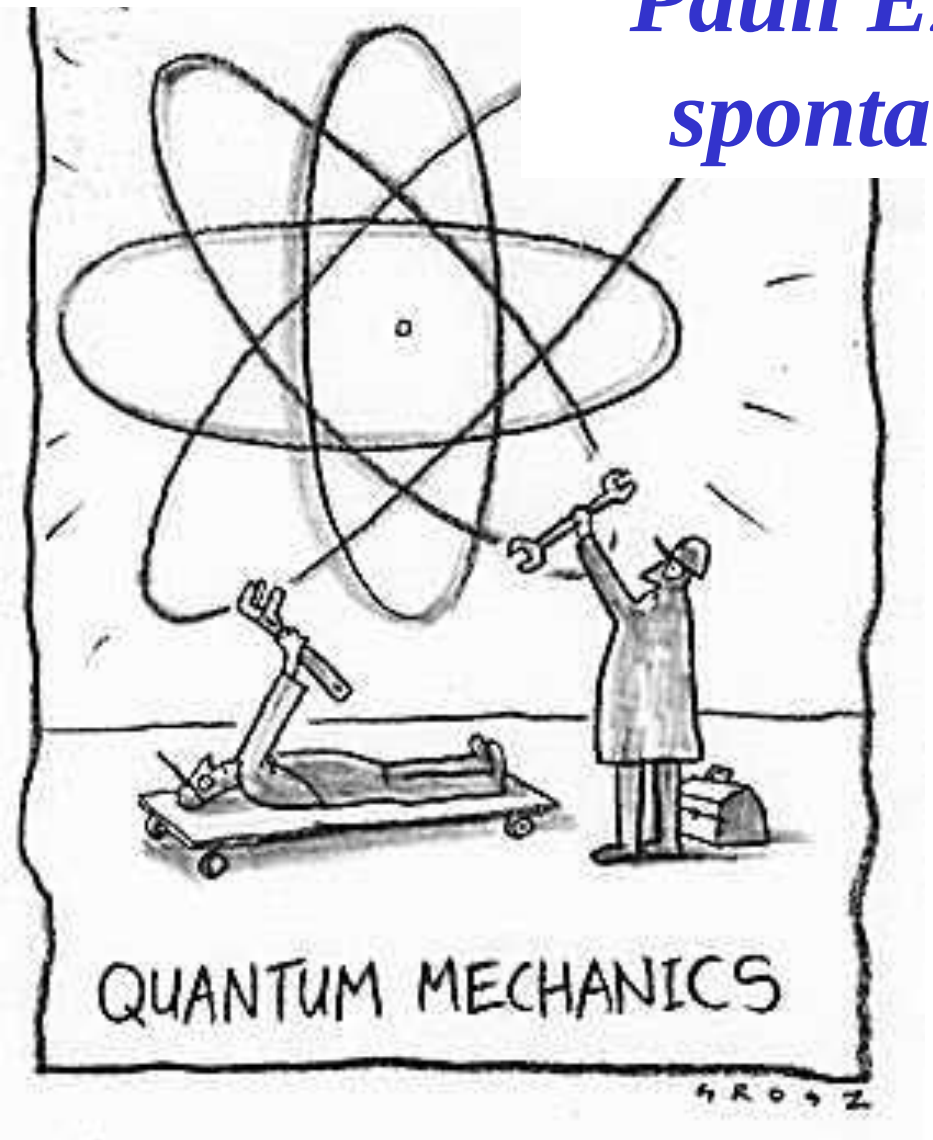


BOREXINO at LNGS



Experimental tests of quantum mechanics

Pauli Exclusion Principle and spontaneous collapse models



PEP lacks a clear, intuitive explanation

... Already in my original paper I stressed the circumstance that I was unable to give a logical reason for the exclusion principle or to deduce it from more general assumptions.

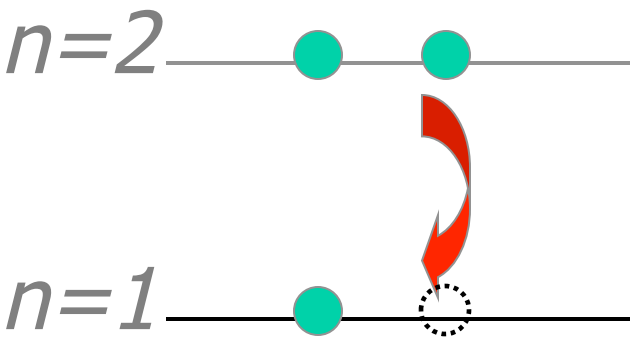
I had always the feeling and I still have it today, that this is a deficiency.

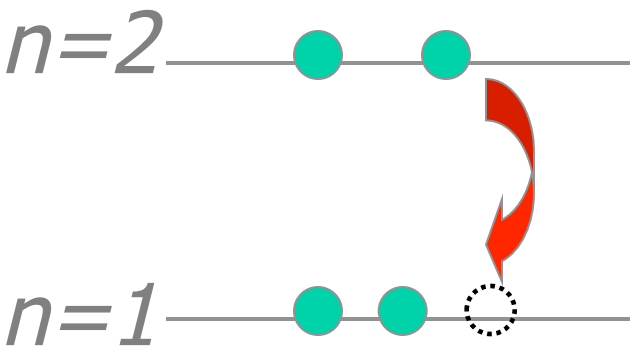
... The impression that the shadow of some incompleteness [falls] here on the bright light of success of the new quantum mechanics seems to me unavoidable.

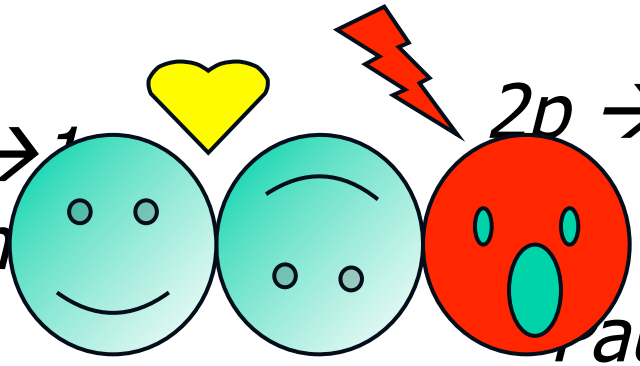
W. Pauli, Nobel lecture 1945

Experimental method

Search for anomalous X-ray transitions







Normal 2p →1
transition

2p →1s transition
violating
Pauli principle

8.05 keV in Cu

~ 7.7 keV in Cu

Goal of VIP

The VIP experiment has the scientific goal of reducing by four orders of magnitude the limits on the probability of a possible violations of the Pauli exclusion principle for the electrons

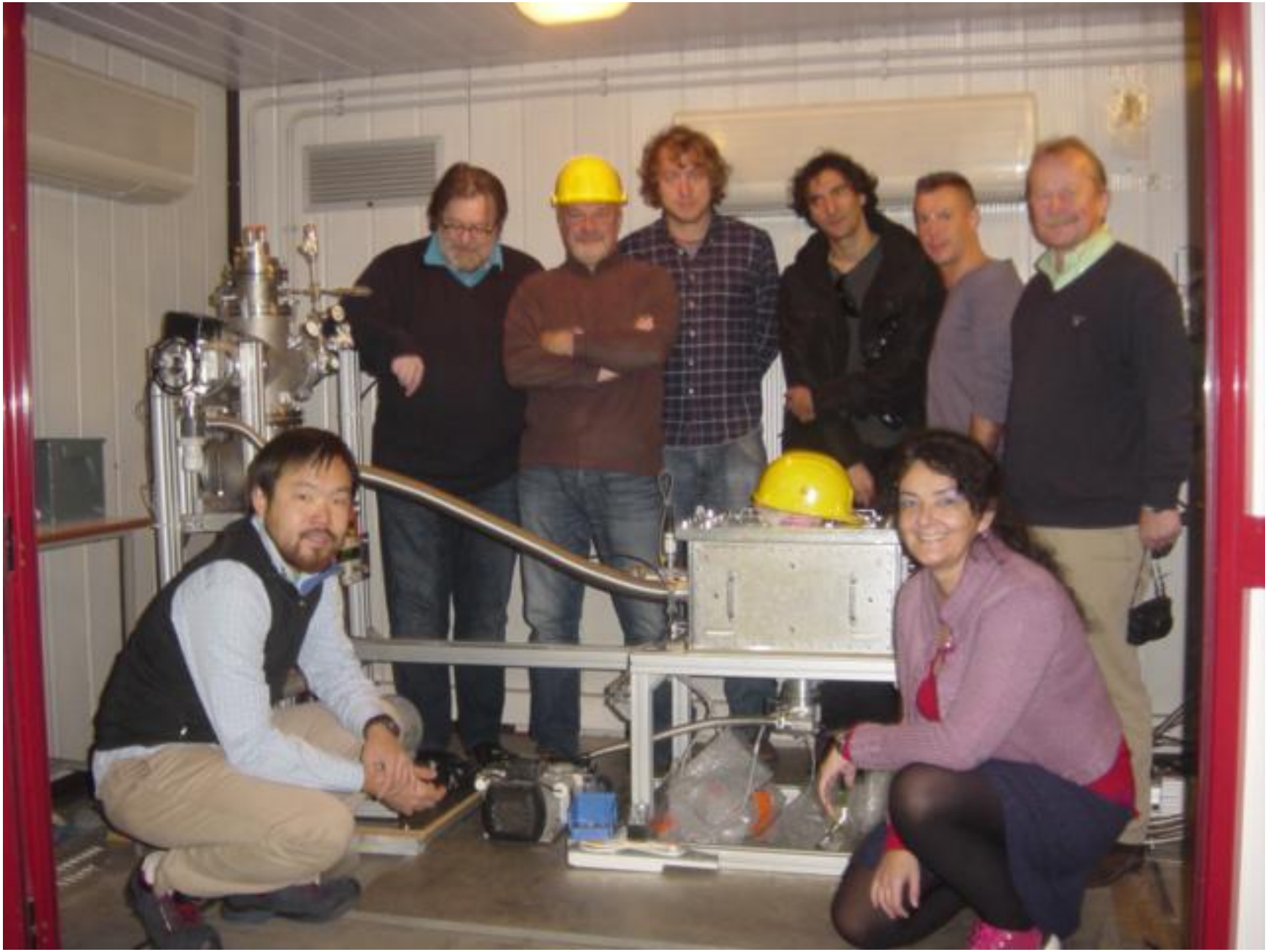
From:

$$\beta^2 / 2 \leq 1.7 \cdot 10^{-26} (> 95\% \ C.L.)$$

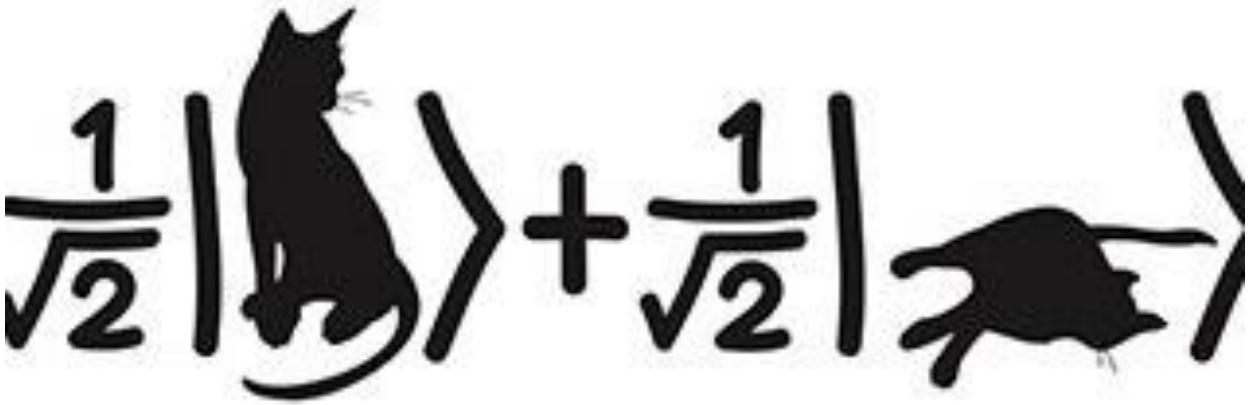
(Ramberg & Snow -1990)

to

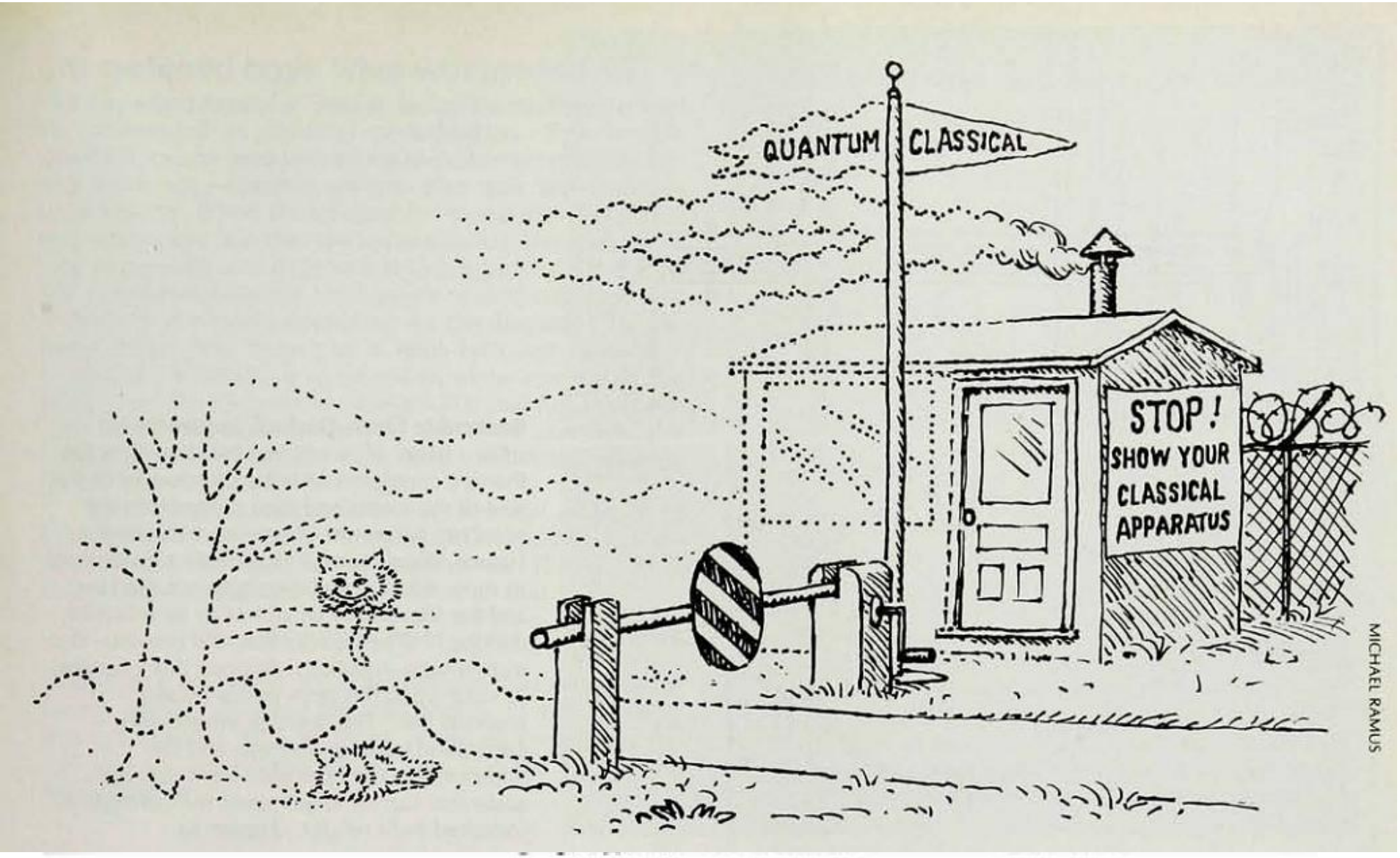
$$\beta^2 / 2 \leq 10^{-30}$$



Movie

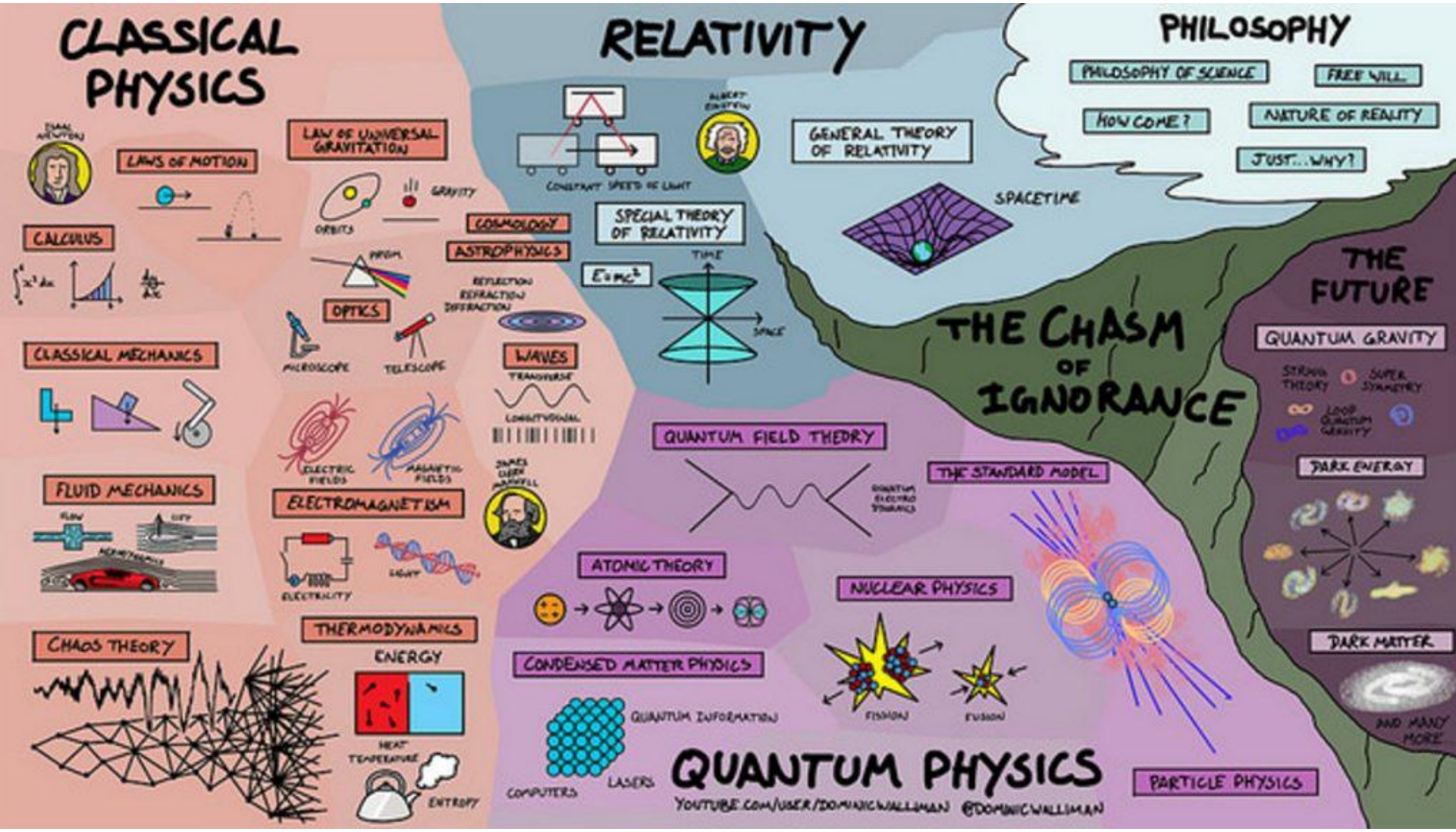

$\frac{1}{\sqrt{2}}|$
$\rangle + \frac{1}{\sqrt{2}}|$
$\rangle$


RESULTS
DEAD
ALIVE
BOTH
SCHRÖDINGER'S CAT
Experiment #001



Drawing by Michael Ramus, 1991.

La Terra Incognita della Fisica moderna




Happy
Valentines
Day