

Introduction to Physics Research

Origin of Universe and Ourselves

Katsushi Arisaka

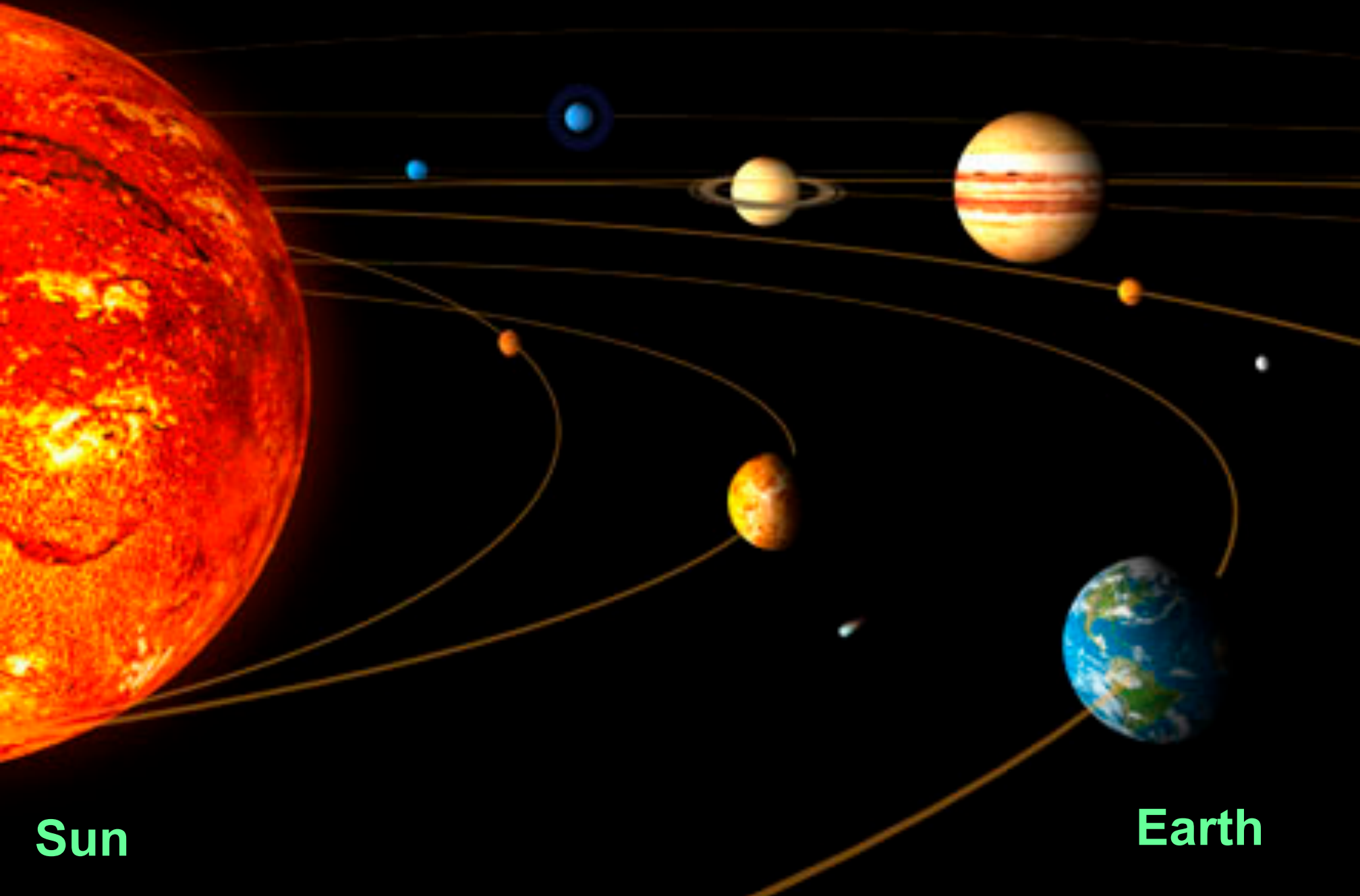
University of California, Los Angeles
Department of Physics and Astronomy

arisaka@physics.ucla.edu



Why are we here?

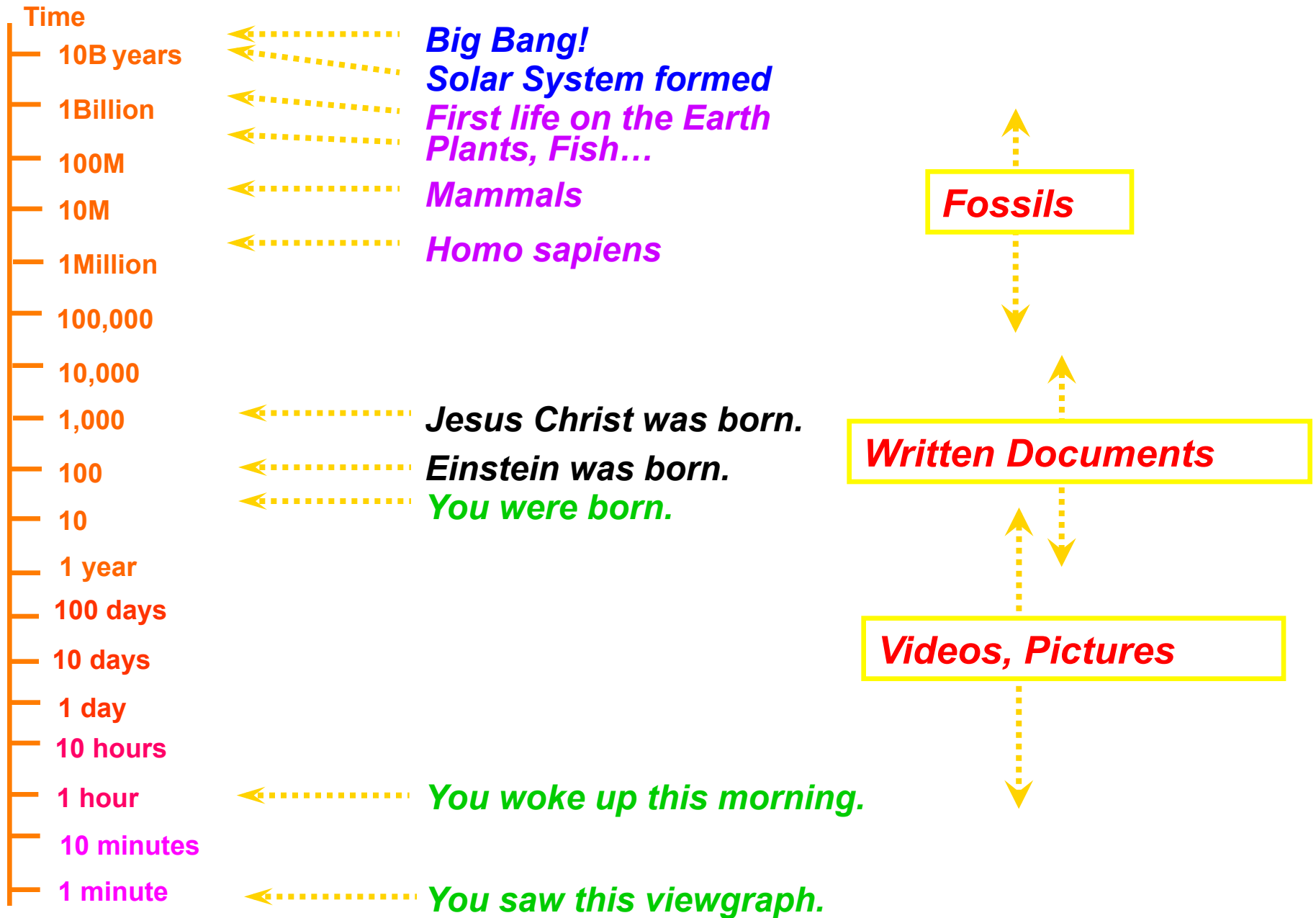
Solar System



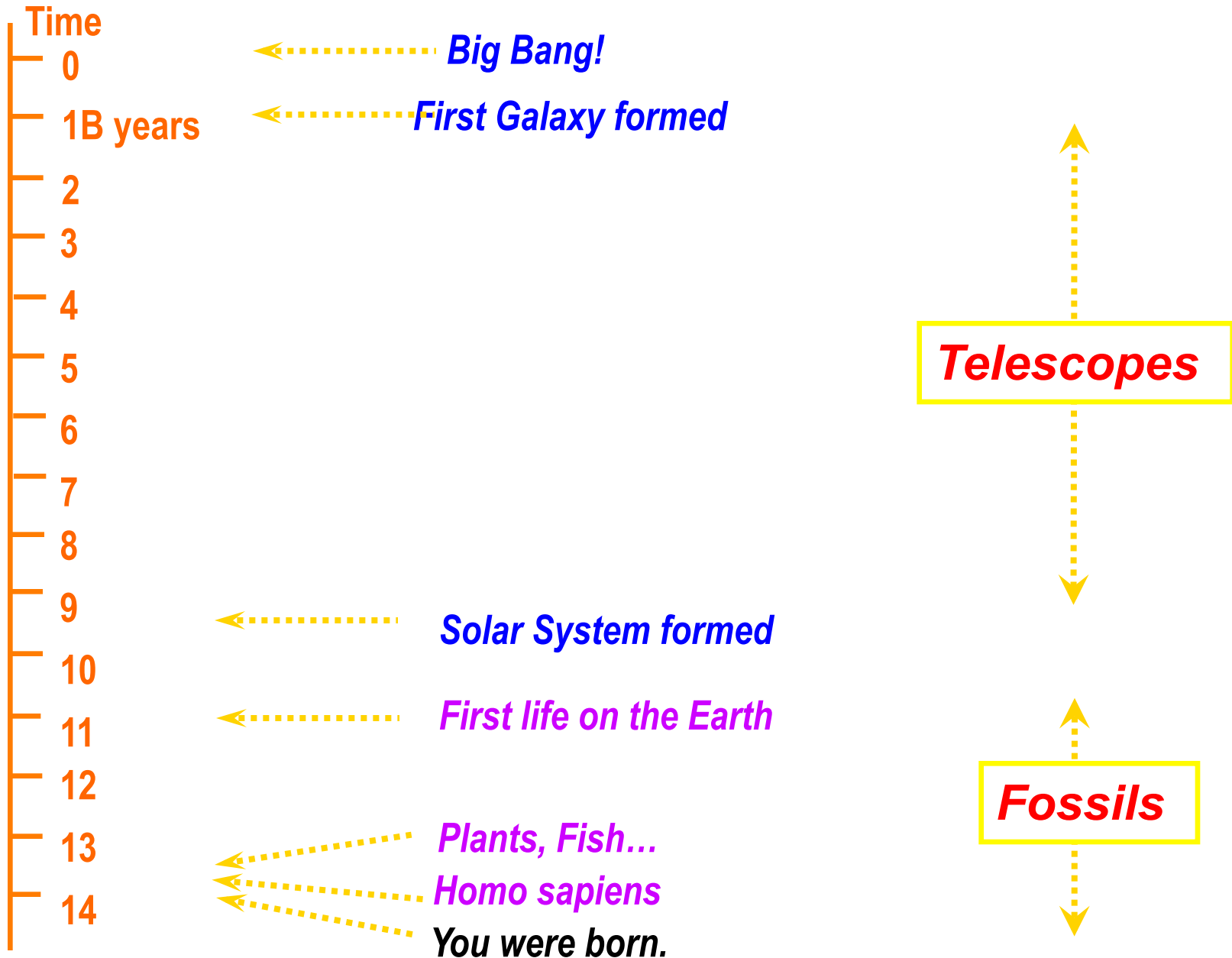
Sun

Earth

History of Life and the Human beings



Brief History of Universe and Life



Andromeda

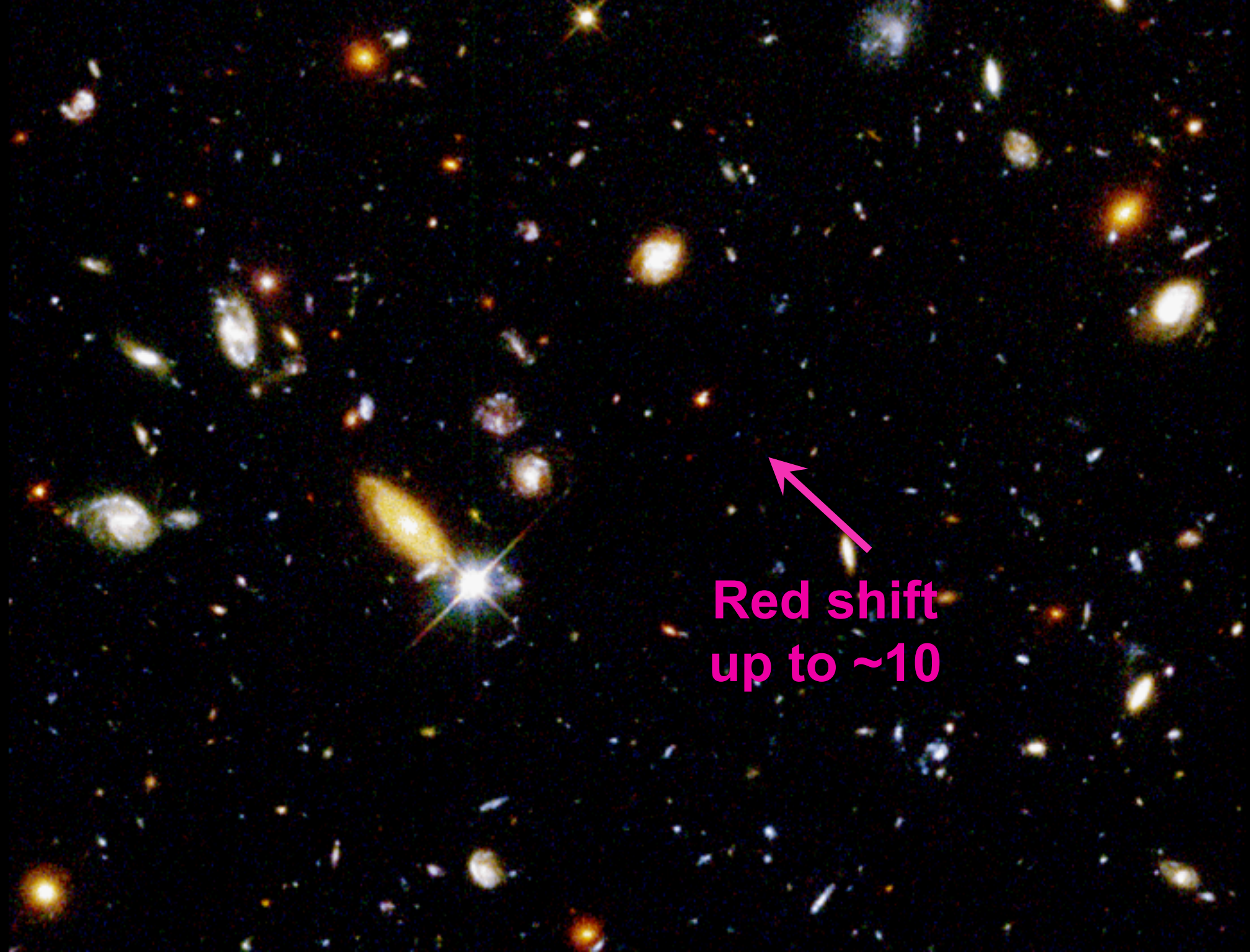


~100 Billions Stars in a Galaxy

Hubble Deep Field

The image displays a dense field of galaxies, including various types such as spirals, ellipticals, and irregular shapes, scattered across a dark background. The galaxies are concentrated in the central and lower-left regions, with some appearing as bright, distinct points of light and others as faint, diffuse structures. The overall appearance is that of a rich, multi-colored stellar population.

~100 Billion Galaxies

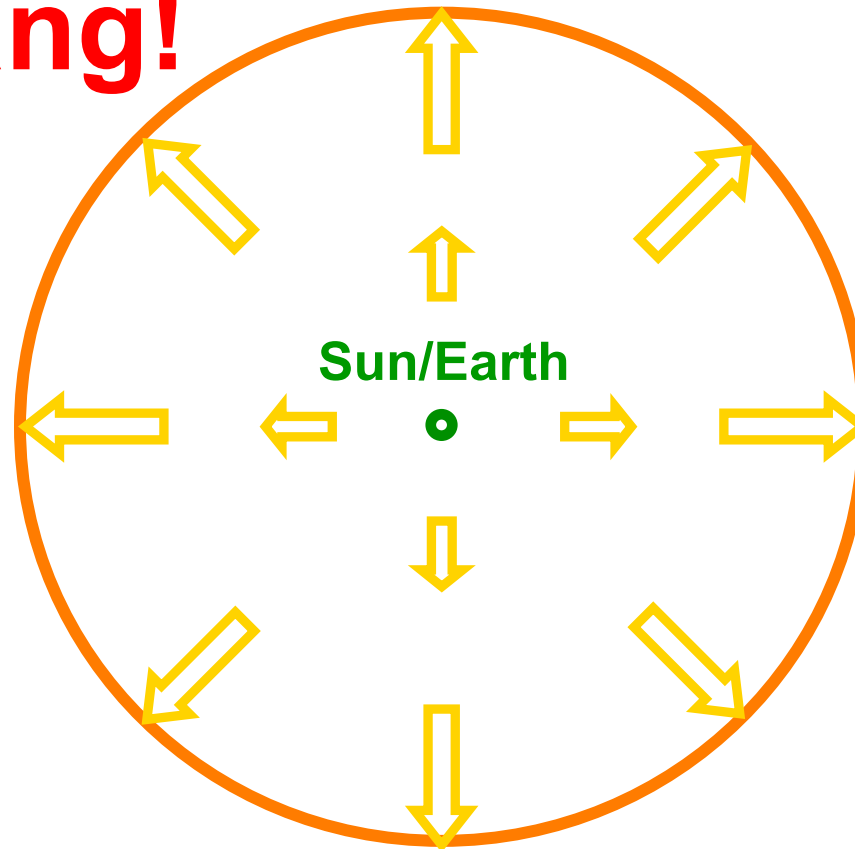


Red shift
up to ~10

Hubble's Law: Expansion of the Universe

Big Bang!

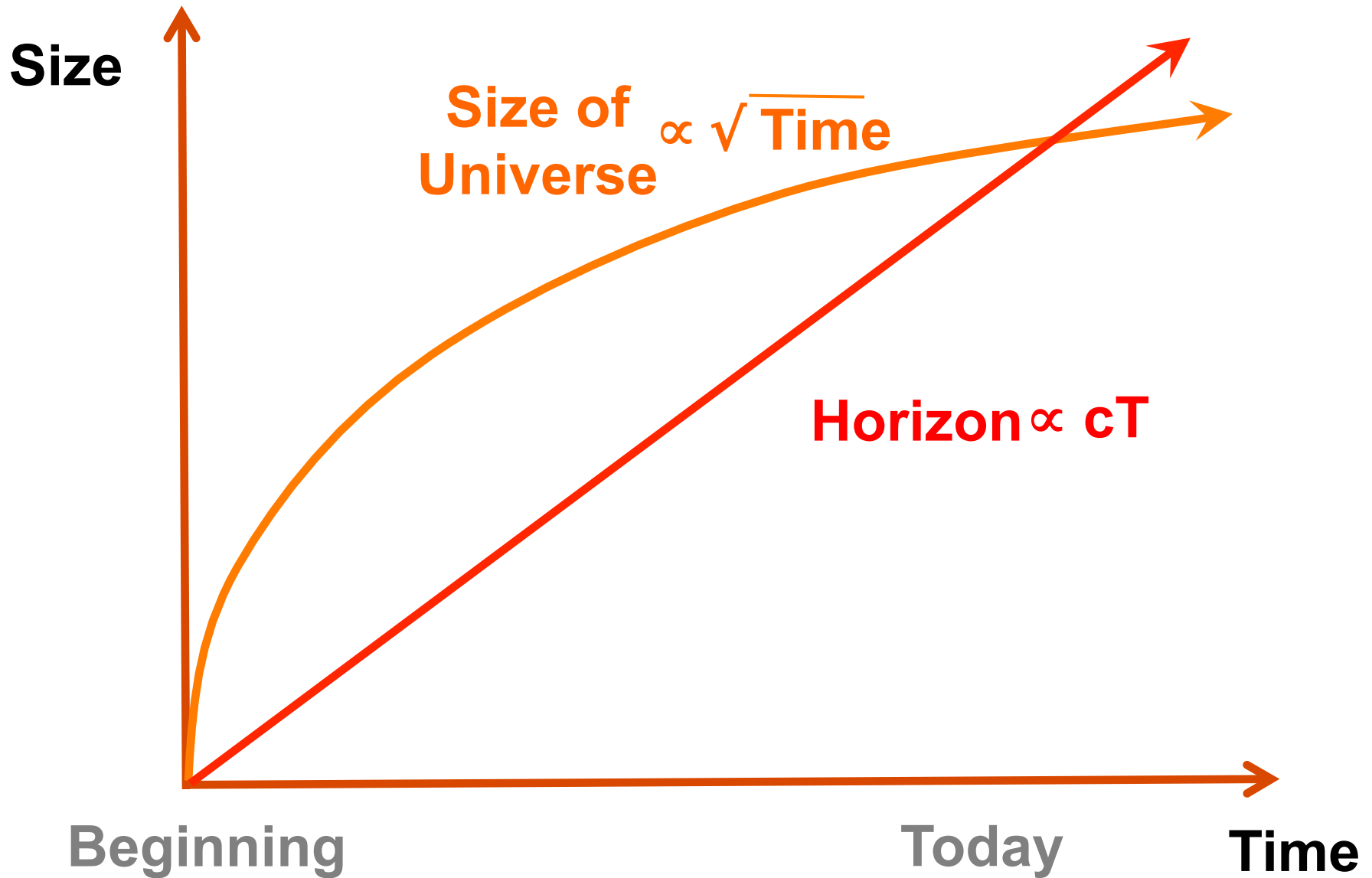
Horizon
of Universe



14 Billion
Light Years

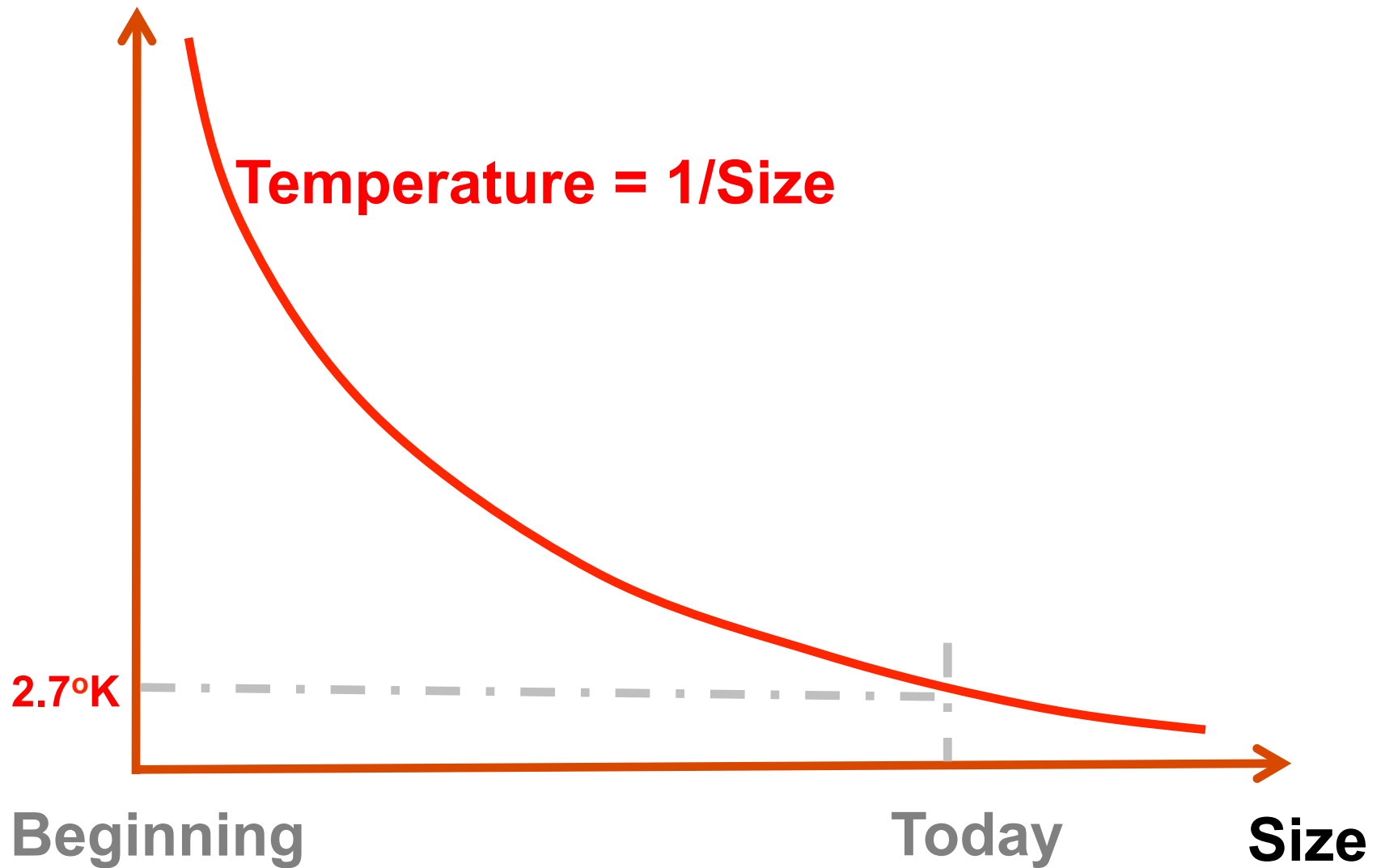
Moving Away
at Speed of Light

Expansion of Universe



Temperature of Universe

Temperature

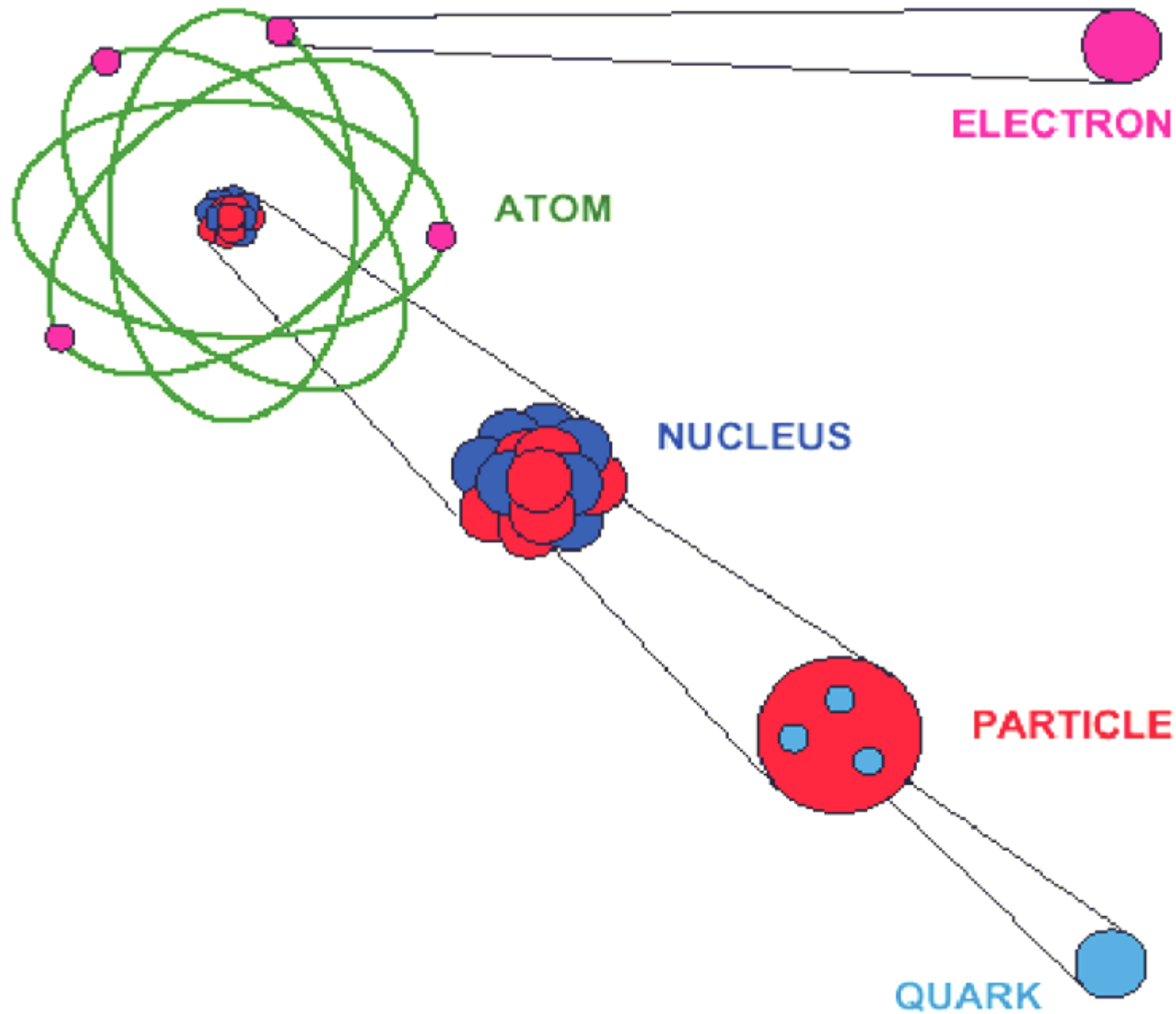


Tevatron at Fermi Lab near Chicago (1980 – 2010)



6km Circumference

Elementary Particles



Elementary Particles

		Fermion			Boson		
Charge						Charge	
+2/3	Quarks	<i>u</i> up	<i>c</i> charm	<i>t</i> top	Force Carriers	γ photon	0
		<i>d</i> down	<i>s</i> strange	<i>b</i> bottom		<i>g</i> gluon	0
-1/3	Leptons	ν_e electron neutrino	ν_μ muon neutrino	ν_τ tau neutrino		<i>Z</i> Z boson	0
0		<i>e</i> electron	μ muon	τ tau		<i>W</i> W boson	0
-1		I	II	III			± 1
Three Families of Matter							

+ Anti-particles

Elementary Particles and Forces

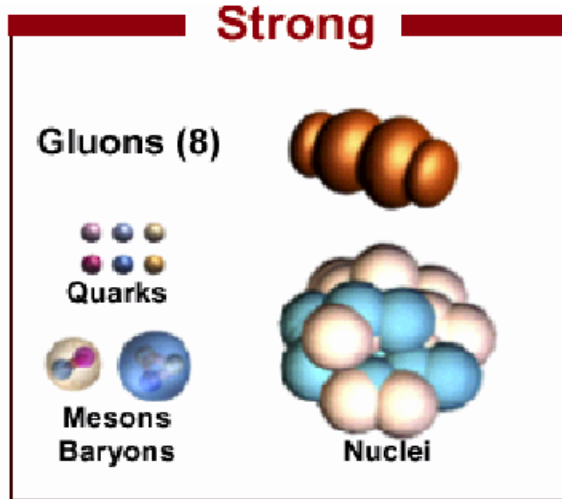
Strong

Gluons (8)

Quarks

Mesons
Baryons

Nuclei

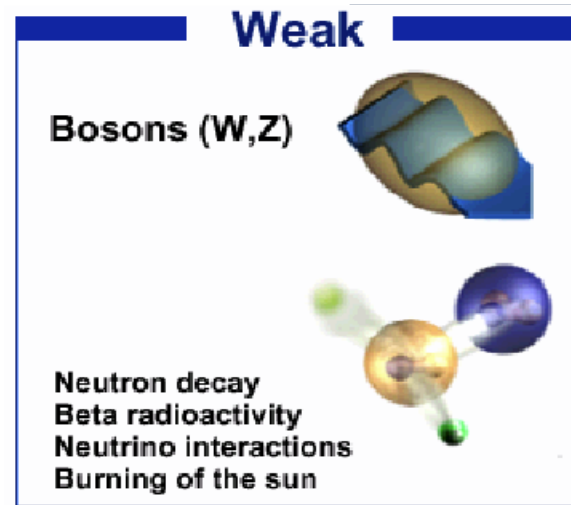
The diagram for the strong force shows various particles and structures. At the top, there are eight orange spheres representing gluons. Below them are six small colored spheres representing quarks. Further down are two pairs of quarks representing mesons and two groups of three quarks representing baryons. At the bottom is a large cluster of quarks representing a nucleus.

1

Weak

Bosons (W,Z)

Neutron decay
Beta radioactivity
Neutrino interactions
Burning of the sun

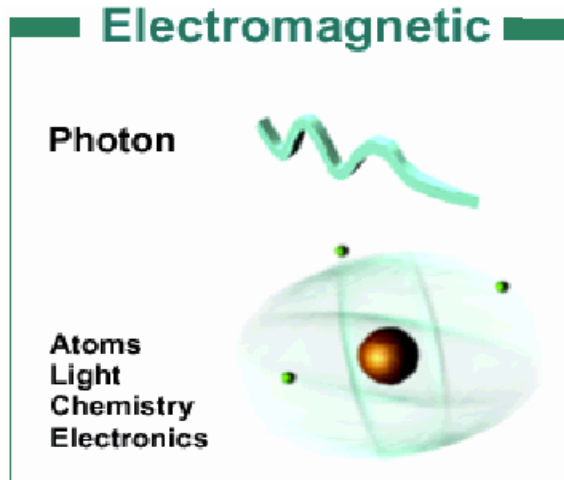
The diagram for the weak force shows two bosons (W and Z) at the top. Below them are three particles representing examples of weak interactions: a neutron decaying into a proton and an electron, a beta particle (electron) being emitted from a nucleus, and a neutrino interacting with a nucleus.

10^{-13}

Electromagnetic

Photon

Atoms
Light
Chemistry
Electronics

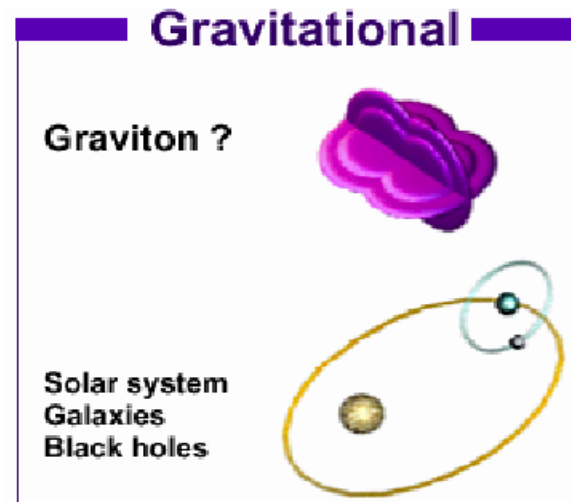
The diagram for the electromagnetic force shows a wavy green line representing a photon at the top. Below it is a model of an atom with a central nucleus and orbiting electrons.

10^{-2}

Gravitational

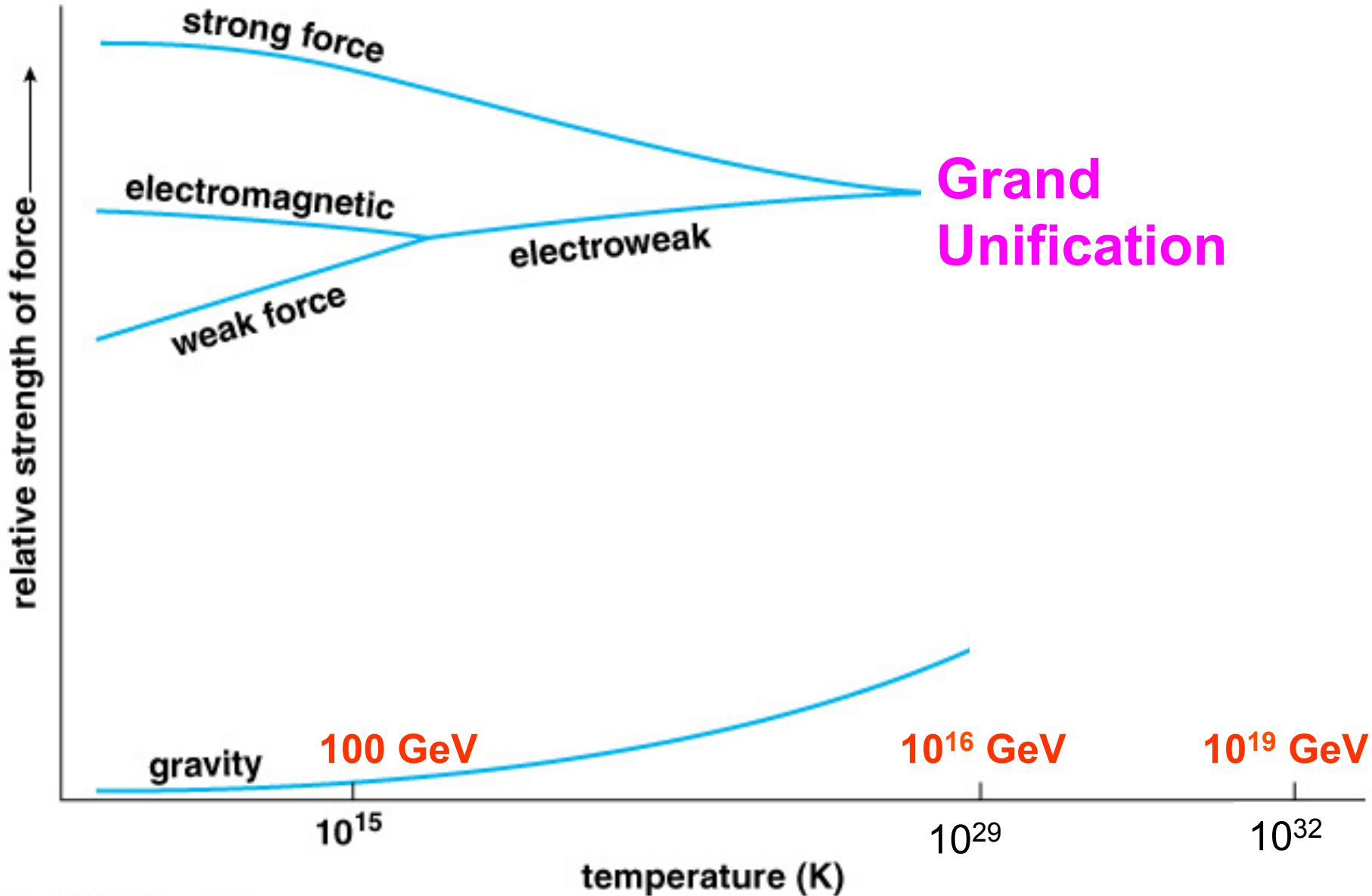
Graviton ?

Solar system
Galaxies
Black holes

The diagram for the gravitational force shows a purple cloud-like shape representing a graviton at the top. Below it are three examples of gravitational interactions: a solar system with a central star and orbiting planets, a galaxy, and a black hole.

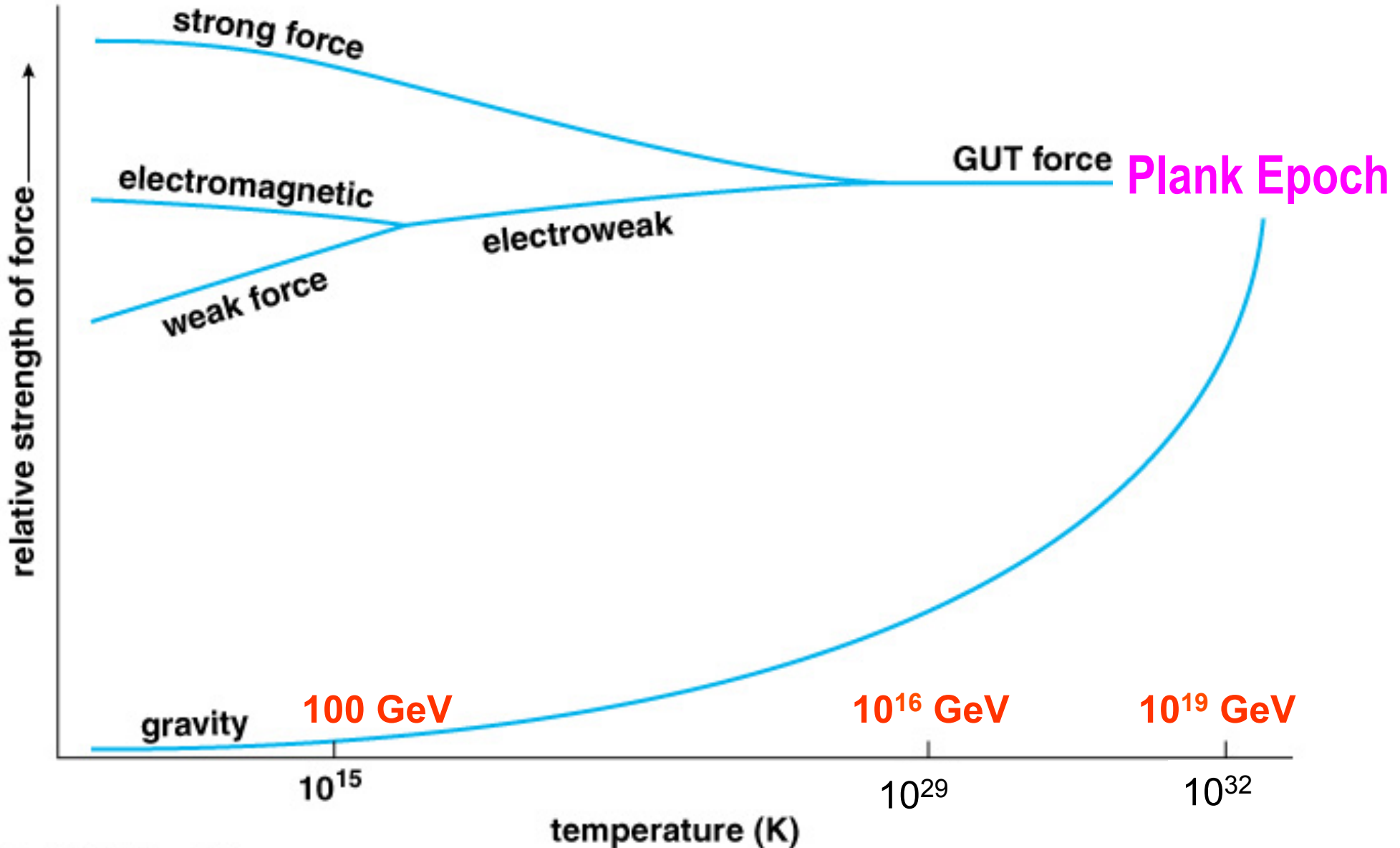
10^{-38}

Unification of Forces (1980)



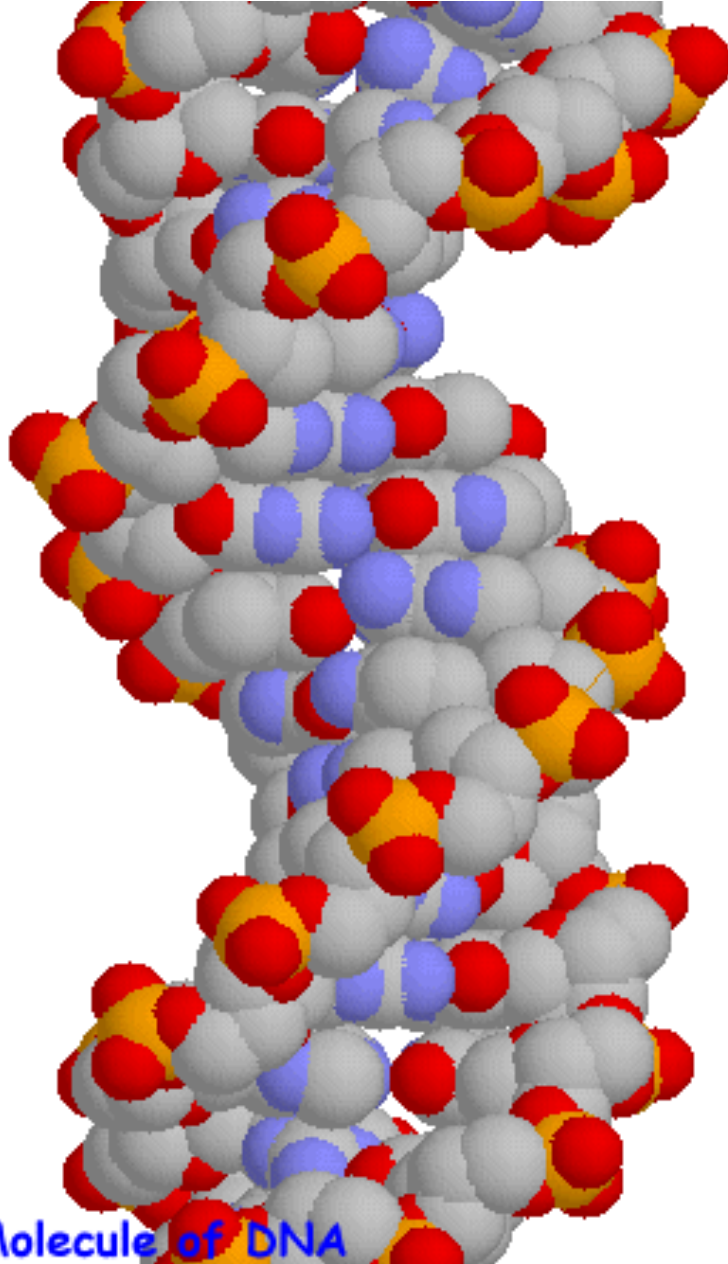
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Unification of Forces (1980)

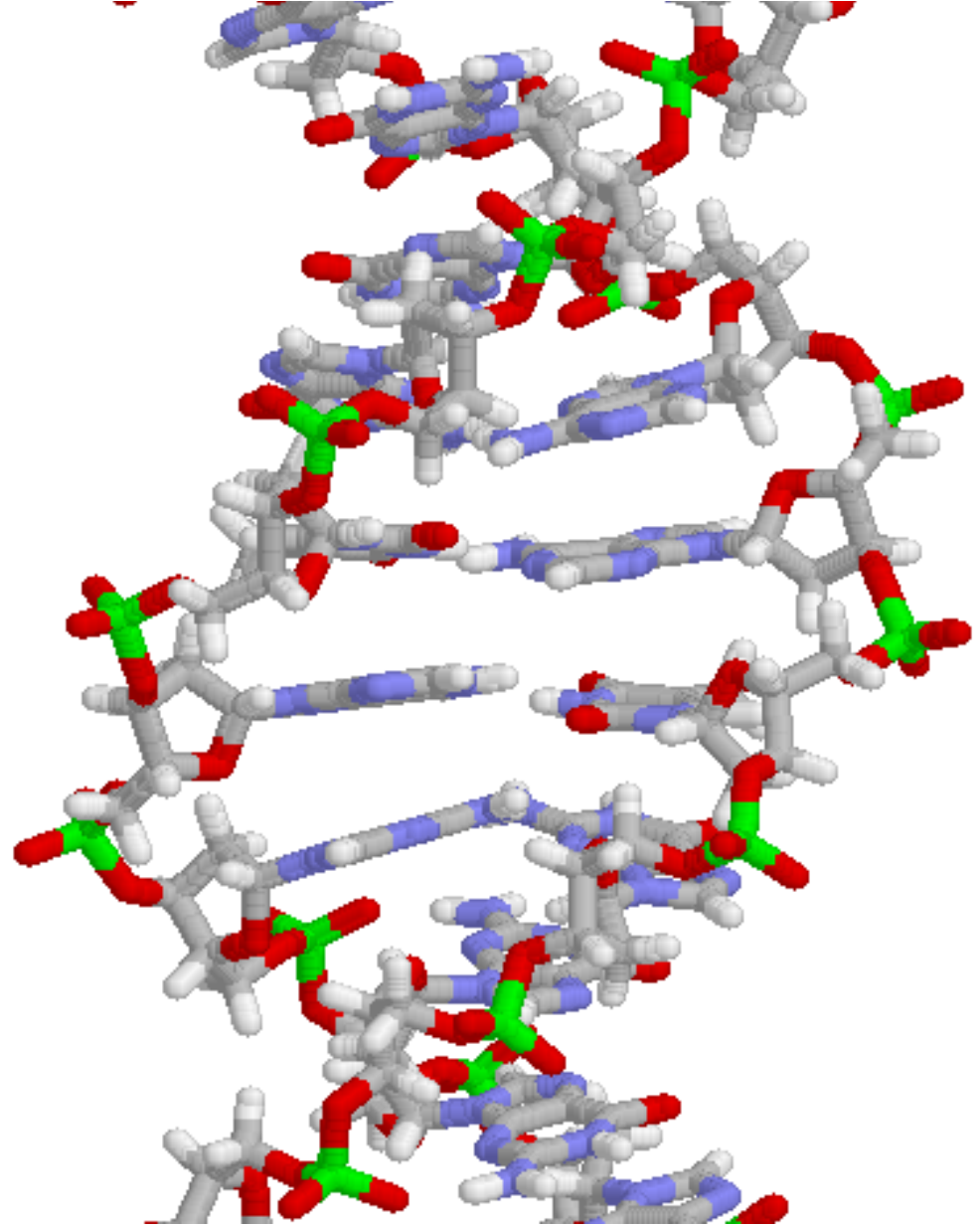


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Structure of DNA



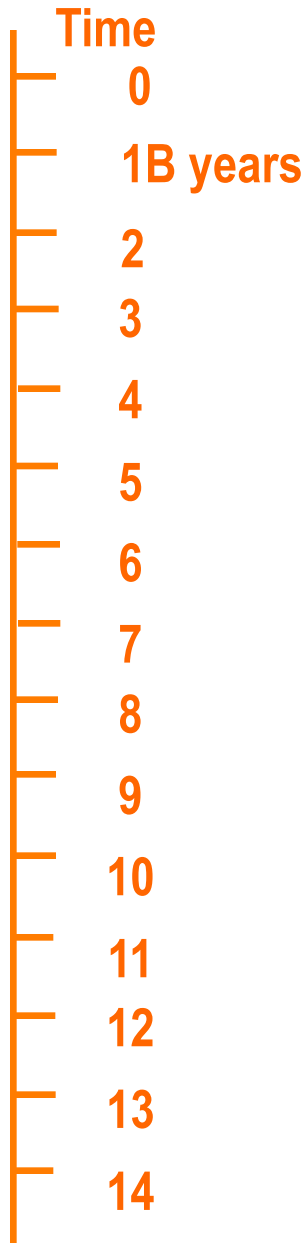
©Rothamsted Experimental Station, 1997, 1998



Molecule of DNA

3 billion base pairs

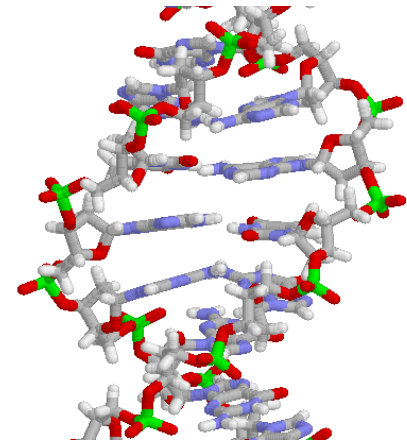
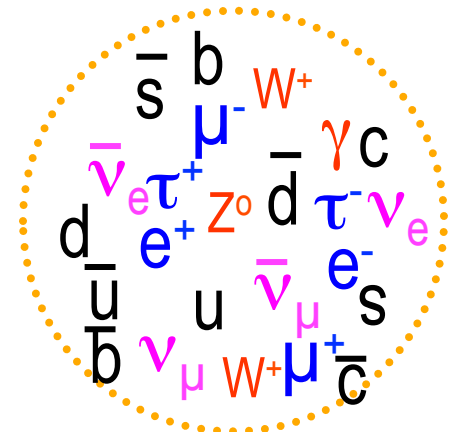
Symmetry Breaking



Simple

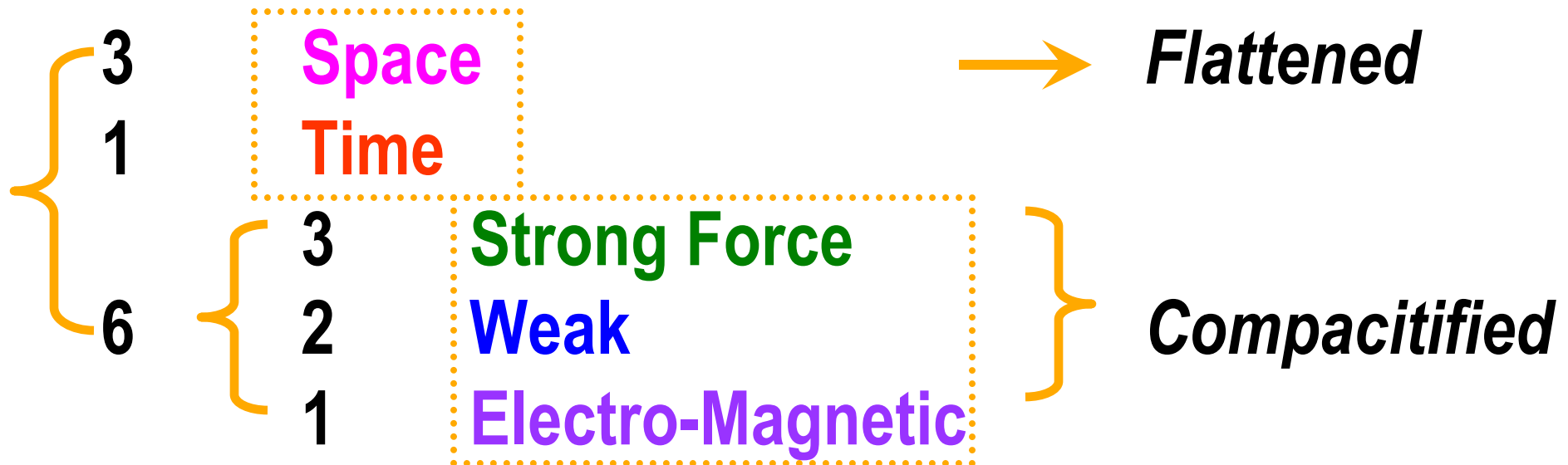
*Symmetry
Break Down*

Complex



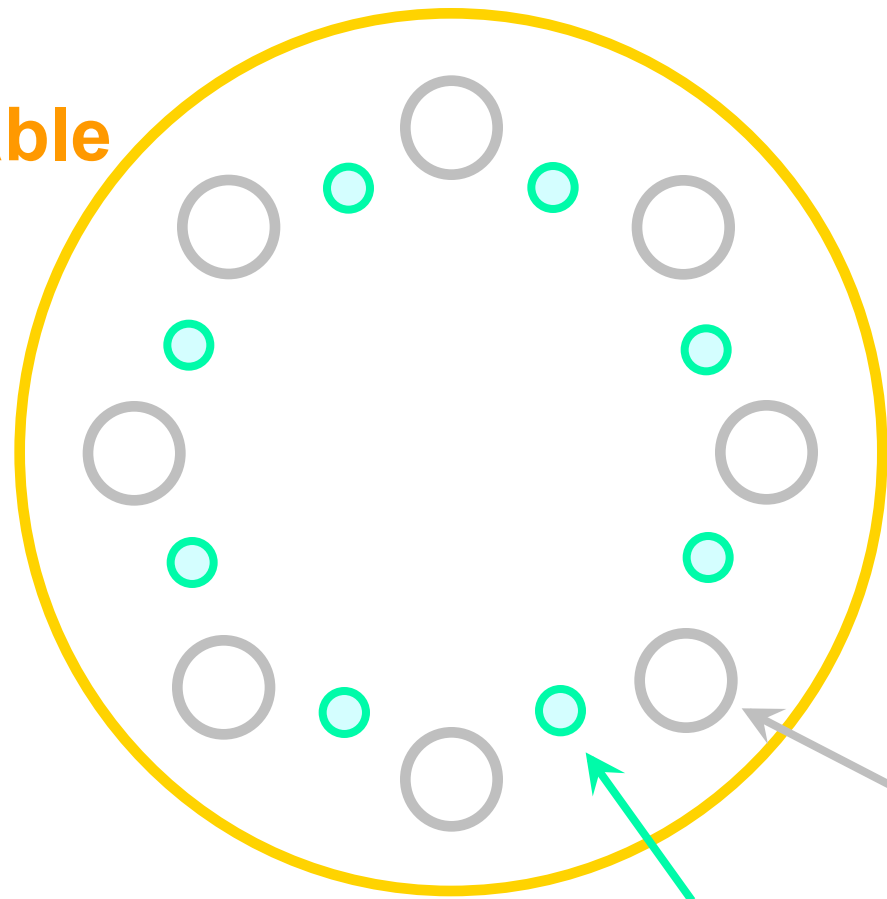
The Beginning

- Everything was the same \leftrightarrow Perfect symmetry.
 - All the particles are the same as photons.
 - All four forces are the same.
- The Universe was 10 dimension.



Spontaneous Symmetry Breakdown at a Dinner Table

Dinner Table



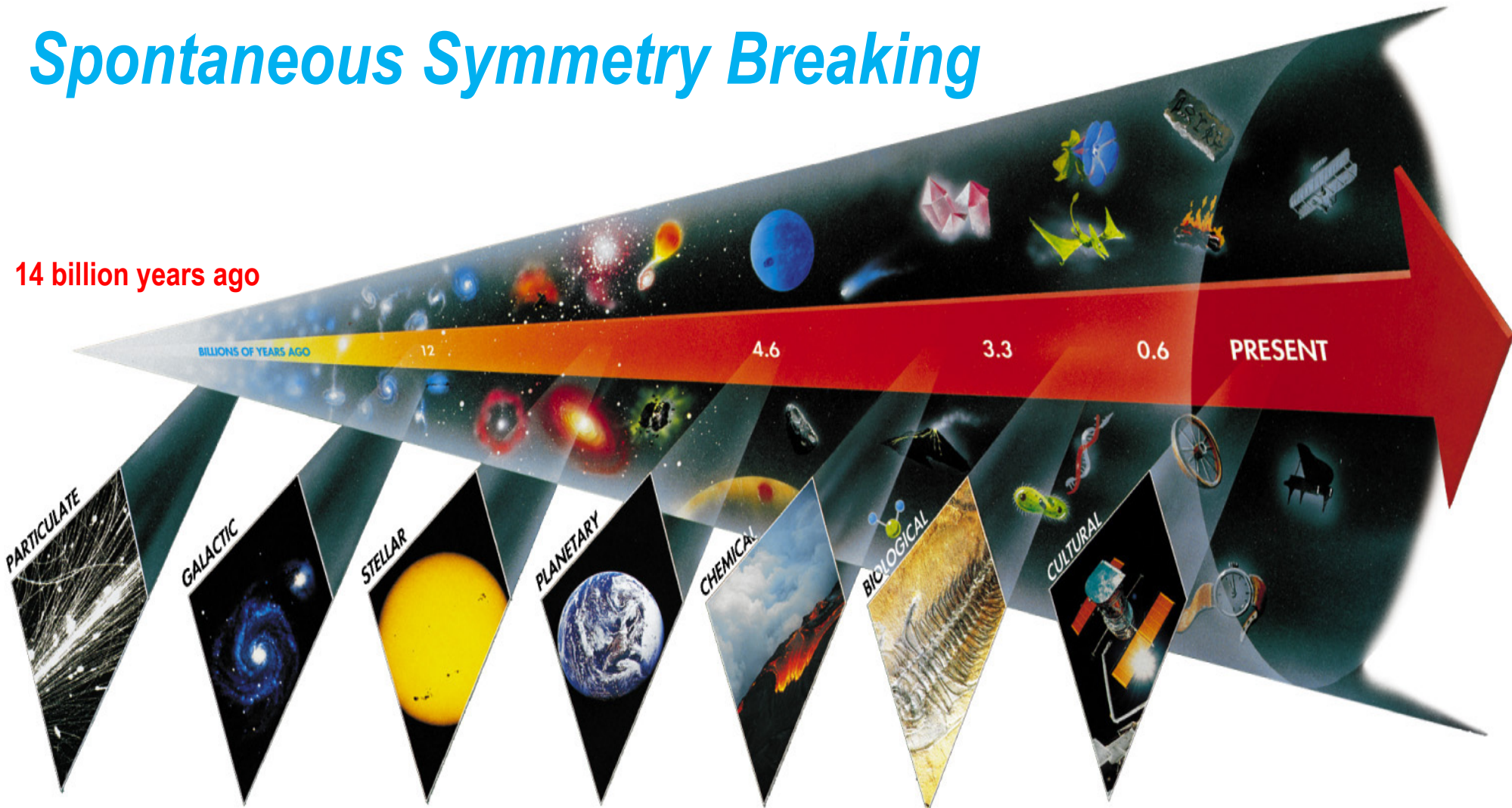
Dish

Glass of Water

by Nambu Yoichiro

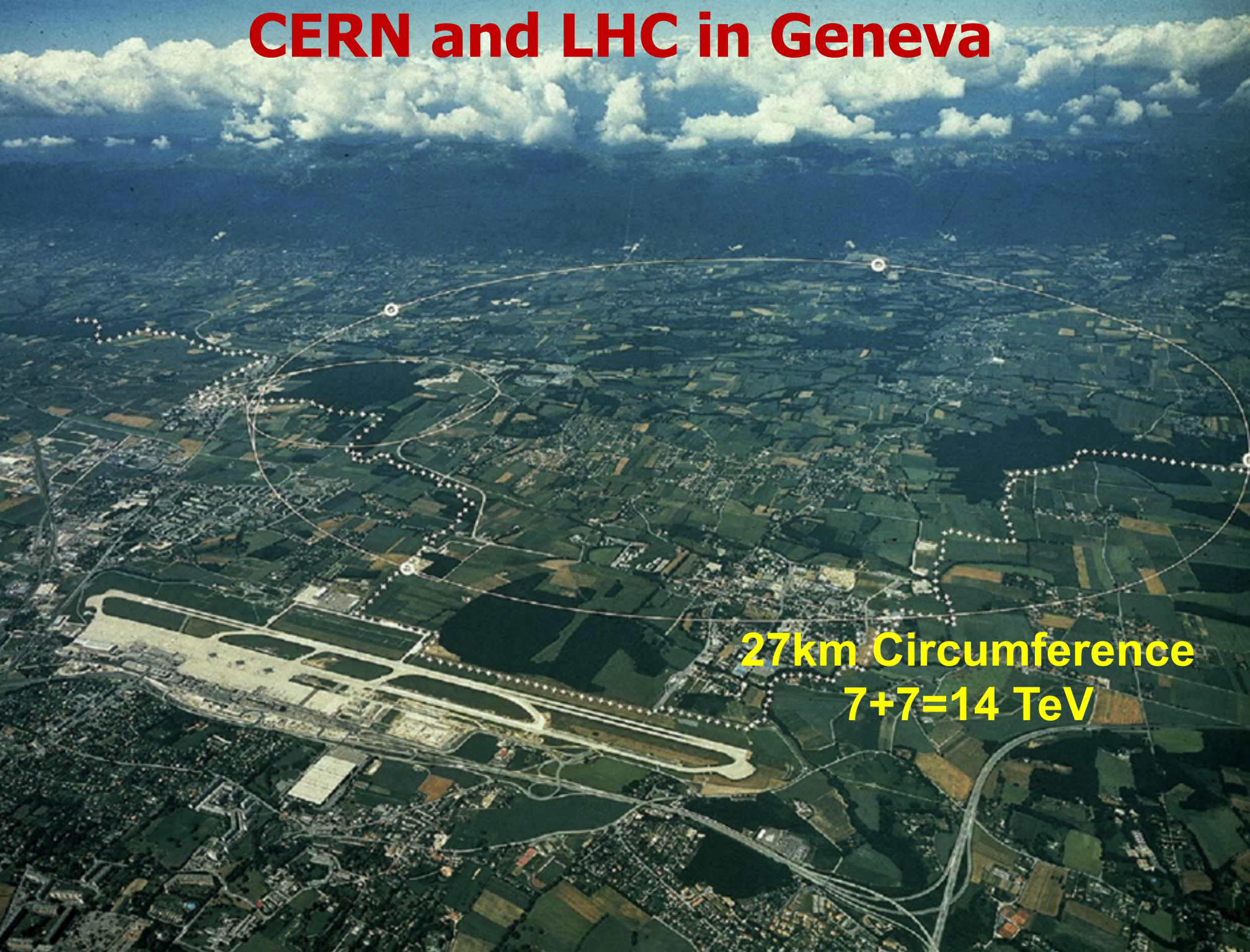
Seven Phases of Cosmic Evolution

Spontaneous Symmetry Breaking



Origin of
Particles

CERN and LHC in Geneva



27km Circumference
7+7=14 TeV

LHC Tunnel with Magnets



CMS Collaboration (1993 ~)

(144 Institutions with about 1700 scientists)



ARMENIA

- Yerevan Physics Inst., Yerevan



AUSTRIA

- HEPHY, Wien



BELARUS

- Institute of Nuclear Problems, Minsk
- National Centre of Part. and HEP, Minsk
- Res. Inst. of Applied Physical Probl., Minsk
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- Inst. of Physics Academy of Science, Tbilisi



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- Soltan Inst. for Nucl. Studies, Warsaw



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- Petersburg Nucl. Phys. Inst., Gatchina (St Petersburg)



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- CERN, Geneva
- Paul Scherrer Inst., Villigen
- Inst. für Teilchenphysik, ETH, Zürich
- Univ. Zürich, Zürich



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- Kharkov Inst. of Phys. and Tech., Kharkov
- Kharkov State Univ., Kharkov



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- Florida State Univ. - SCRI, Tallahassee
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- Los Alamos Nat. Lab., Los Alamos
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- Univ. of Rochester, Rochester
- Rutgers, the State Univ. of New Jersey, Piscataway
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- Univ. of Texas at Dallas, Richardson
- Univ. of California at Davis, Davis
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UZBEKISTAN

- Inst. of Nucl. Phys. of the Uzbekistan Acad. of Sciences, Tashkent

electromagnetic calorimeter

solenoid

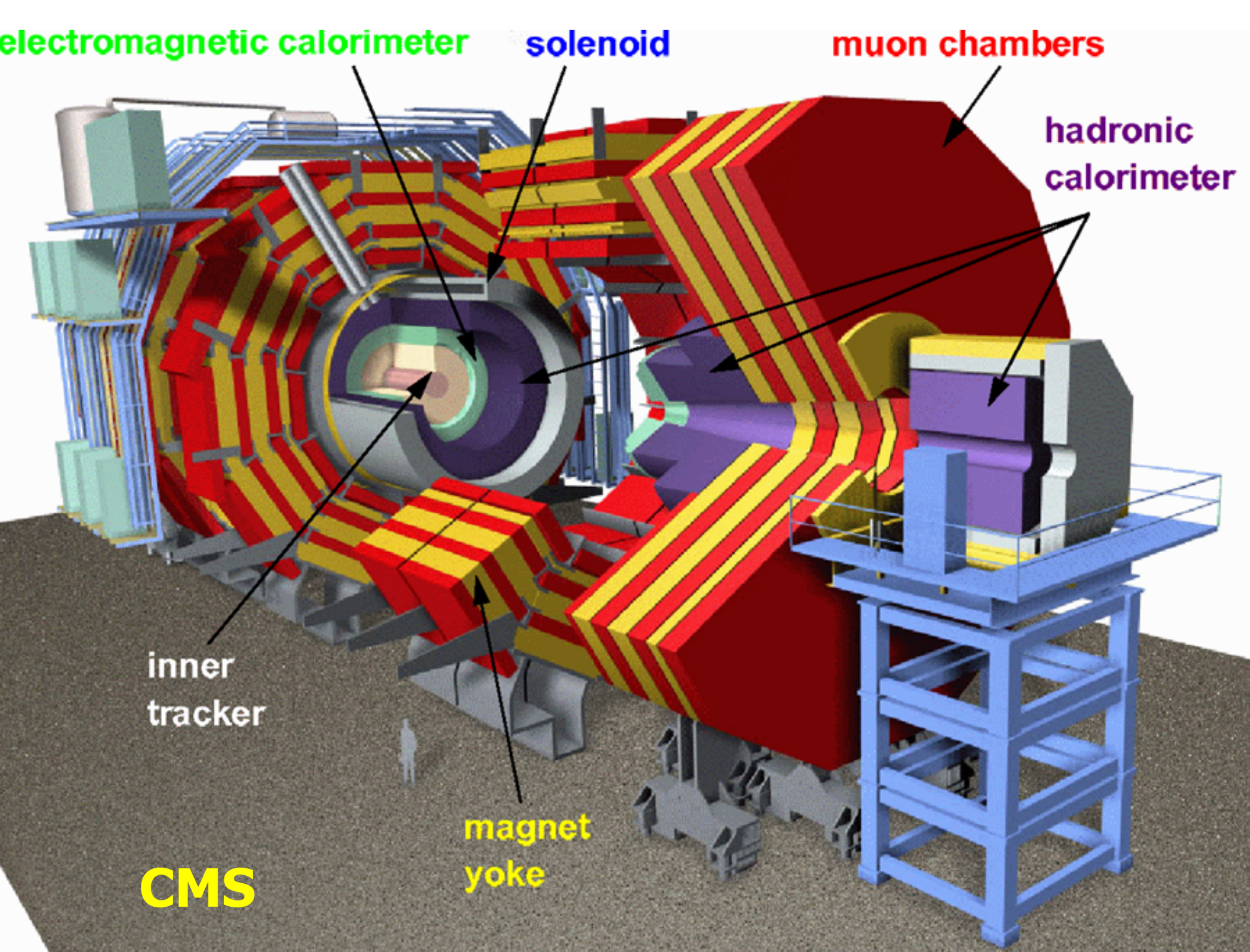
muon chambers

hadronic calorimeter

inner tracker

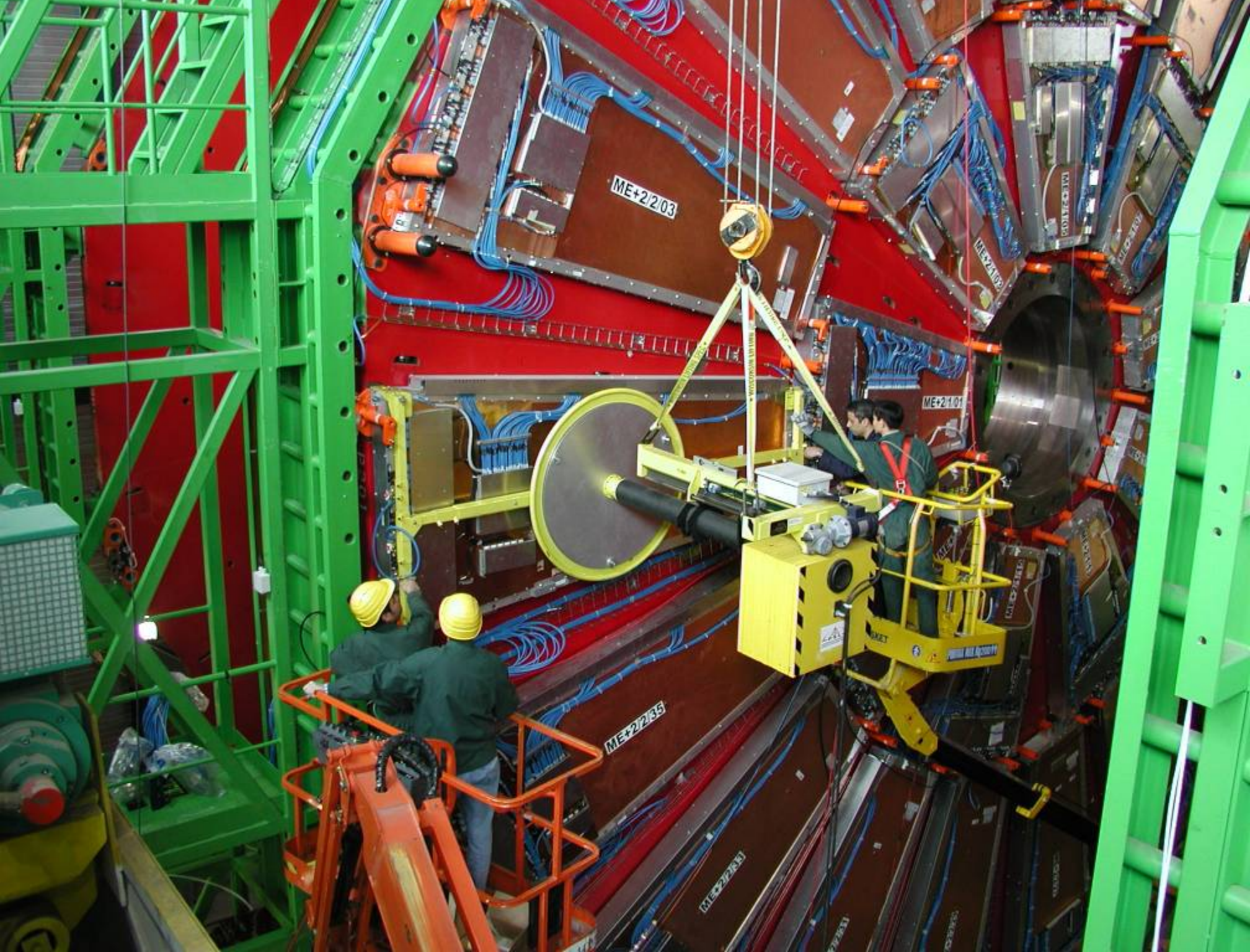
magnet yoke

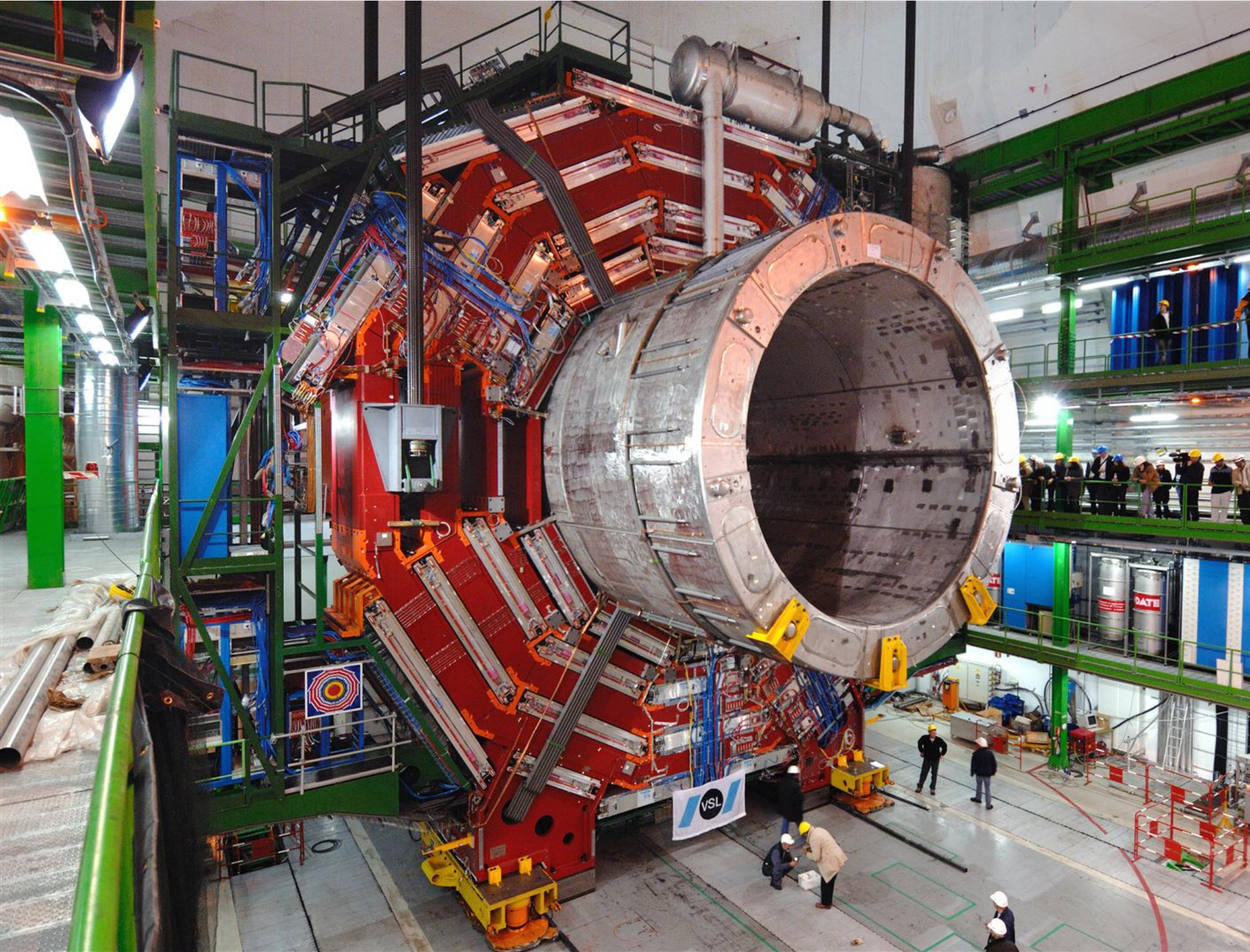
CMS

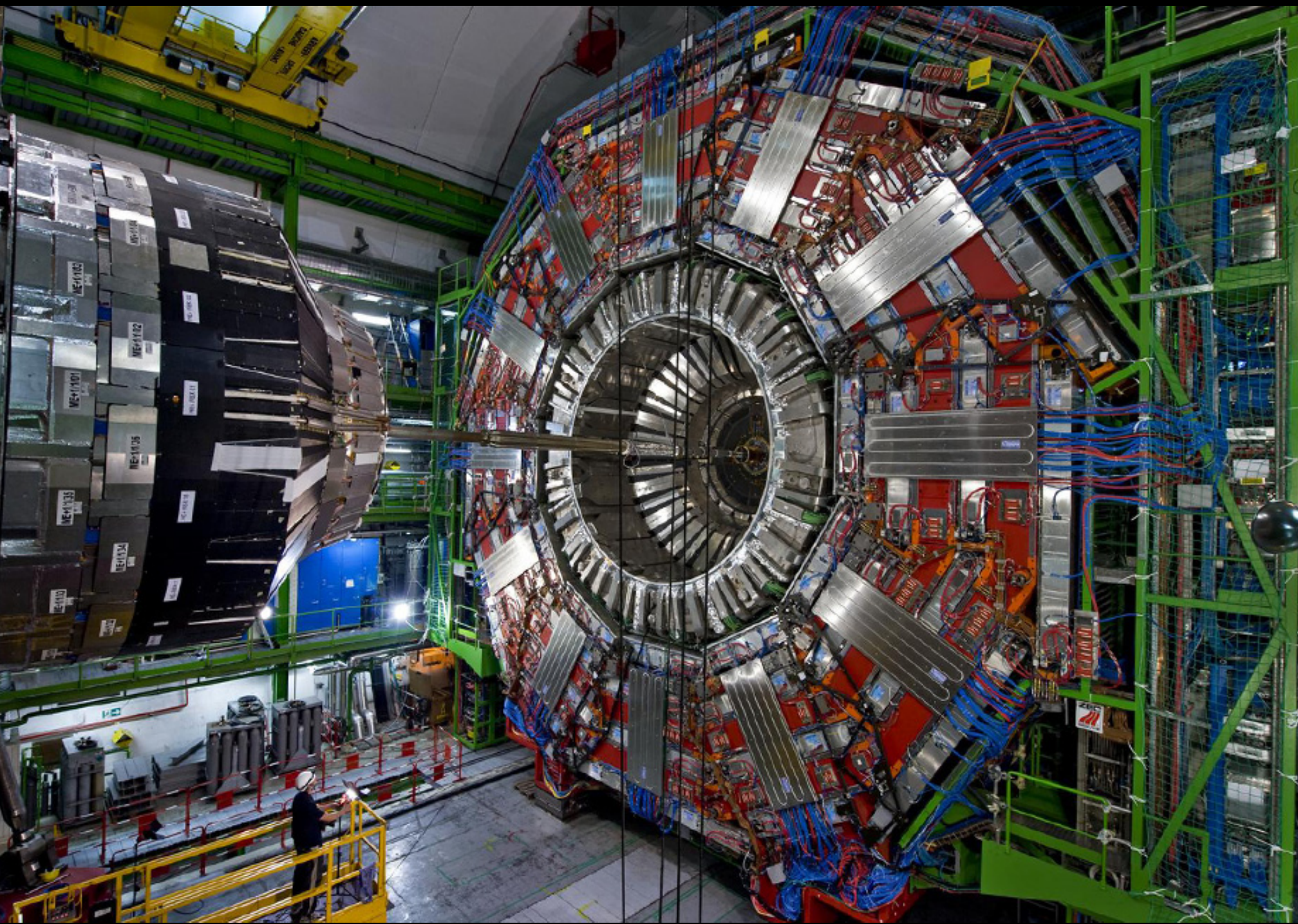


CMS Barrel Yoke









Newsweek

The Biggest Experiment Ever (And It's European)



Particle detectors constructed at Westwood, now at LHC, CERN



newswk.com SEPTEMBER 15, 2008 PHOTOGRAPH BY MARTIAL TREZZINI-AP

The new CERN collider in Geneva



Albania	Lek 600	Finland	€4.40	Israel	NIS 20.00	Netherlands	€4.40	Slovenia	€3.40
Austria	€4.40	France	€4.40	Italy	€4.40	Norway	Kr 41.00	Spain	€4.40
Belgium	€4.40	Germany	€4.40	Kazakhstan	\$4.40	Poland (incl tax)	PLN 12.30	Sweden	SKr 34.00
Bulgaria	BGL 4.50	Gibraltar	€2.90	Latvia	€4.40	Portugal Cont	€4.40	Switzerland	SF 7.70
Croatia	KN 22.00	Greece	€4.40	Lithuania	\$4.40	Romania	Lei 11.00	Turkey	YTL 4.00
Cyprus	€2.58/€4.40	Hungary	FL 700.00	Luxembourg	€4.40	Russia	€4.40	Ukraine	€4.40
Czech Republic	CZK 115.00	Iceland	IKR 390.00	Malta	Lm 1.70/€3.96	Serbia	DIN 240	United Kingdom	€2.80
Denmark	Kr 38.00	Ireland (incl tax)	€4.40	Montenegro	DIN 240	Slovakia	SK 120.00/€3.98	U.S. Forces	\$3.25

Sept 15, 2008 Issue

CMS Experiment, CERN

Data_taken 2009-11-07 19:12:36.880368 GMT

Run_no 120015

Event_no 8

Lumi_sec 1

Orbit 584946

Crossing 2603

<http://iguana.cern.ch/iss/>

L1 Triggers:

L1_DoubleHEBitCountsRing1_P1N1

L1_DoubleHEBitCountsRing2_P1N1

L1_ETM20

L1_ETM30

L1_MinBias_HTT10

L1_Mu3QE8_Jet6

L1_SingleEG1

L1_SingleEG10

L1_SingleEG12

L1_SingleEG15

L1_SingleEG20

L1_SingleEG25

L1_SingleEG30

L1_SingleEG35

L1_SingleHEBitCountsRing1_1

L1_SingleHEBitCountsRing2_1

L1_SingleJet10

L1_SingleJet15

L1_SingleJet20

L1_SingleJet30

L1_SingleJet6

L1_SingleMu

L1_SingleMu5

L1_SingleMuBeam10

L1_SingleMuBeam15

L1_SingleMuBeam20

L1_SingleMuBeam25

L1_SingleMuBeam30

First Event at LHC – Recreation of the Big Bang! (Nov 7, 2009)

Los Angeles Times

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Physicists find 'tantalizing hints' of Higgs boson 'God particle'

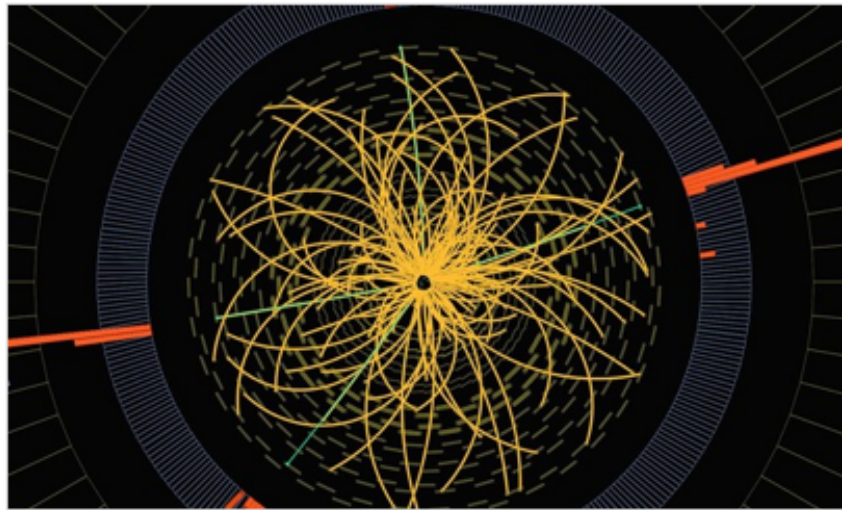
Two teams of scientists at the Large Hadron Collider near Geneva separately saw what they believe are telltale tracks of the maddeningly elusive particle in the aftermath of about 400 trillion proton collisions carried out since January.

News release on July 4th !

December 13, 2011 | By Eryn Brown, Los Angeles Times

Physicists announced Tuesday that they had detected "tantalizing hints," but not definitive proof, of the long-sought Higgs boson, the so-called God particle that is crucial to physicists' understanding of why mass exists in the universe.

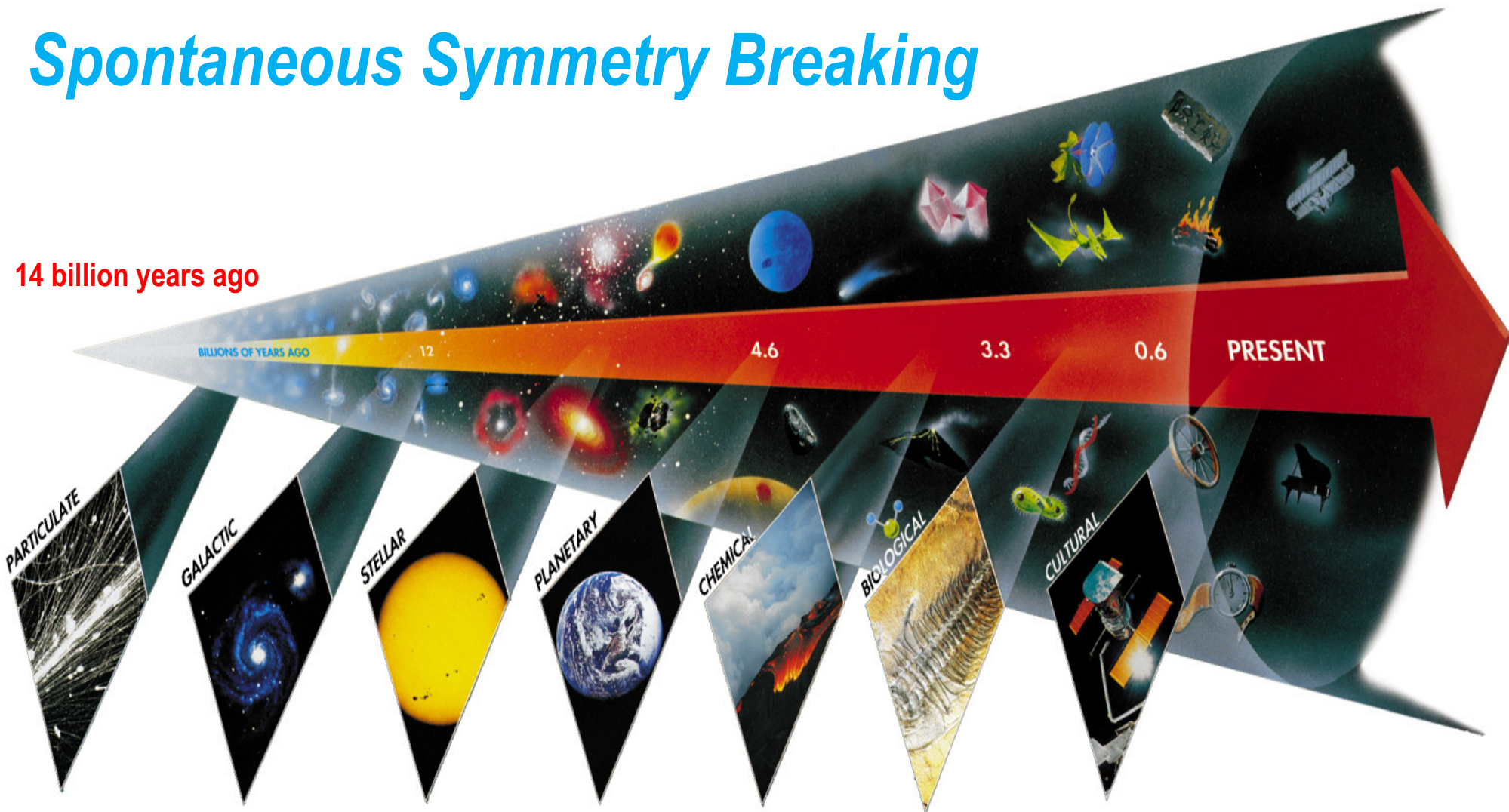
Two large teams of scientists based at the Large Hadron Collider near Geneva separately saw what they believe are telltale tracks of the maddeningly elusive particle in the aftermath of about 400 trillion proton collisions carried out since January.



A graphic shows traces of a proton collision measured in a detector at the... (CERN)

Seven Phases of Cosmic Evolution

Spontaneous Symmetry Breaking



Origin of
Particles

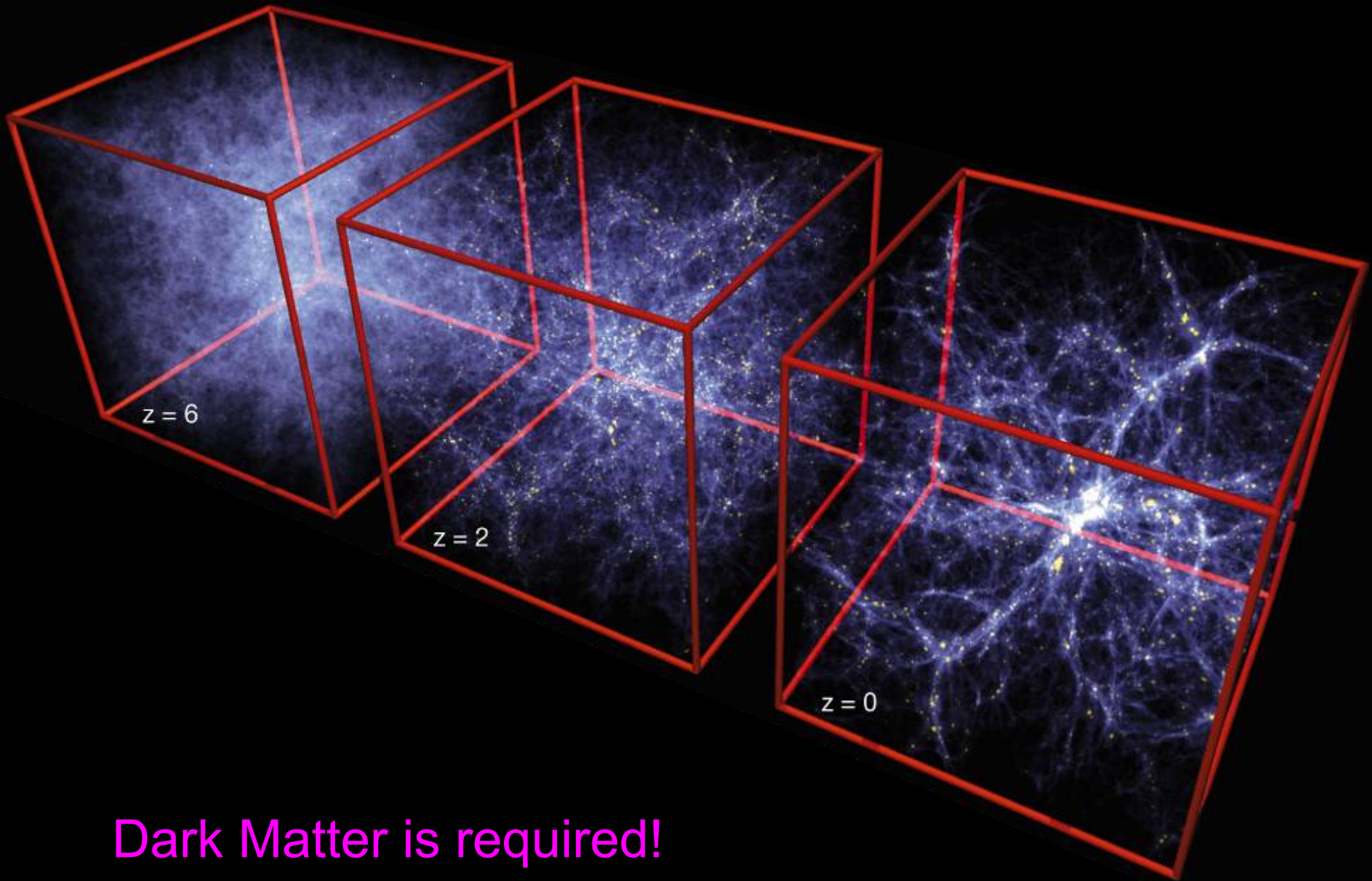
Origin of
Structure



Dark Matter is required!

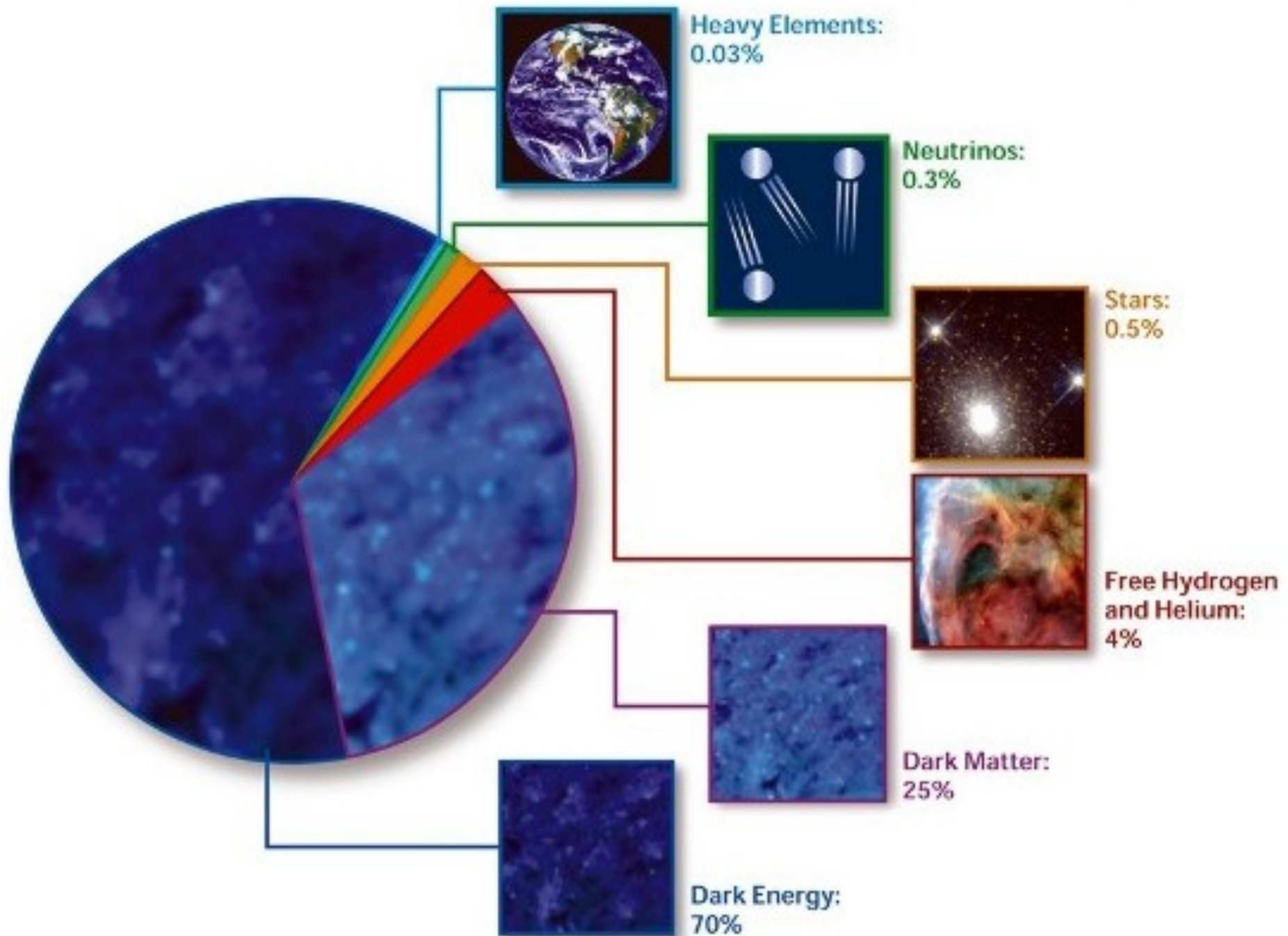
ANDROMEDA
GALAXY.

Formation of Structure in the Universe



Dark Matter is required!

Cosmic Pie Chart



What is Dark Matter?

➤ Must be a heavy particle

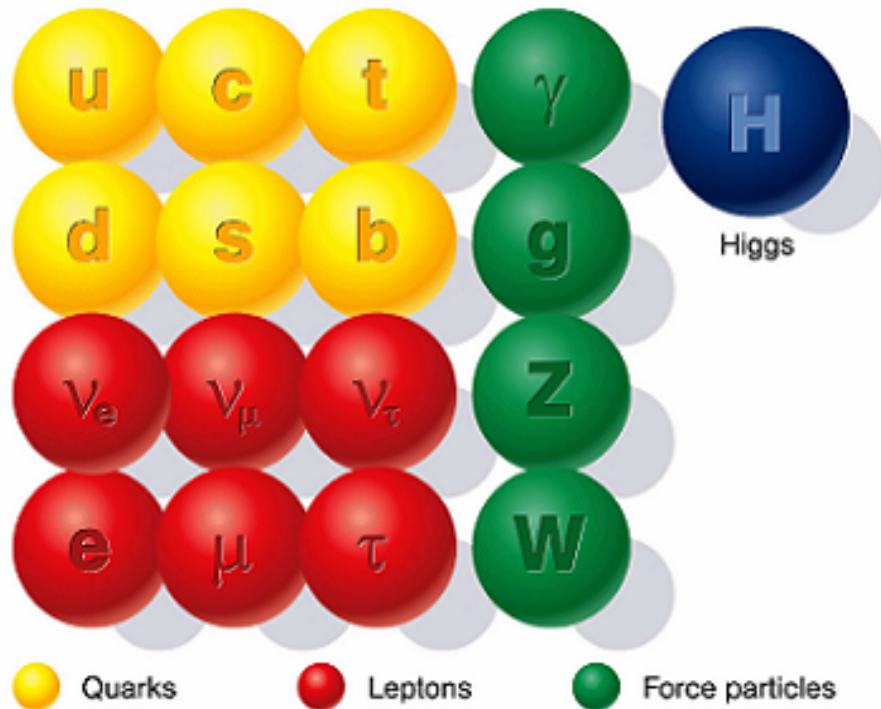
- Only weakly interacting.
- Gravitationally attracted.

➤ Candidates

- “MACHO” (Massive Compact Halo Objects) ✗
 - → Baryonic Dark Matter
- Heavy Neutrino ✗
 - → Hot Dark Matter
- “WIMP” (Weakly Interacting Massive Particle)
 - → Cold Dark Matter

SUSY Particles and Neutralino

Standard particles



Spin 1/2 1 0

SUSY Particles and Neutralino

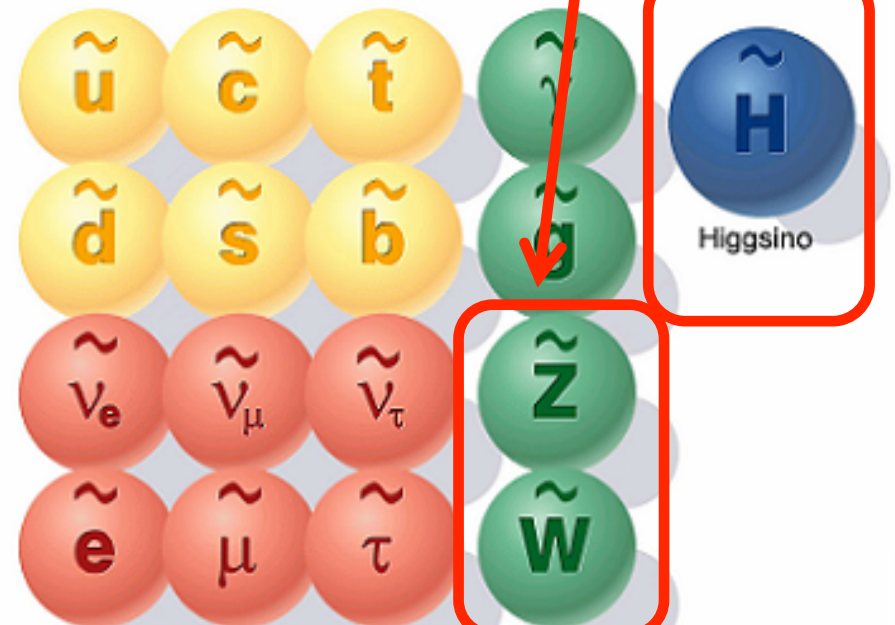
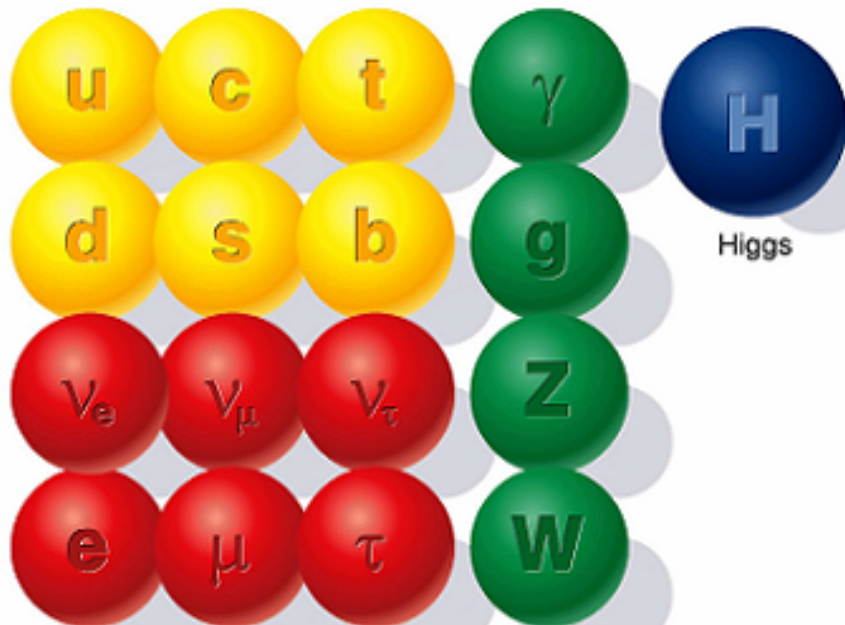
Super Symmetry

Neutralino



Standard particles

SUSY particles



● Quarks ● Leptons ● Force particles

● Squarks ● Sleptons ● SUSY force particles

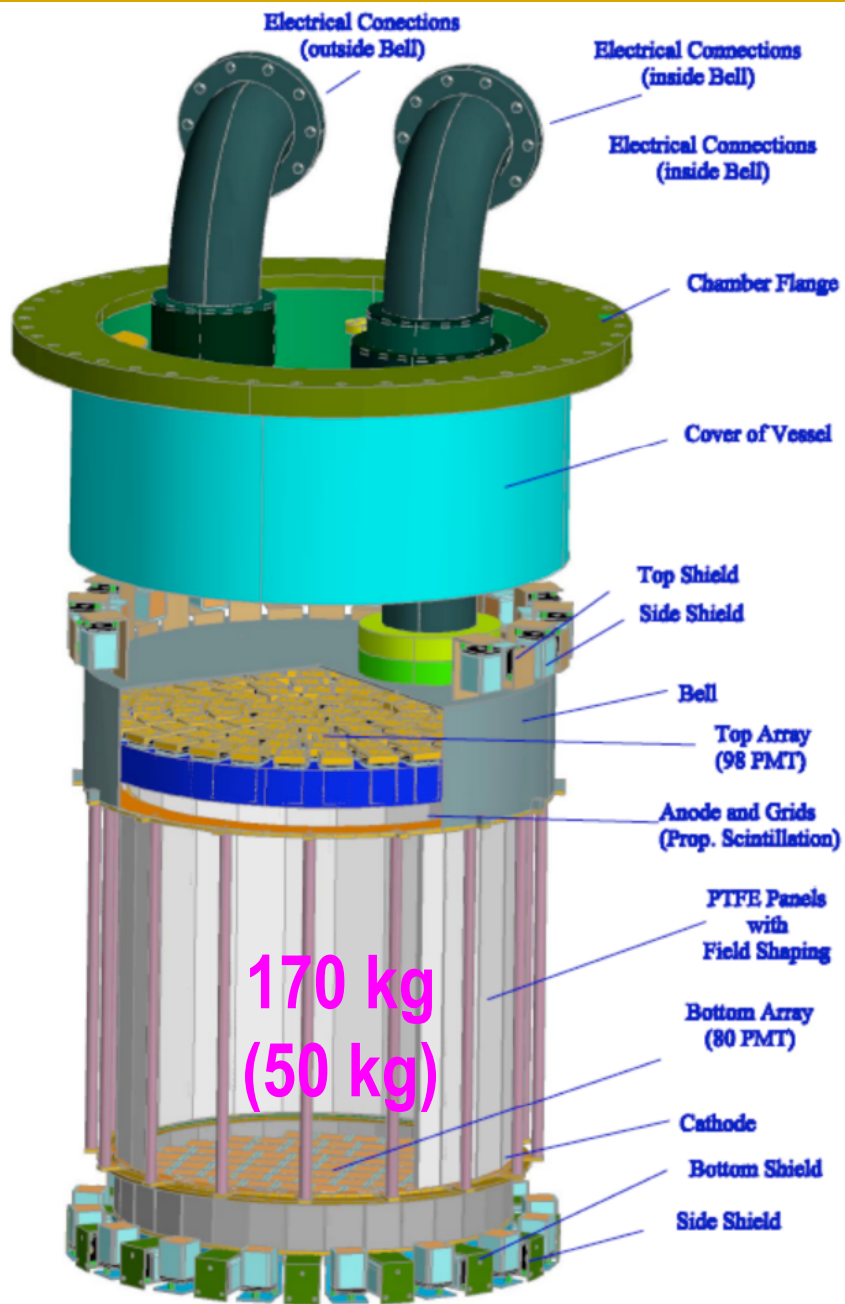
Spin 1/2 1 0 0 1/2 1/2

Laboratori Nazionali del Gran Sasso, Italy

LNGS 1400 m Rock (3100 w.m.e)



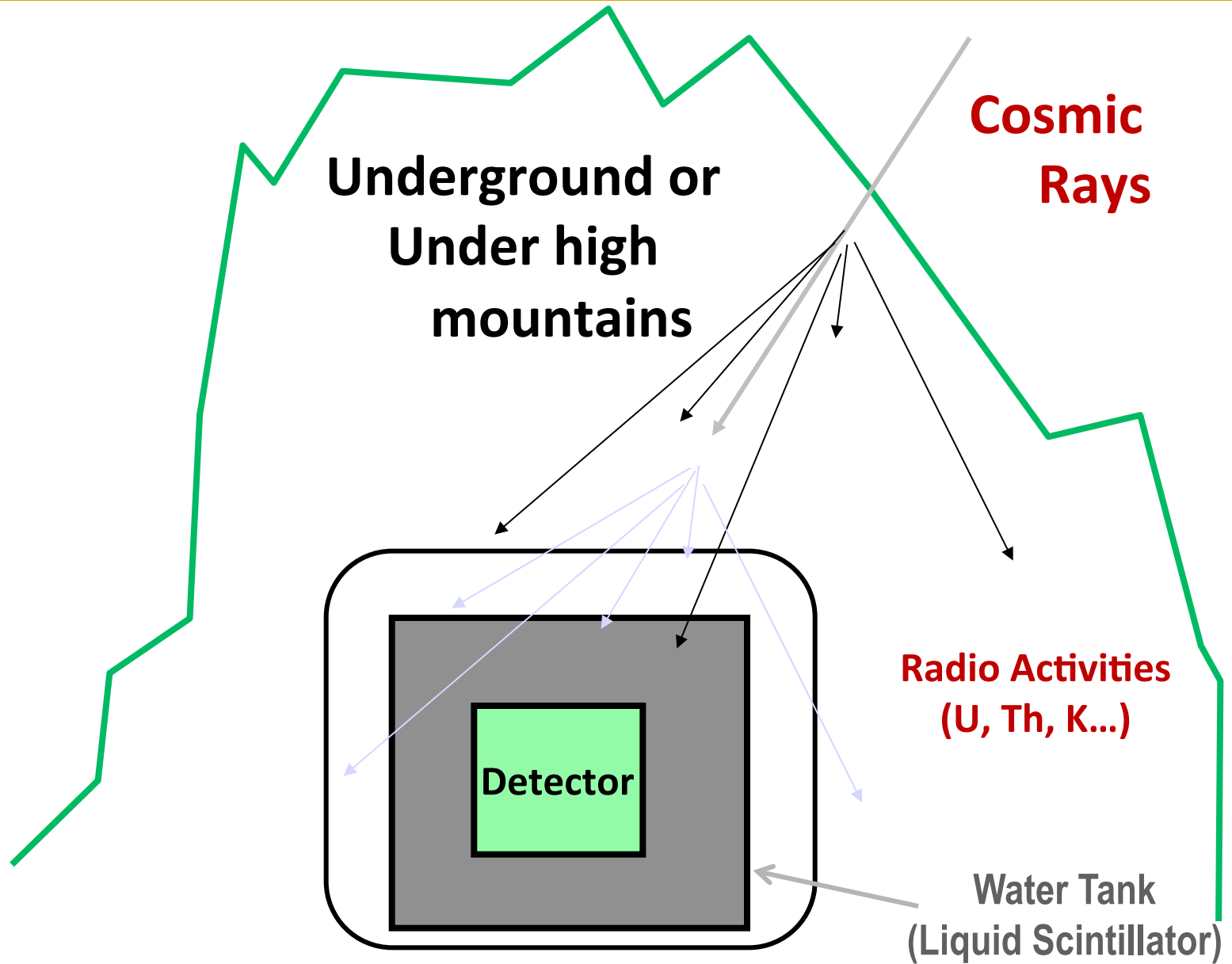
XENON100 Detector



XENON100 Detector (2009)

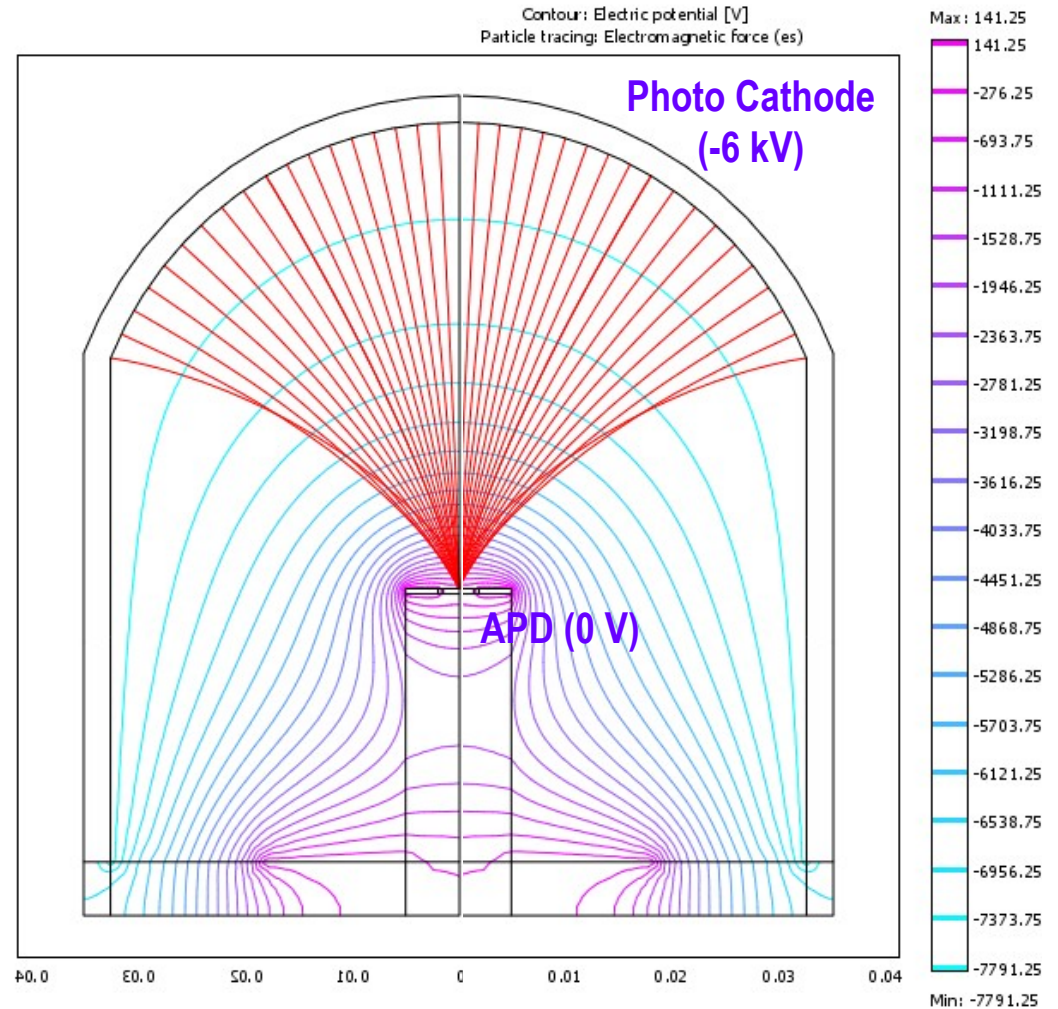
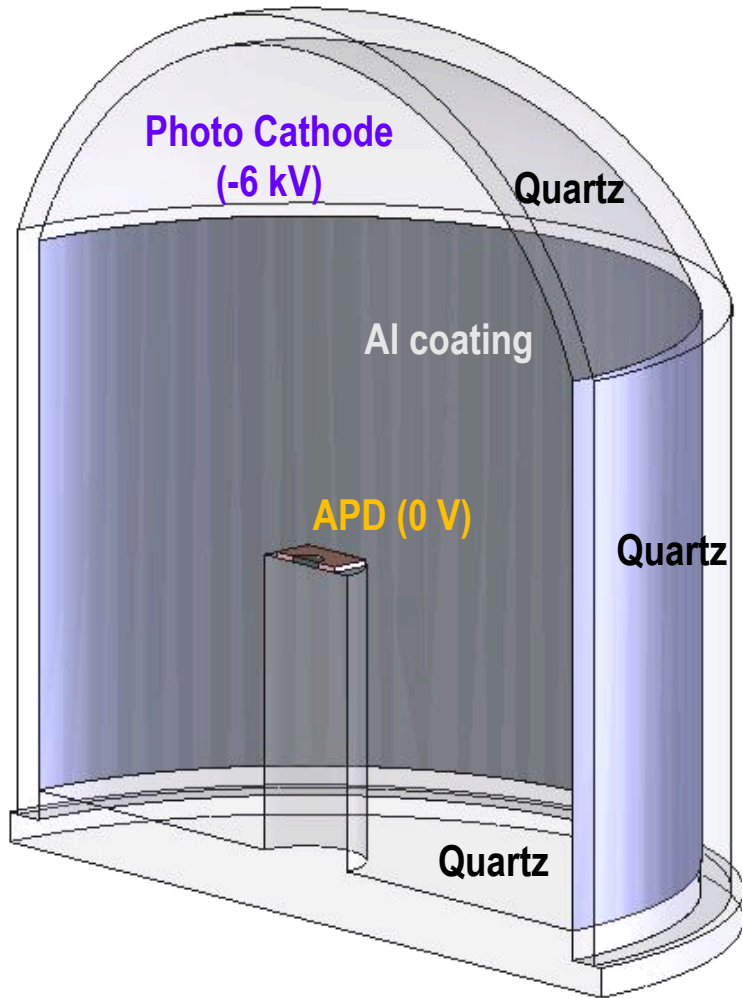


Where backgrounds come from?



Ultimately photon detectors are the major source of backgrounds.

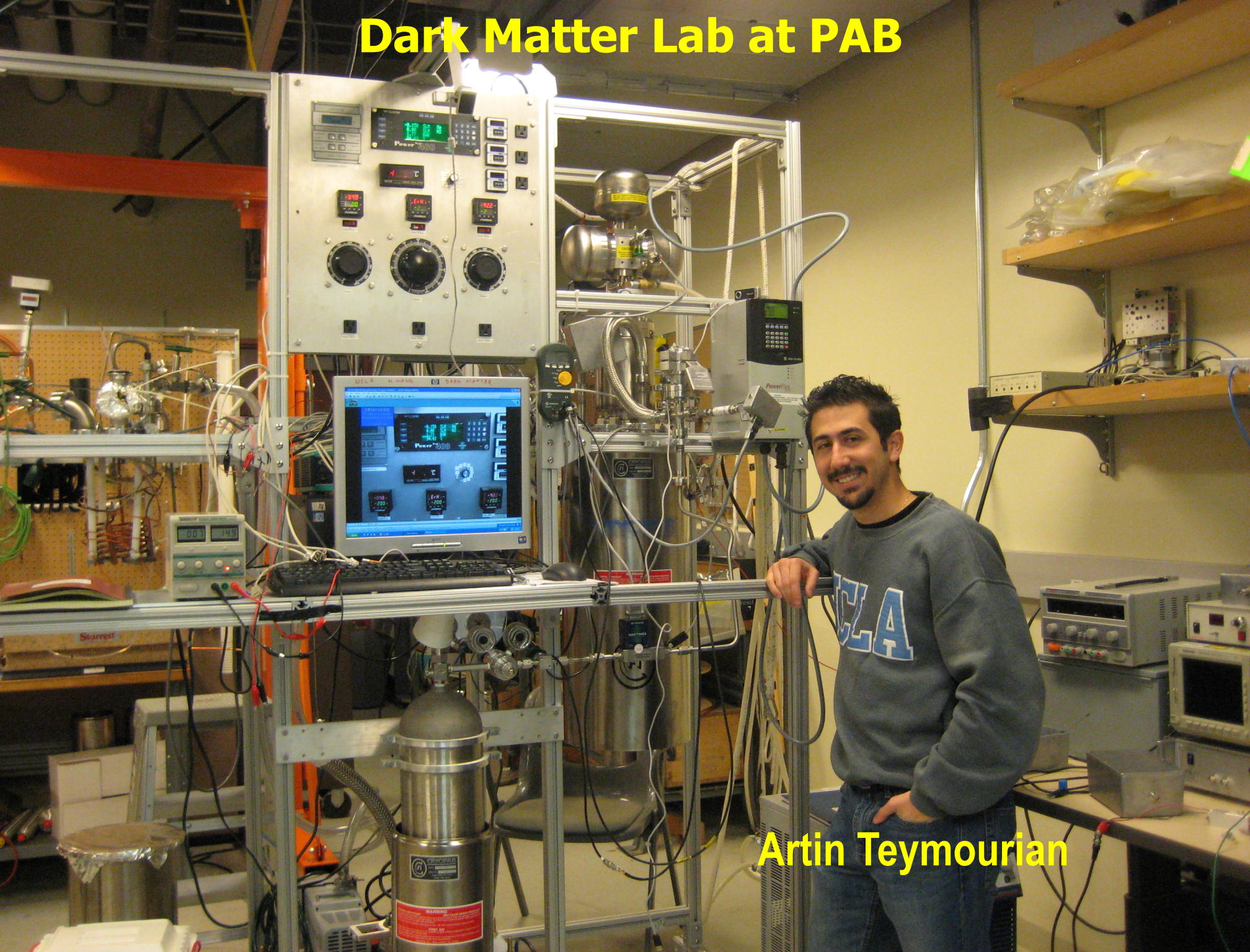
Structure and Electron Trajectories of 3" QUPID



Mechanical Samples on Base plate

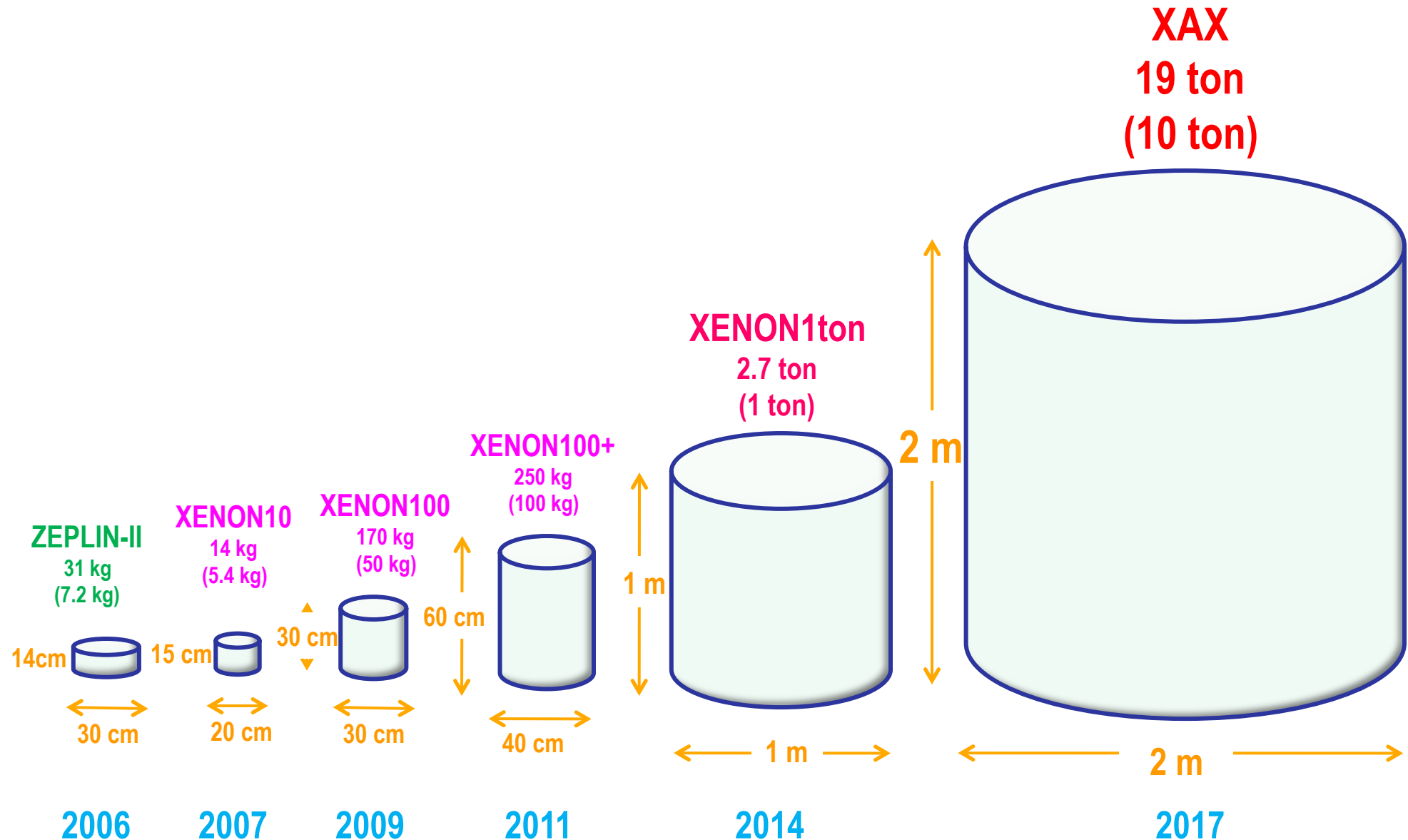


Dark Matter Lab at PAB

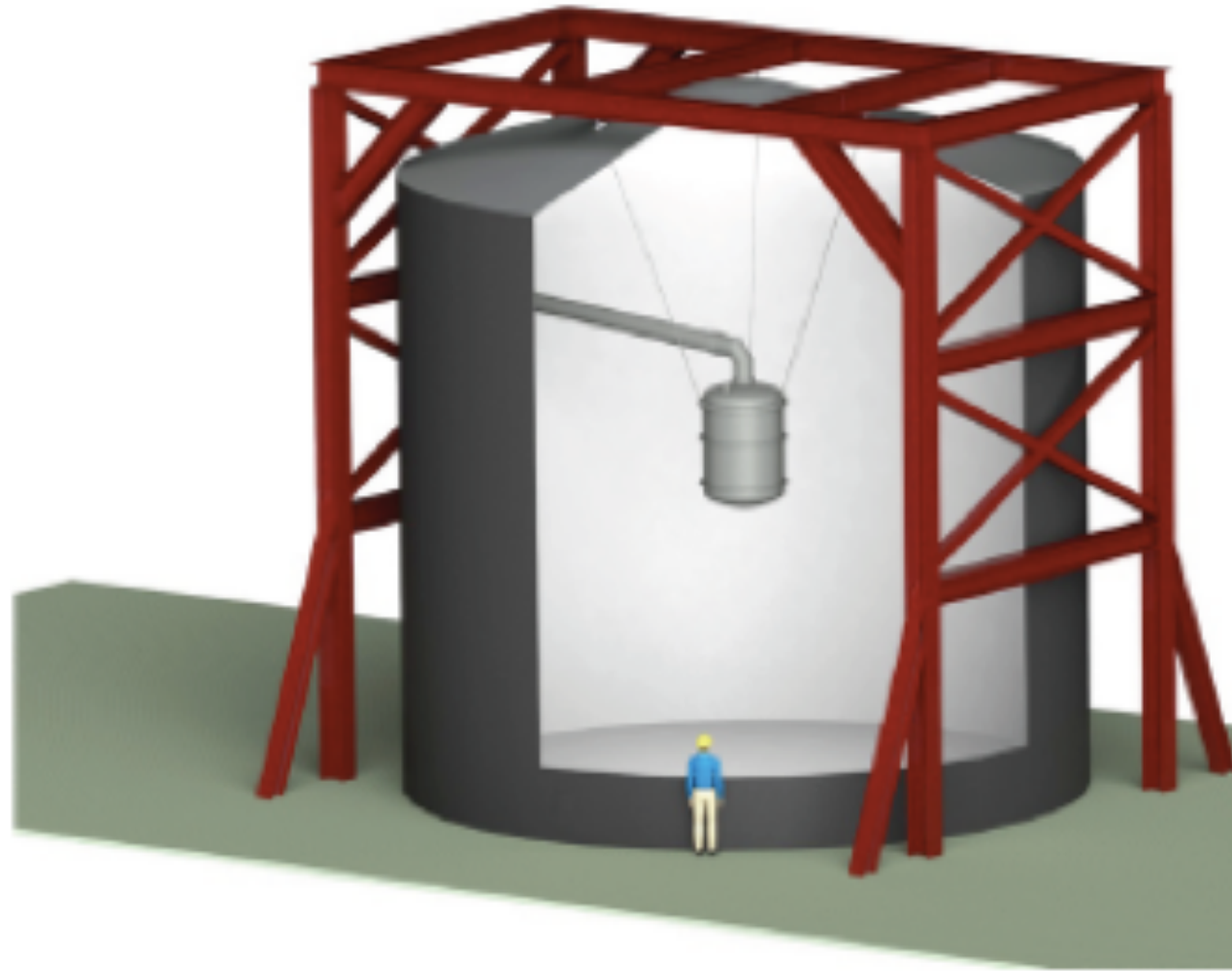
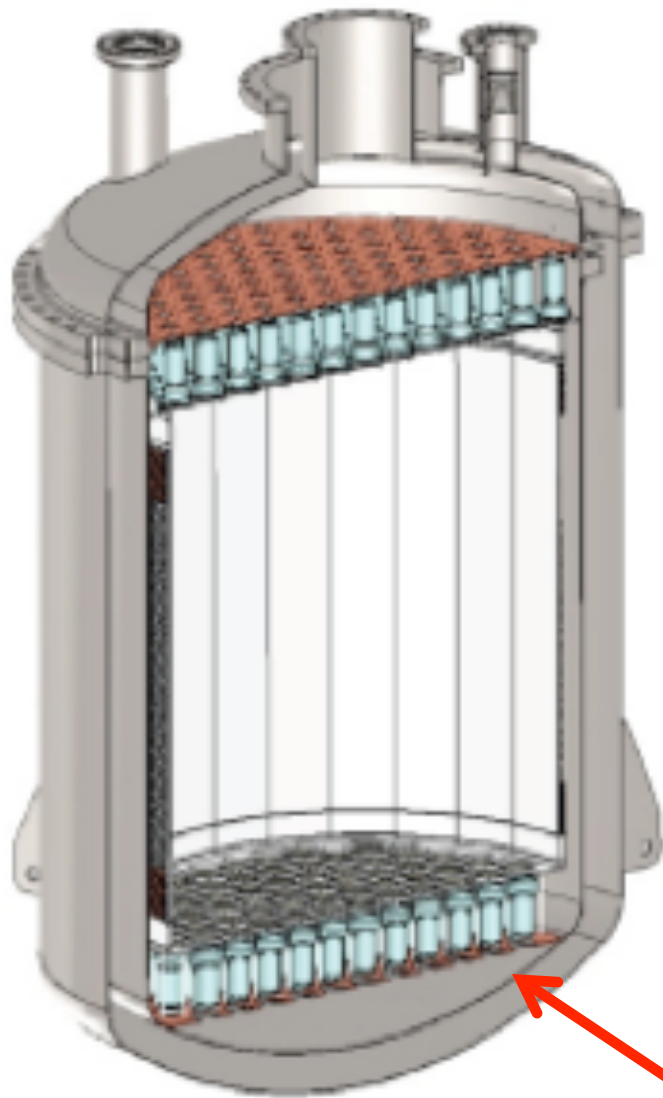


Artin Teymourian

Comparison of Detector Size

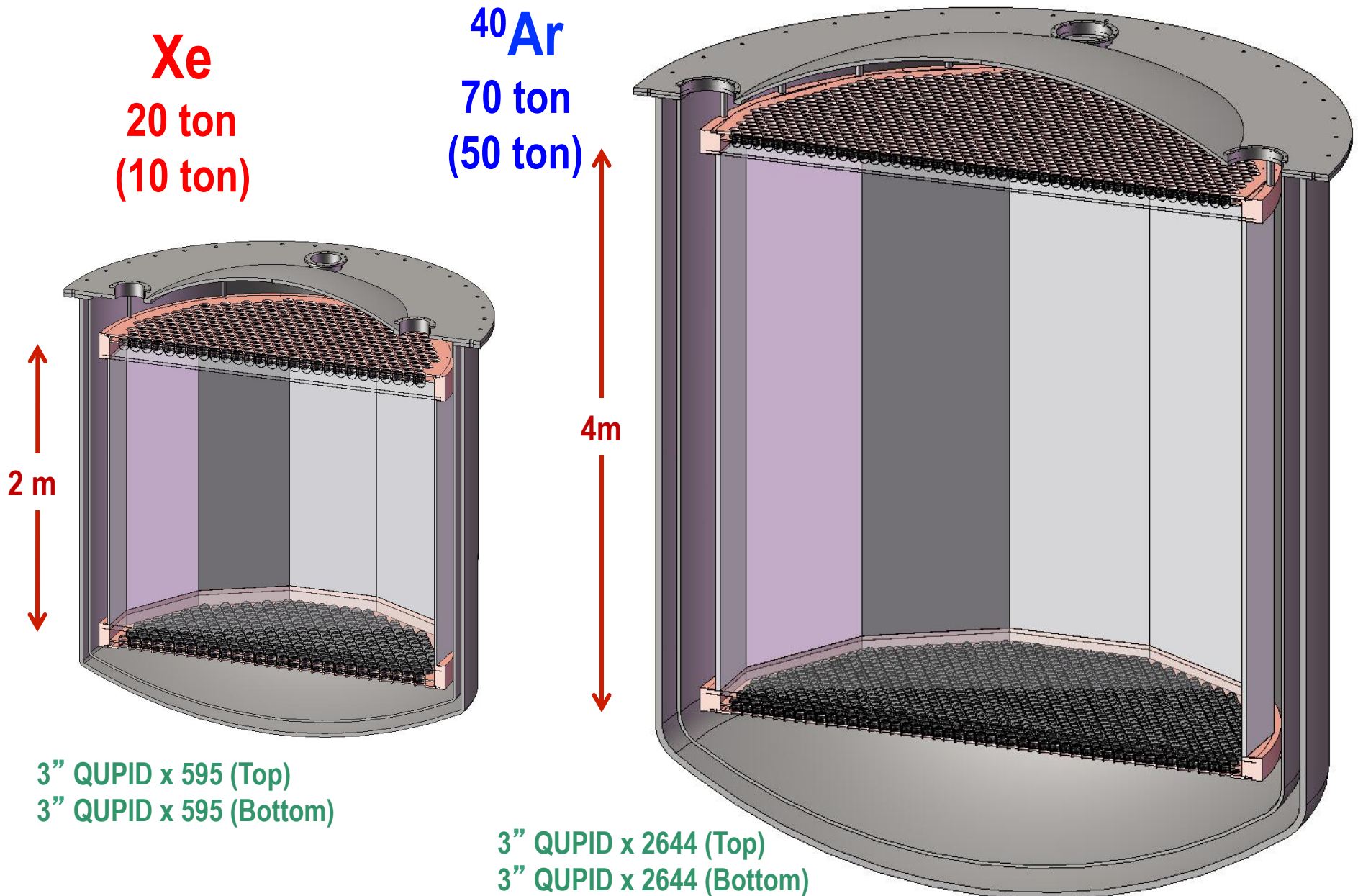


XENON1T



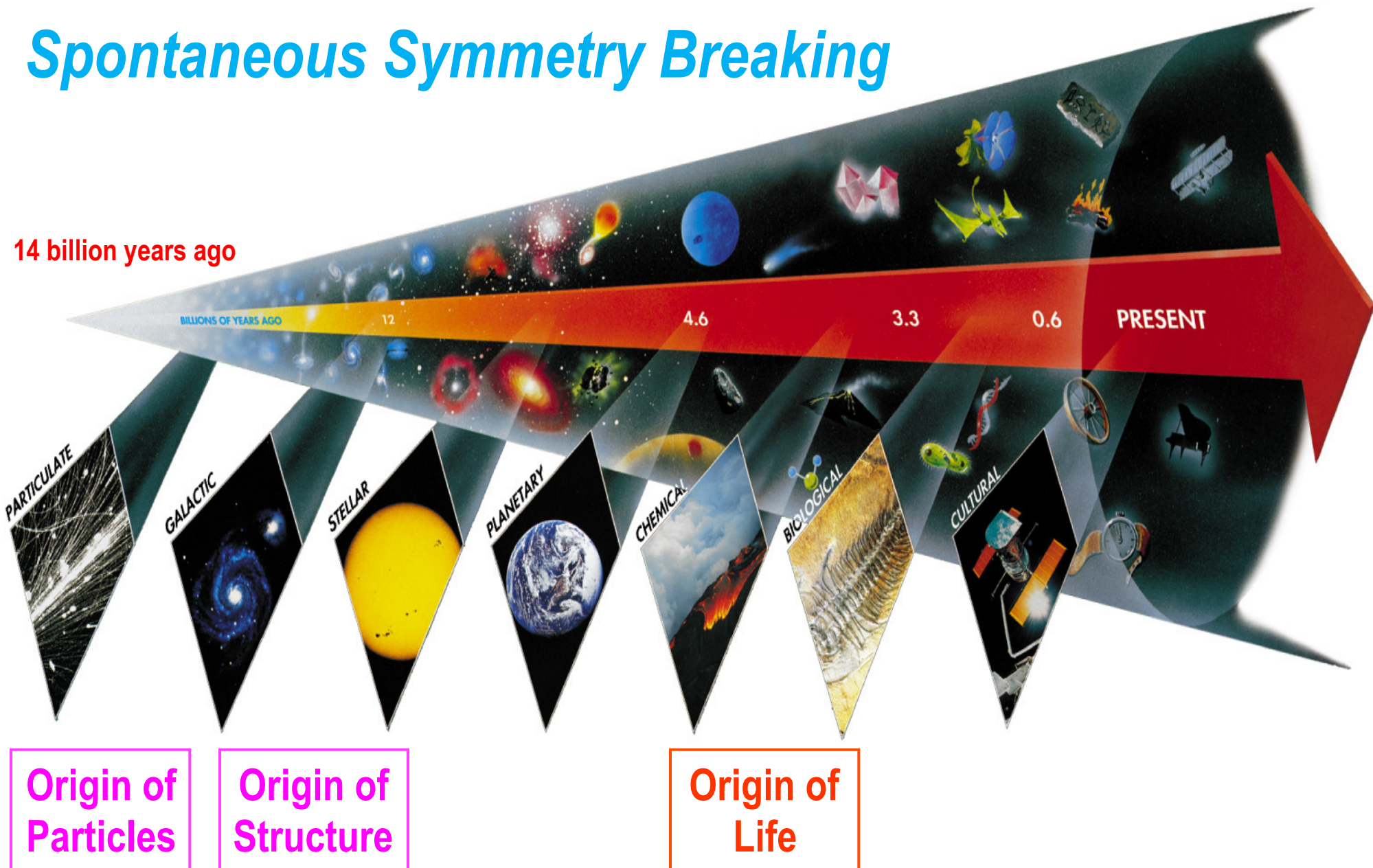
Alex's Project

MAX Detector (G3)

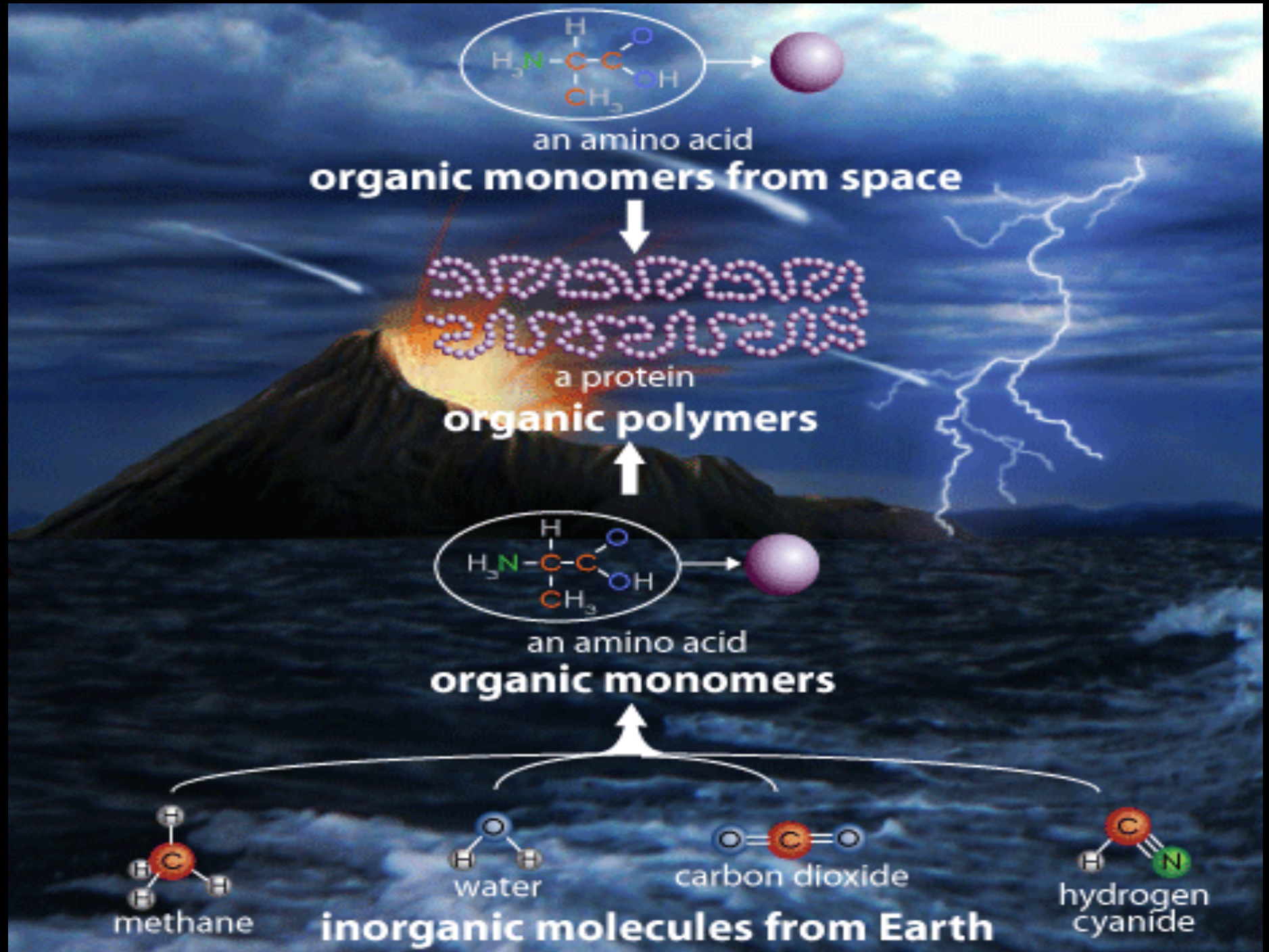


Seven Phases of Cosmic Evolution

Spontaneous Symmetry Breaking

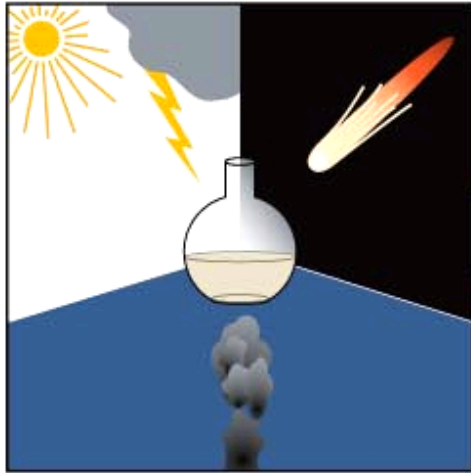


Organic Polymers (4.5B → 4B years)

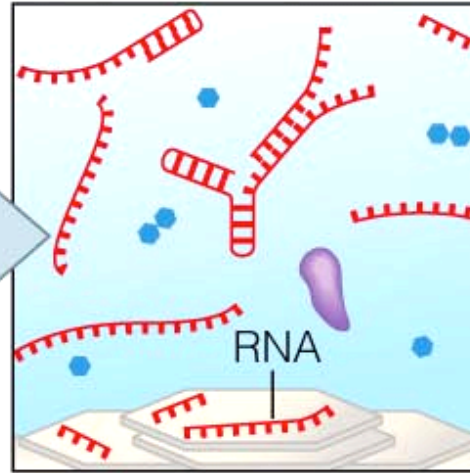


RNA World (4B → 3.5B years ago)

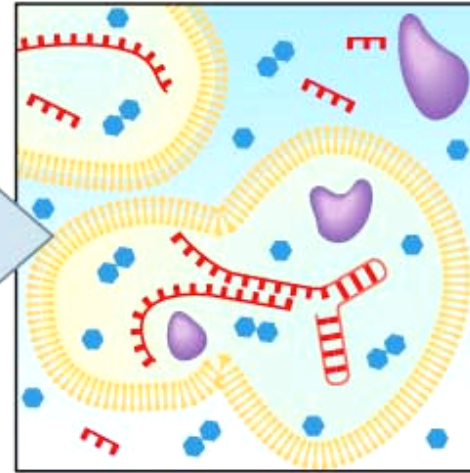
1. Organic precursor molecules appear.



2. RNA molecules become self-replicating.

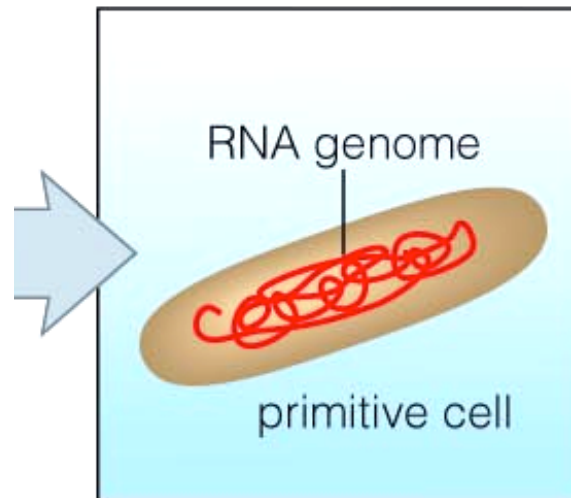


3. Membrane-enclosed pre-cells arise.

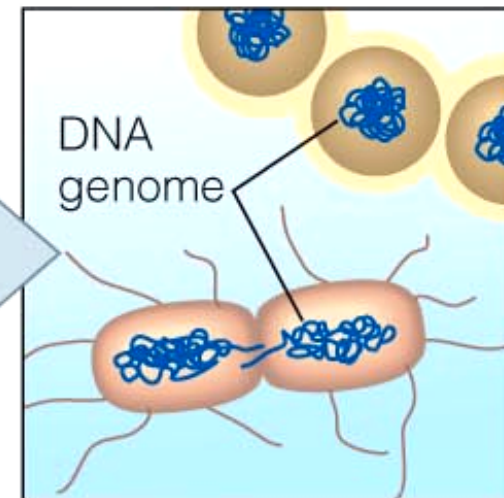


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4. True cells with RNA genome appear.



5. Modern cells with DNA genome evolve.



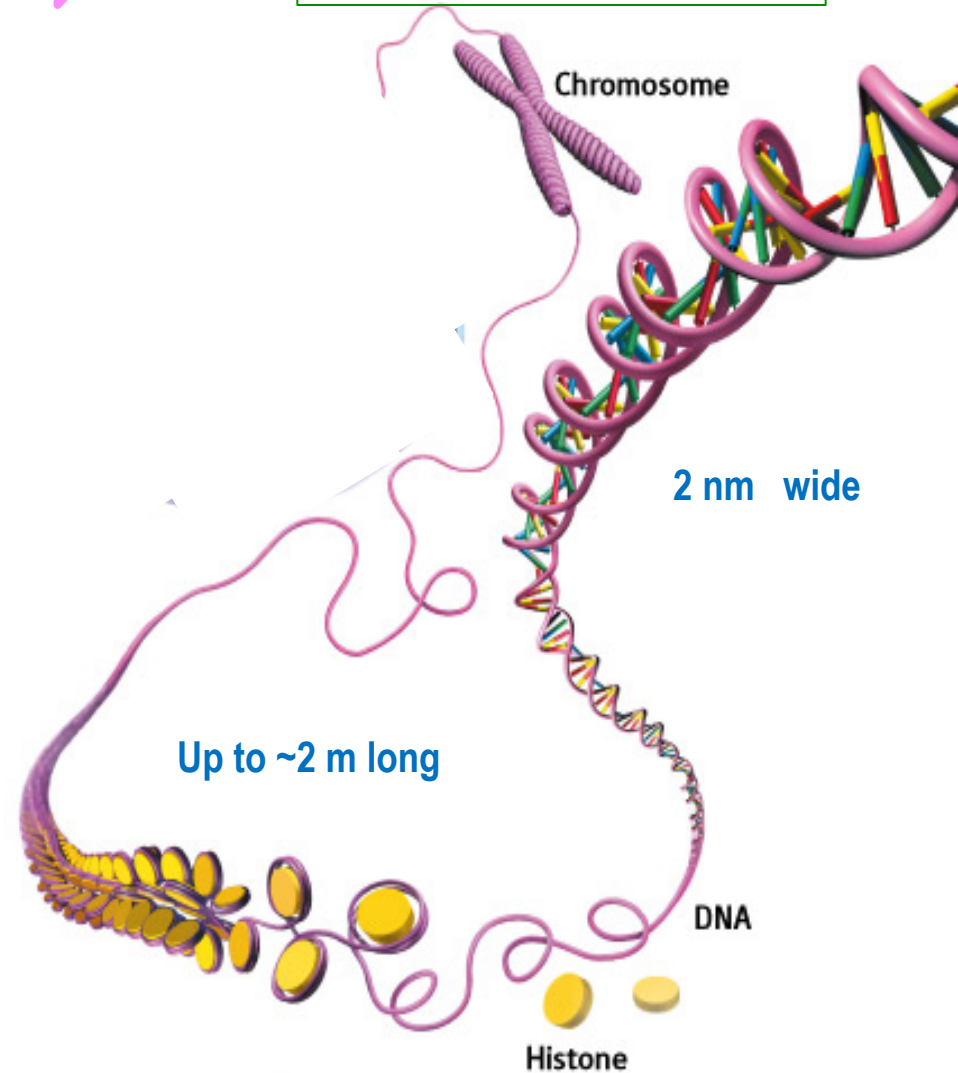
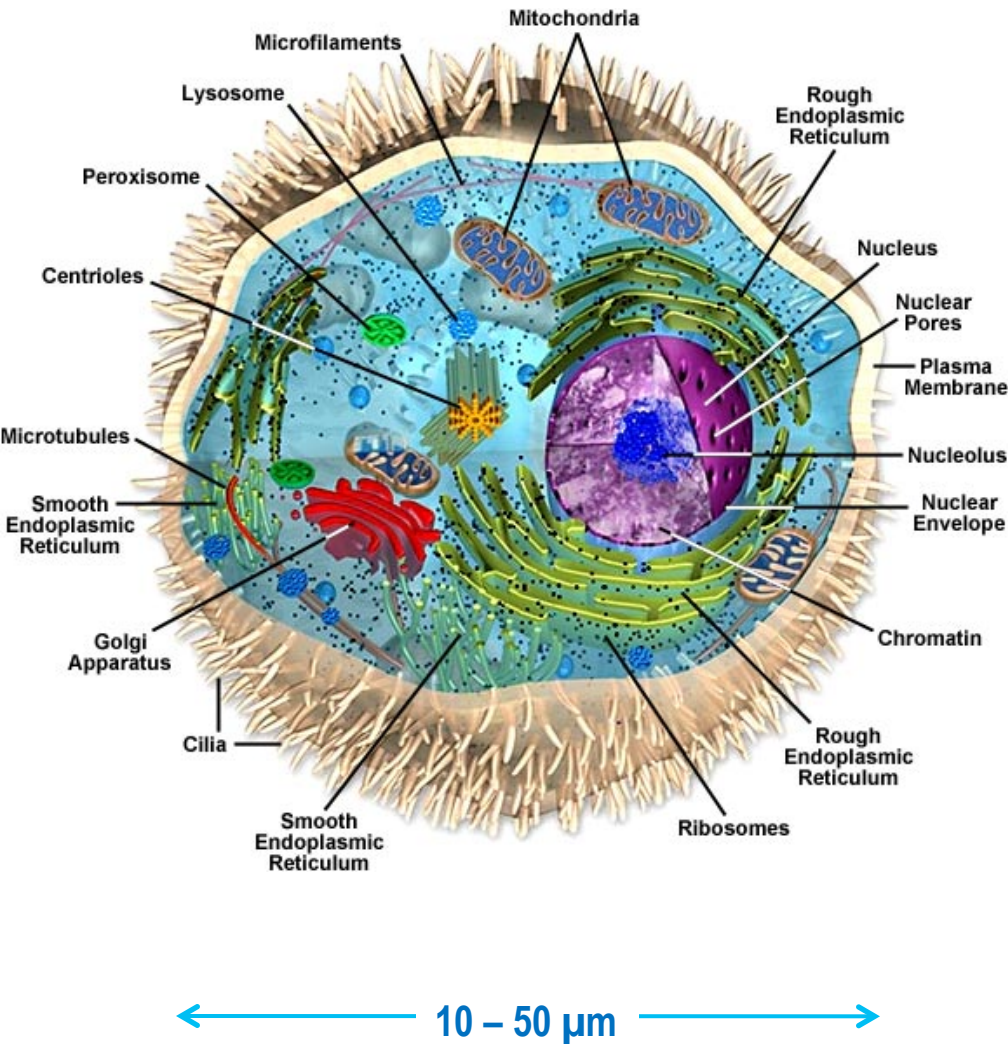
Eukaryote (~2B years ago)

Symmetry breaking

Cell made by proteins



Gene made by DNA



How to observe the “Origin of Life”

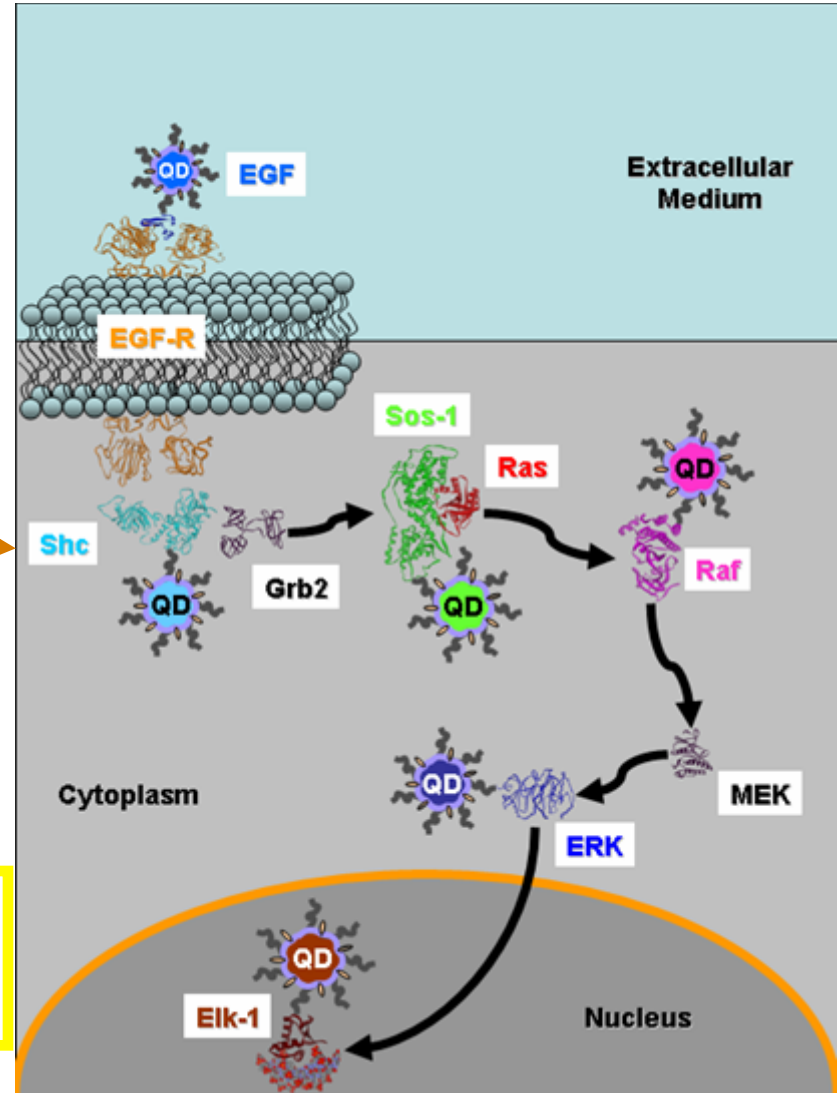
- Exactly the same way as we look for the “Origin of Universe”

Telescope ↔ Microscope

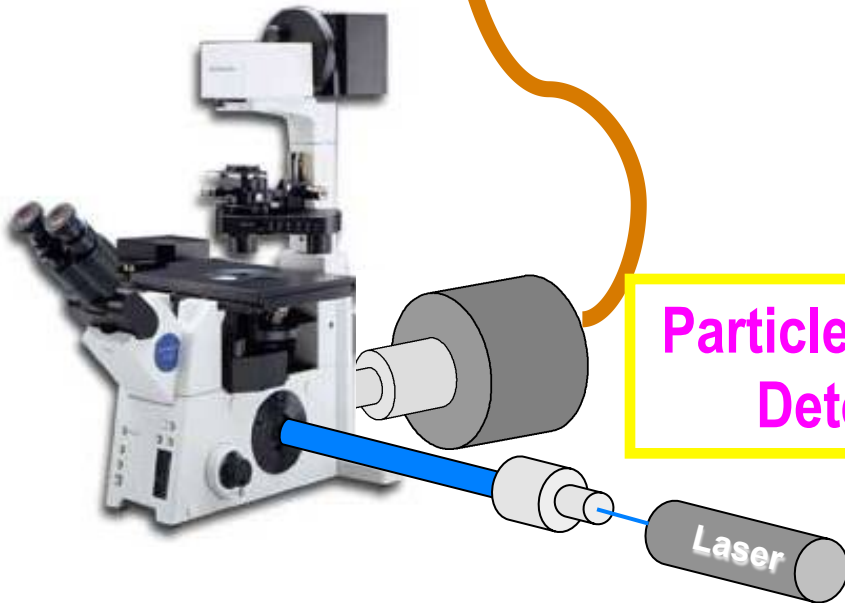
- We must look for “Live Life”
- Take advantages of the state of art “Photon Detectors” in particle physics.

Single Molecule Imaging

Nano Technology



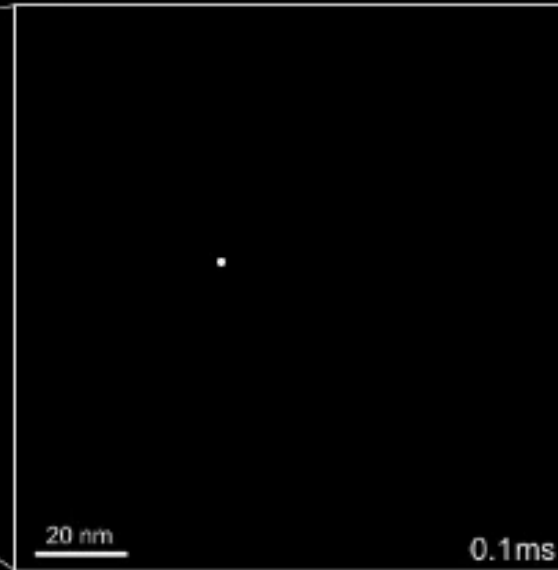
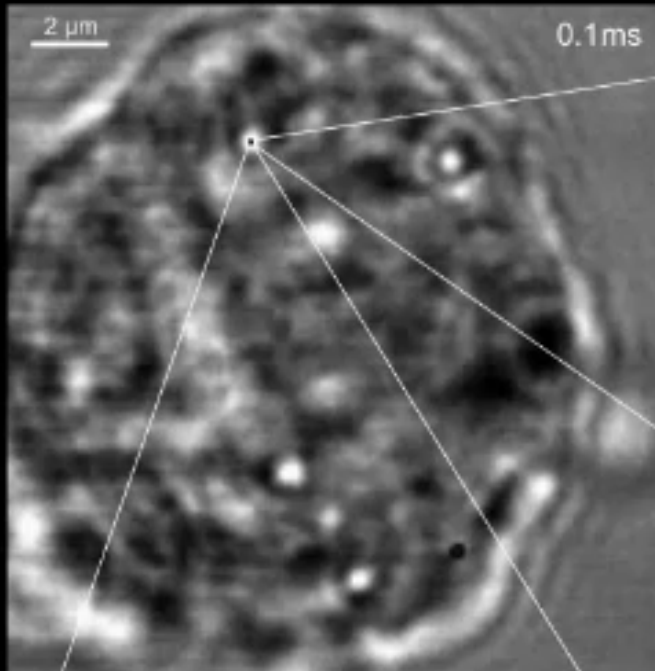
Particle Physics
Detector



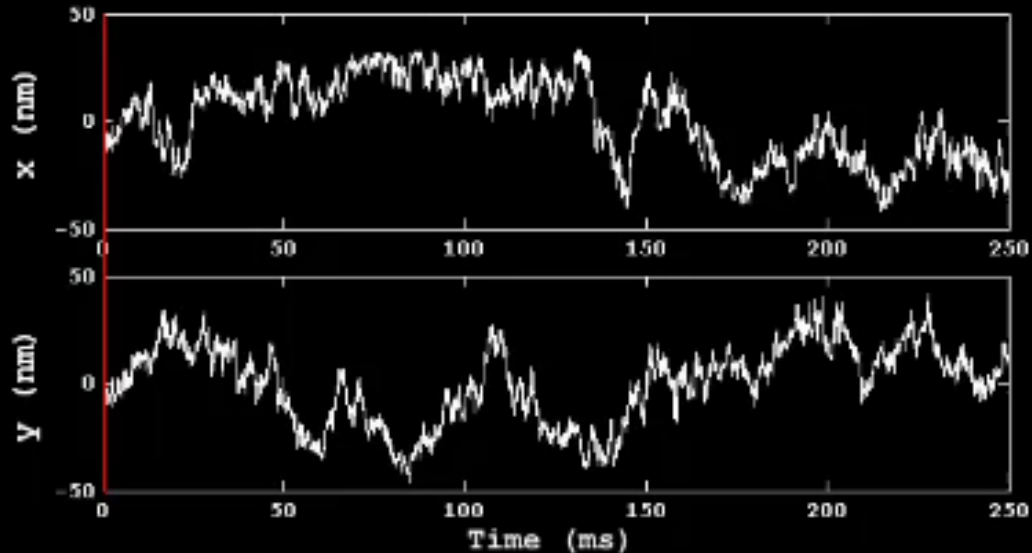
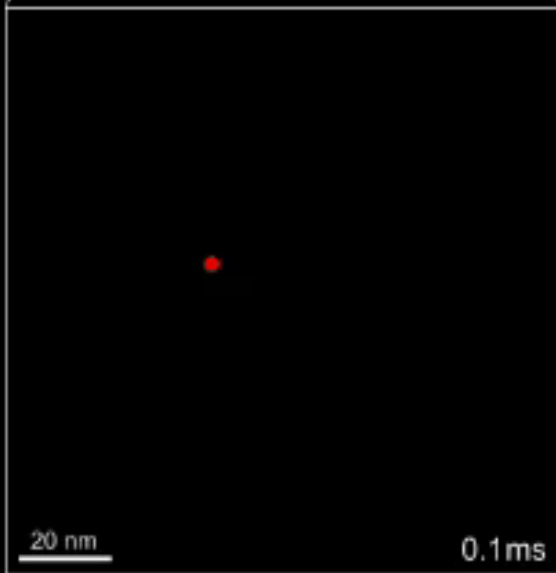
Prof. Shimon Weiss

Gold nano particle (40nm) attached to Transferrin Receptor (TfR) on Cancer Cell

Prof. Manuel Penichet (Oncology)



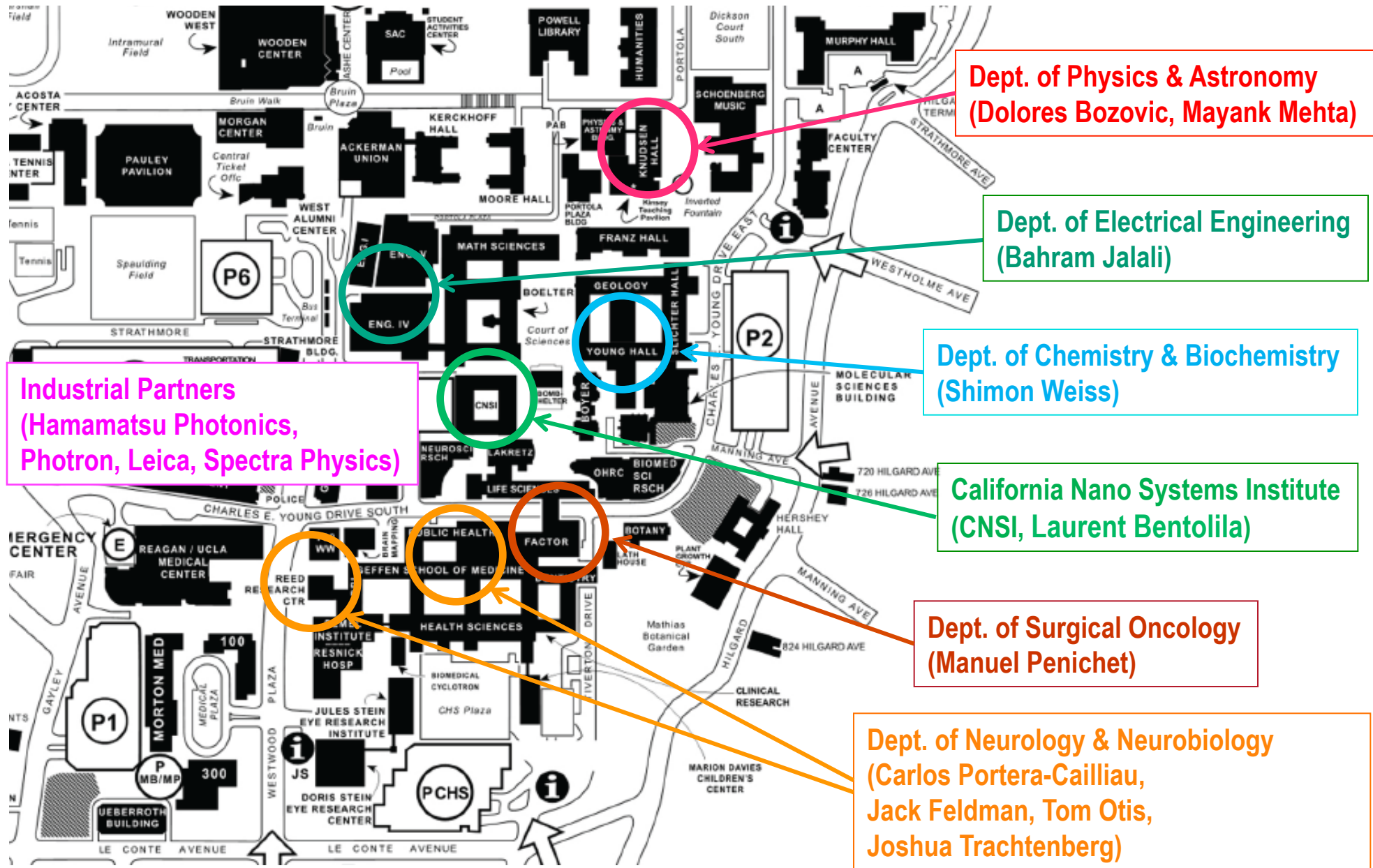
(10,000 frame/sec)



UCLA Fast Bio-Imaging Group

L. Fredrickson, J. Rodriguez, A. Cheng, K. Jewhurst, J. Miao, K. Arisaka

Arisaka's Campus-wide Collaborations on High-Speed Bio-imaging



High-speed Confocal Microscope with ICMOS at CNSI

(1,000 frame/s)

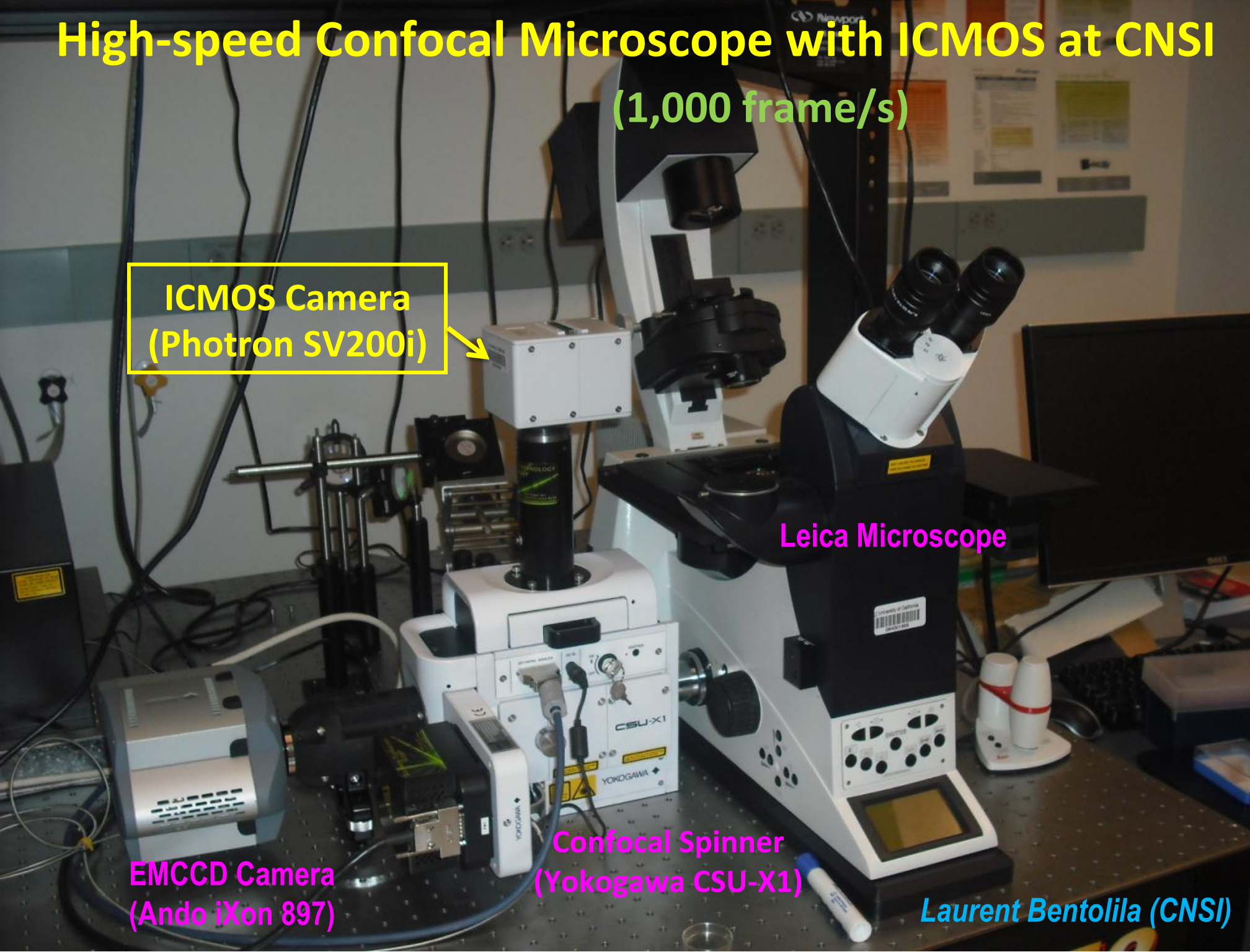
ICMOS Camera
(Photron SV200i)

Leica Microscope

EMCCD Camera
(Ando iXon 897)

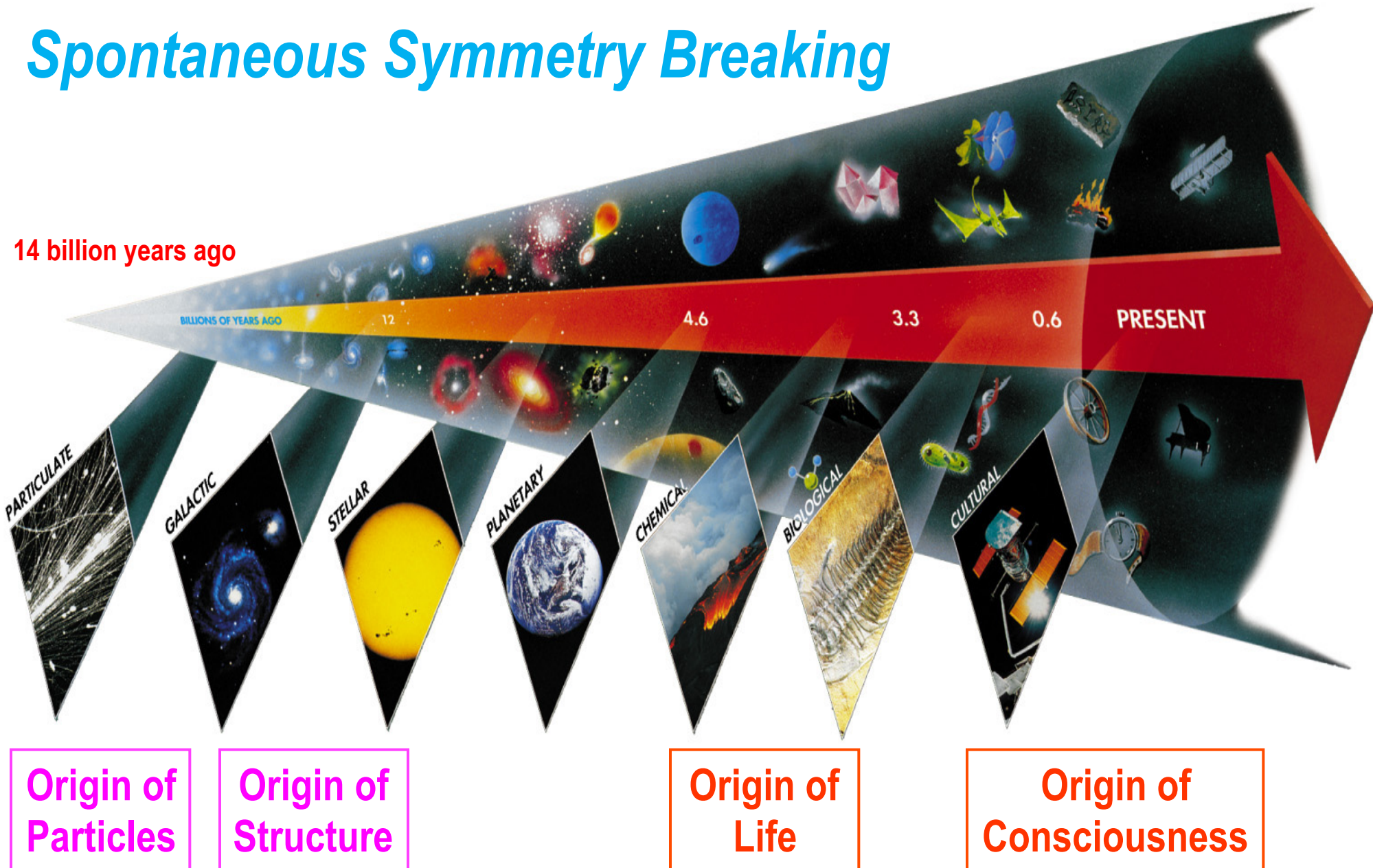
Confocal Spinner
(Yokogawa CSU-X1)

Laurent Bentolila (CNSI)



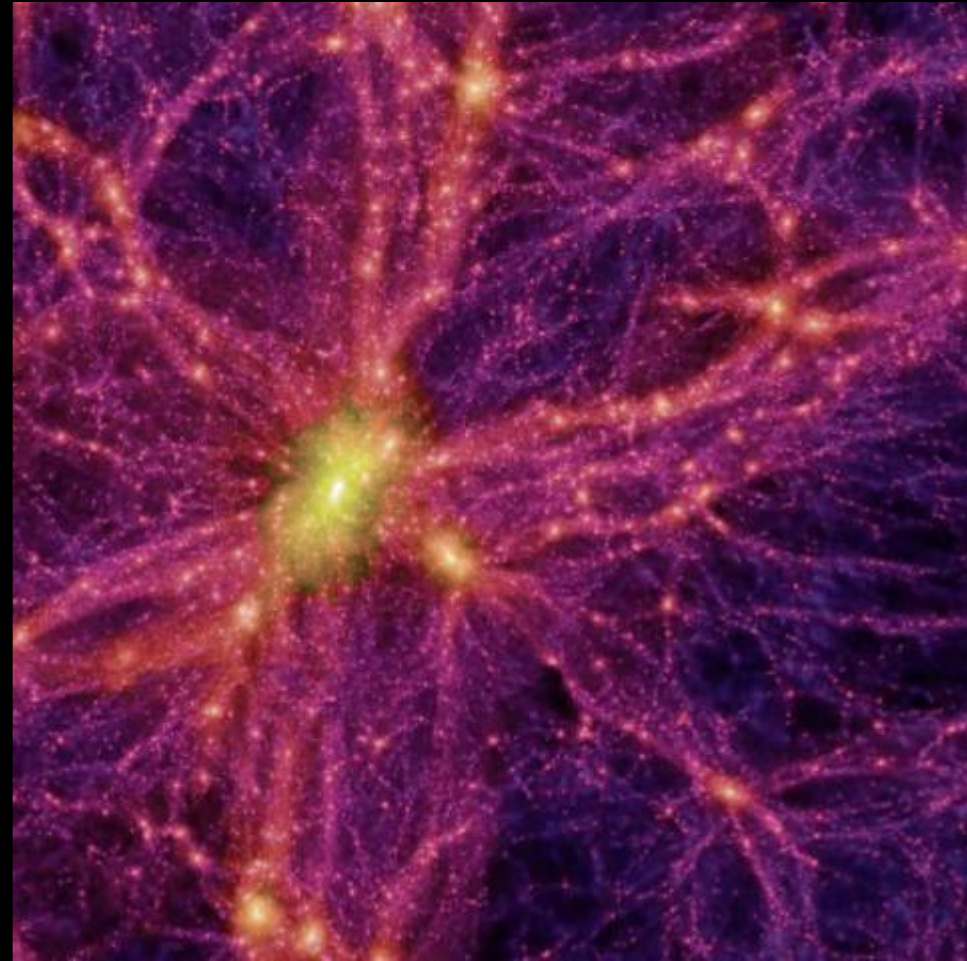
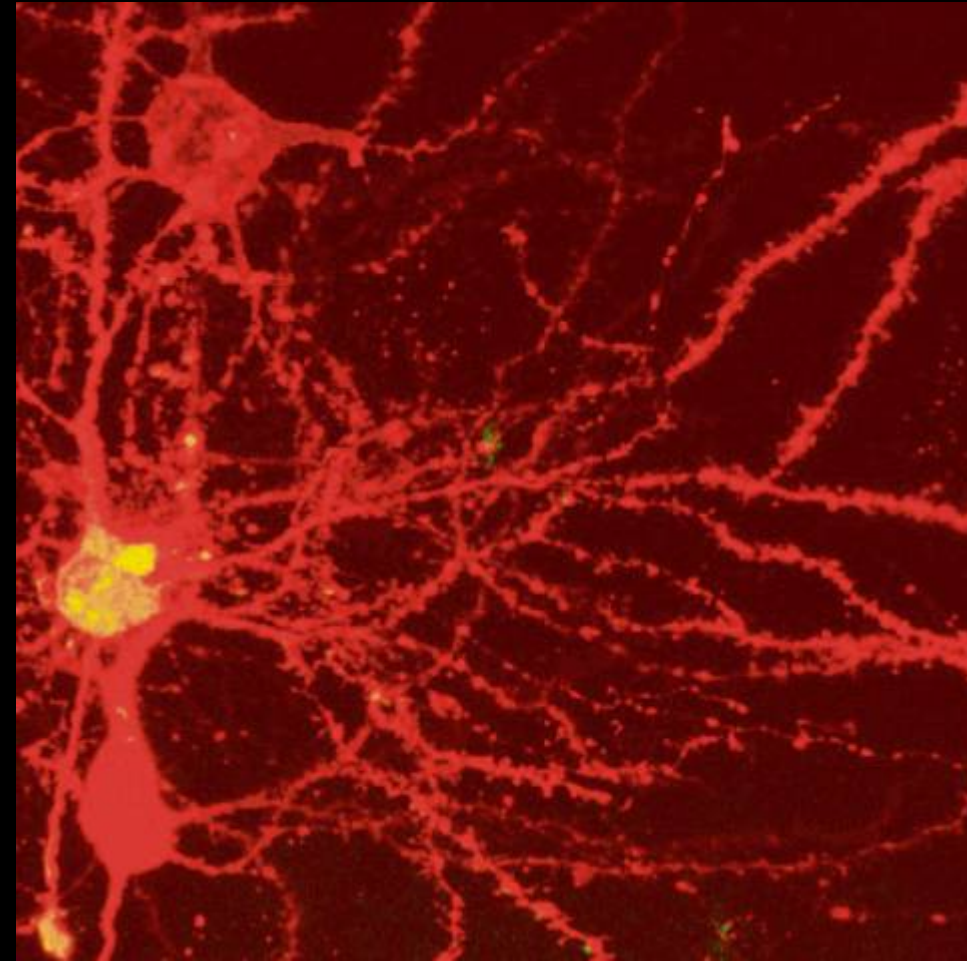
Seven Phases of Cosmic Evolution

Spontaneous Symmetry Breaking



Brain

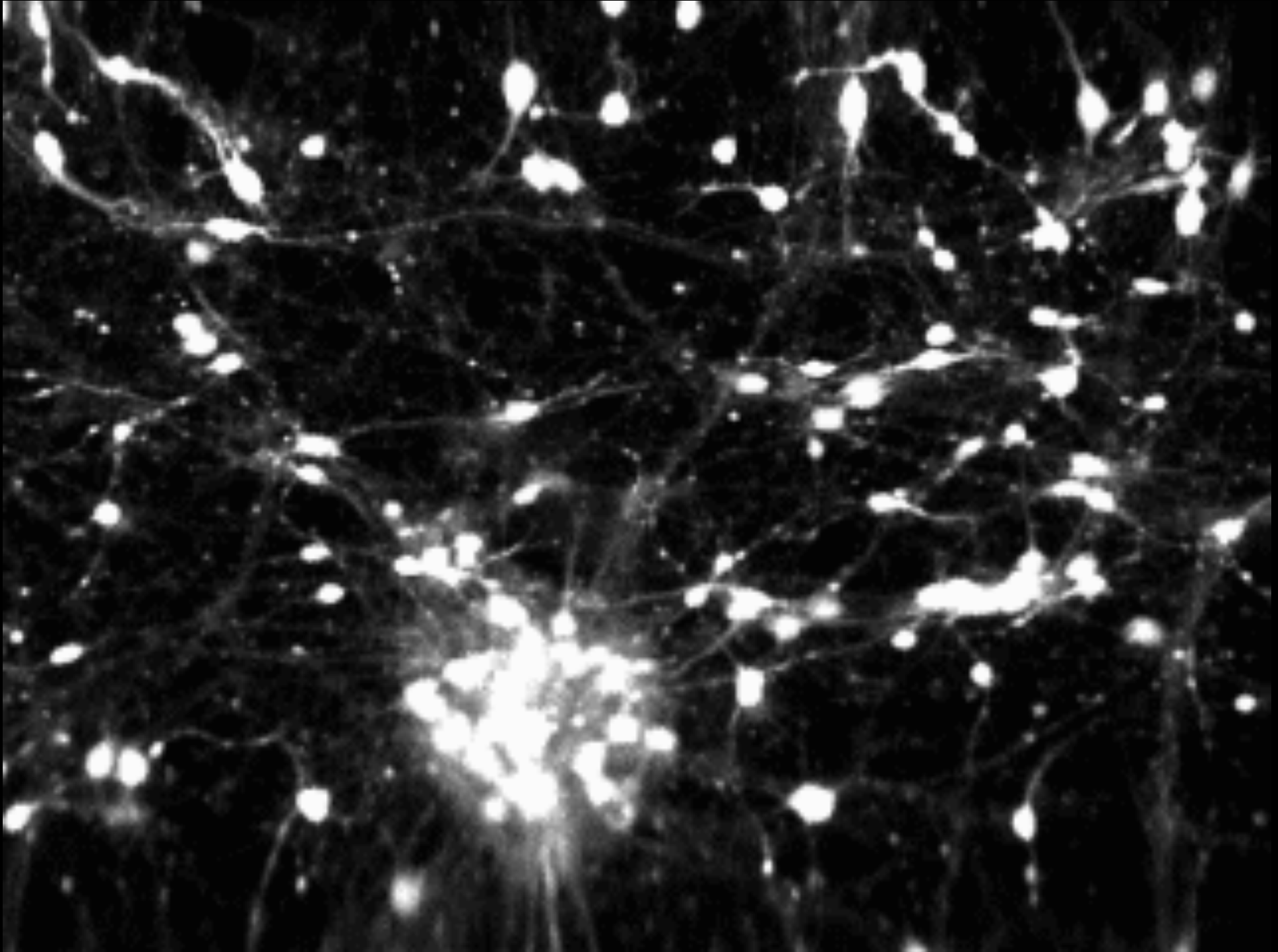
Universe



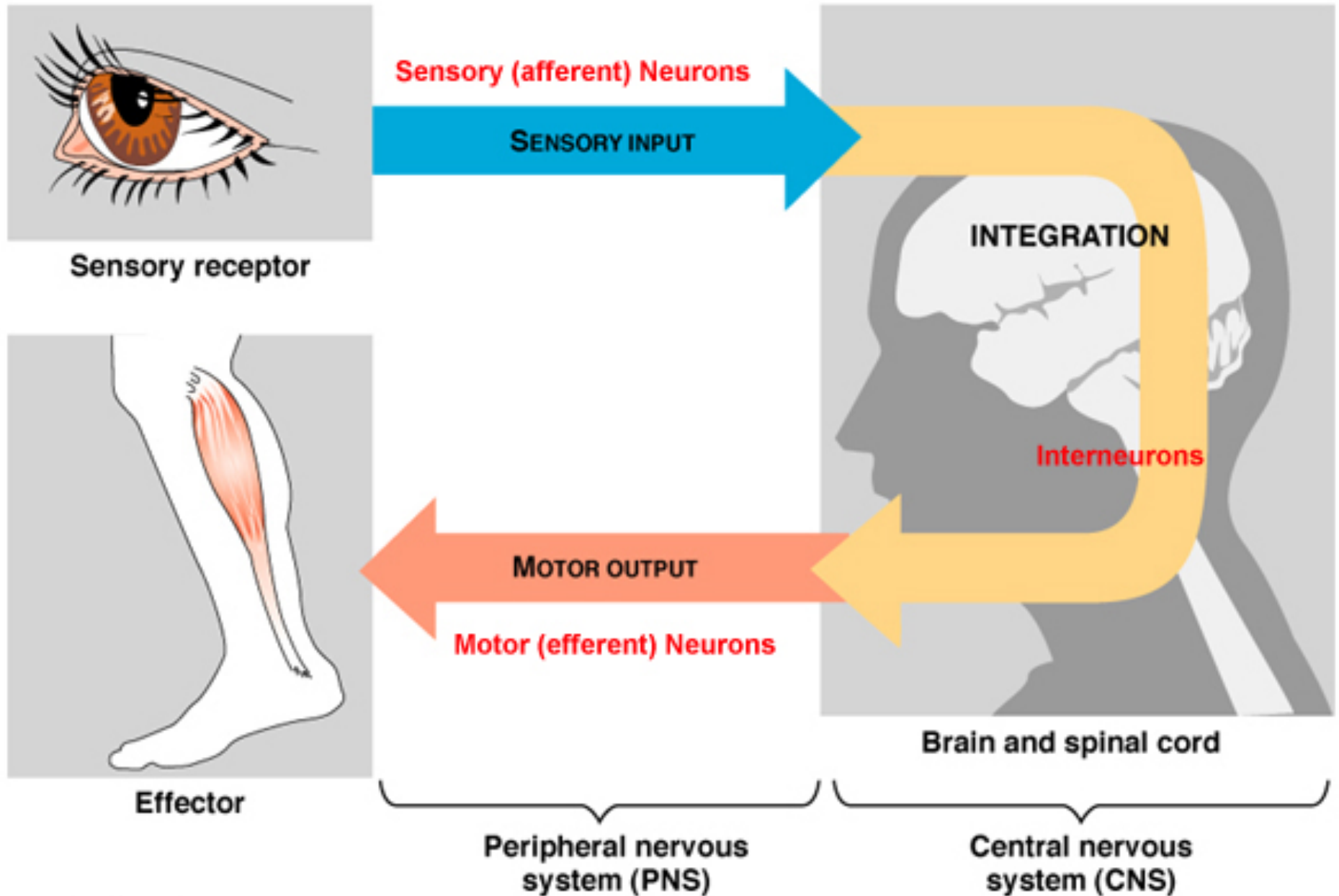
100 Billions Neurons

100 Billions Galaxies

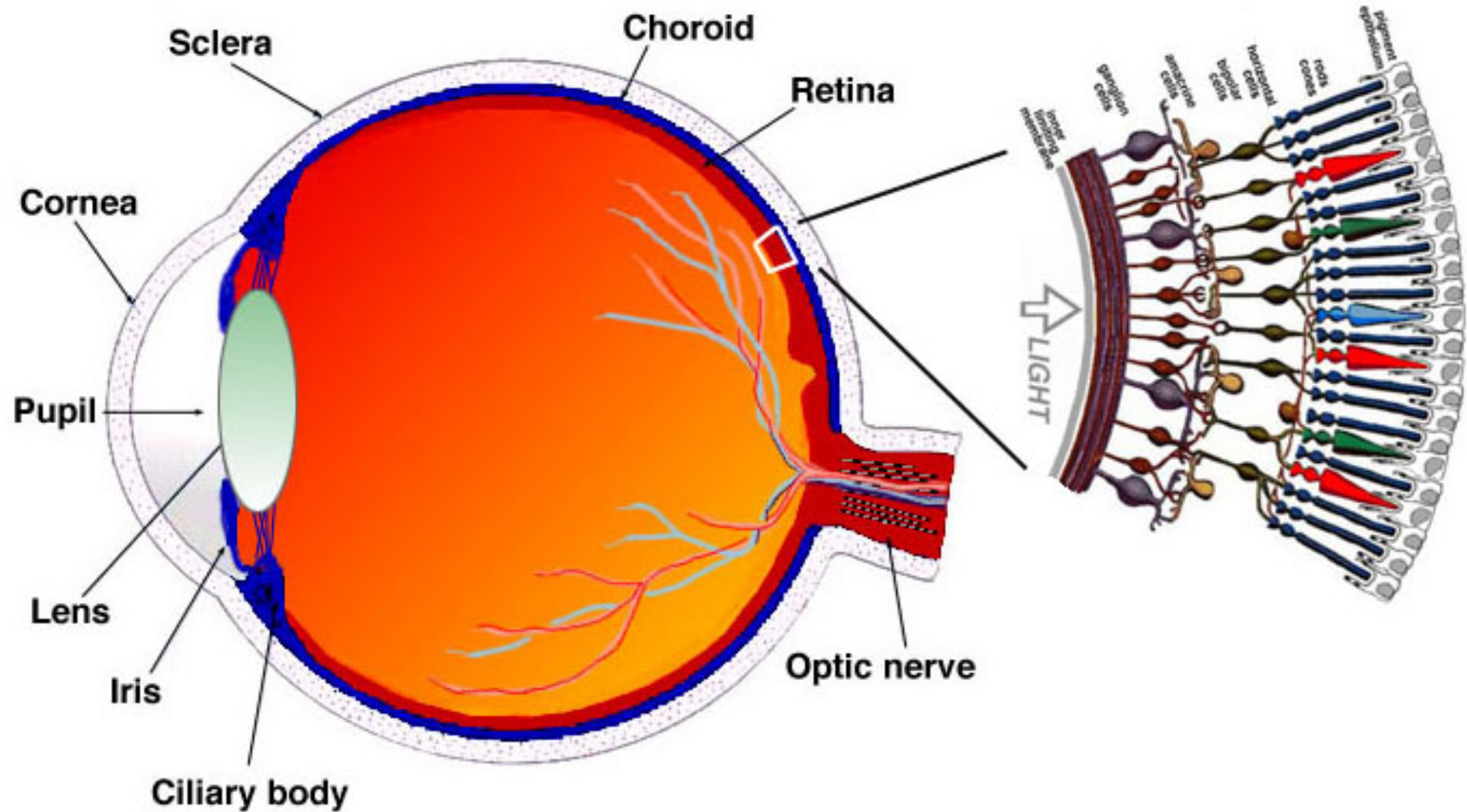
Ca²⁺ Signal in cultivated Rat's Brain



Assembly of cortical circuits during development



Human Eyes



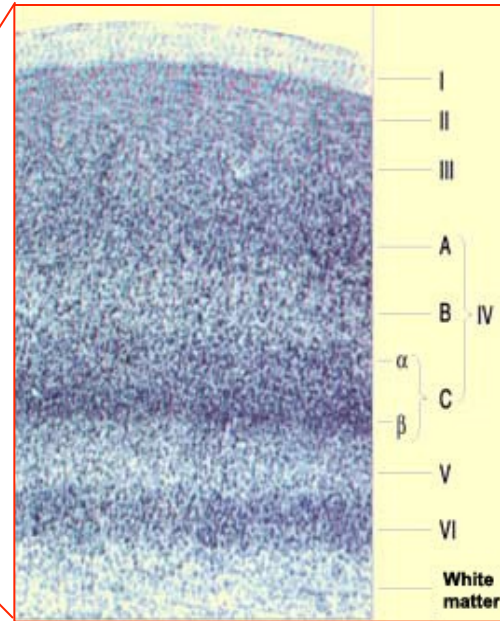
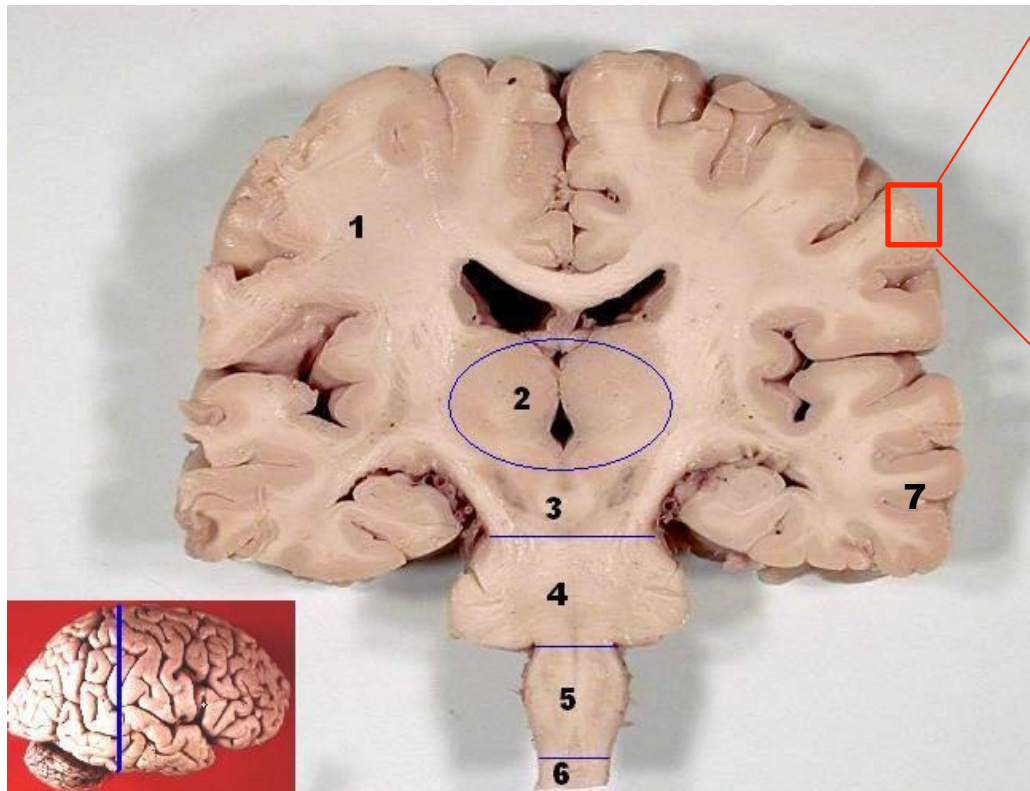
How can I recognize a woman so far away?



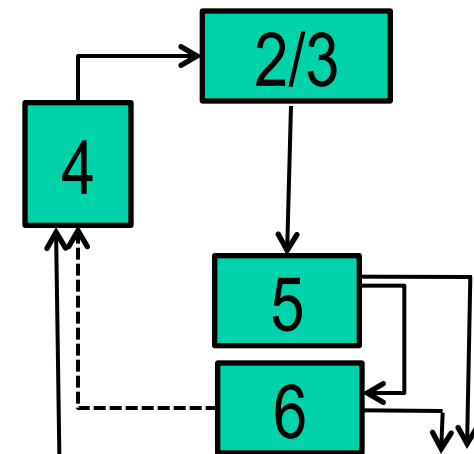
- Genetically encoded?
- Learning and memory?

The Cerebral Cortex

Conscious



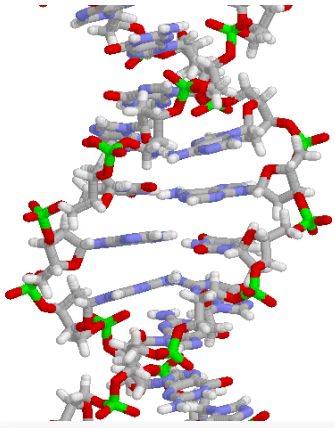
Unconscious



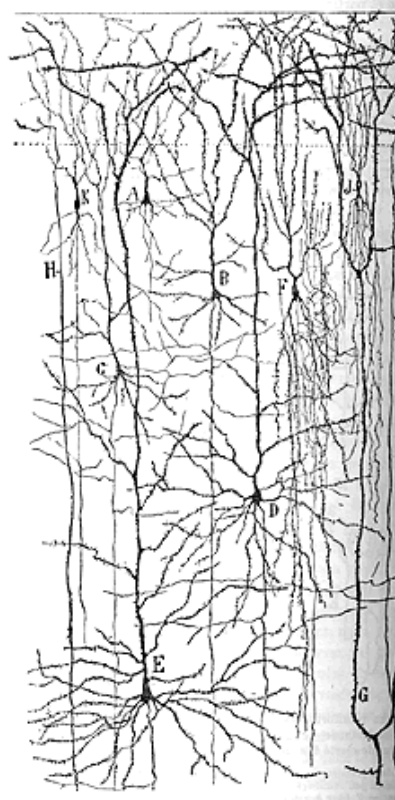
Thalamus

Subcortical areas

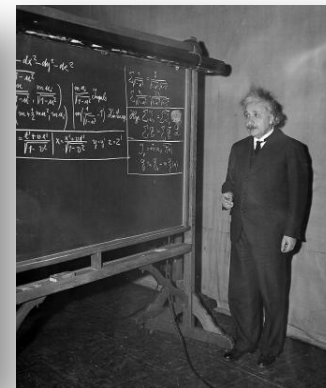
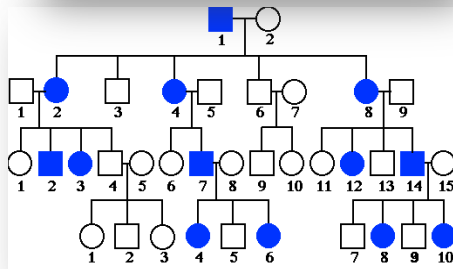
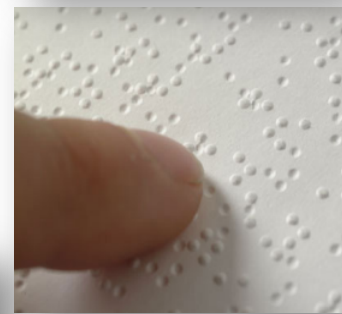
Nature vs. Nurture



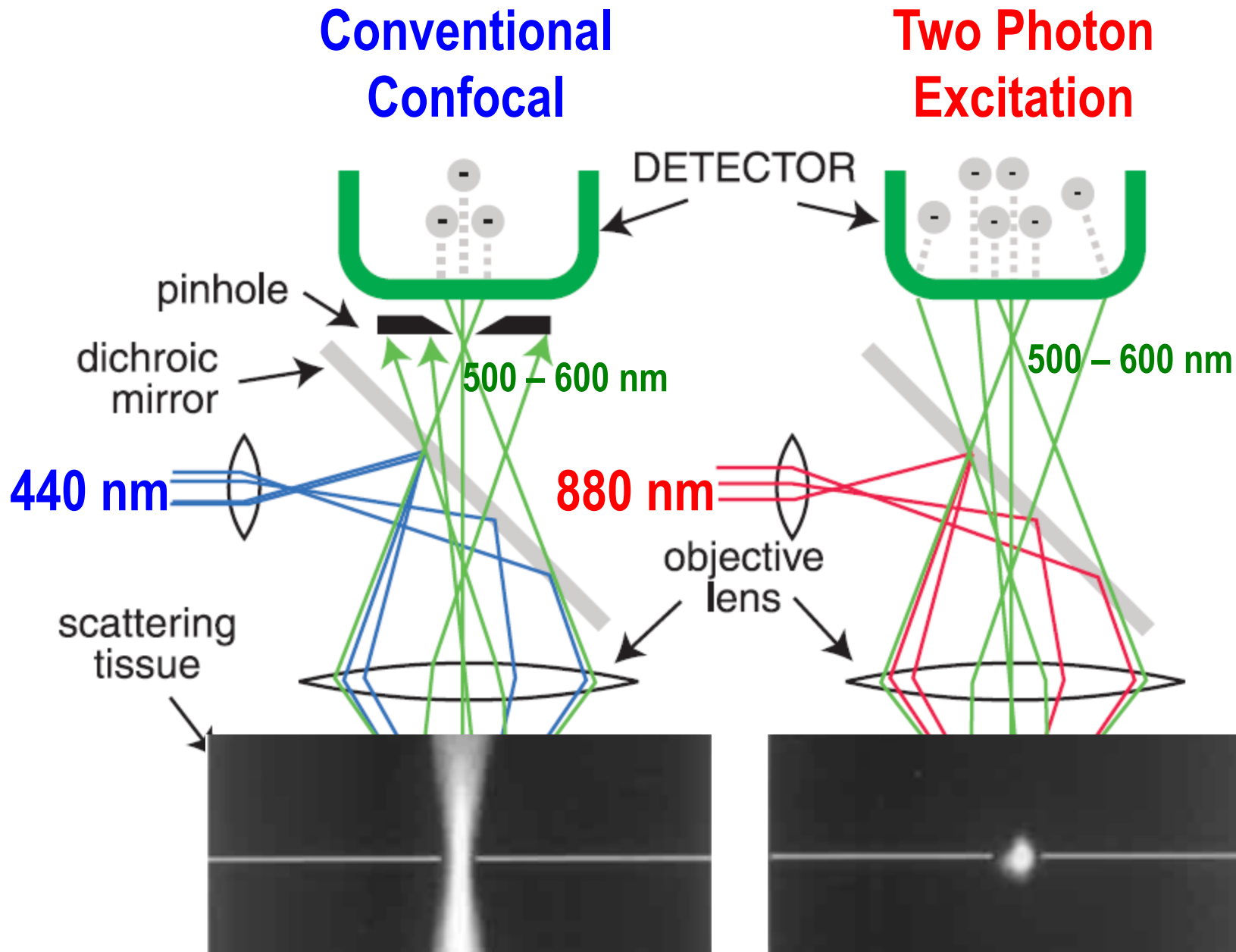
Nature



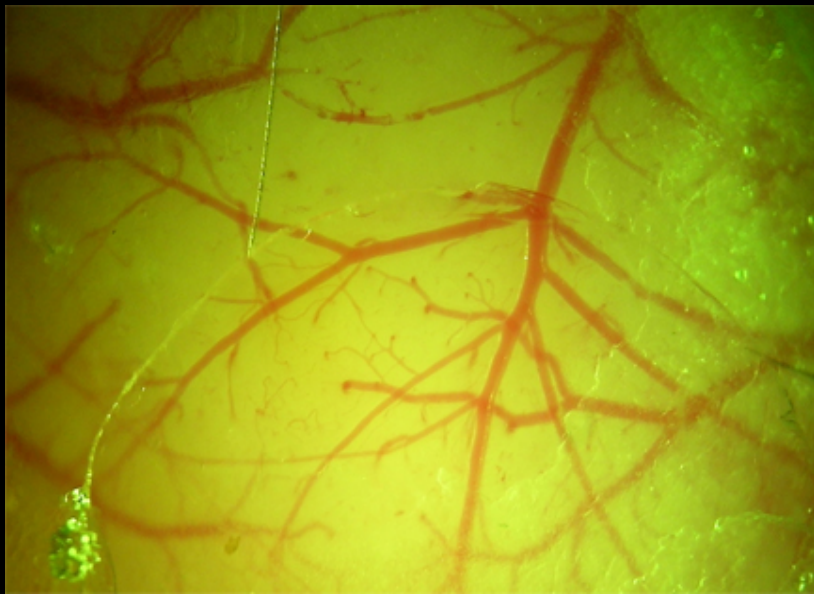
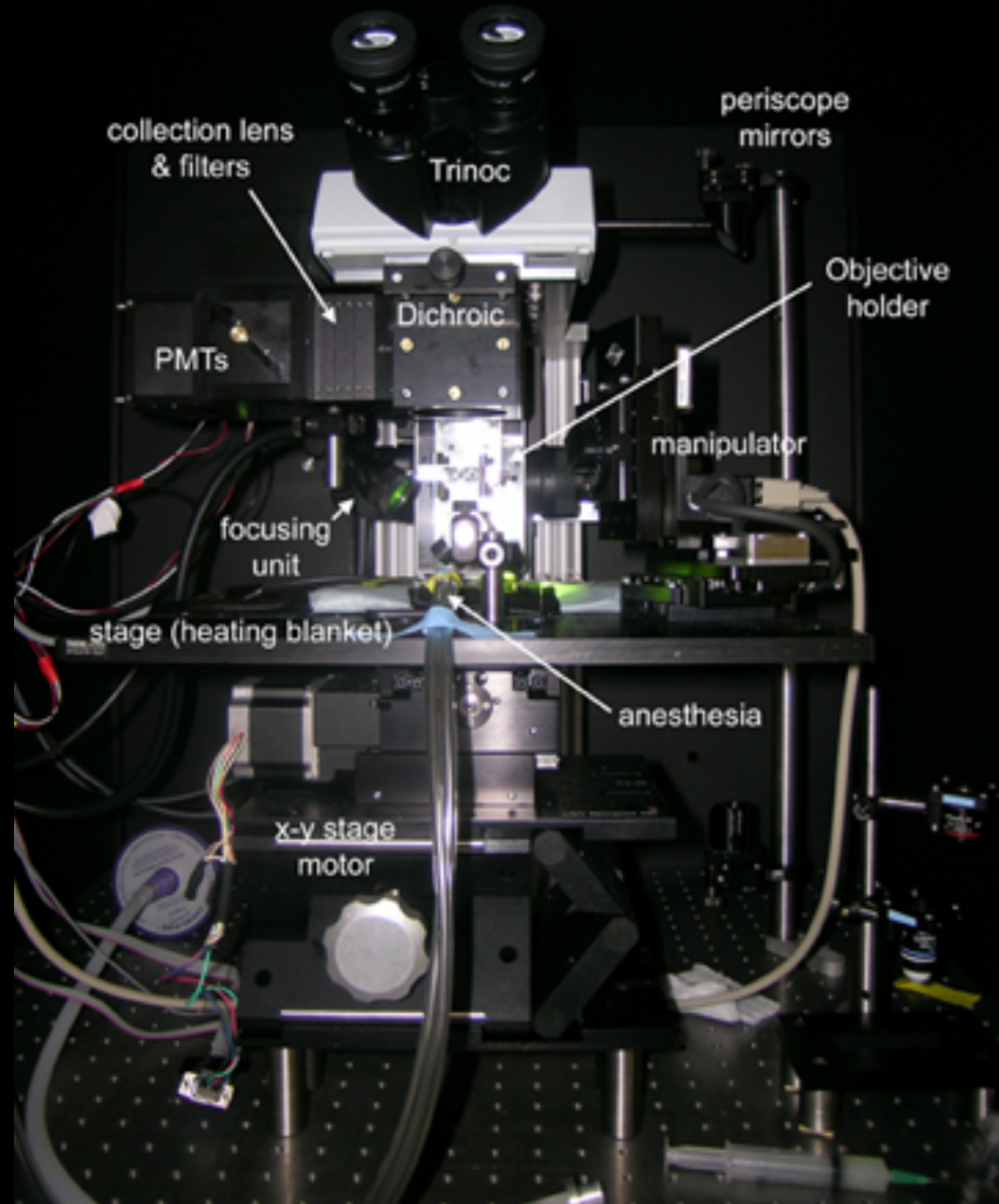
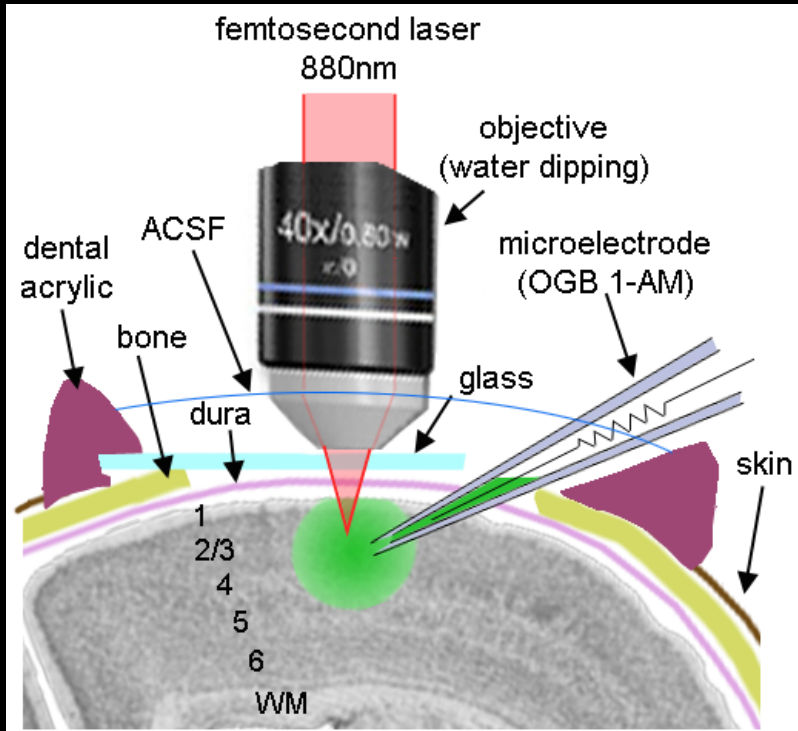
Nurture



Multiphoton Microscope



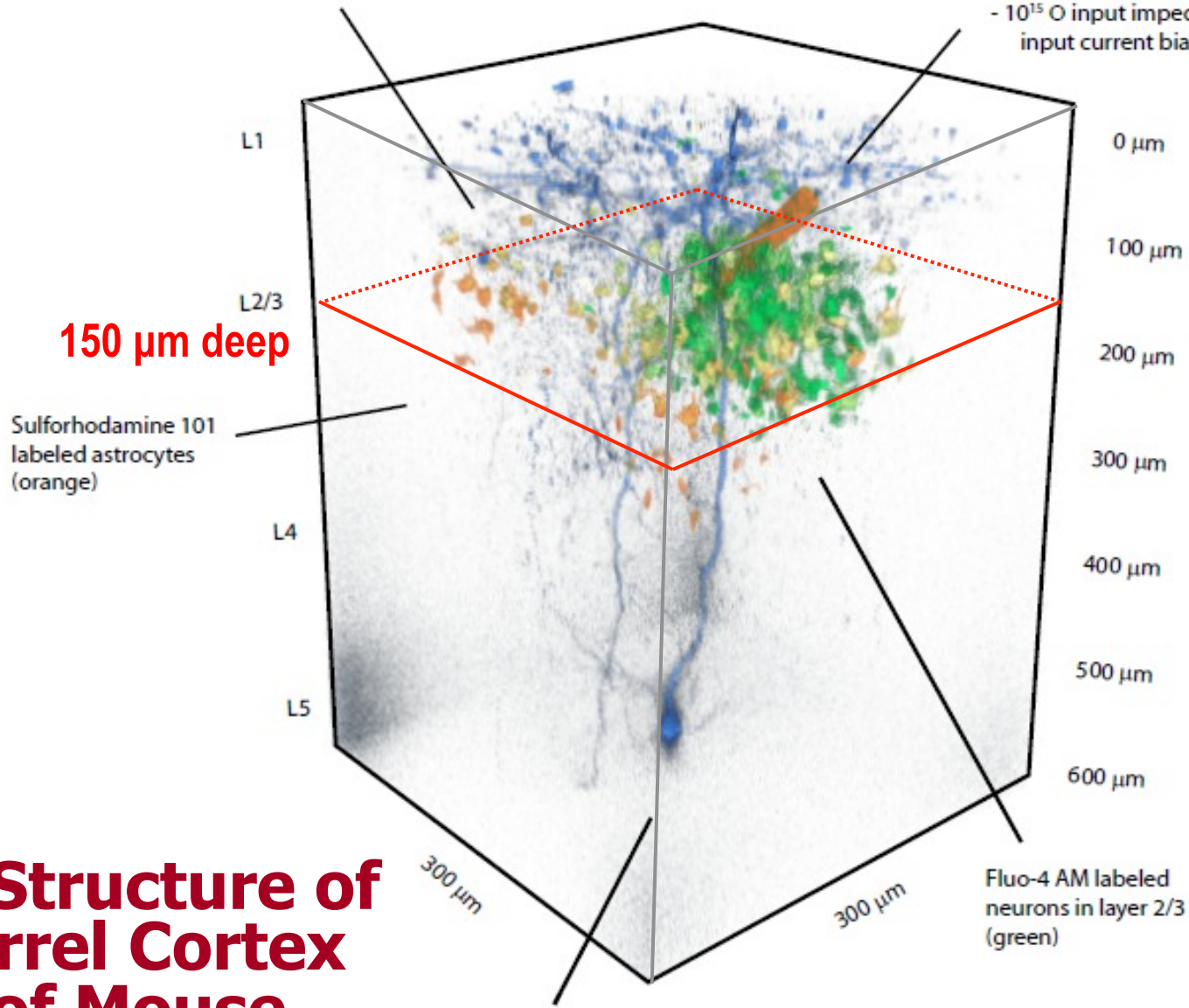
In vivo calcium imaging of neuronal activity



Fluo-4 AM labeled astrocytes are colabeled with sulforhodamine 101 to eliminate background (yellow)

Glass microelectrode for dye injection and electrophysiology

- cell-attached voltage follower
- whole-cell voltage/current clamp
- $10^{15} \Omega$ input impedance, $< 150 \text{ fA}$ input current bias



150 μm deep

Sulforhodamine 101 labeled astrocytes (orange)

Fluo-4 AM labeled neurons in layer 2/3 (green)

Layer 5 pyramidal neuron soma and apical dendrite from a transgenic animal demonstrates imaging depth (blue)

*Adrian Cheng
(Physics)*

*Tiago Goncalves,
Peyman Golshani,
Carlos Portera-Cailliau
(Neurology)*

3D Structure of Barrel Cortex of Mouse

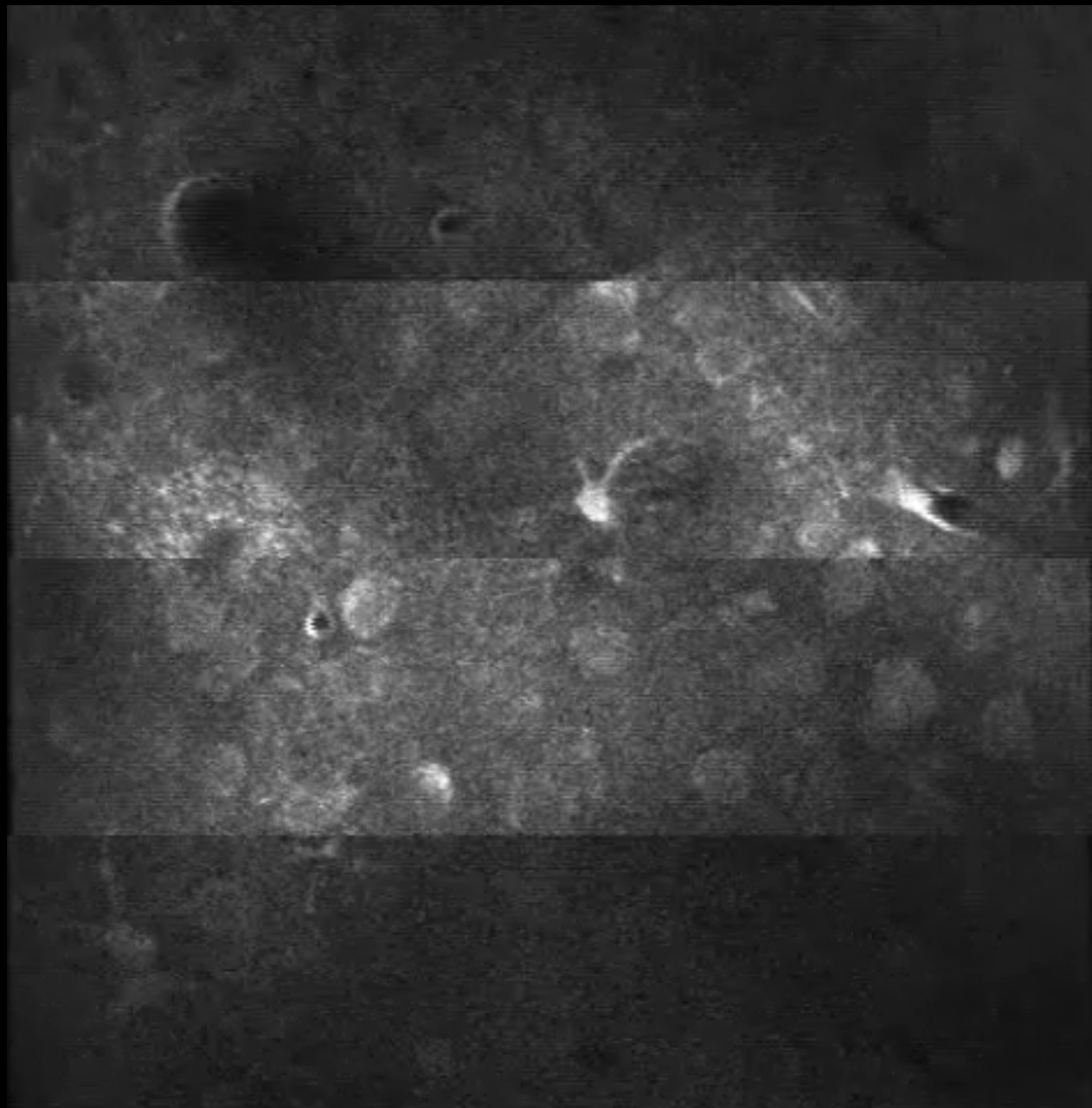
In vivo calcium imaging of Barrel Cortex of Mouse

**Barrel Cortex
Layer 2/3**

150 μm deep

**240 fps
Raw Data**

**(x3 faster
than real)**



**Beam 1
(0 ns)**

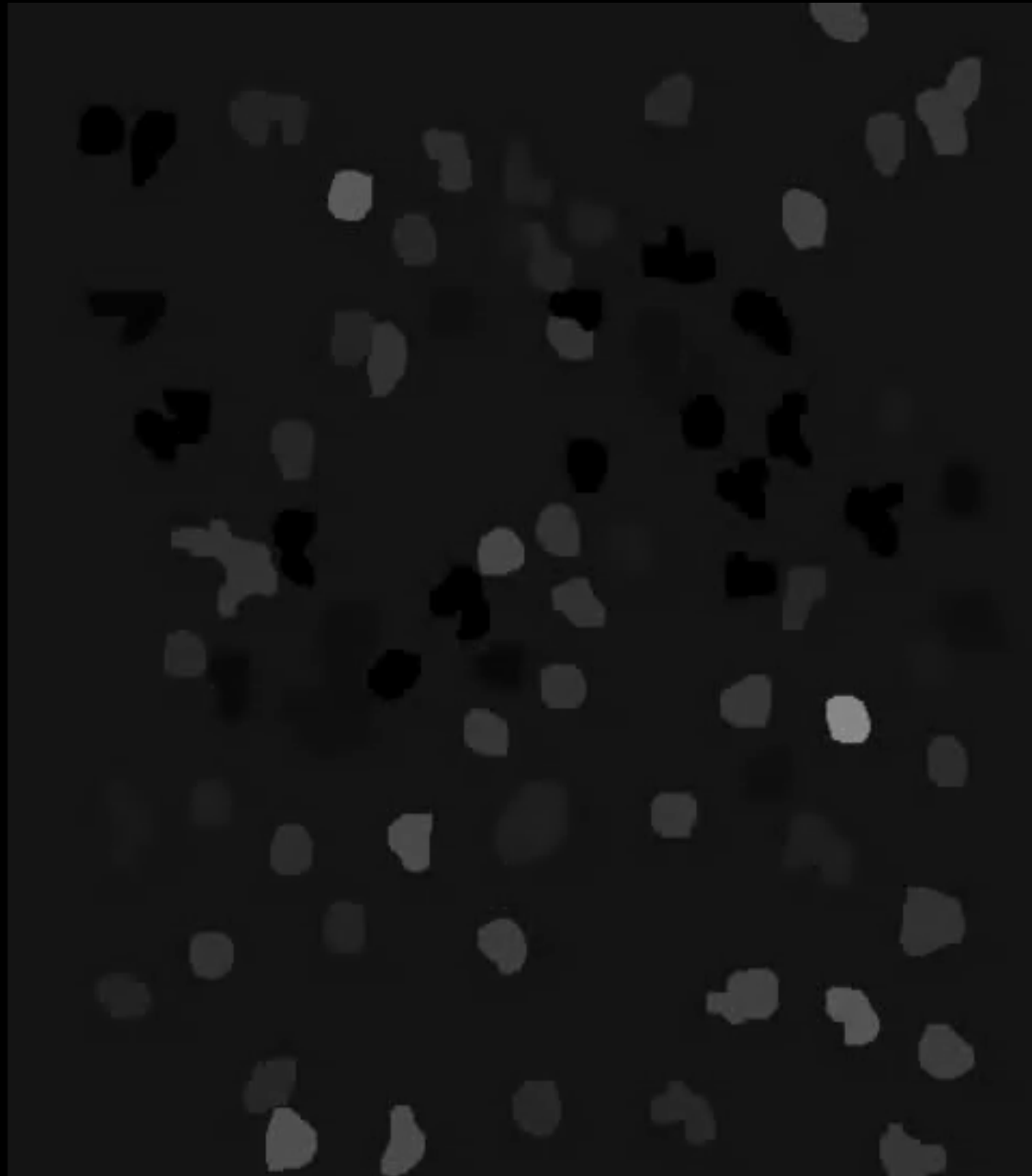
**Beam 2
(+3 ns)**

**Beam 3
(+6 ns)**

**Beam 4
(+9 ns)**

← 300 μm →

In vivo calcium imaging of Barrel Cortex of Mouse



**Barrel
Cortex
Layer 2/3**

**150 μm
deep**

**After
averaging**

**(x3 faster
than real)**

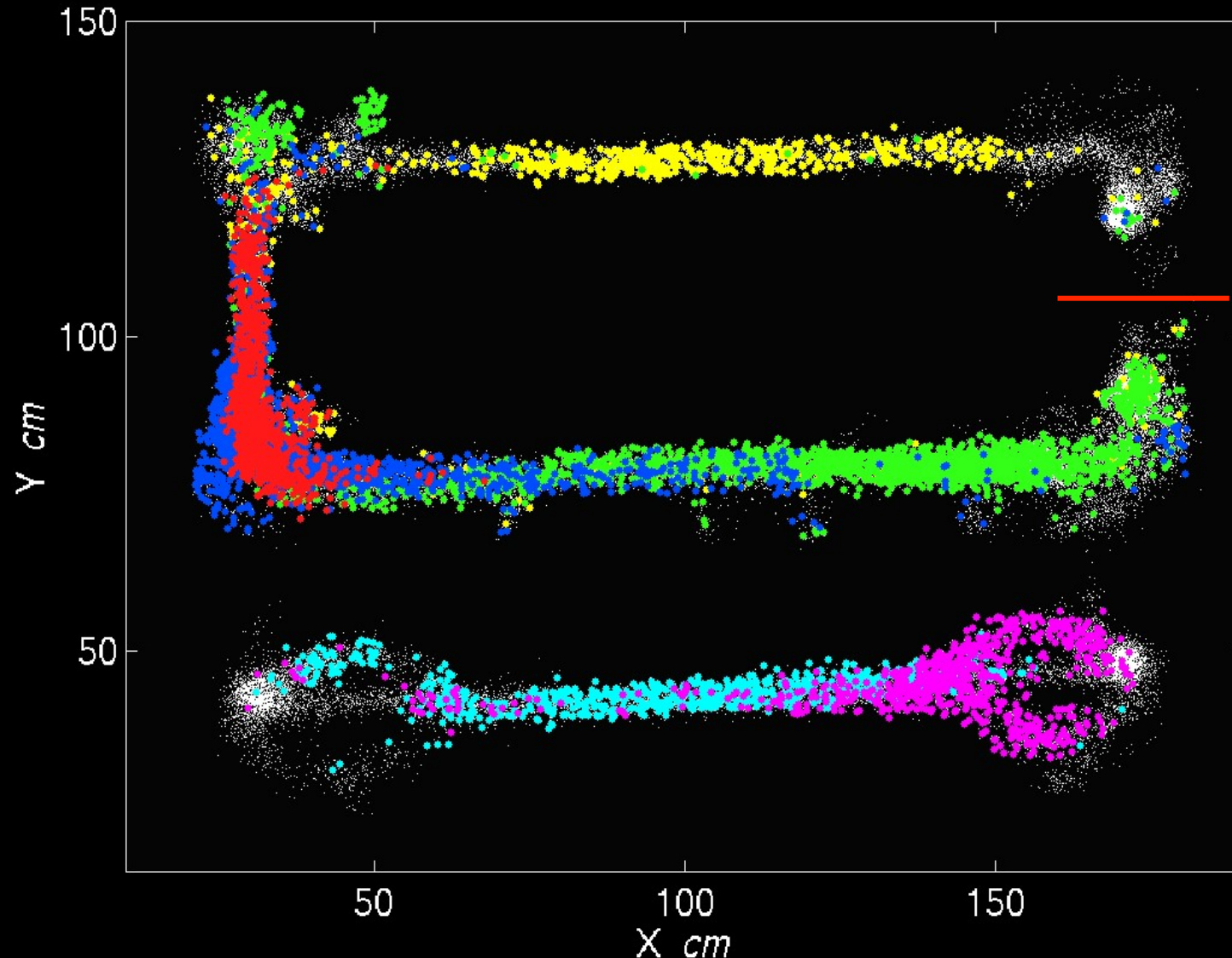
58 neurons

*(~100 billions
neurons
in our brain)*

← 300 μm →

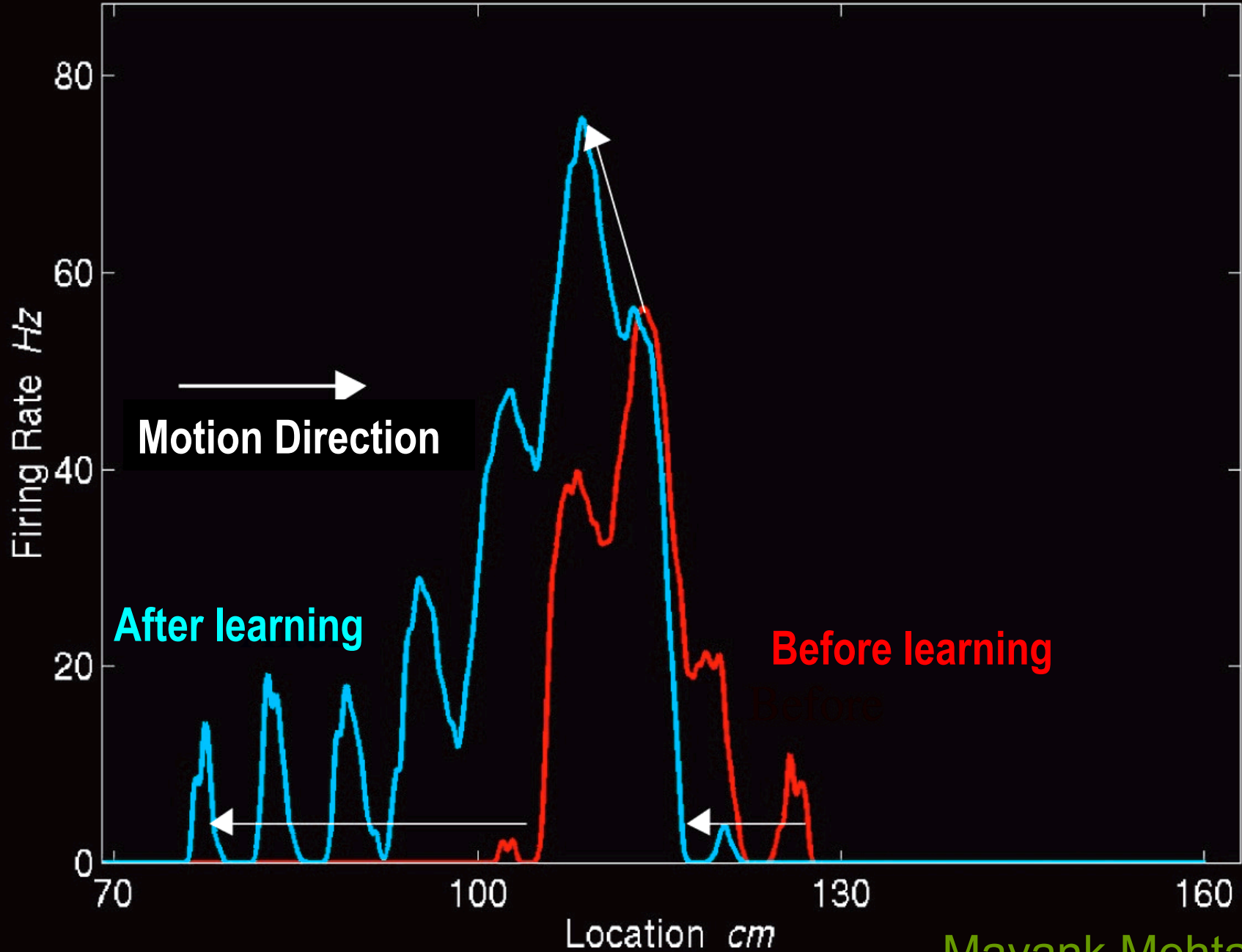
Activity of (excitatory) pyramidal neurons in CA depends on rat's position: place cells

Mayank Mehta (Physics, Neurology)

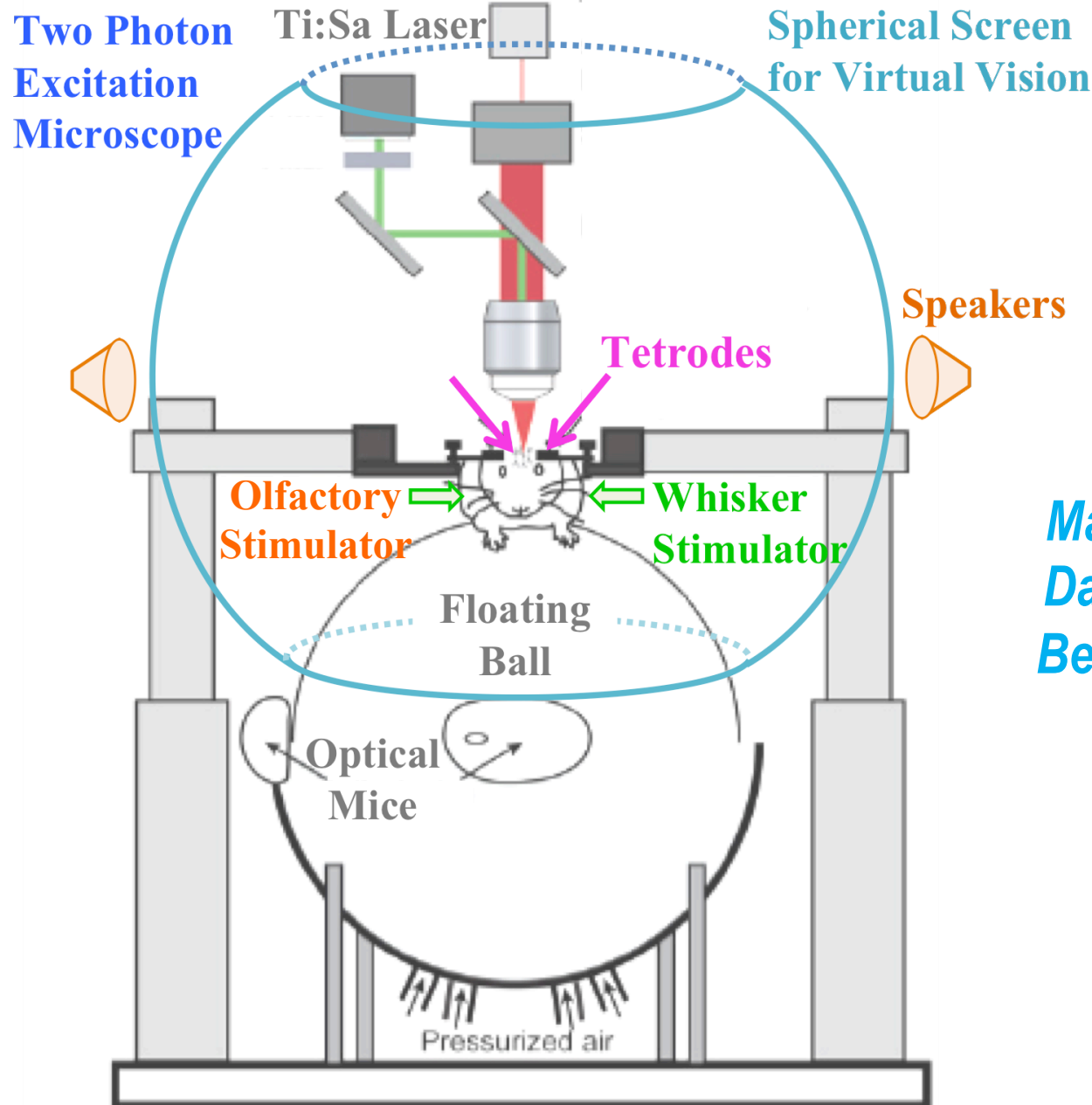


Hippocampus has a cognitive map of space

Learning and Memory by Hippocampus



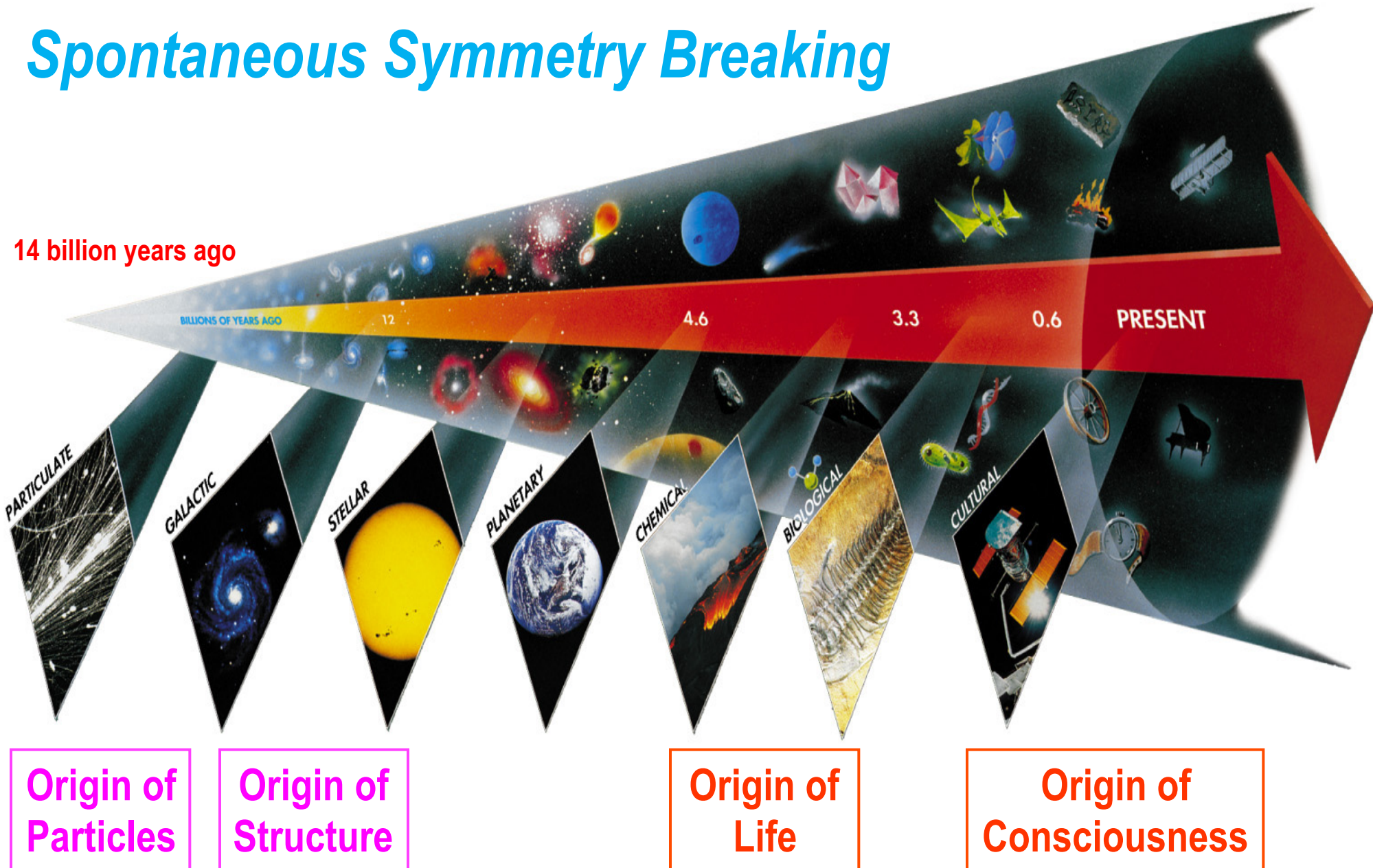
Virtual Reality Experiment on Awake Rats



*Mayank Mehta
Daniel Aharoni
Bernard Willers*

Seven Phases of Cosmic Evolution

Spontaneous Symmetry Breaking

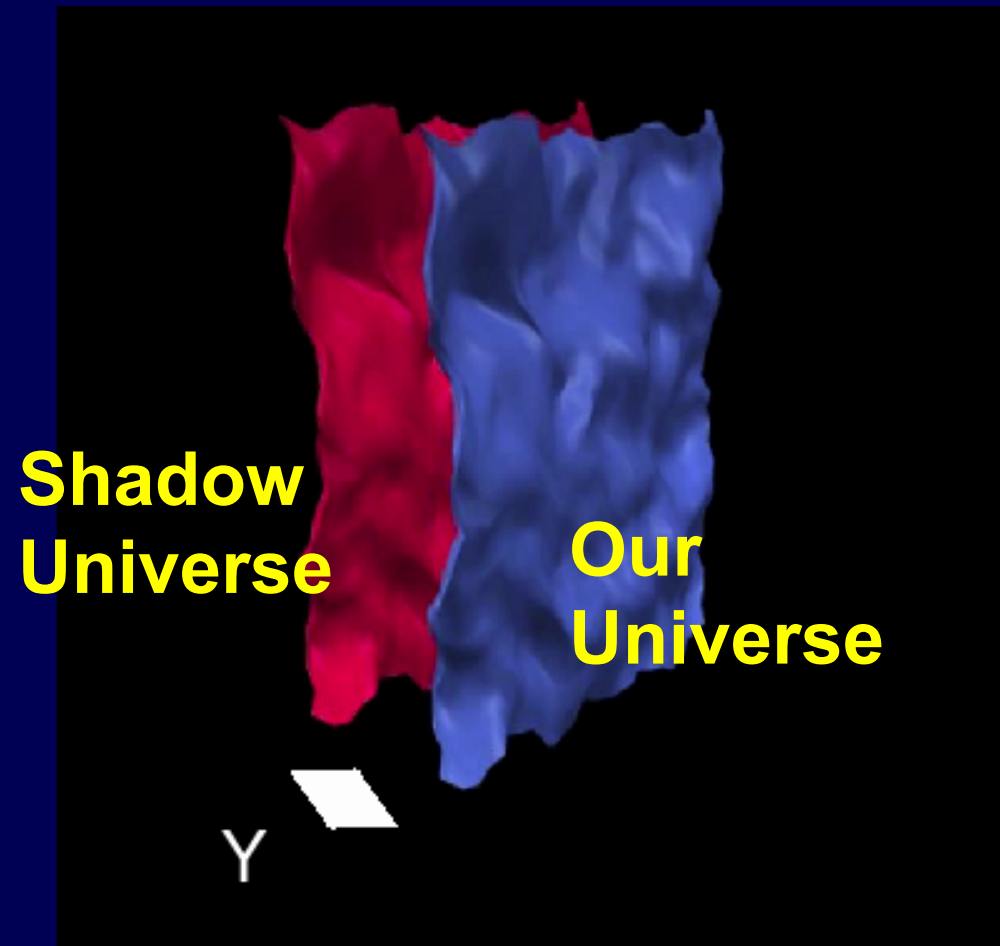
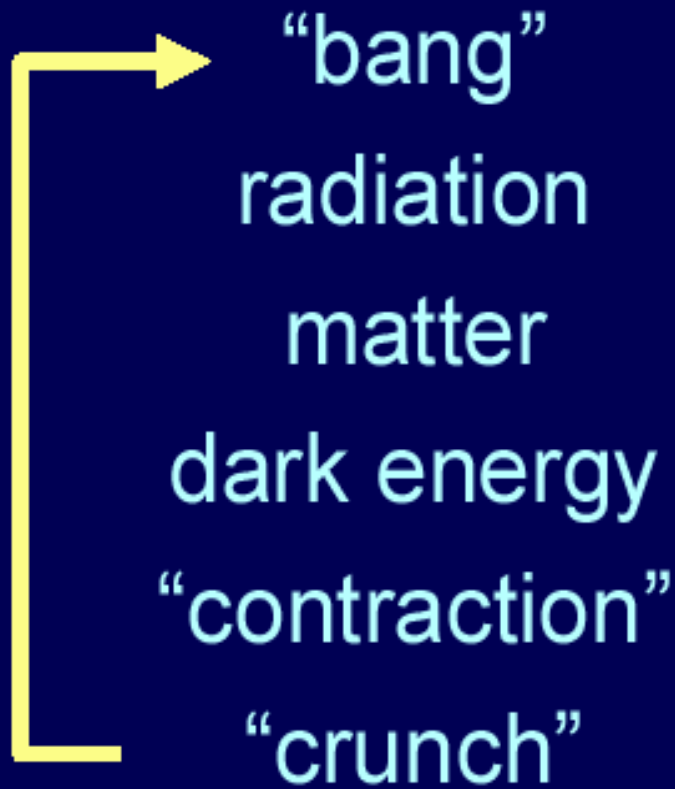




Why are we here?

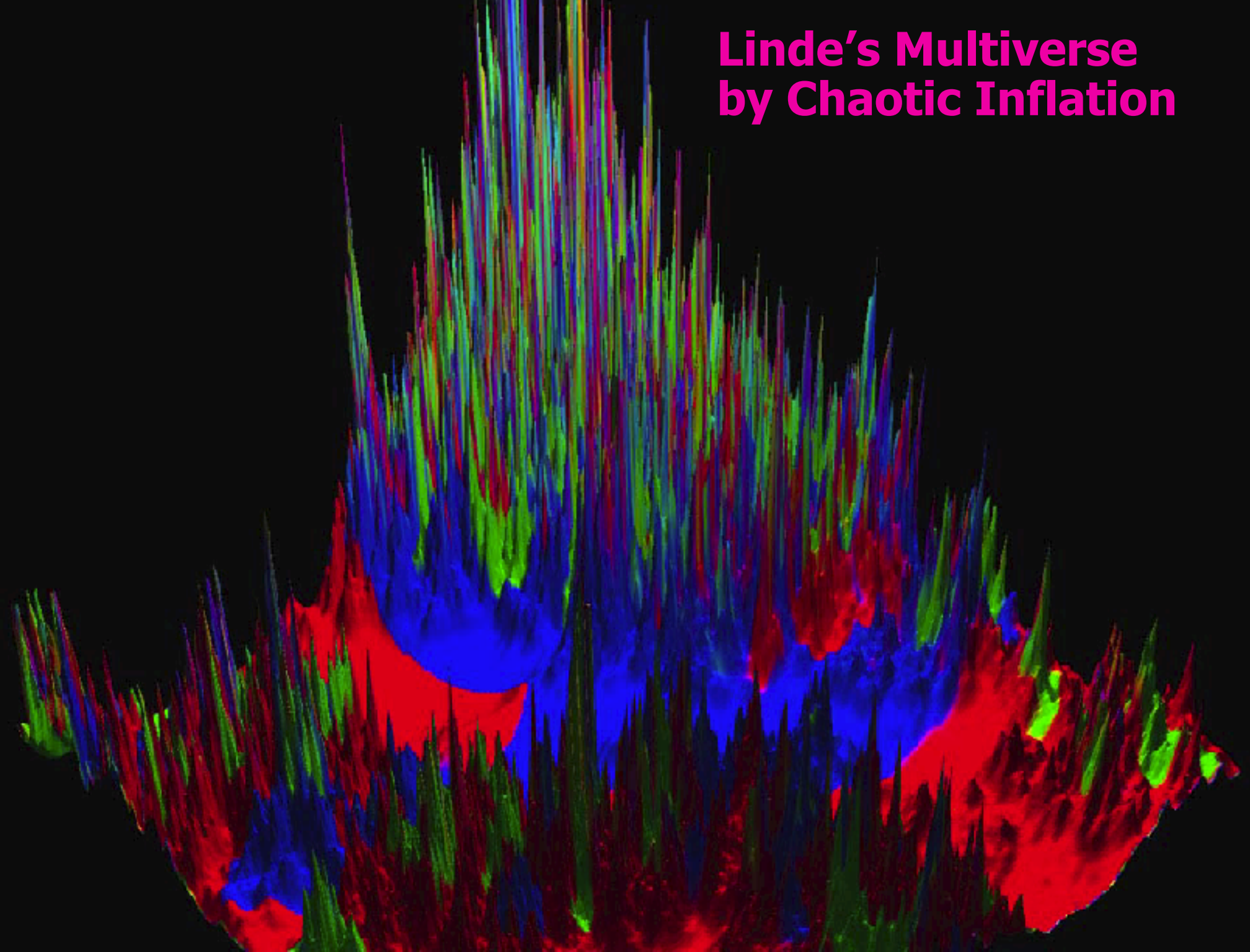
Cyclic Model

M theory



**Are there more than
one Universe?**

Linde's Multiverse by Chaotic Inflation



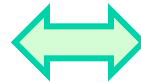


There may be ~100 Billion Universes.

Four Major Science

Origin of Particles
Particle Physics

Origin of Universe
Cosmology



Origin of Life
Molecular Biology

Origin of Consciousness
Neurophysics

