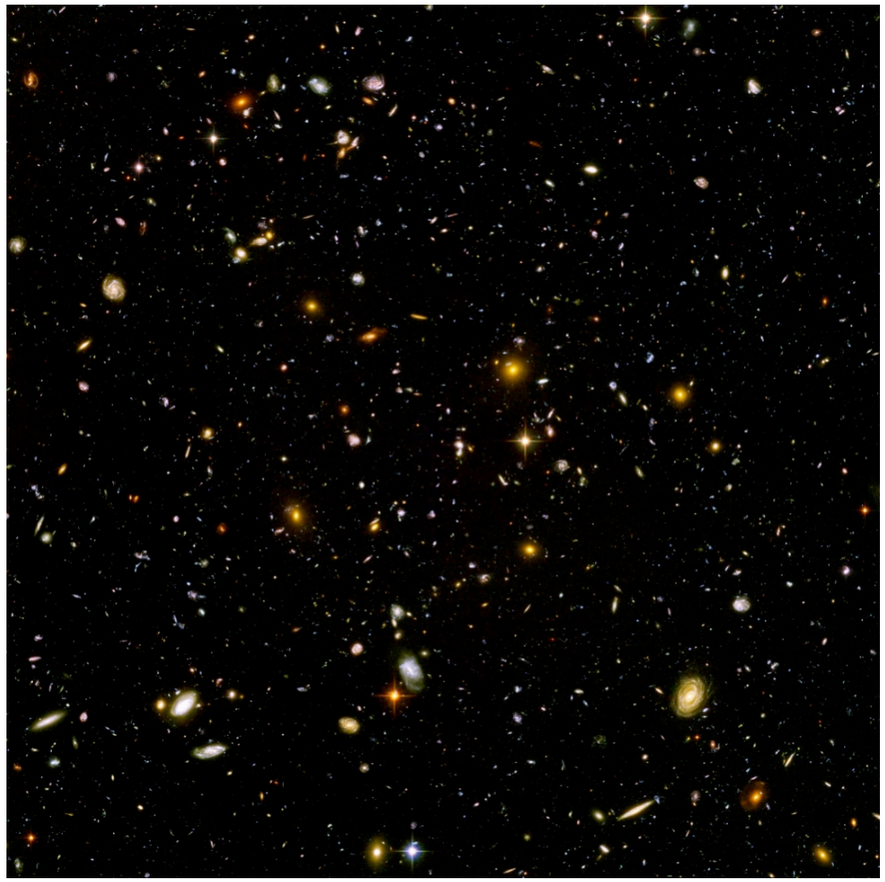
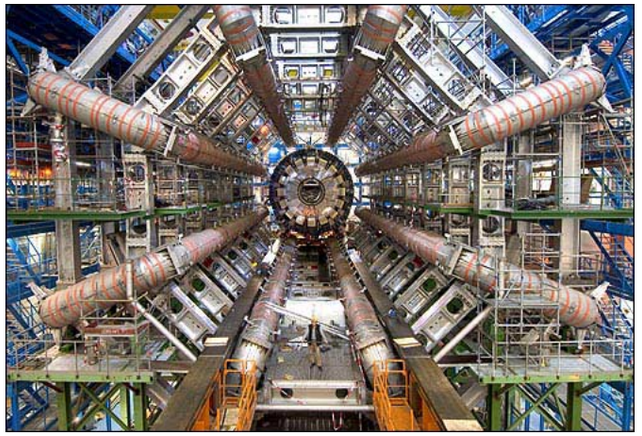
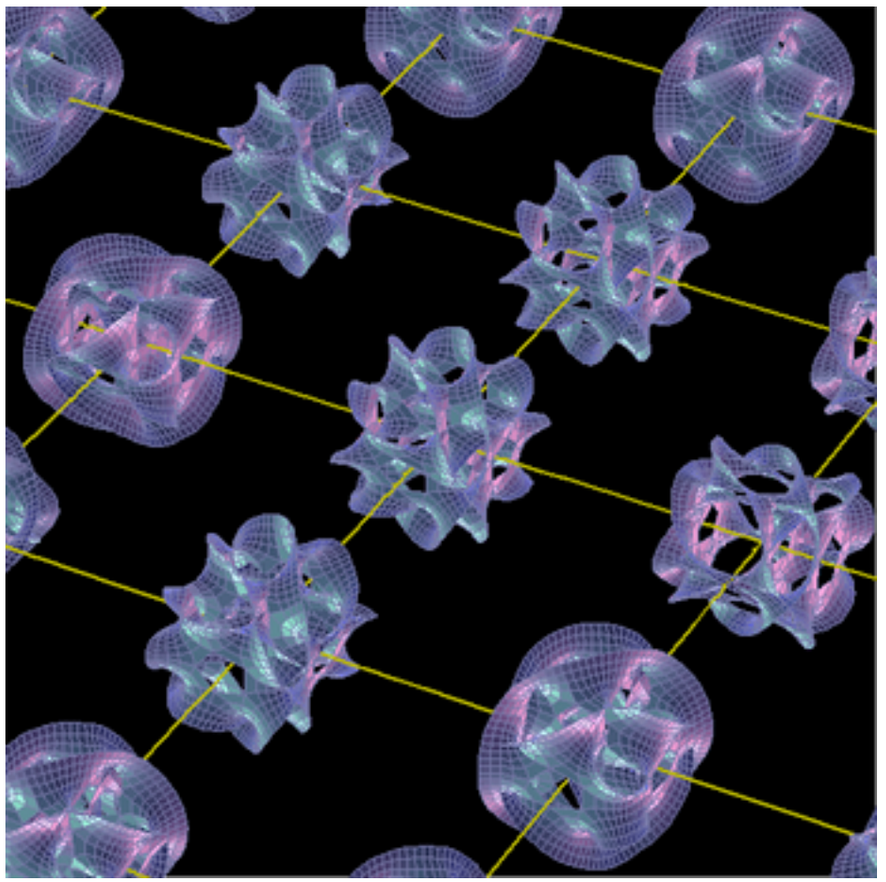
The Large Hadron Collider and the search for dark matter



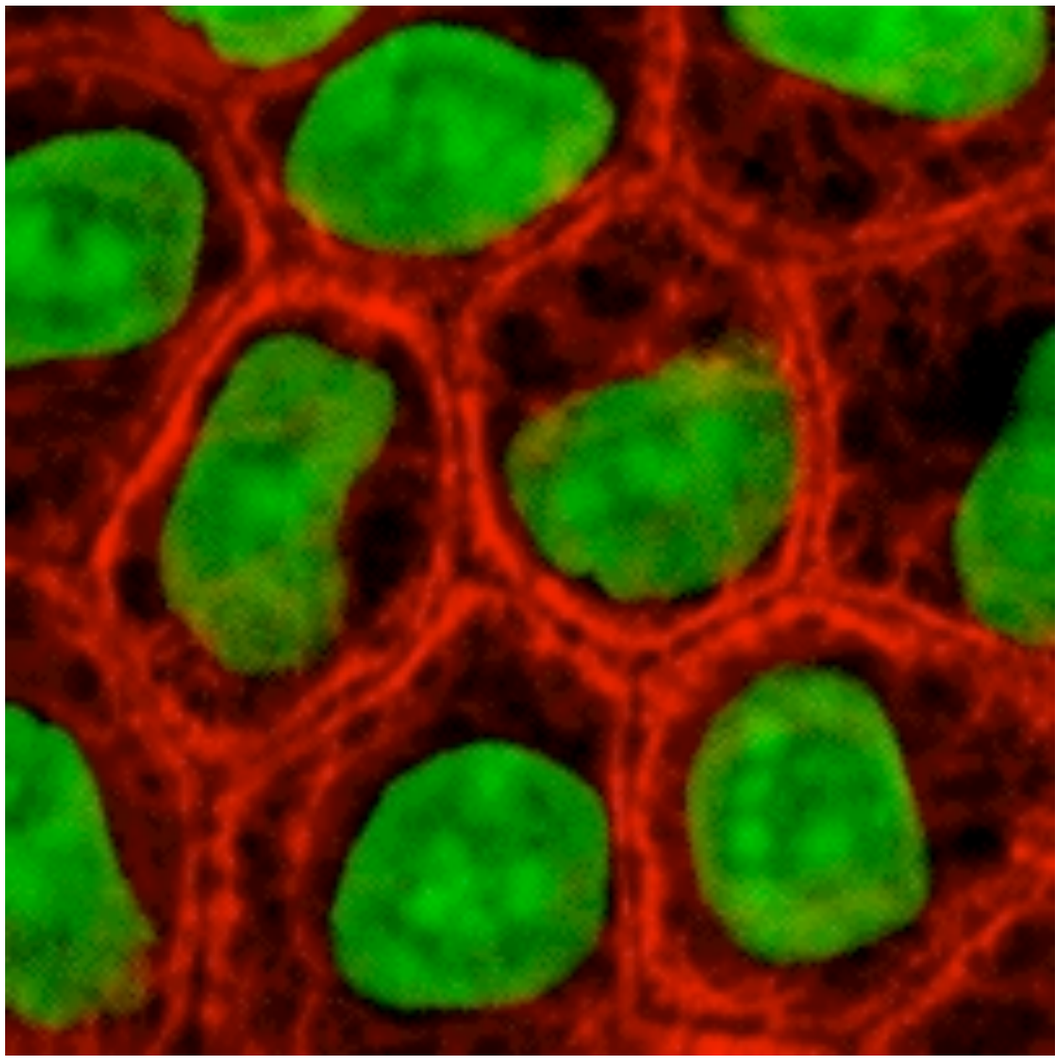




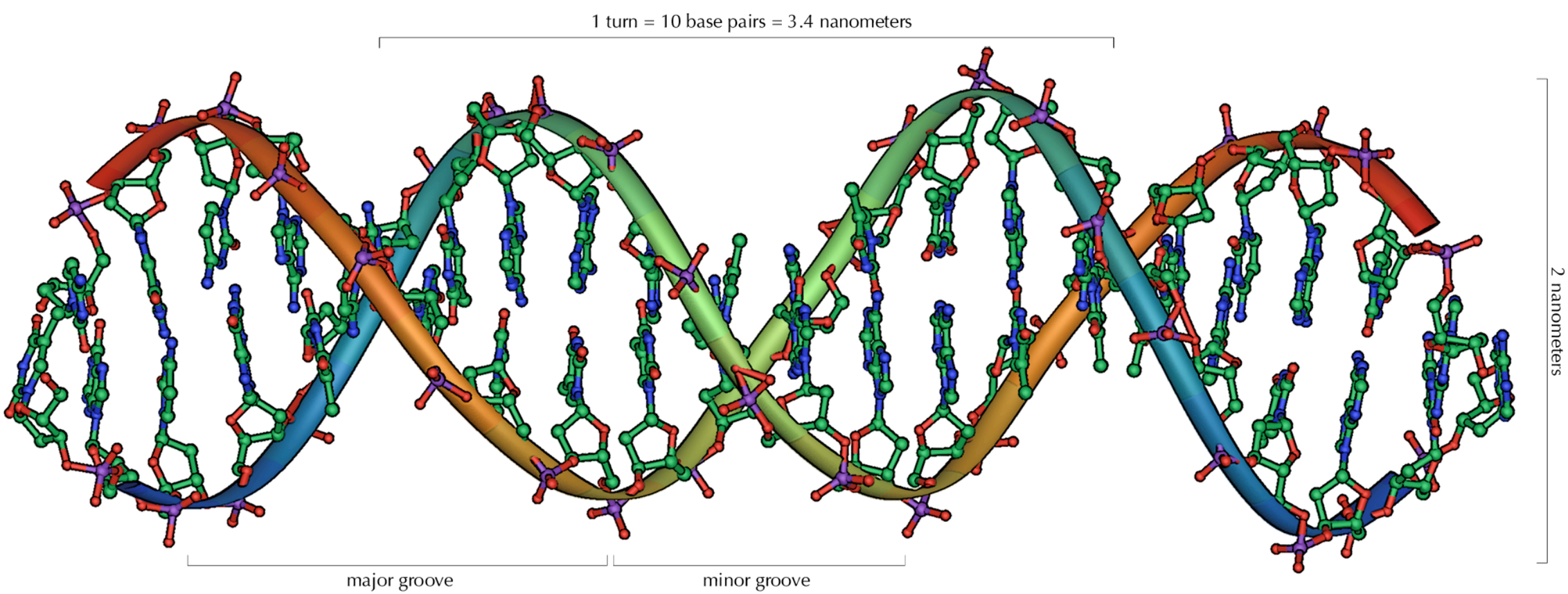
Anne Green

The University of Nottingham

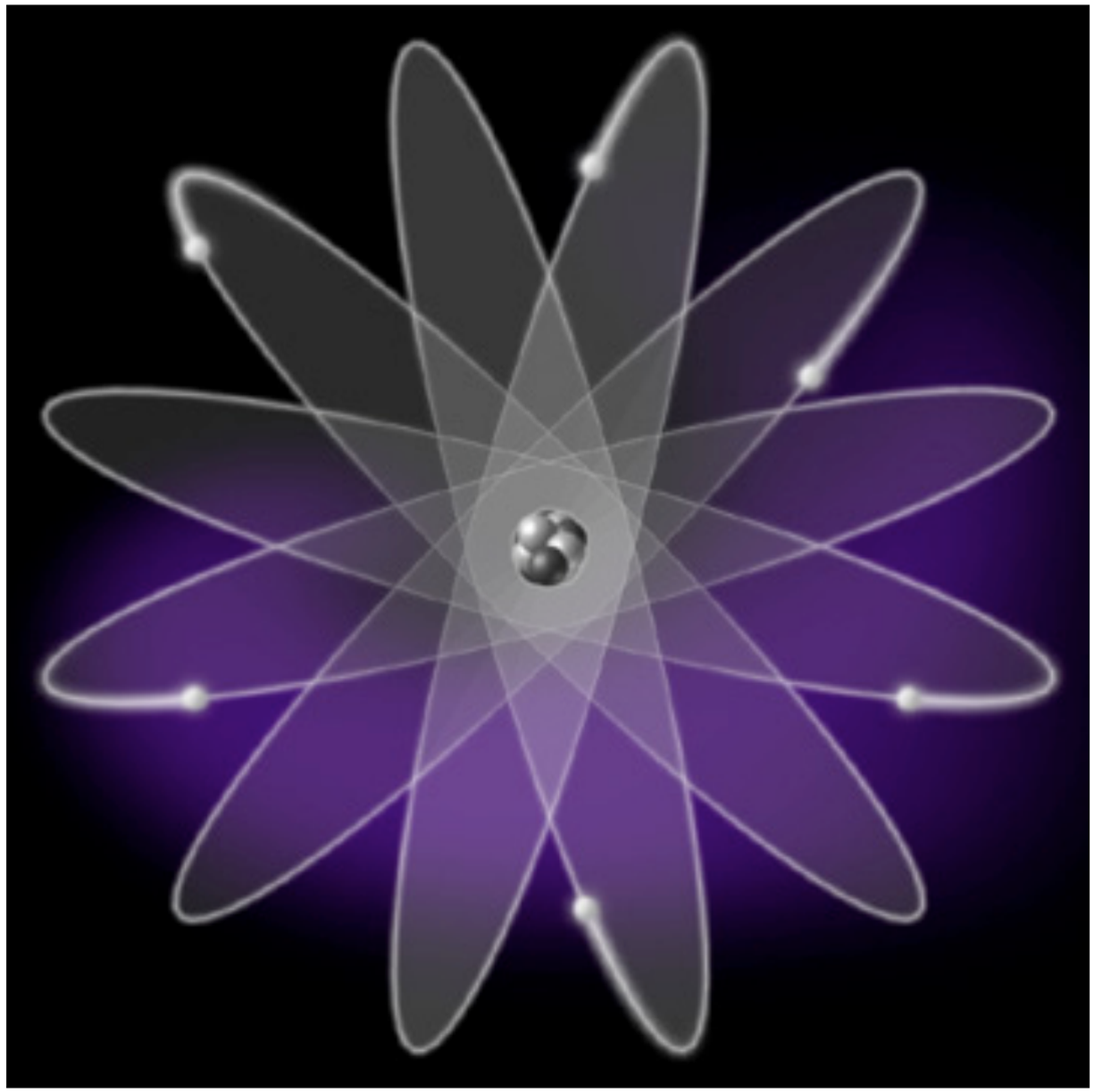
a person: ~1 metre



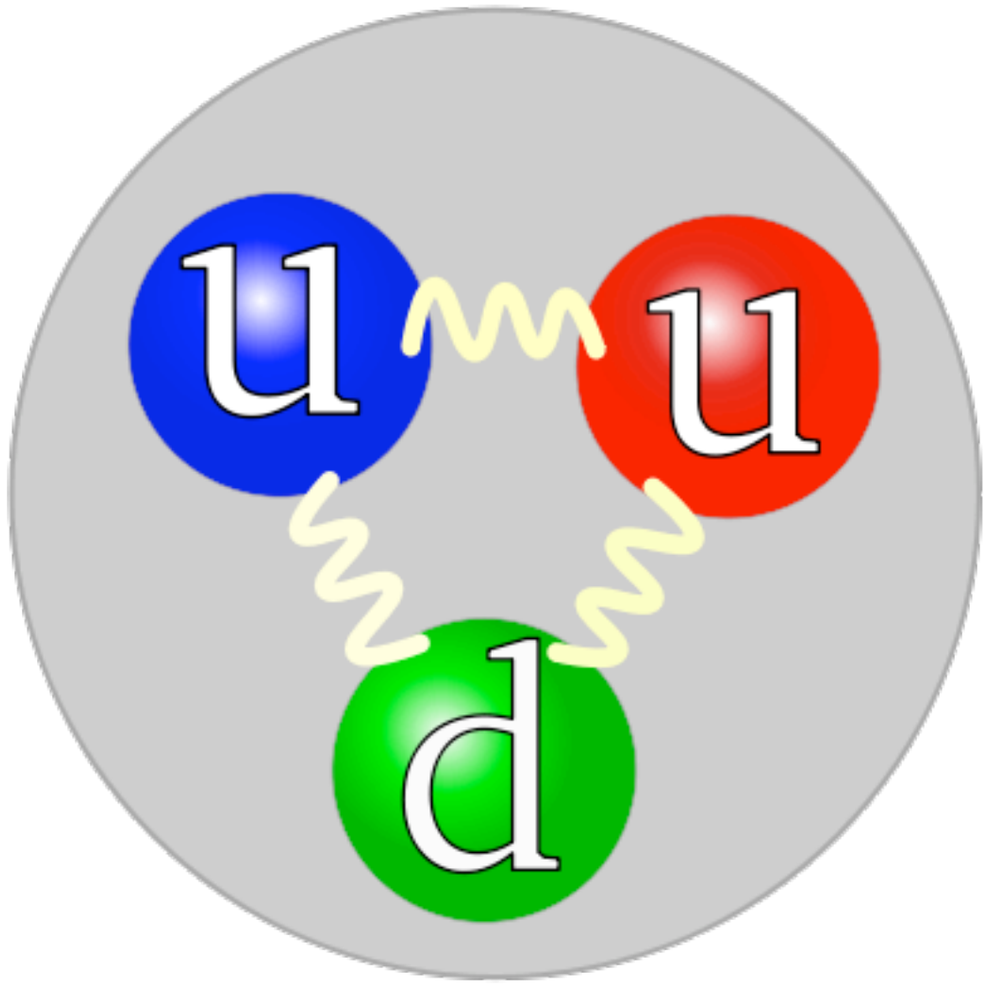
cell ~ 0. 000 010 m ~ 10^{-5} m ~ 10 μm



DNA ~ 0. 000 000 001m ~ 10^{-9} m

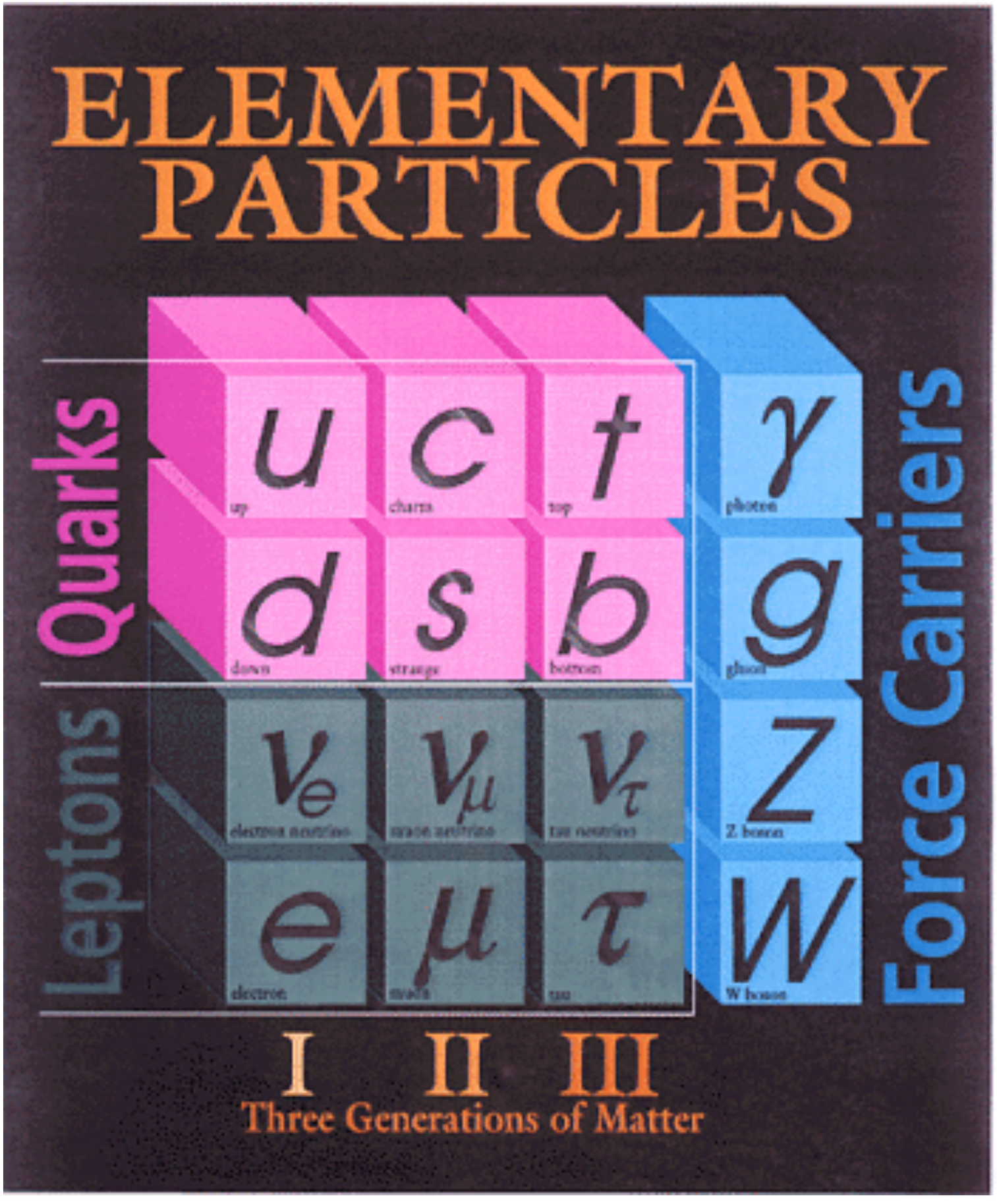


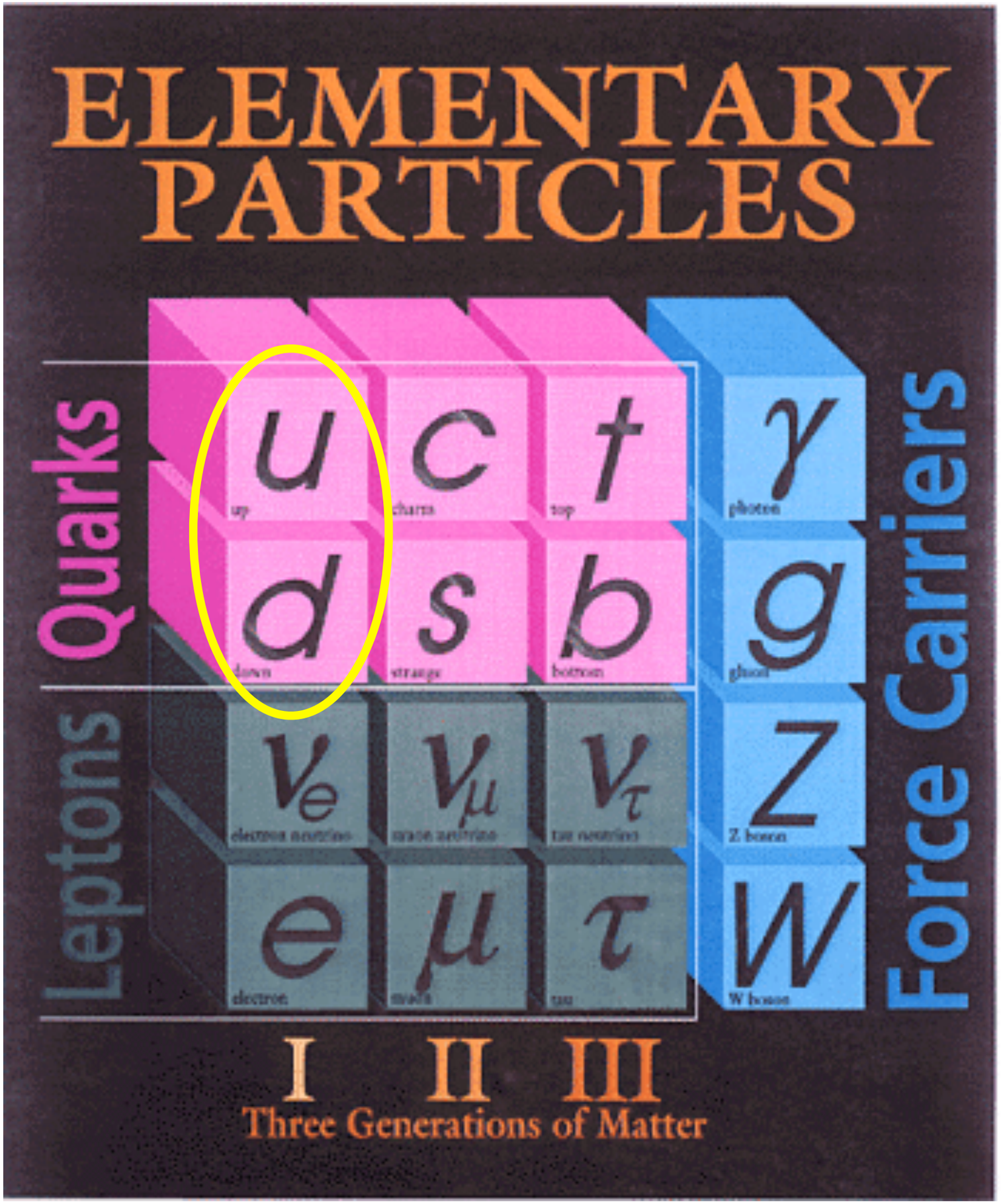
a Carbon atom: ~ 10^{-10} m



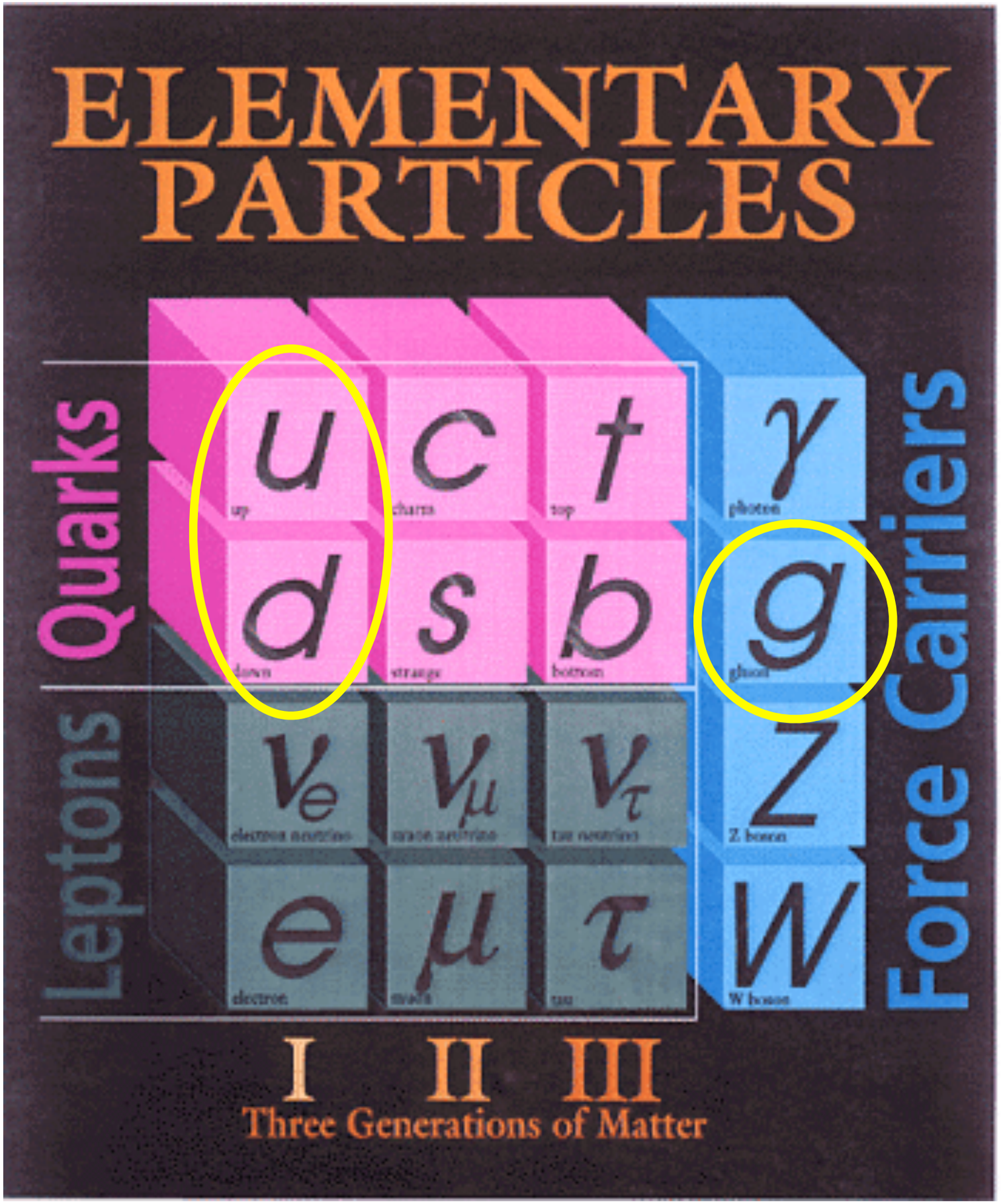
a proton: ~ 10^{-15} m

ELEMENTARY PARTICLES

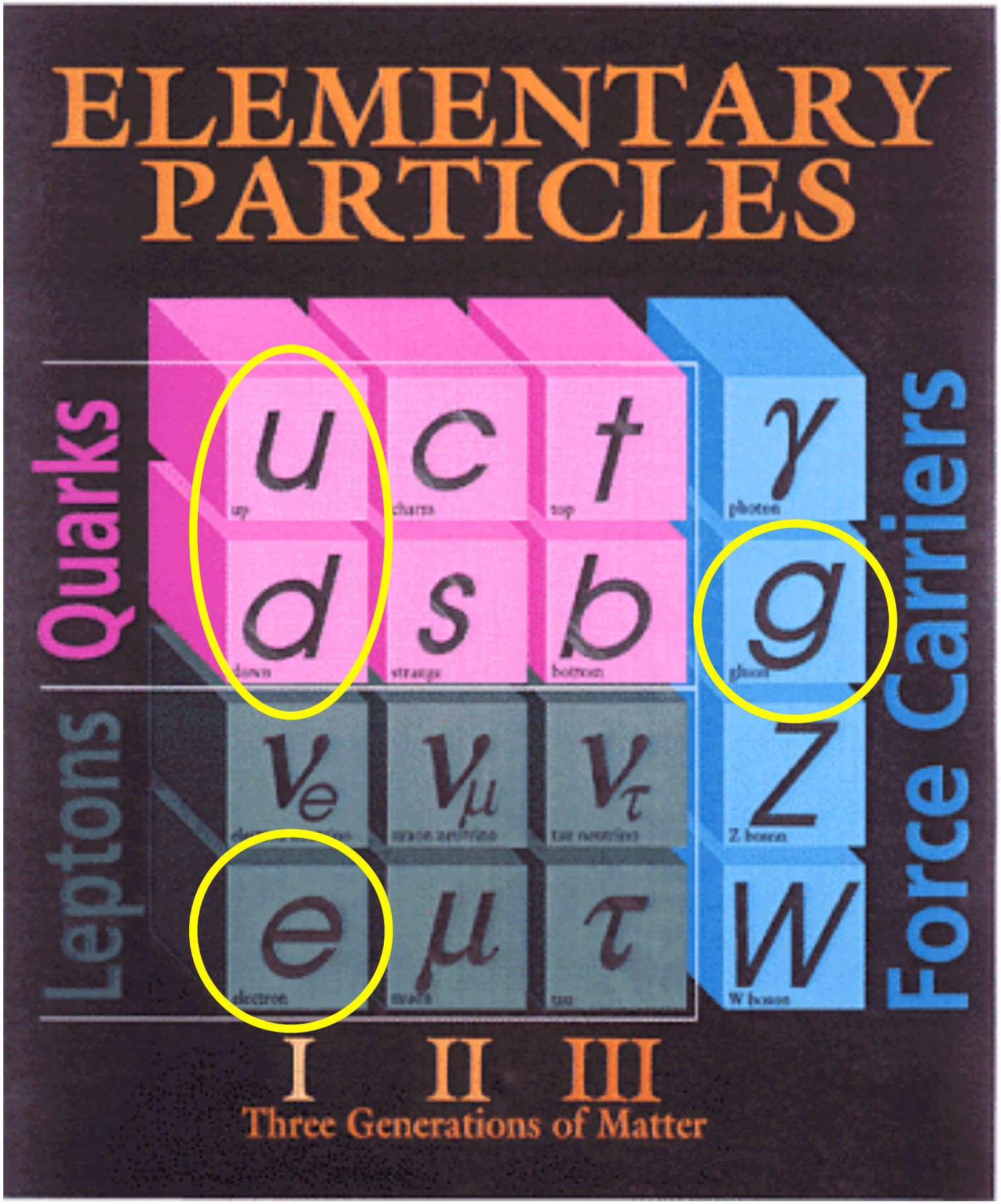


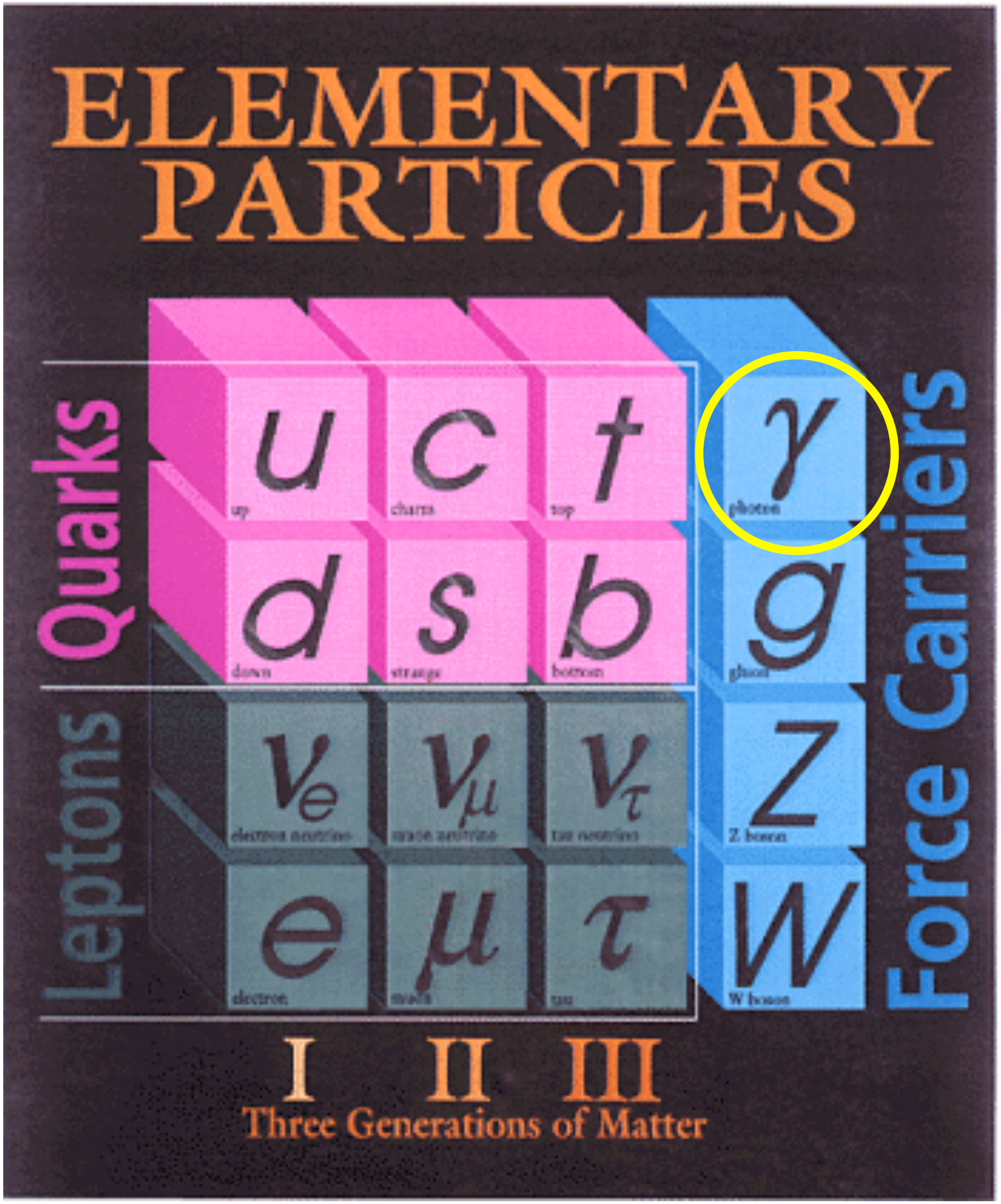

ELEMENTARY PARTICLES
Quarks
Leptons
Force Carriers
u
up
c
charm
t
top
γ
photon
d
down
s
strange
b
bottom
g
gluon
ν_e
electron neutrino
ν_μ
muon neutrino
ν_τ
tau neutrino
Z
Z boson
e
electron
μ
muon
τ
tau
W
W boson
I II III
Three Generations of Matter

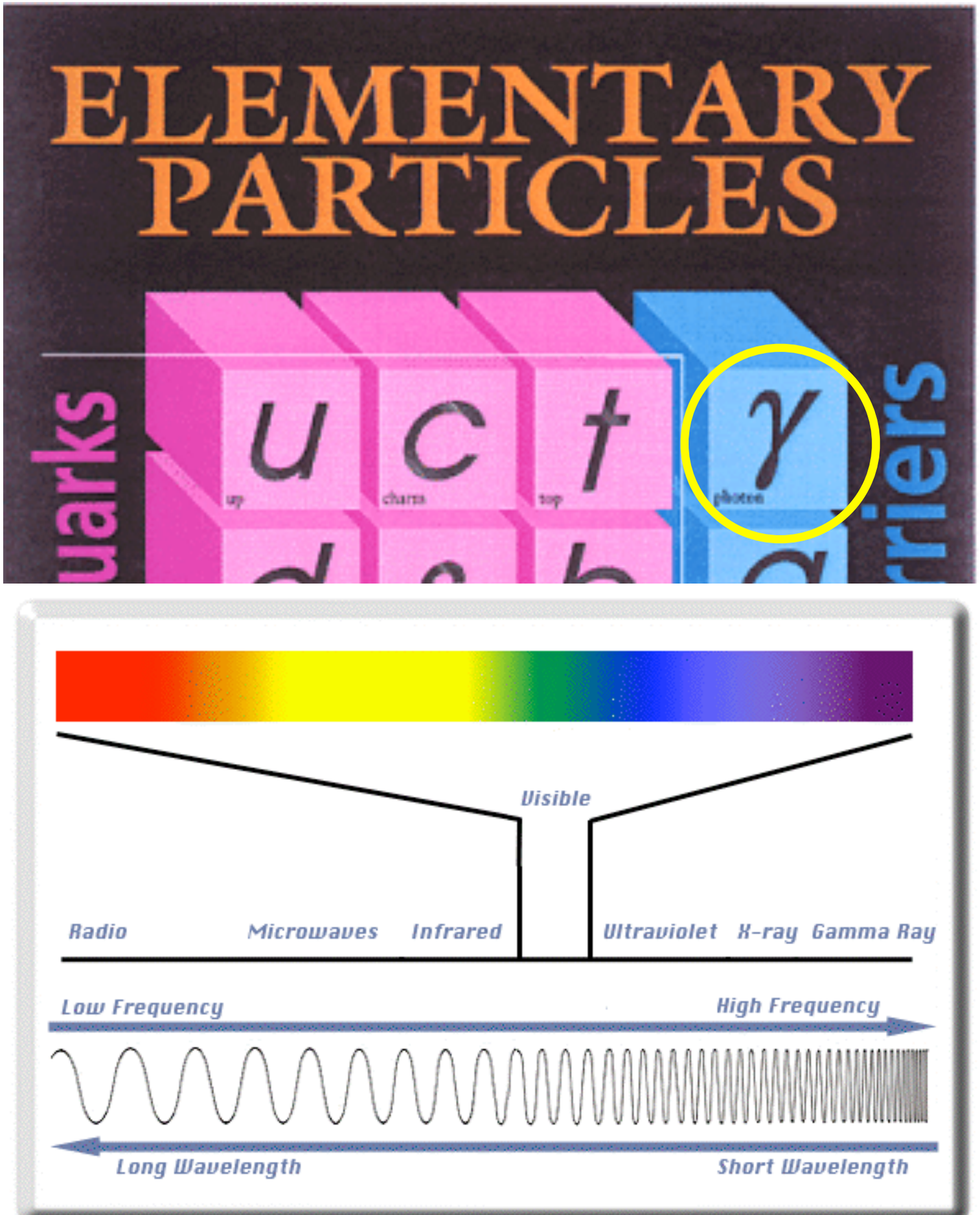
ELEMENTARY PARTICLES



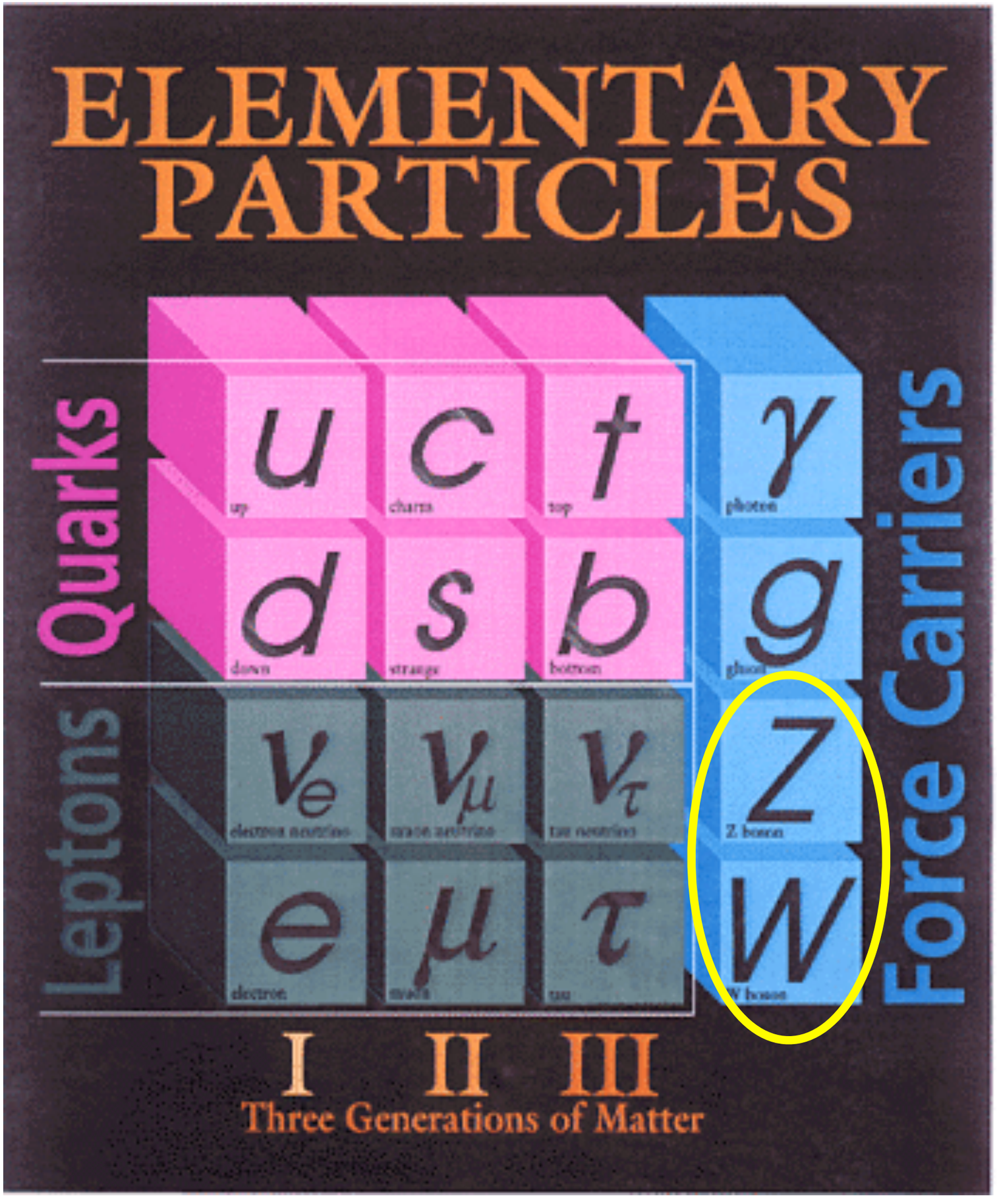
ELEMENTARY PARTICLES

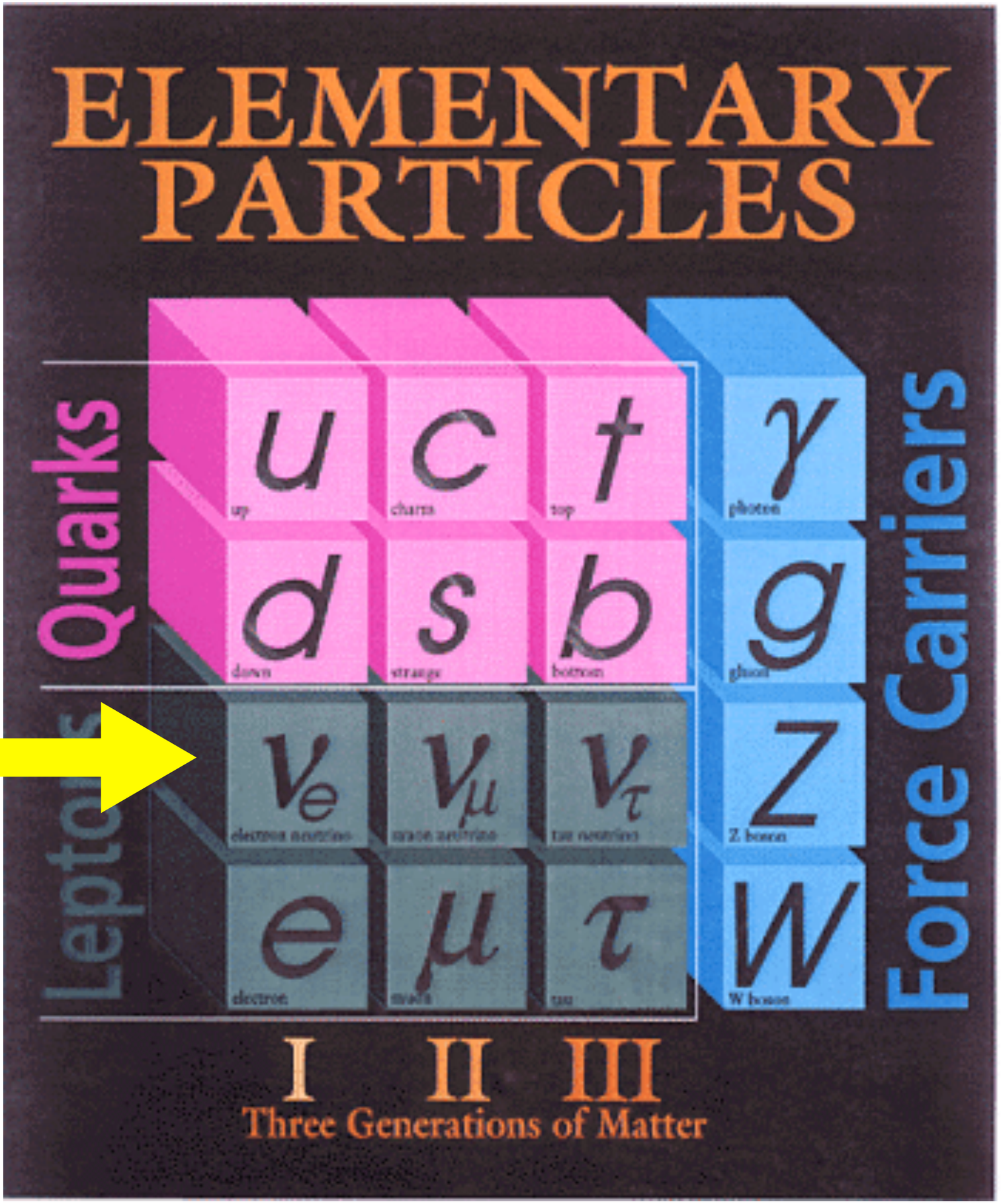


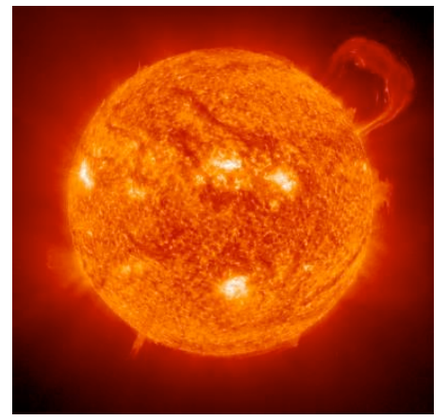

ELEMENTARY PARTICLES
Quarks
u
up
c
charm
t
top
d
down
s
strange
b
bottom
Leptons
ν_e
electron neutrino
ν_μ
muon neutrino
ν_τ
tau neutrino
e
electron
μ
muon
τ
tau
Force Carriers
γ
photon
g
gluon
Z
Z boson
W
W boson
I
II
III
Three Generations of Matter

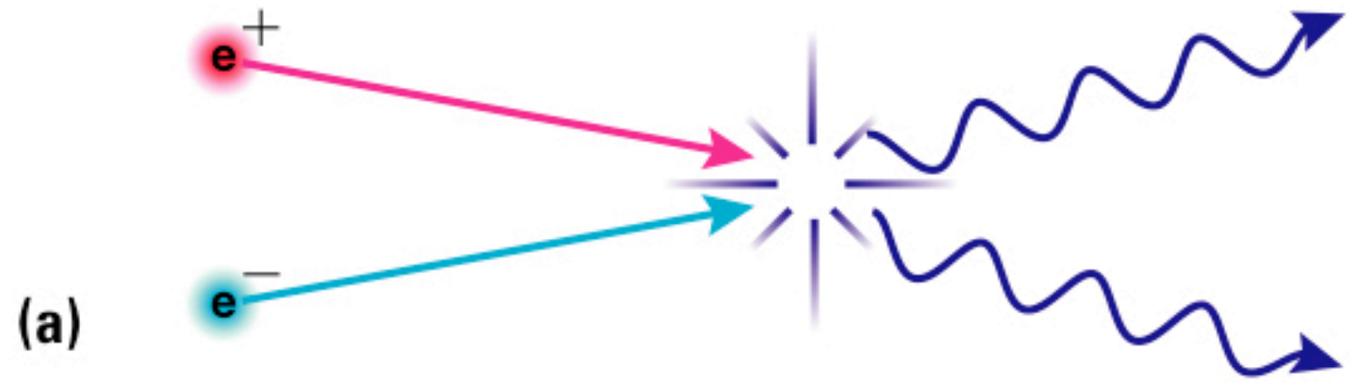

ELEMENTARY PARTICLES
quarks
u
up
c
charm
t
top
γ
photon
riers
Visible
Radio
Microwaves
Infrared
Ultraviolet
X-ray
Gamma Ray
Low Frequency
High Frequency
Long Wavelength
Short Wavelength

ELEMENTARY PARTICLES




ELEMENTARY PARTICLES
Quarks
u
up
c
charm
t
top
γ
photon
d
down
s
strange
b
bottom
g
gluon
Leptons
ν_e
electron neutrino
ν_μ
muon neutrino
ν_τ
tau neutrino
Z
Z boson
e
electron
μ
muon
τ
tau
W
W boson
Force Carriers
I II III
Three Generations of Matter

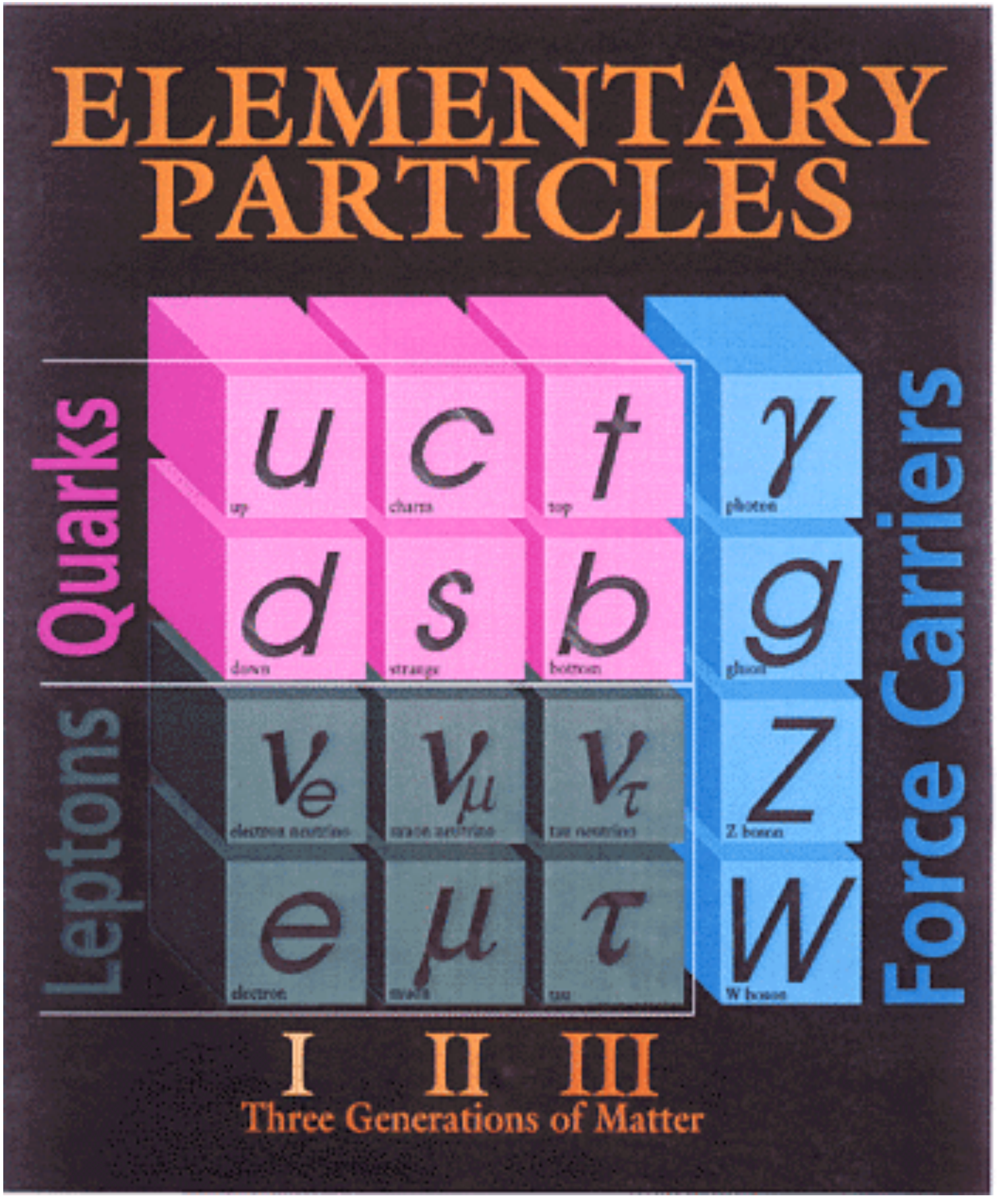


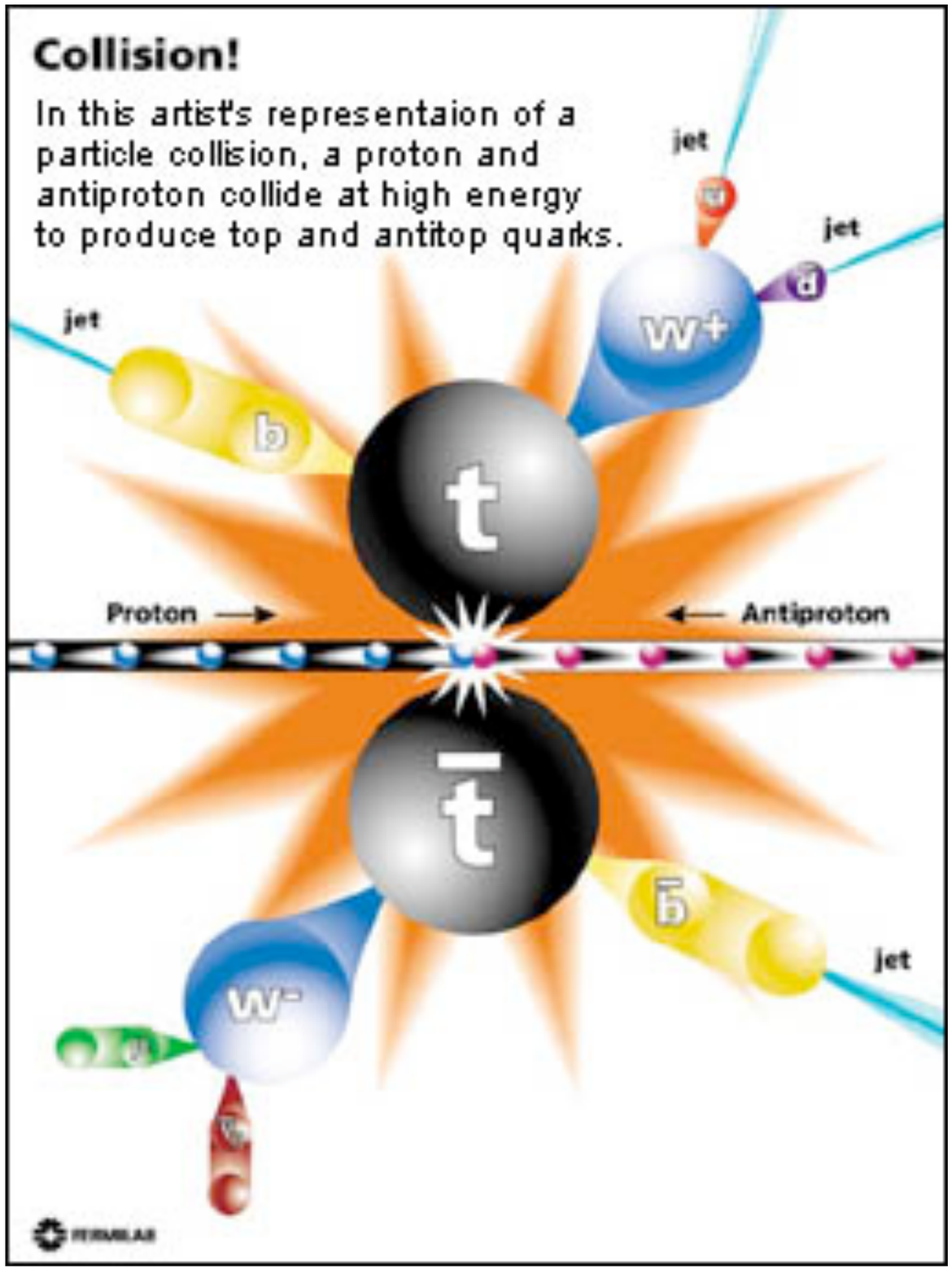


(a)

(b)

ELEMENTARY PARTICLES



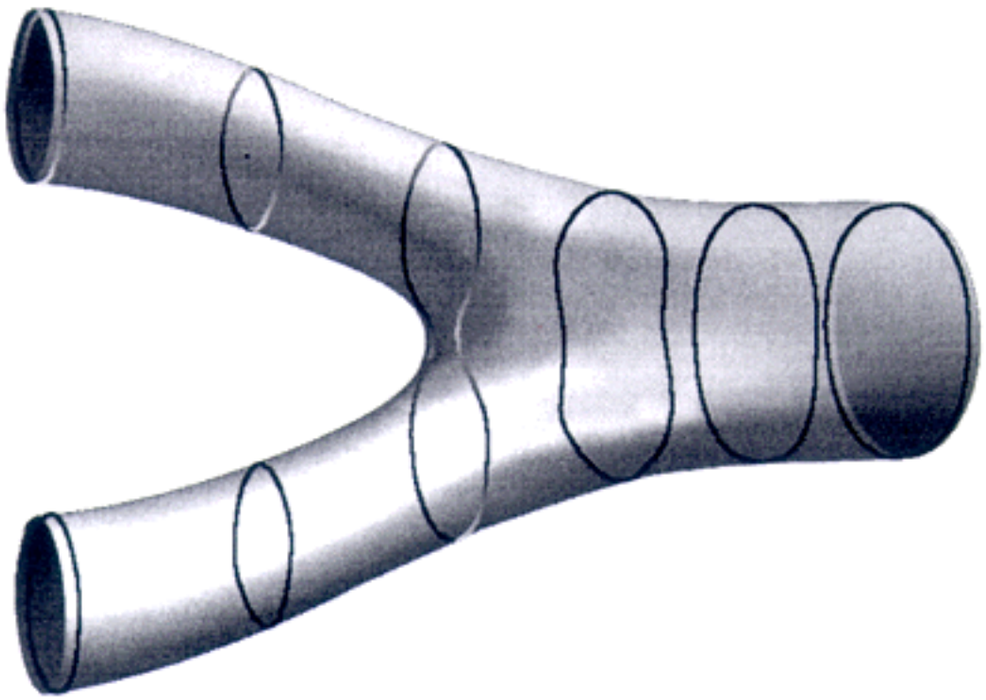

Collision!
In this artist's representaion of a particle collision, a proton and antiproton collide at high energy to produce top and antitop quarks.
jet
jet
jet
W+
b
t
Proton
Antiproton
t̄
b̄
jet
W-

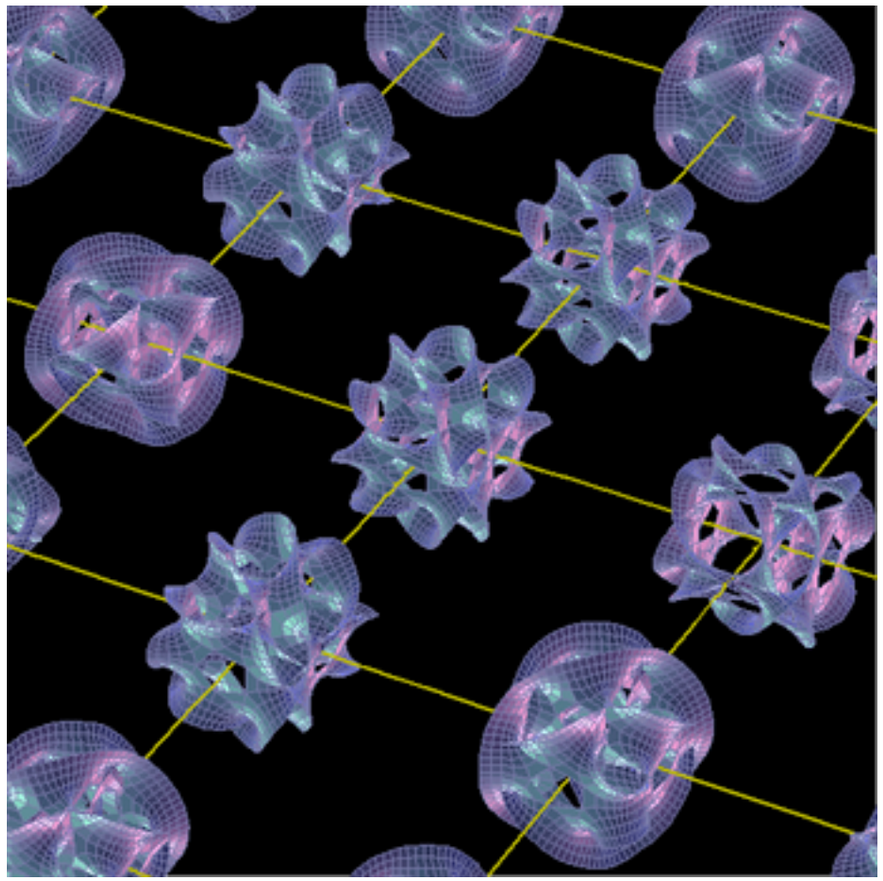
THREE GENERATIONS OF MATTER

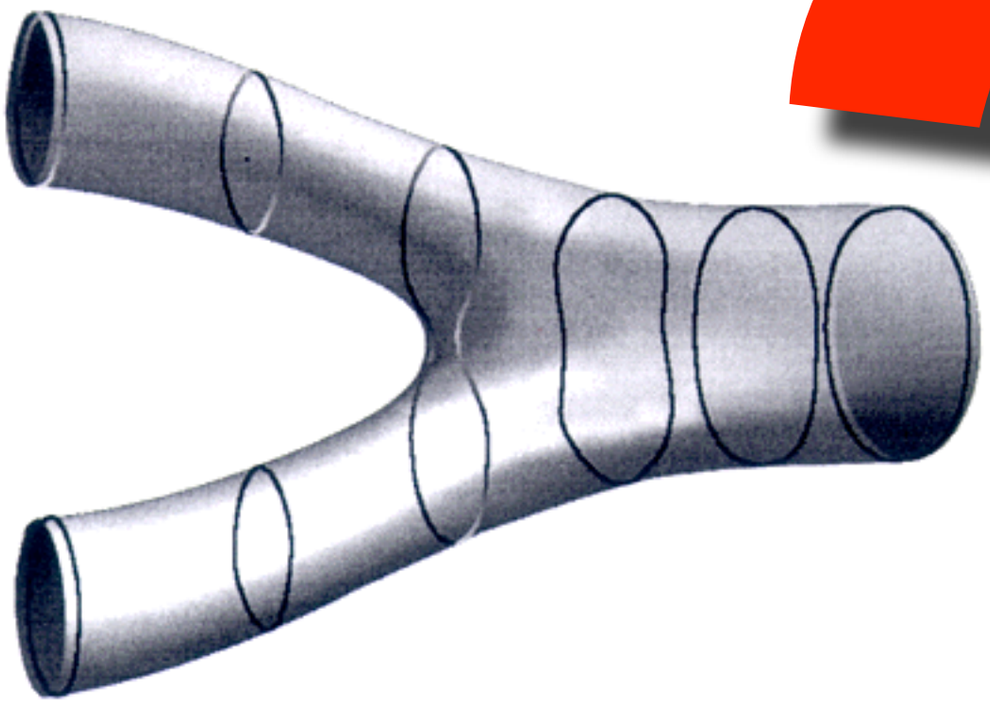
	I	II	III	CHARGE:	
MATTER CONSTITUENTS: FERMIONS — QUARKS	2.75 UP	1300 CHARM	178000 TOP	$+2/3$	91188 Z^0
	6 DOWN	110 STRANGE	4500 BOTTOM	$-1/3$	80430 W^+/W^-
LEPTONS	0.511 ELECTRON	105.7 MUON	1777 TAU	-1	$< 10^{-23}$ PHOTON
	$< 3 \cdot 10^{-6}$ ν_e NEUTRINO	< 0.19 ν_μ NEUTRINO	< 18.2 ν_τ NEUTRINO	0	theory: 0 GLUON
				0	FORCE CARRIERS: BOSONS

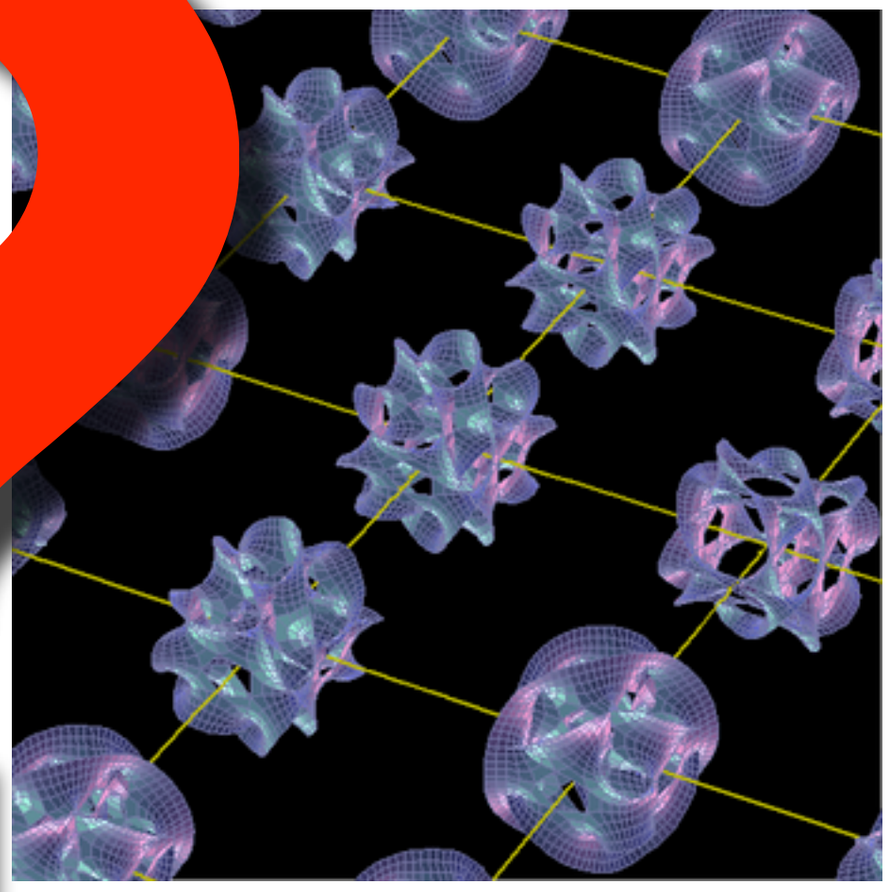
ALL MASSES IN MEV;
ANIMAL MASSES
SCALE WITH
PARTICLE MASSES

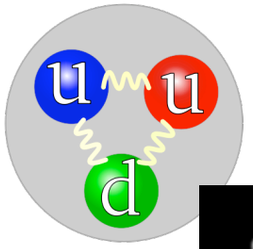
The Standard Model
fundamental particle zoo

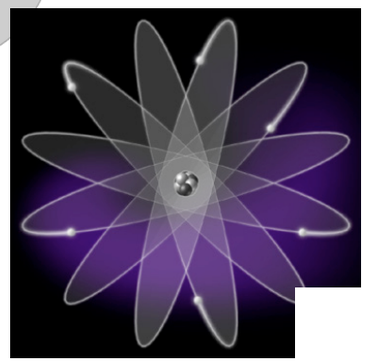


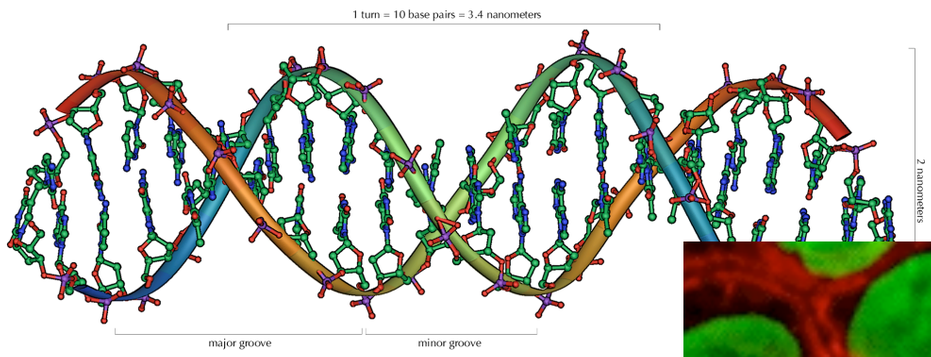


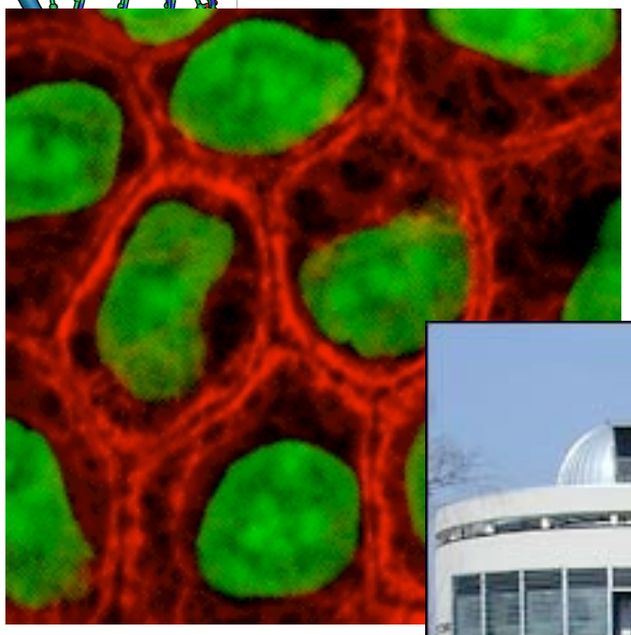




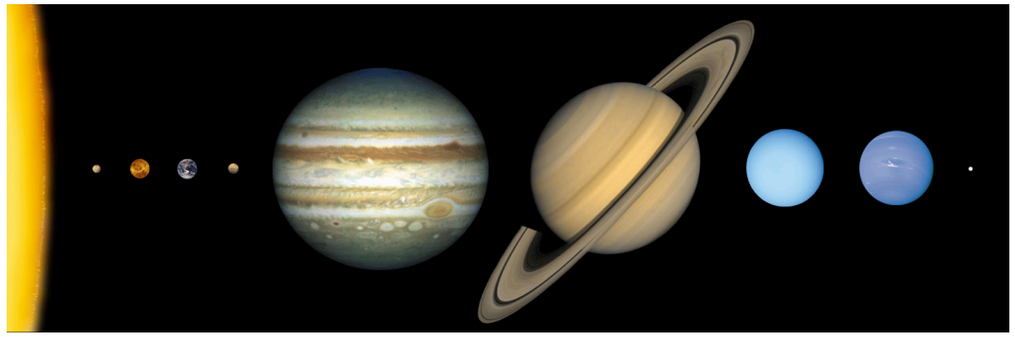

u
u
d

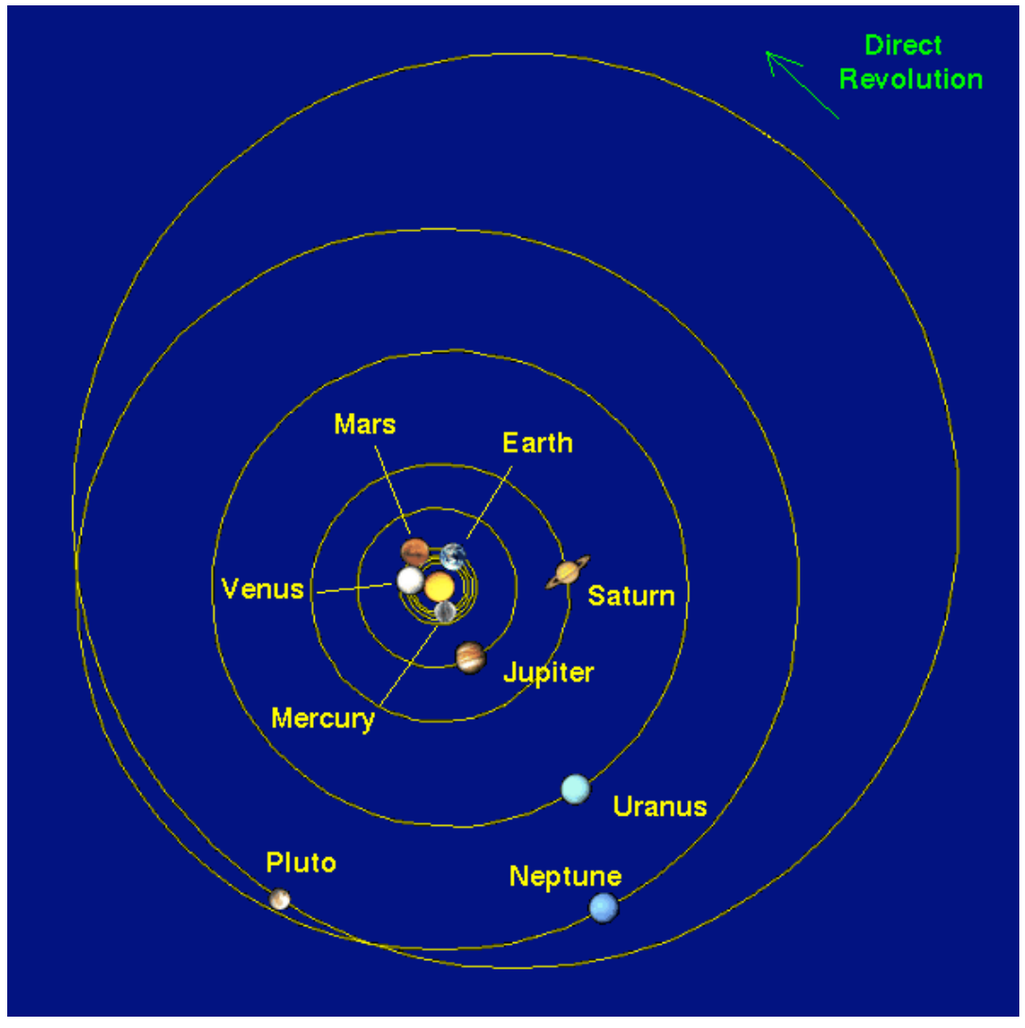



1 turn = 10 base pairs = 3.4 nanometers
2 nanometers
major groove
minor groove



the Earth: ~10 000 km ~ 10^7 m

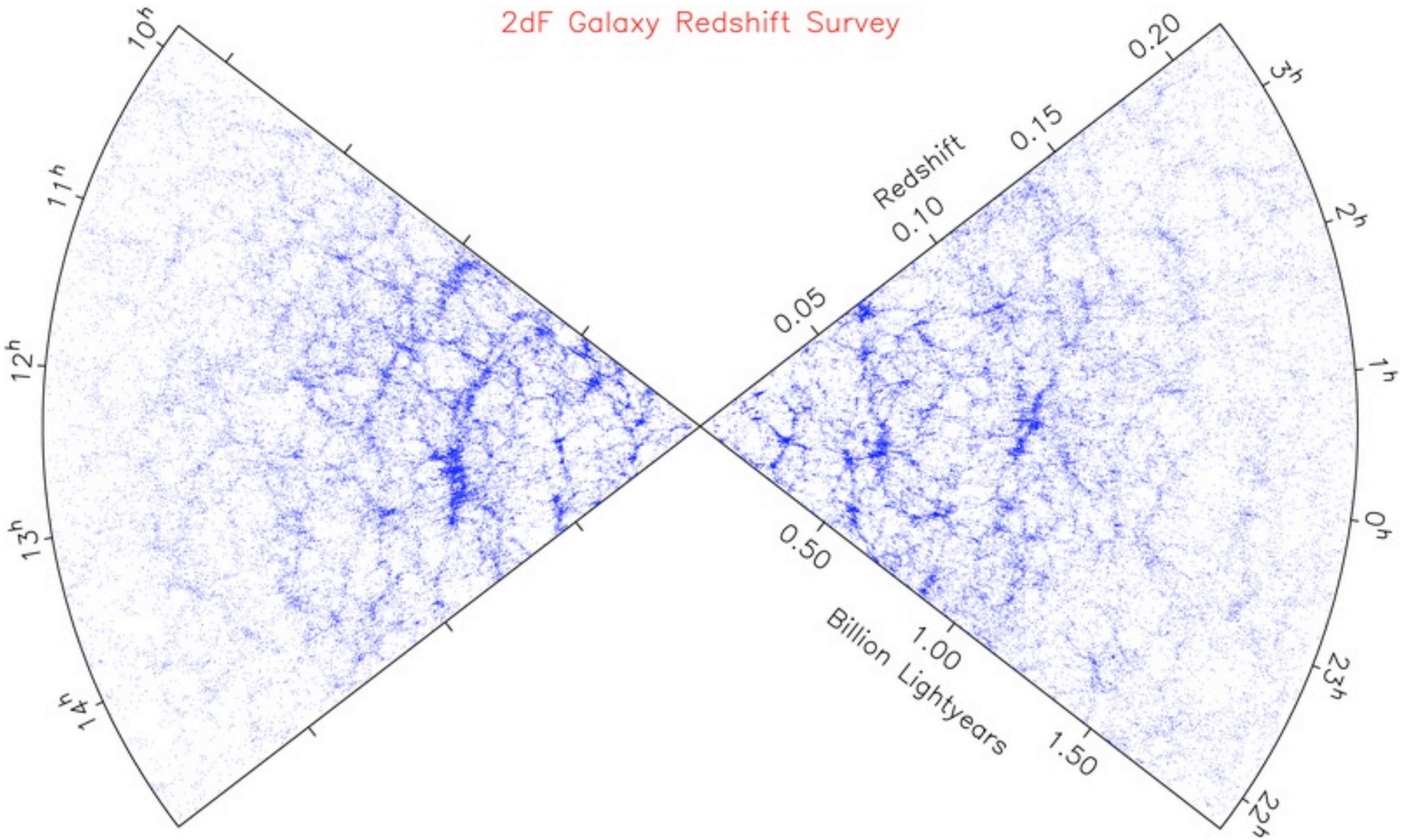




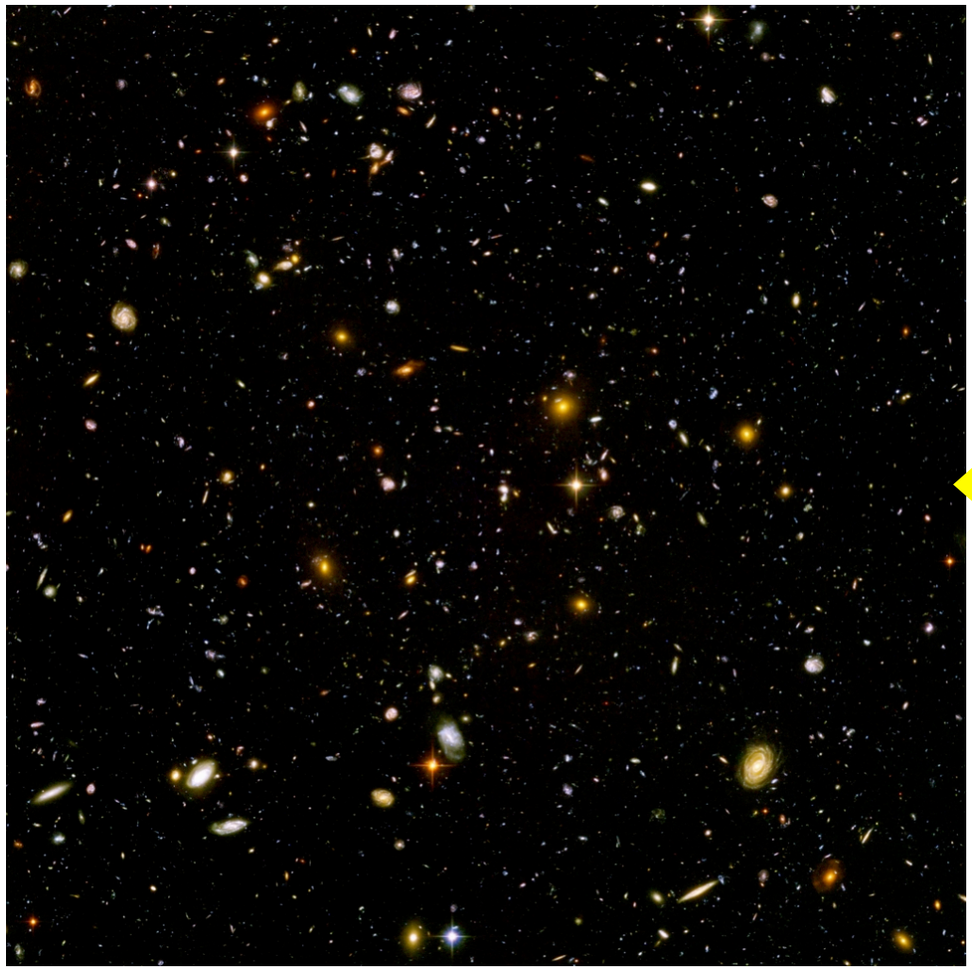
the Solar System: ~ 10^{12} m

the Milky Way: ~ 10^{21} m ~ 10^{5} light years

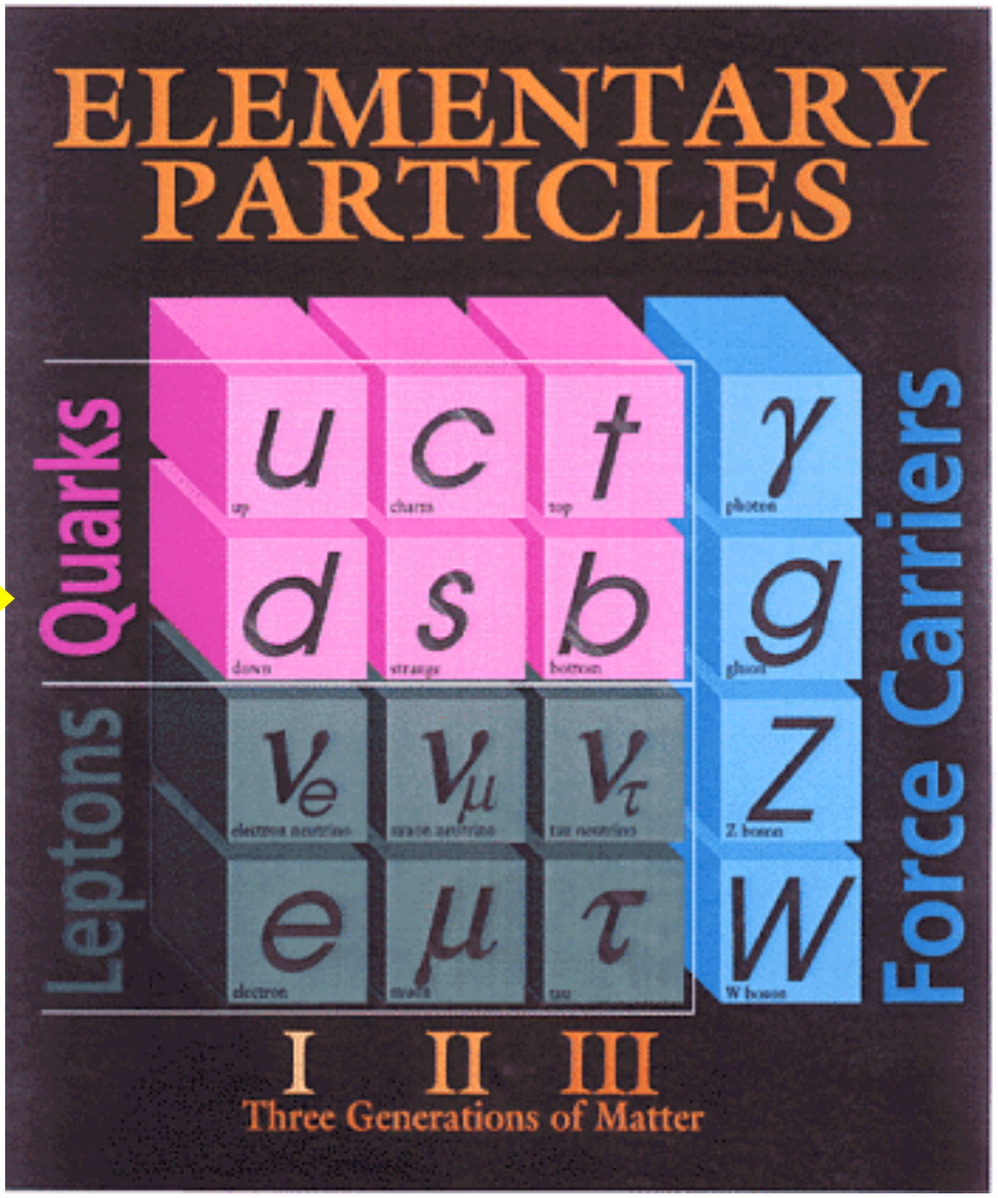
the Virgo cluster, radius ~ 10 million light years

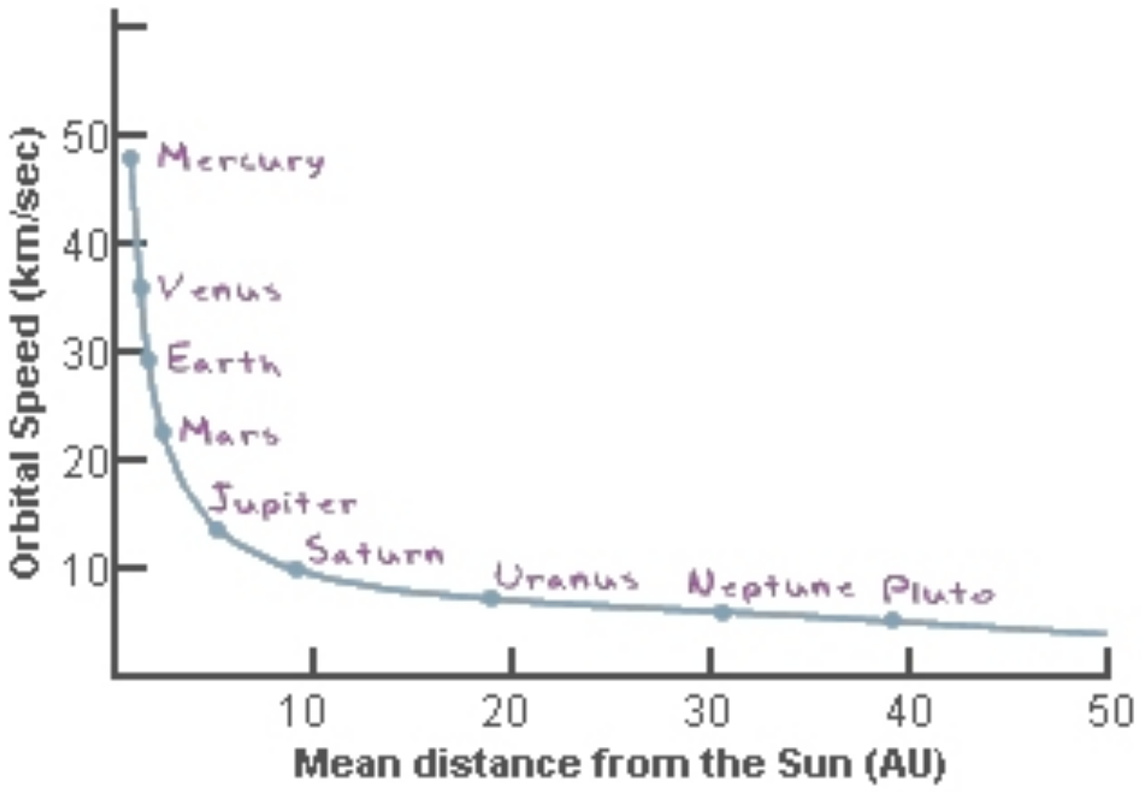


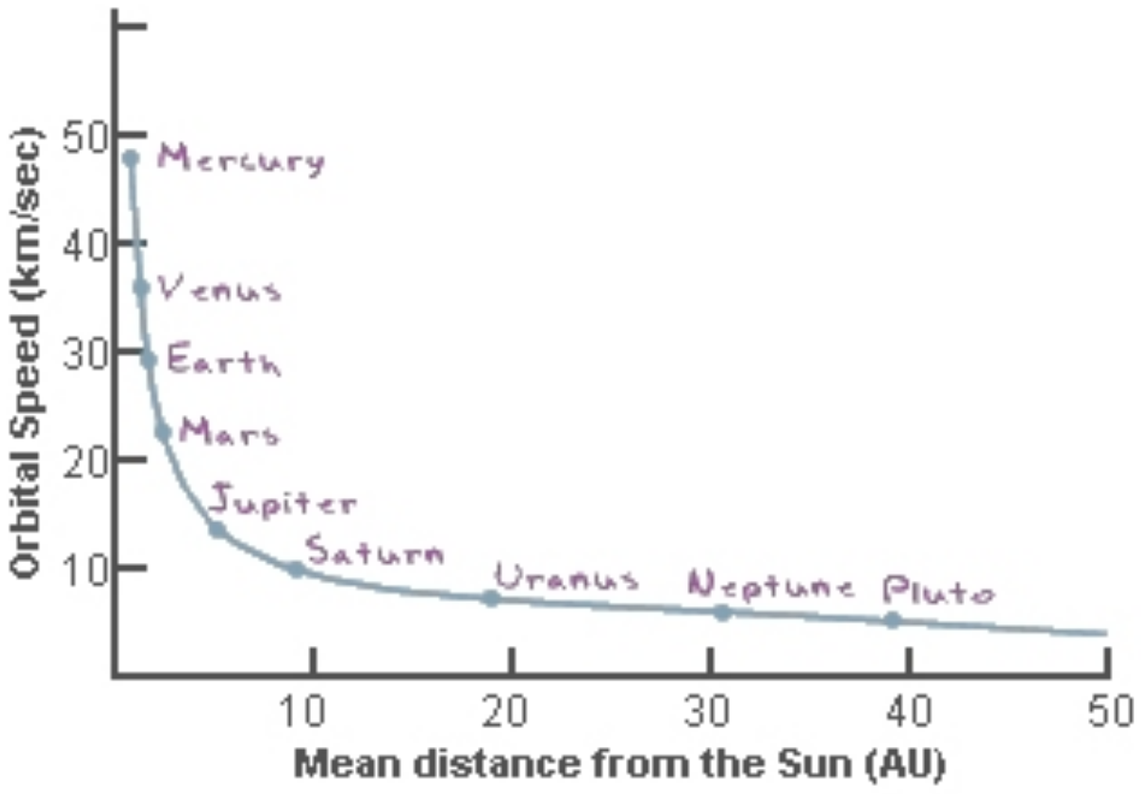
250, 000 million galaxies within 1 billion light years

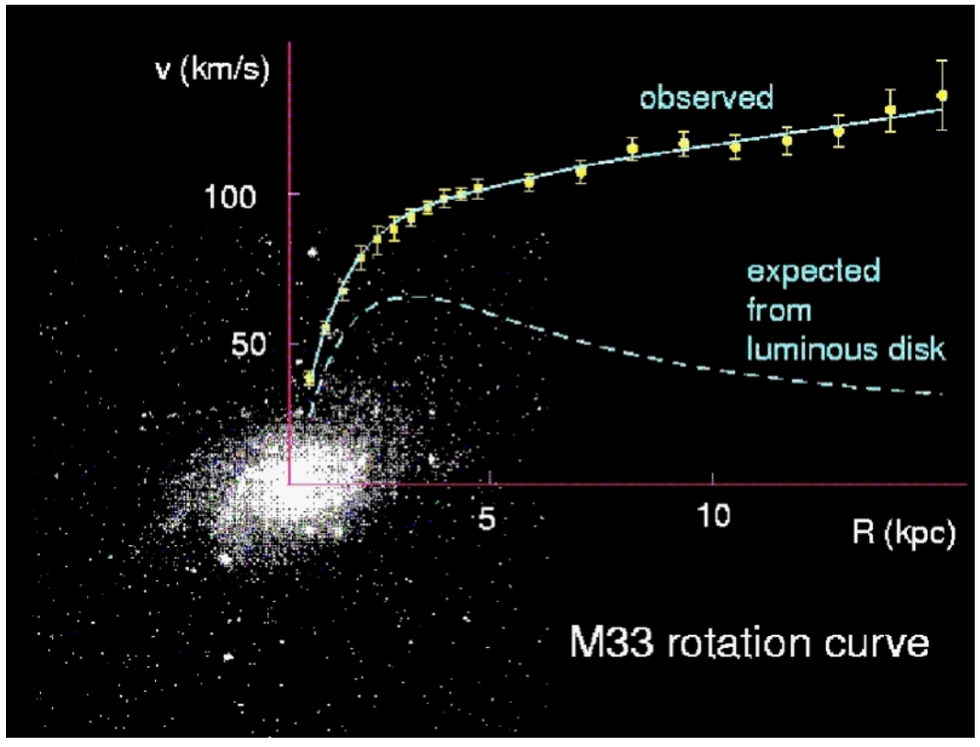


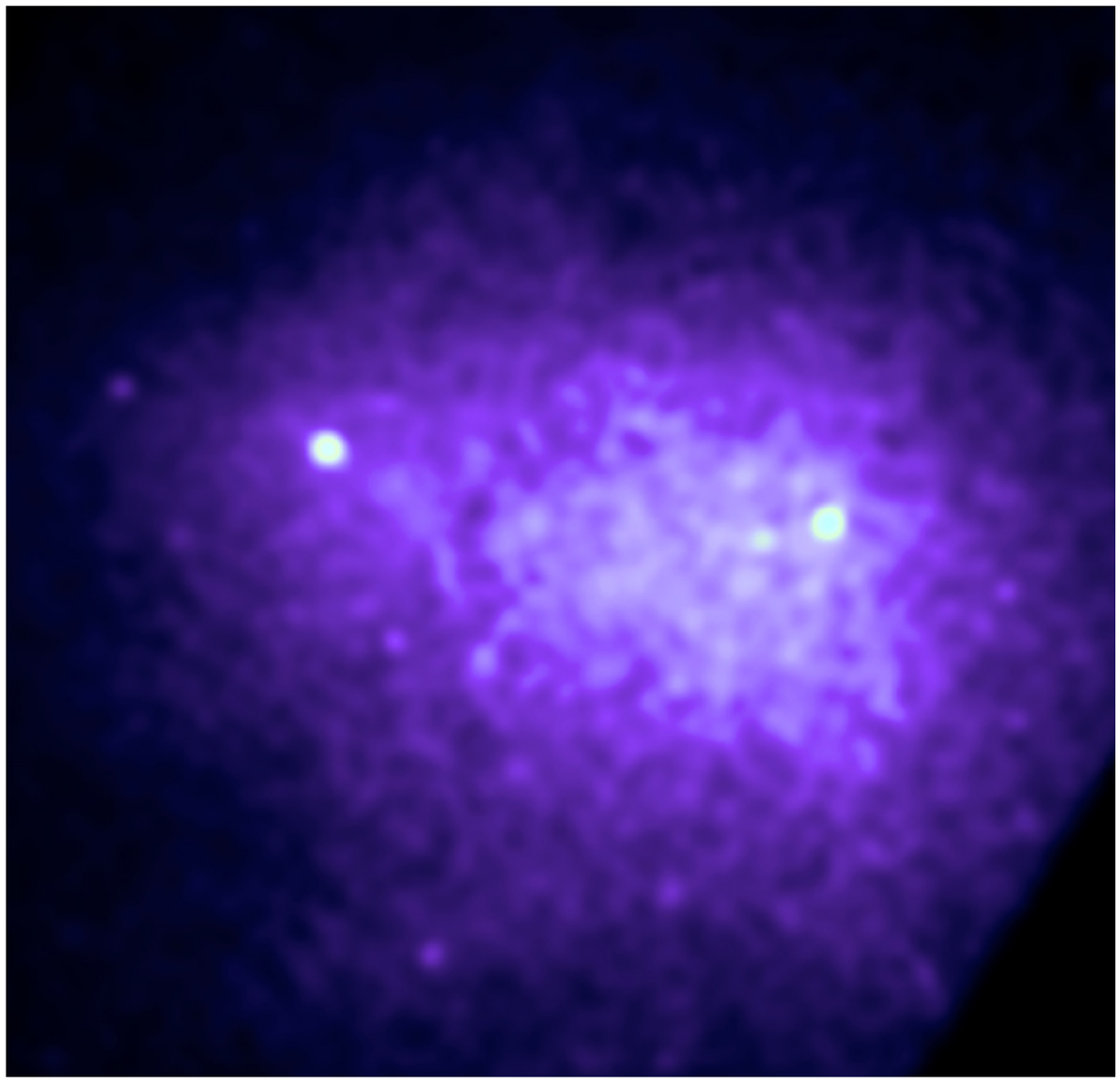
?

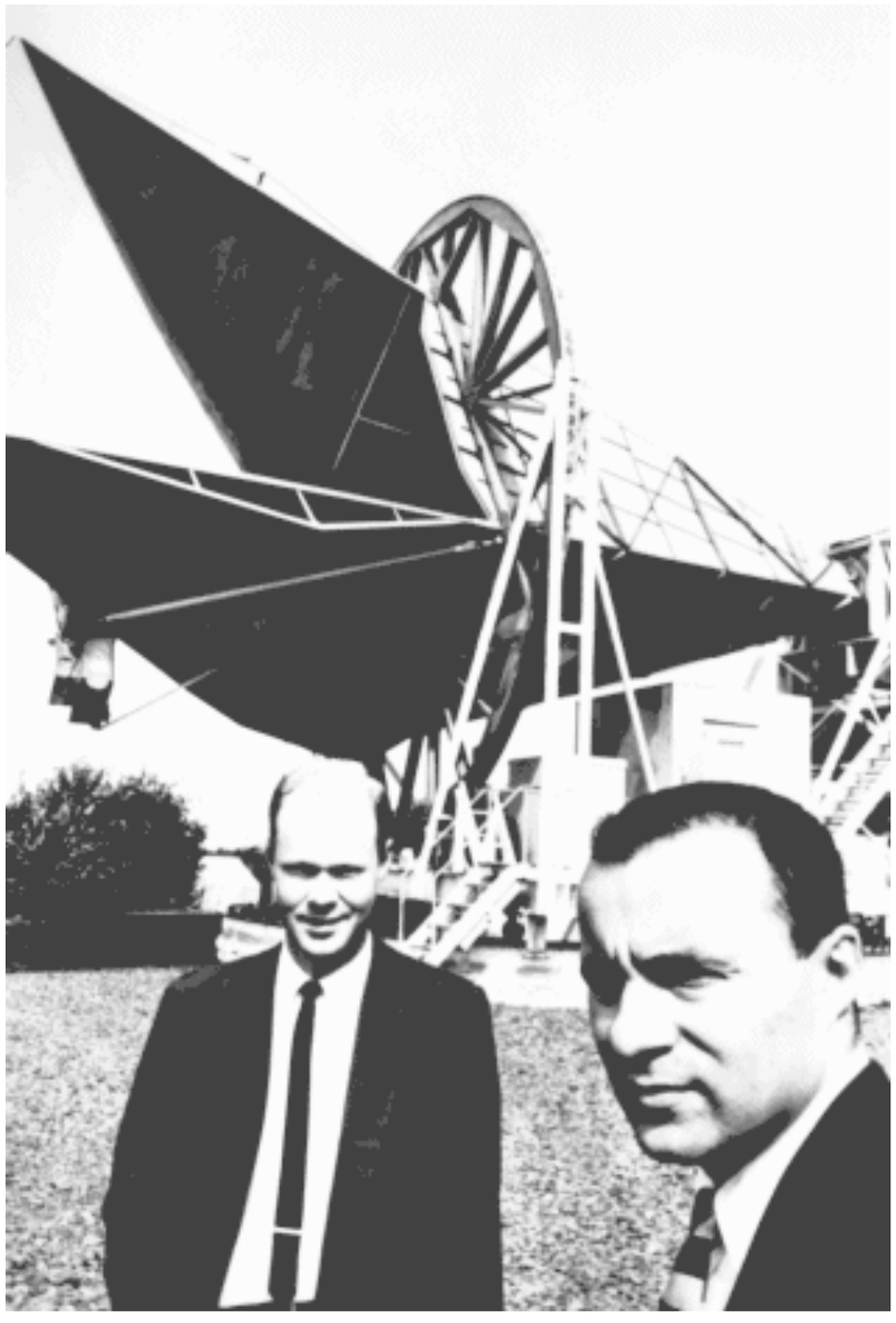

ELEMENTARY PARTICLES
Quarks
Leptons
Force Carriers
u
c
t
γ
up
charm
top
photon
d
s
b
g
down
strange
bottom
gluon
ν_e
ν_μ
ν_τ
Z
electron neutrino
muon neutrino
tau neutrino
Z boson
e
μ
τ
W
electron
muon
tau
W boson
I II III
Three Generations of Matter

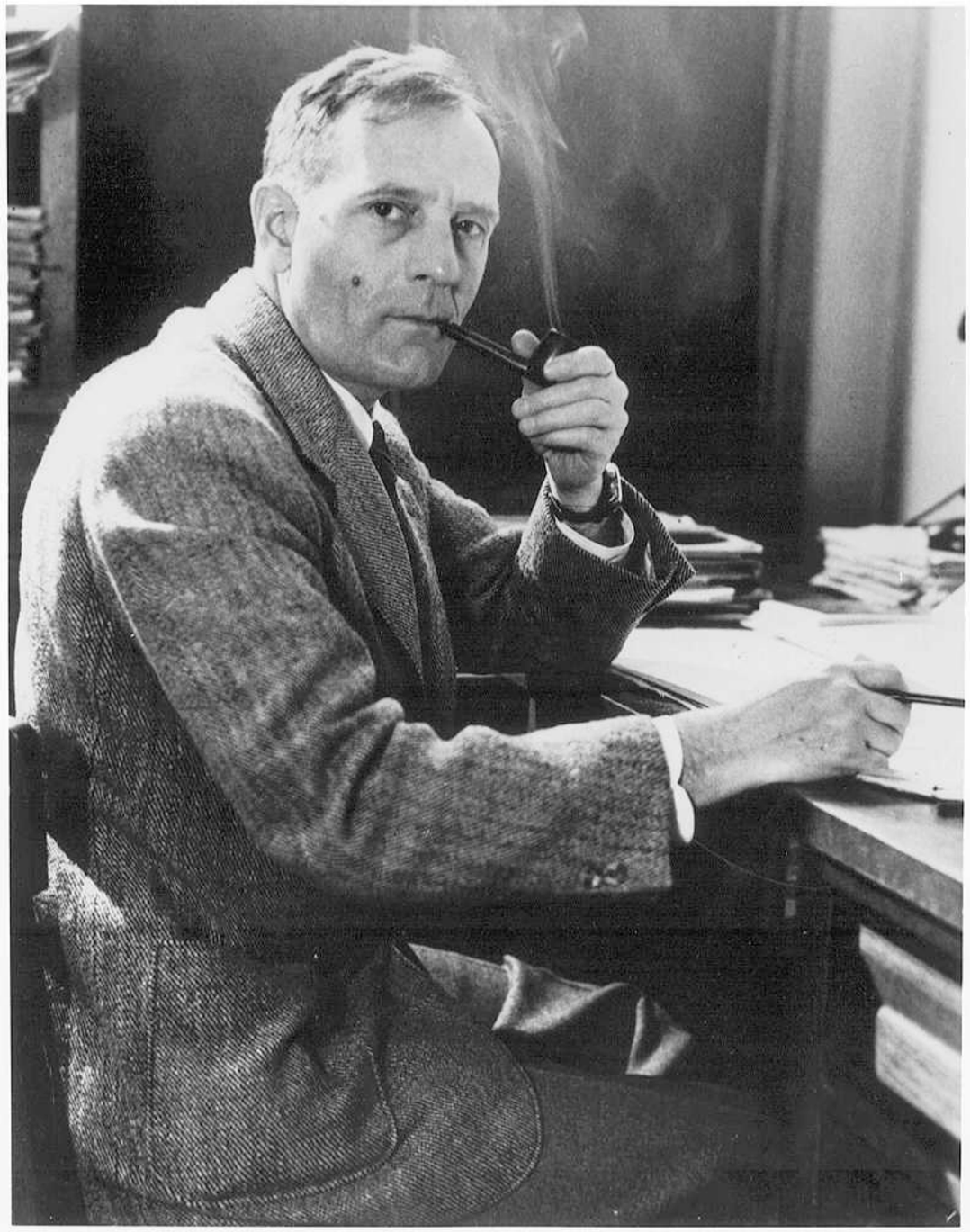

Orbital Speed (km/sec)
50
40
30
20
10
Mercury
Venus
Earth
Mars
Jupiter
Saturn
Uranus
Neptune
Pluto
10
20
30
40
50
Mean distance from the Sun (AU)

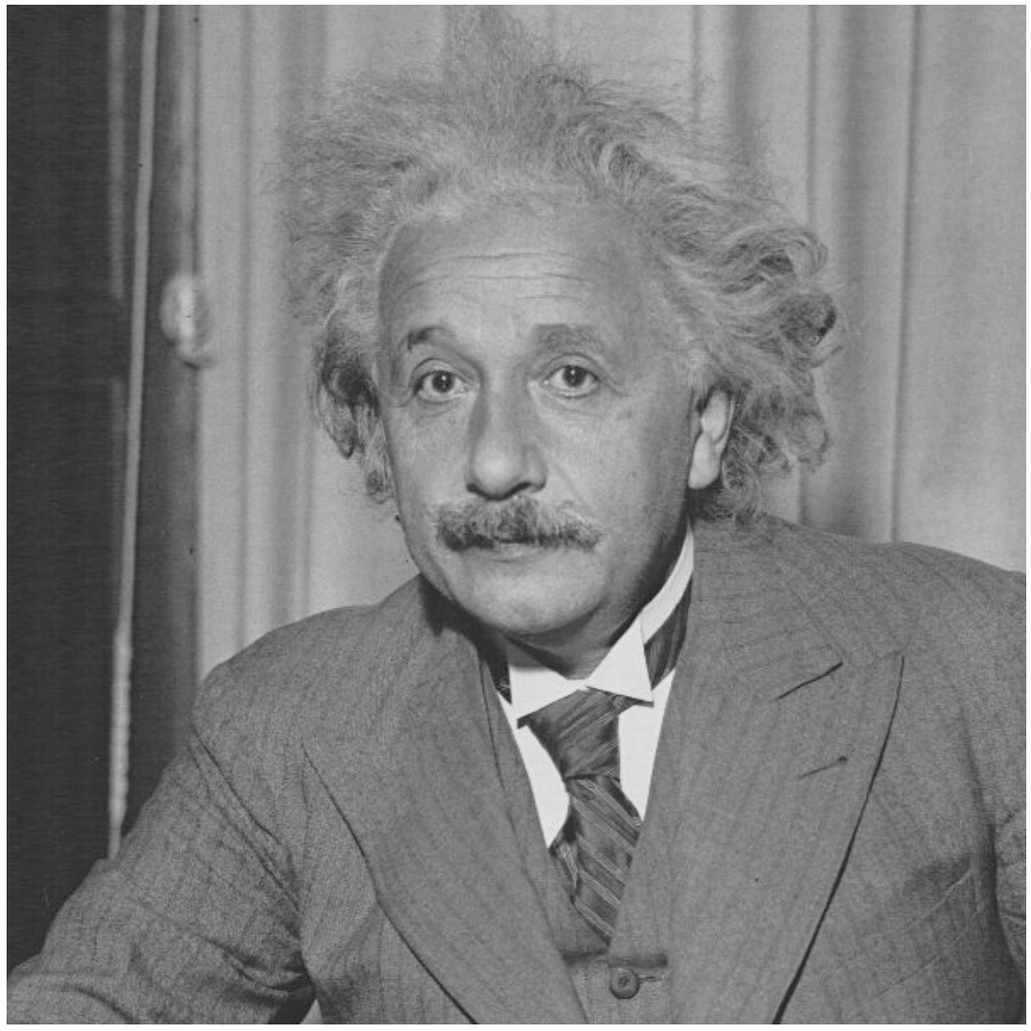

Orbital Speed (km/sec)
50
40
30
20
10
Mercury
Venus
Earth
Mars
Jupiter
Saturn
Uranus
Neptune
Pluto
10
20
30
40
50
Mean distance from the Sun (AU)

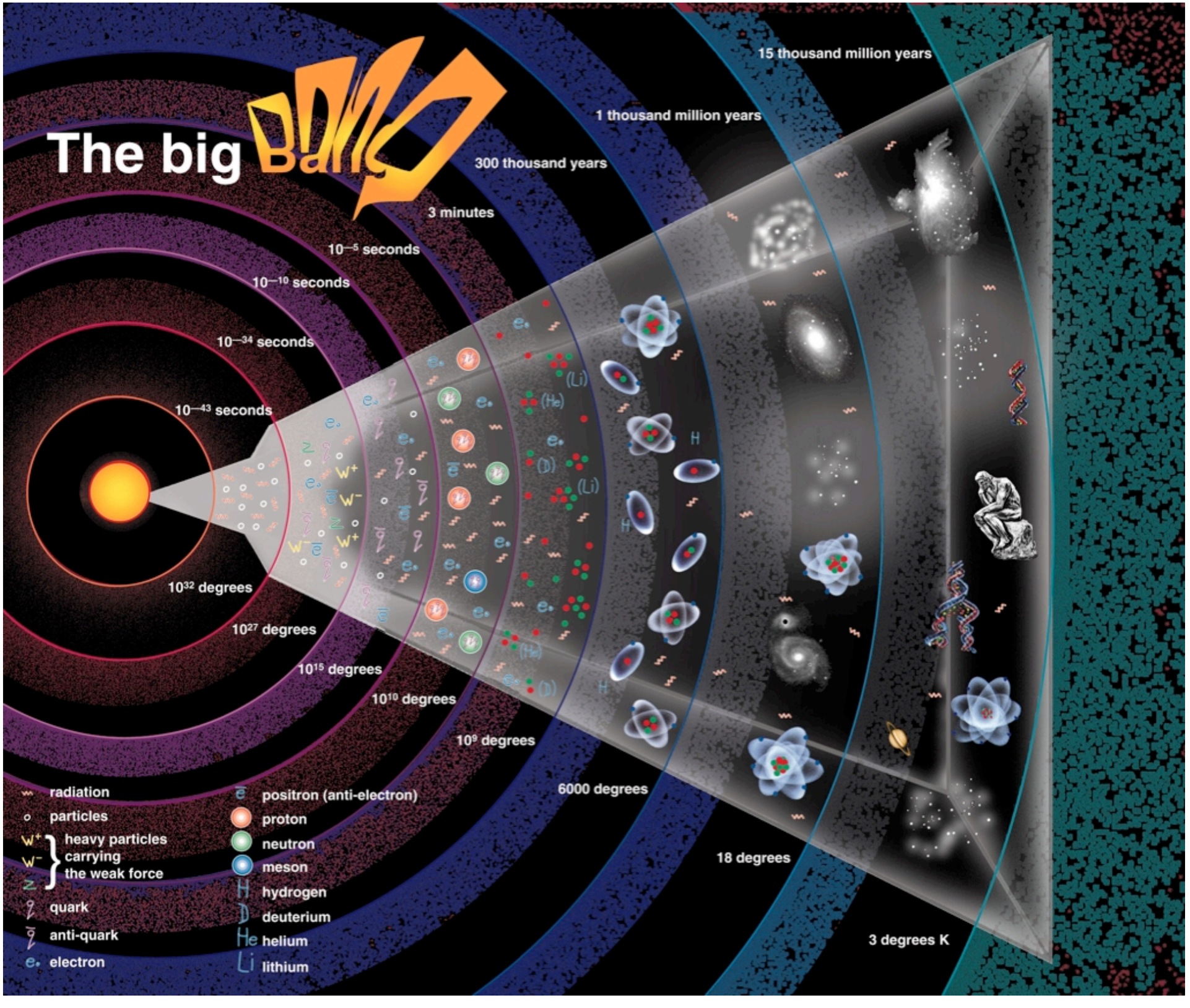

v (km/s)
observed
100
50
expected
from
luminous disk
5
10
R (kpc)
M33 rotation curve

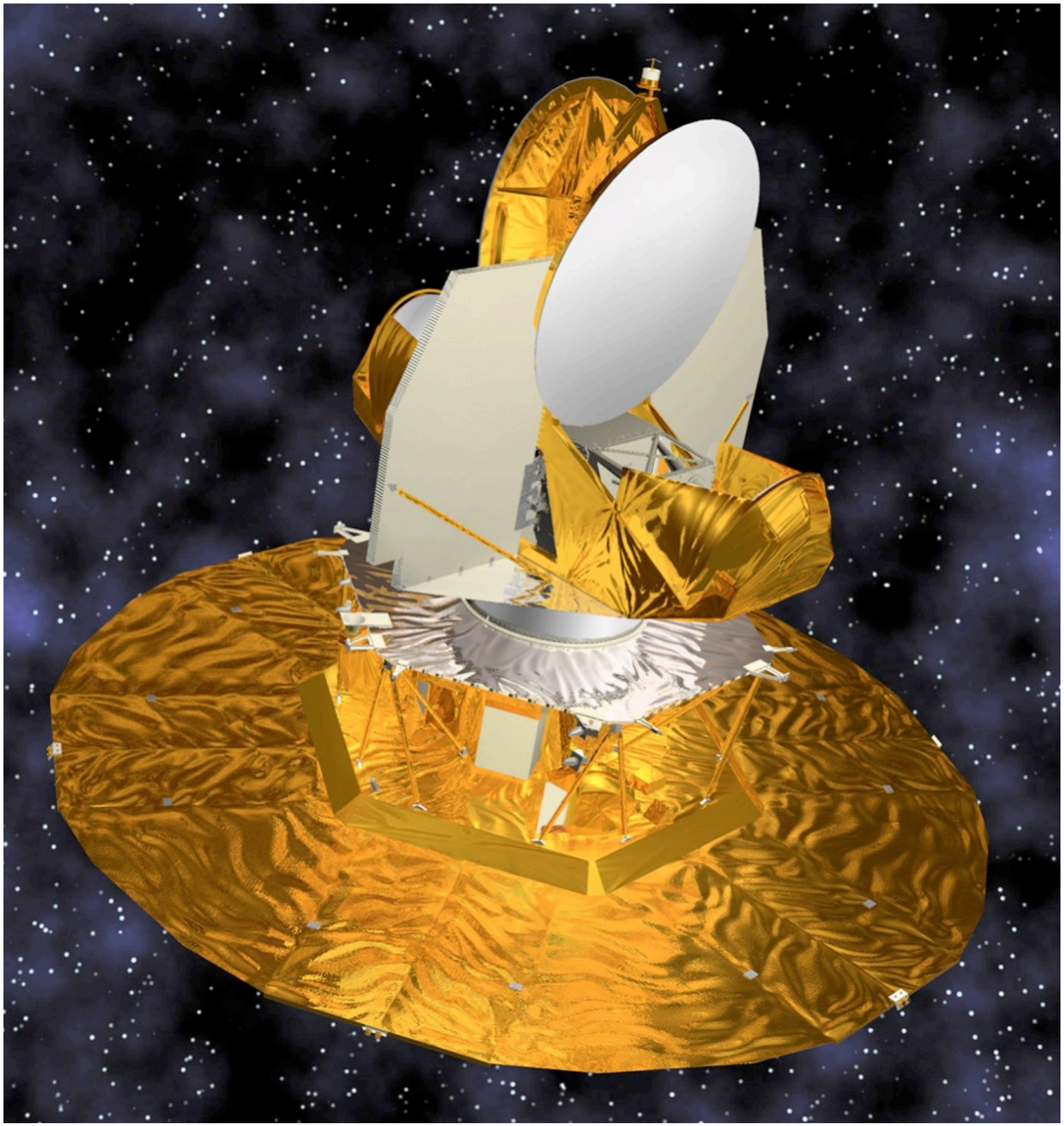


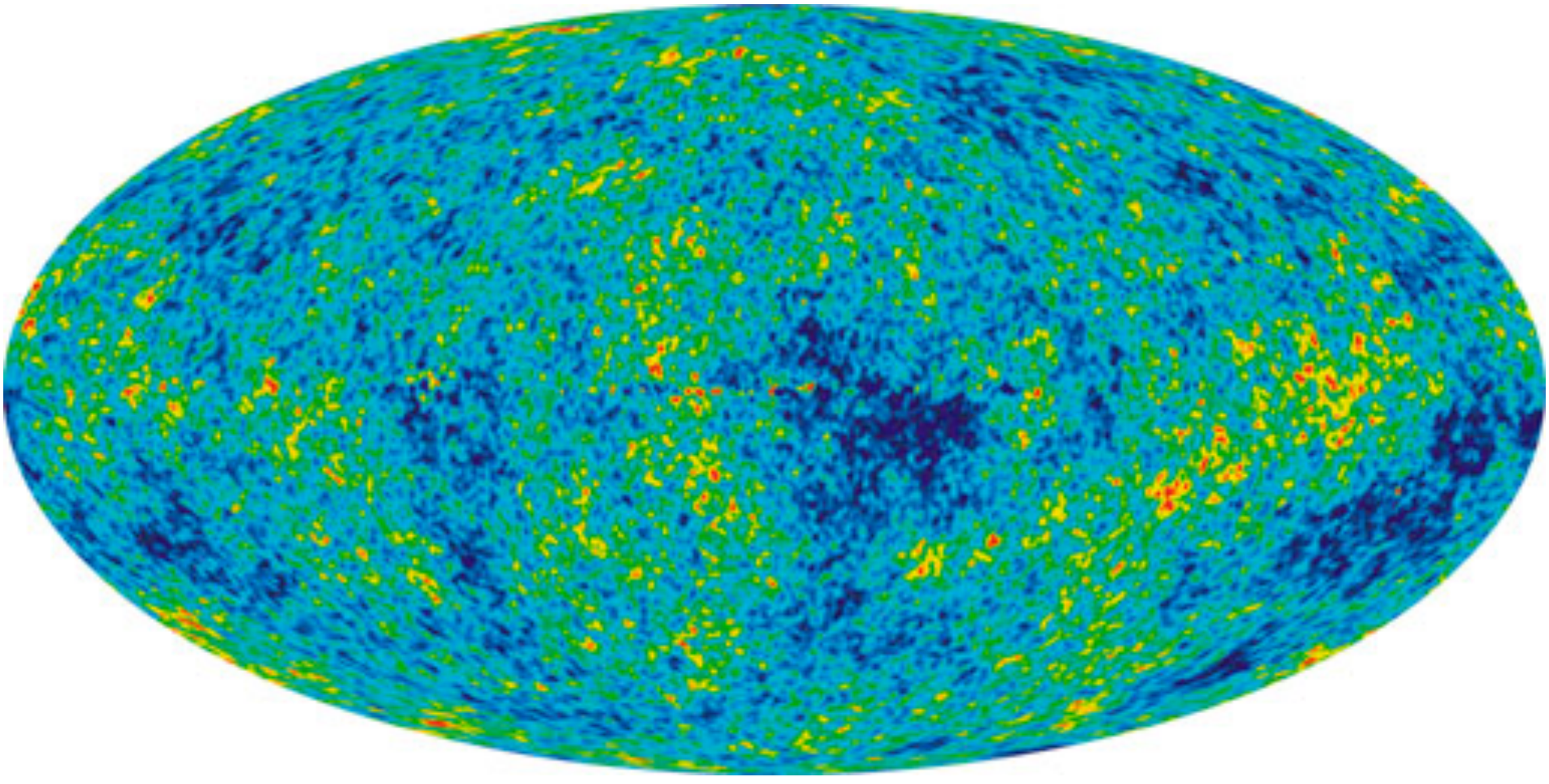




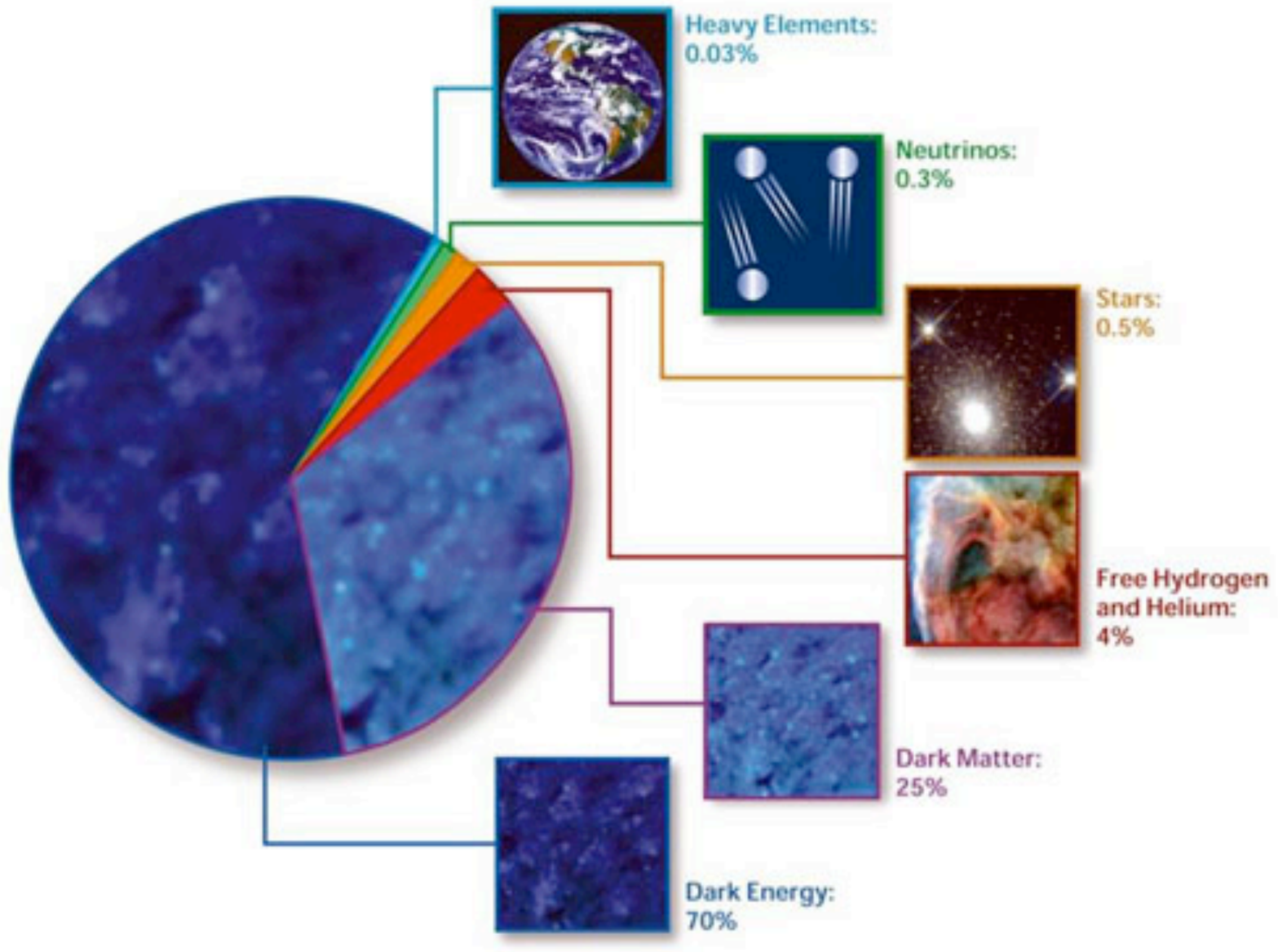


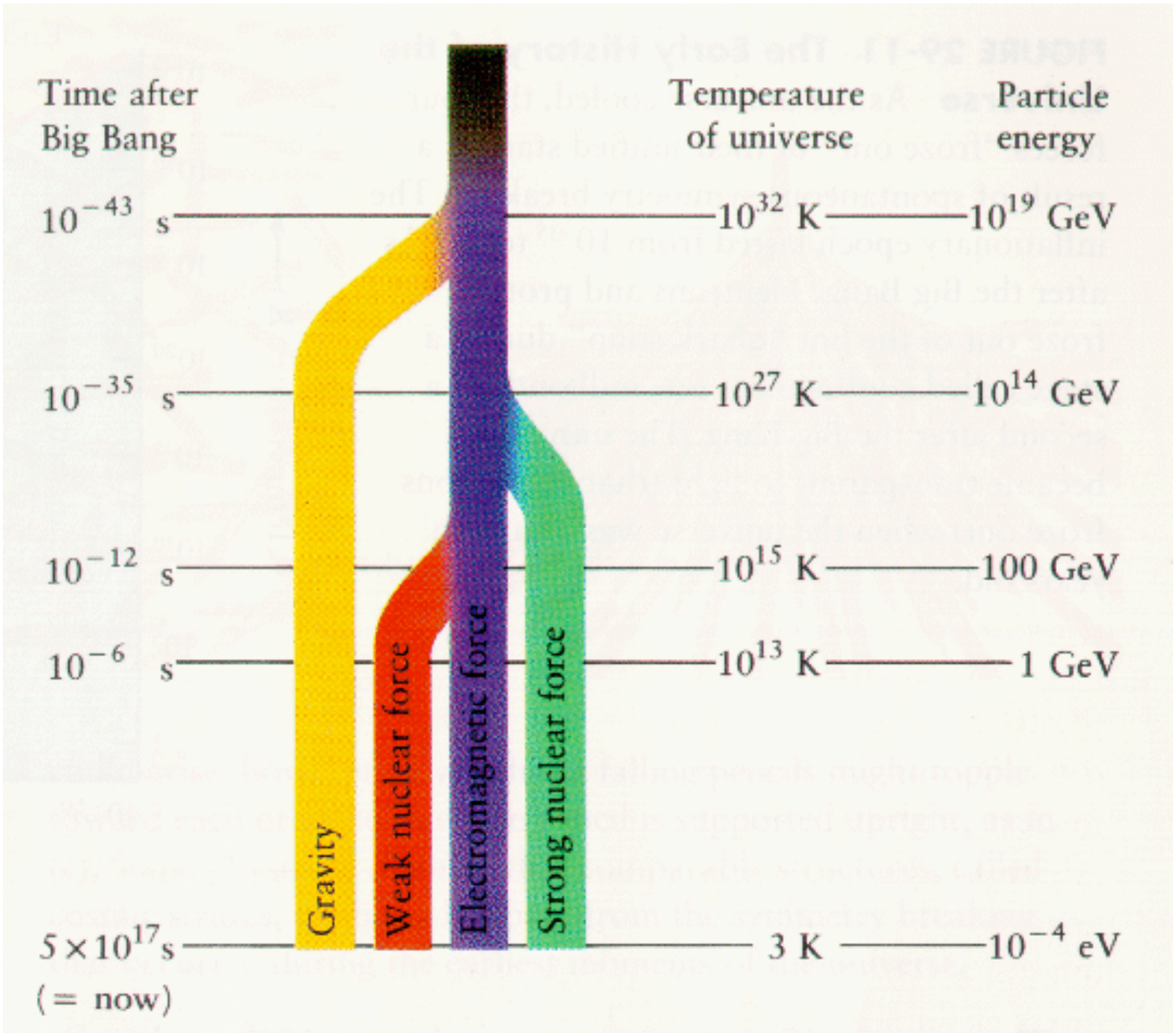

The big Bang
15 thousand million years
1 thousand million years
300 thousand years
3 minutes
10⁻⁵ seconds
10⁻¹⁰ seconds
10⁻³⁴ seconds
10⁻⁴³ seconds
10³² degrees
10²⁷ degrees
10¹⁵ degrees
10¹⁰ degrees
10⁹ degrees
6000 degrees
18 degrees
3 degrees K
radiation
particles
heavy particles carrying the weak force
quark
anti-quark
electron
positron (anti-electron)
proton
neutron
meson
hydrogen
deuterium
helium
lithium





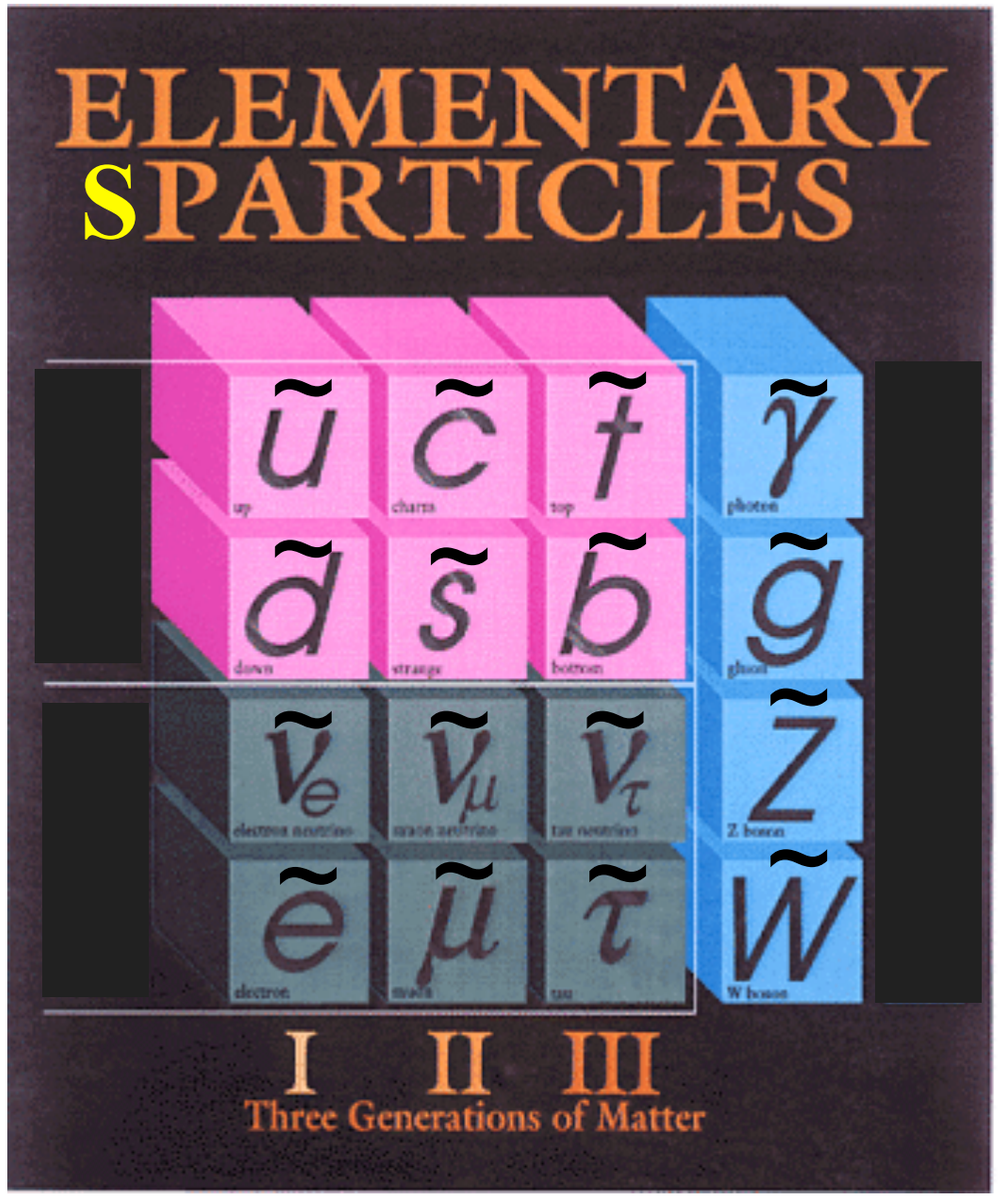
COMPOSITION OF THE COSMOS



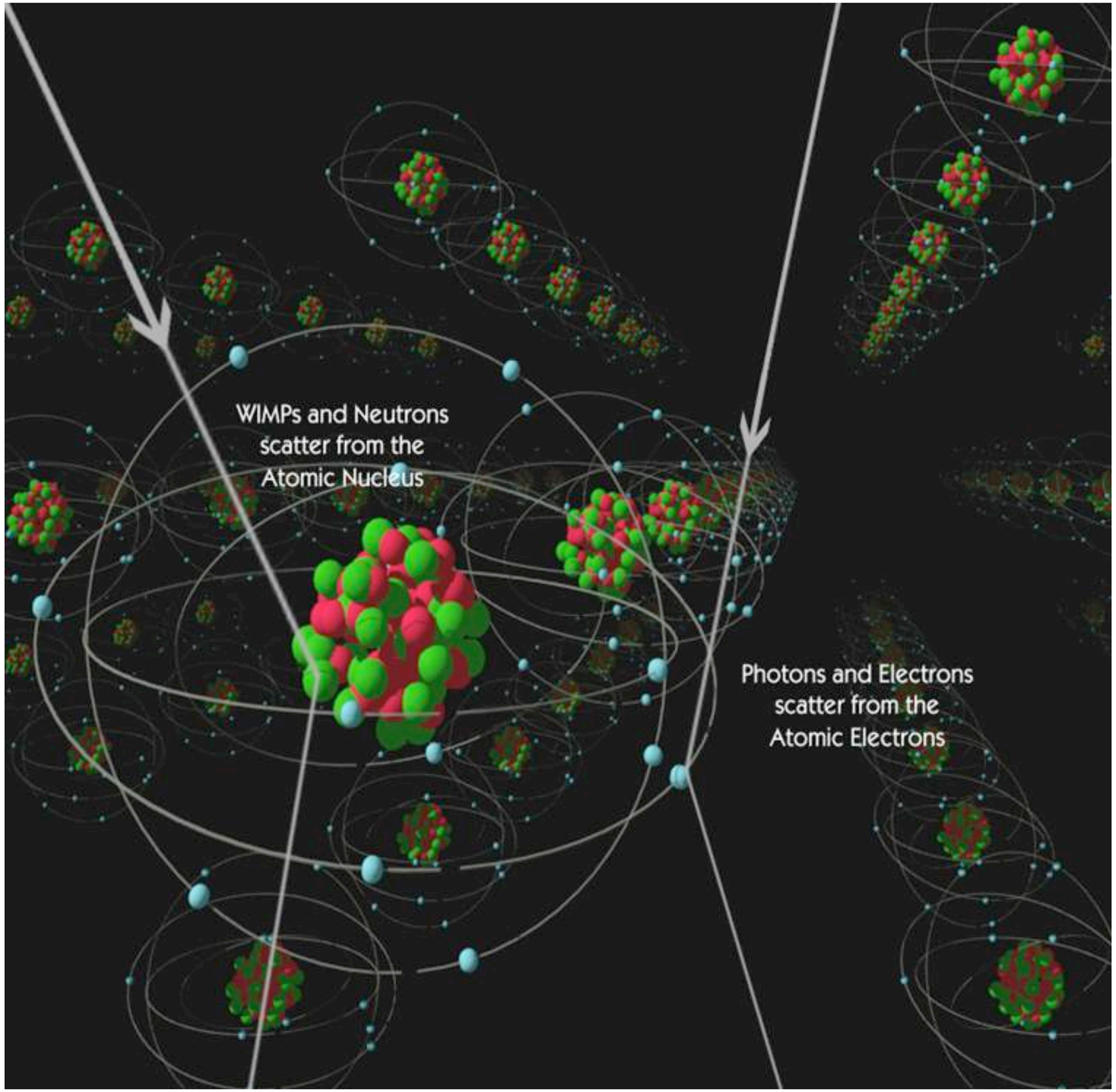

Time after Big Bang
Temperature of universe
Particle energy
10^{-43} s
10^{32} K
10^{19} GeV
10^{-35} s
10^{27} K
10^{14} GeV
10^{-12} s
10^{15} K
100 GeV
10^{-6} s
10^{13} K
1 GeV
5×10^{17} s
(= now)
3 K
10^{-4} eV
Gravity
Weak nuclear force
Electromagnetic force
Strong nuclear force

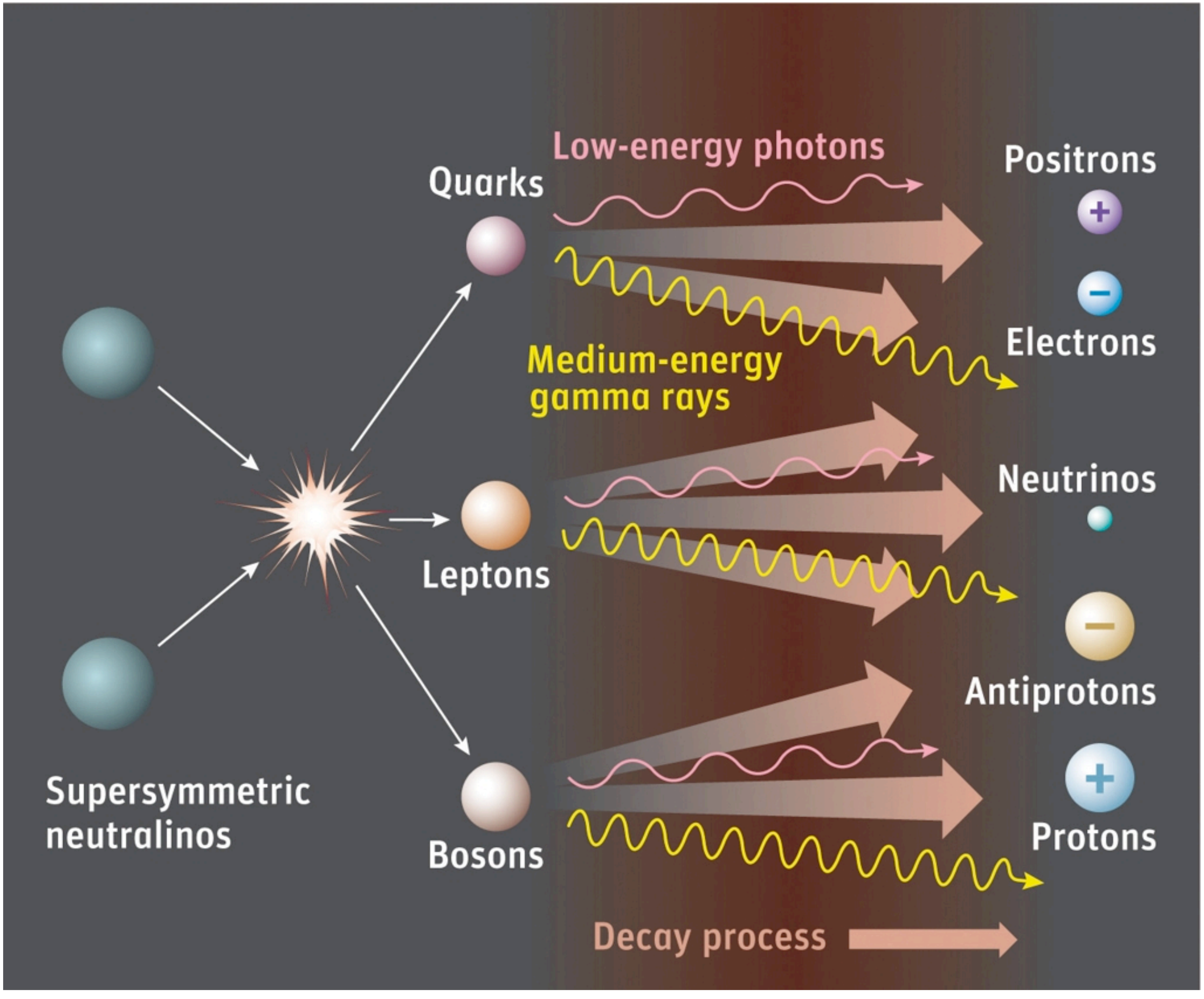
squarks

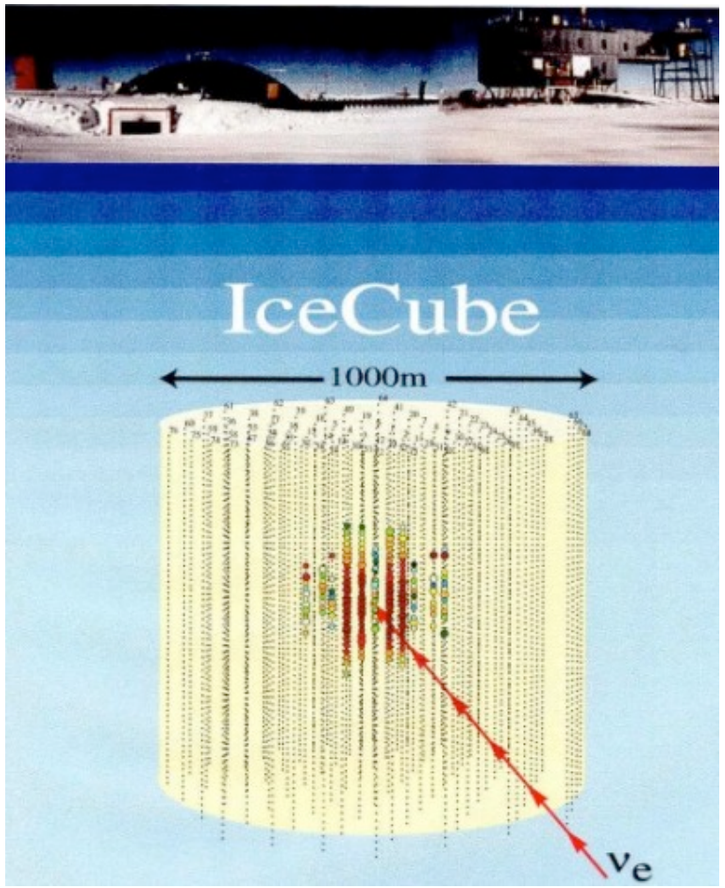
sleptons

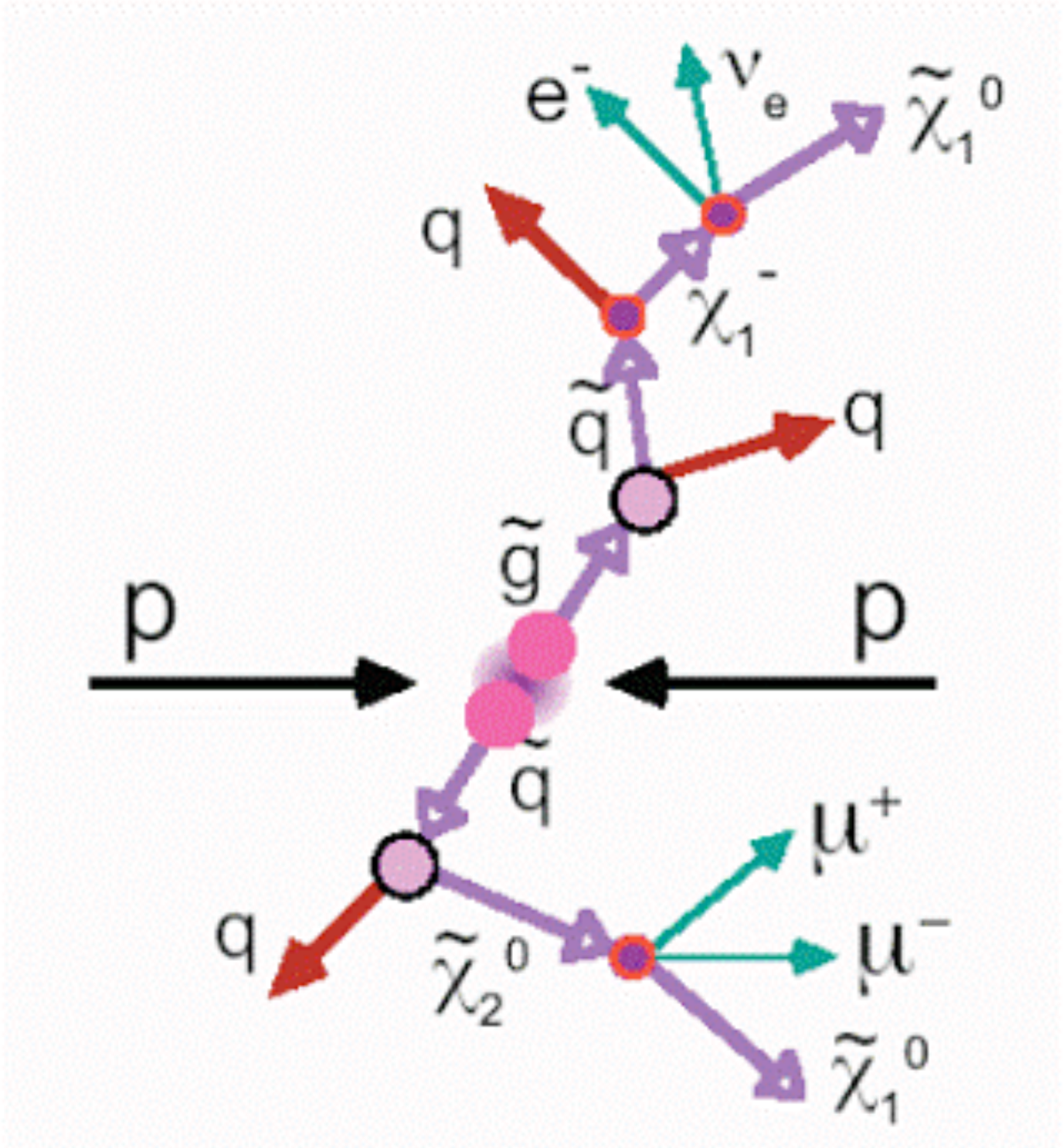


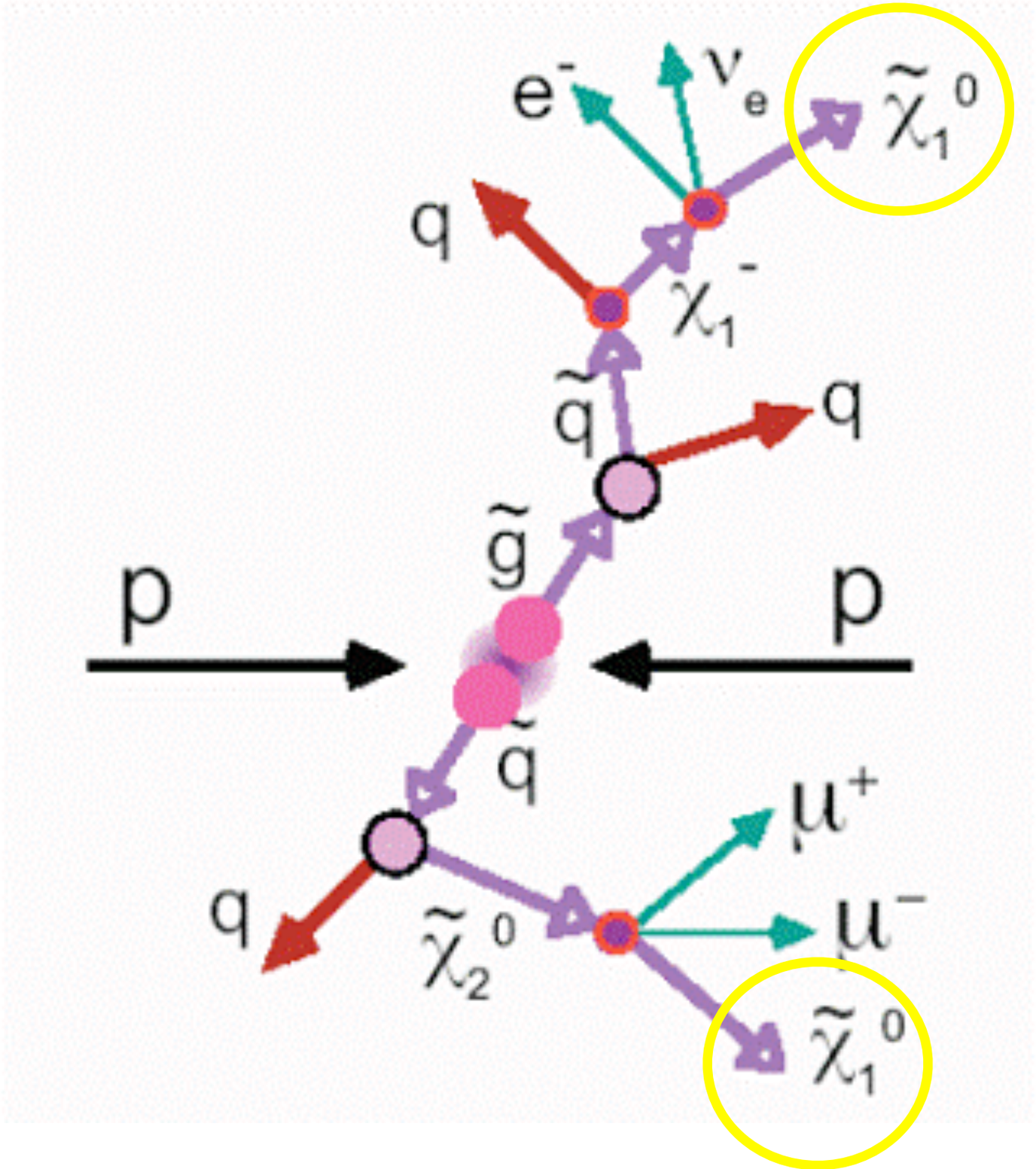
-inos

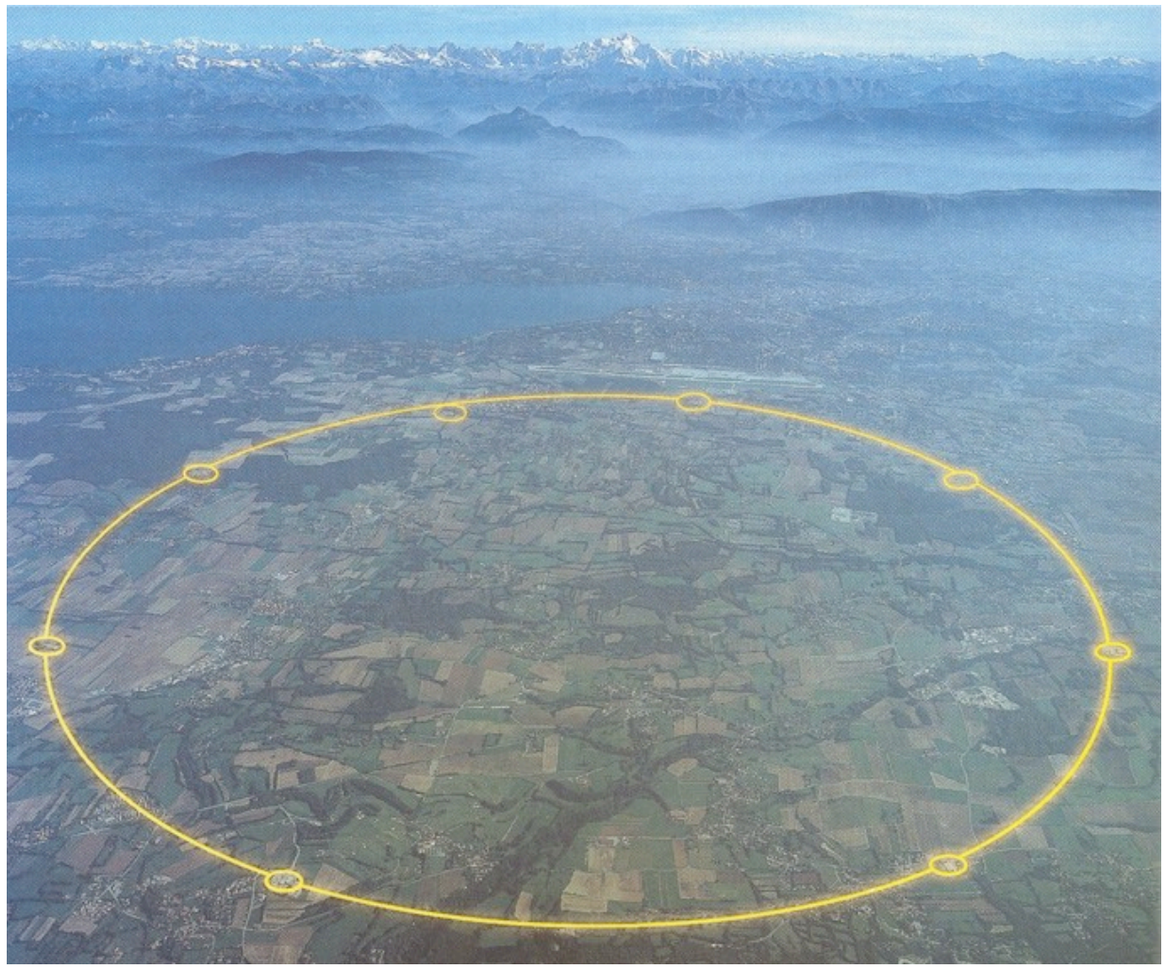

WIMPs and Neutrons
scatter from the
Atomic Nucleus
Photons and Electrons
scatter from the
Atomic Electrons

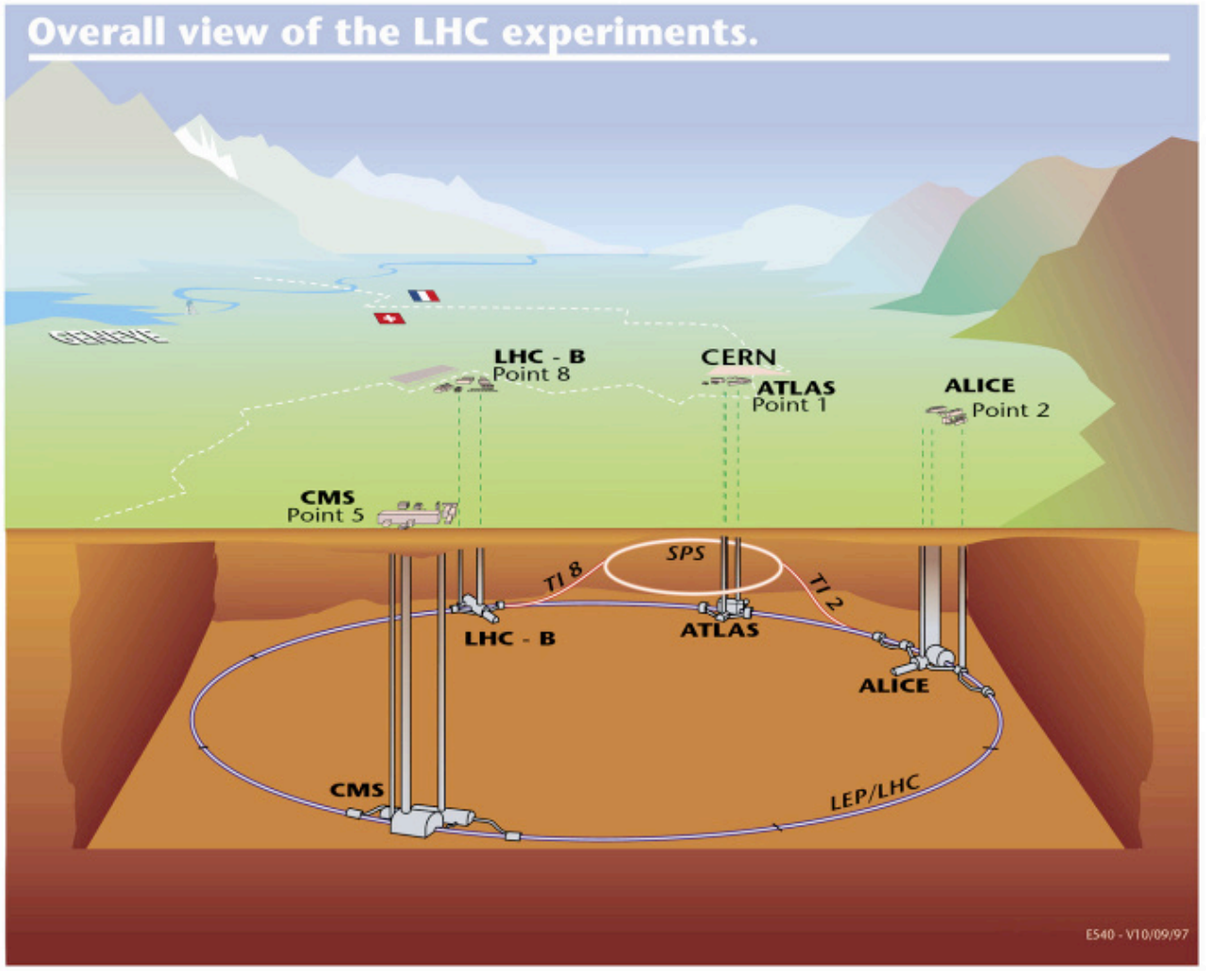

Low-energy photons
Quarks
Positrons
Electrons
Medium-energy
gamma rays
Neutrinos
Leptons
Antiprotons
Supersymmetric
neutralinos
Bosons
Protons
Decay process


IceCube
1000m
ν_e


e⁻
ν_e
χ̃₁⁰
q
χ₁⁻
q̃
q
g̃
p
p
q̃
μ⁺
q
χ̃₂⁰
μ⁻
χ̃₁⁰


e⁻
ν_e
χ̃₁⁰
q
χ̃₁⁻
q̃
q
g̃
p
p
q̃
μ⁺
q
χ̃₂⁰
μ⁻
χ̃₁⁰



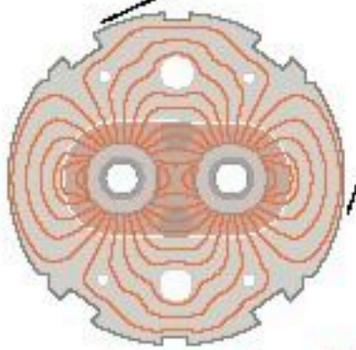

Overall view of the LHC experiments.
GENEVE
LHC - B
Point 8
CERN
ATLAS
Point 1
ALICE
Point 2
CMS
Point 5
SPS
TI 8
TI 2
LHC - B
ATLAS
ALICE
CMS
LEP/LHC
ES40 - V10/09/97

ATLAS

PS

SPS

ALICE

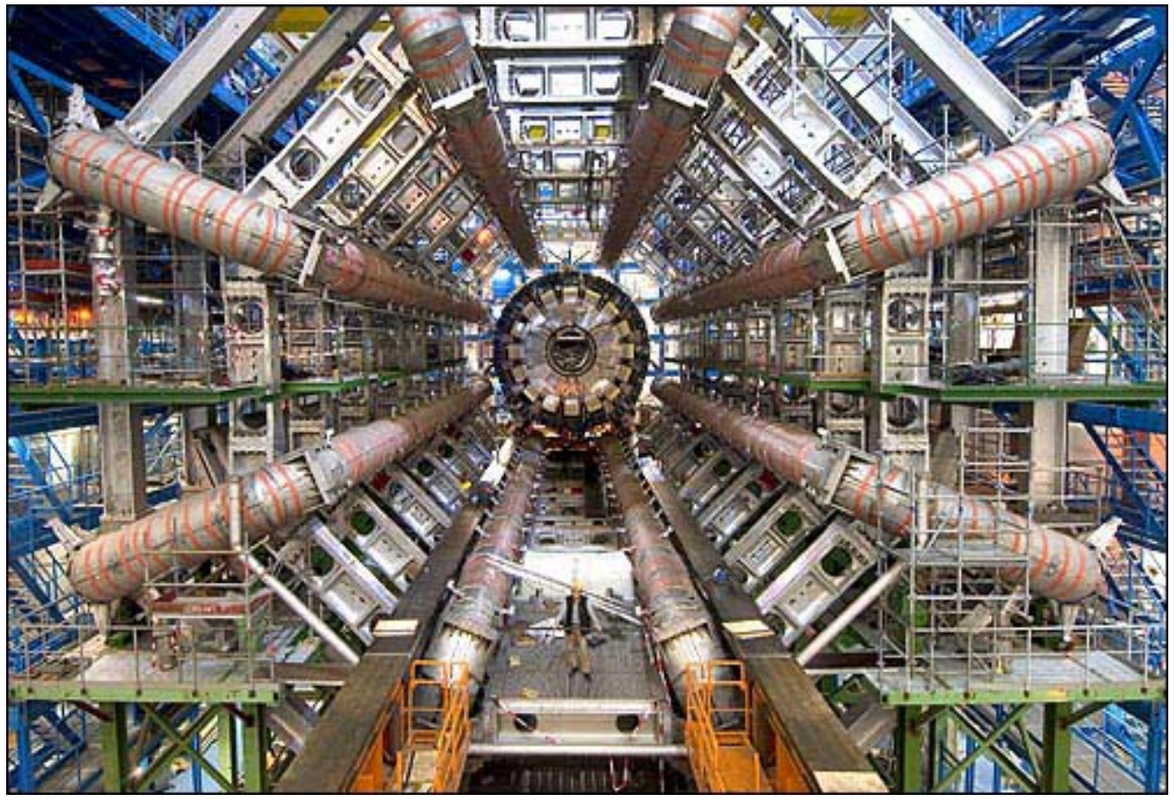


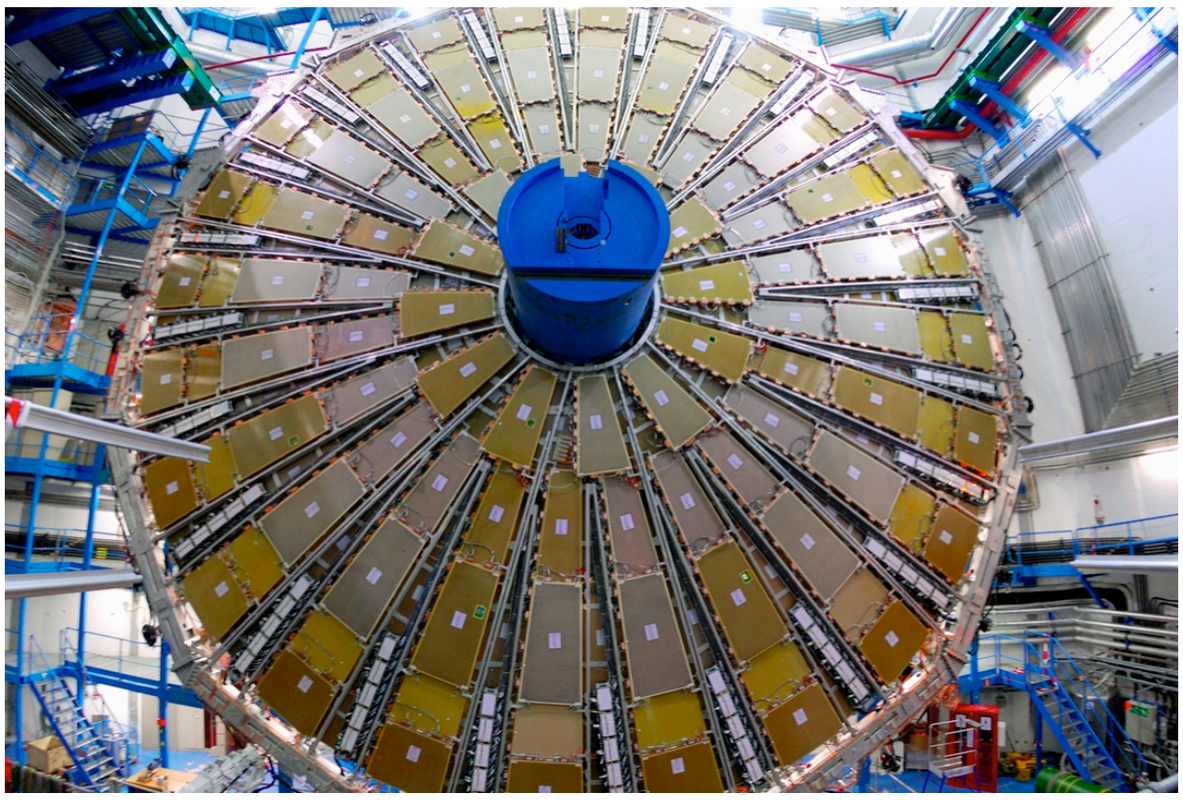
Superconducting magnets

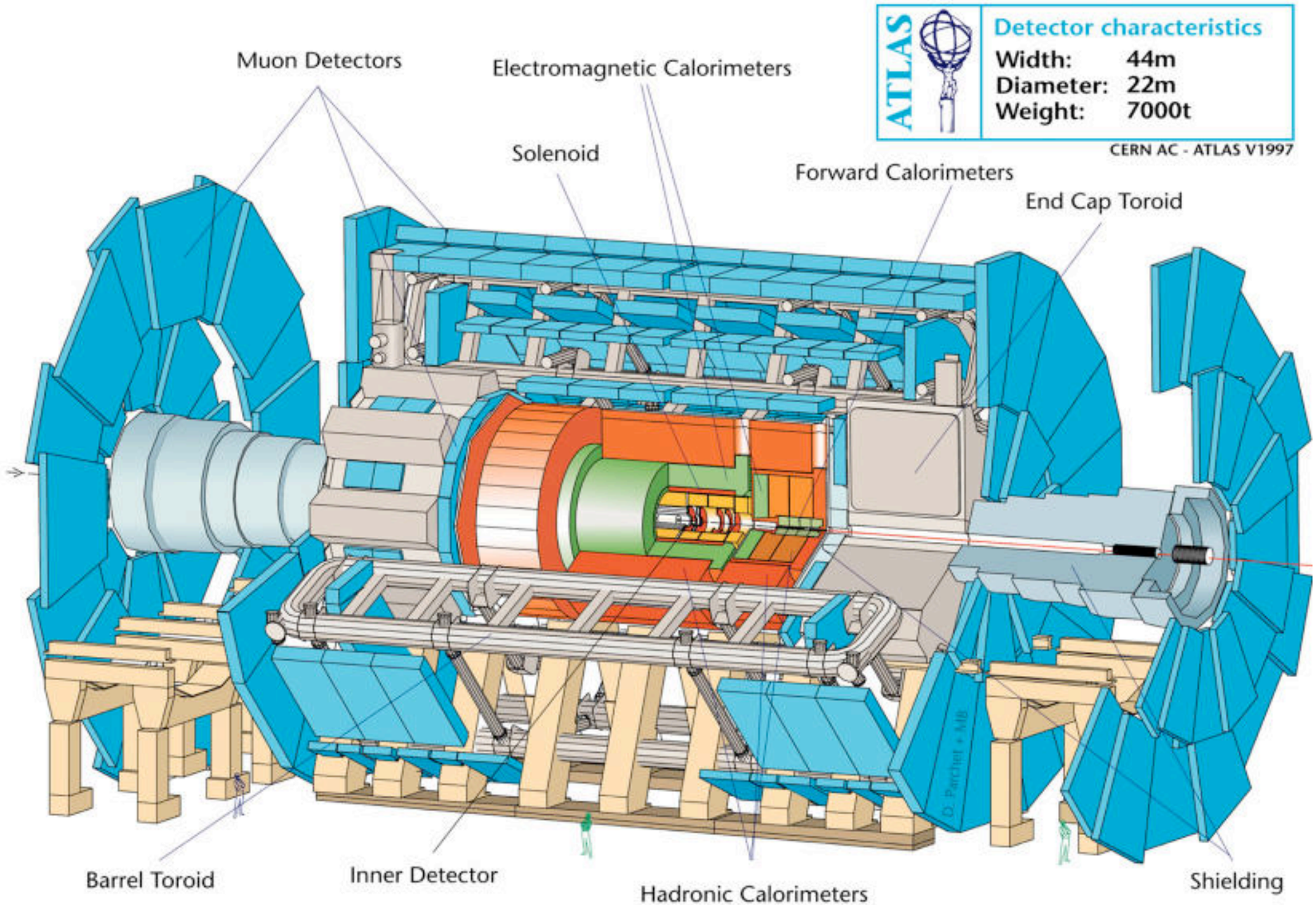
LHC-B

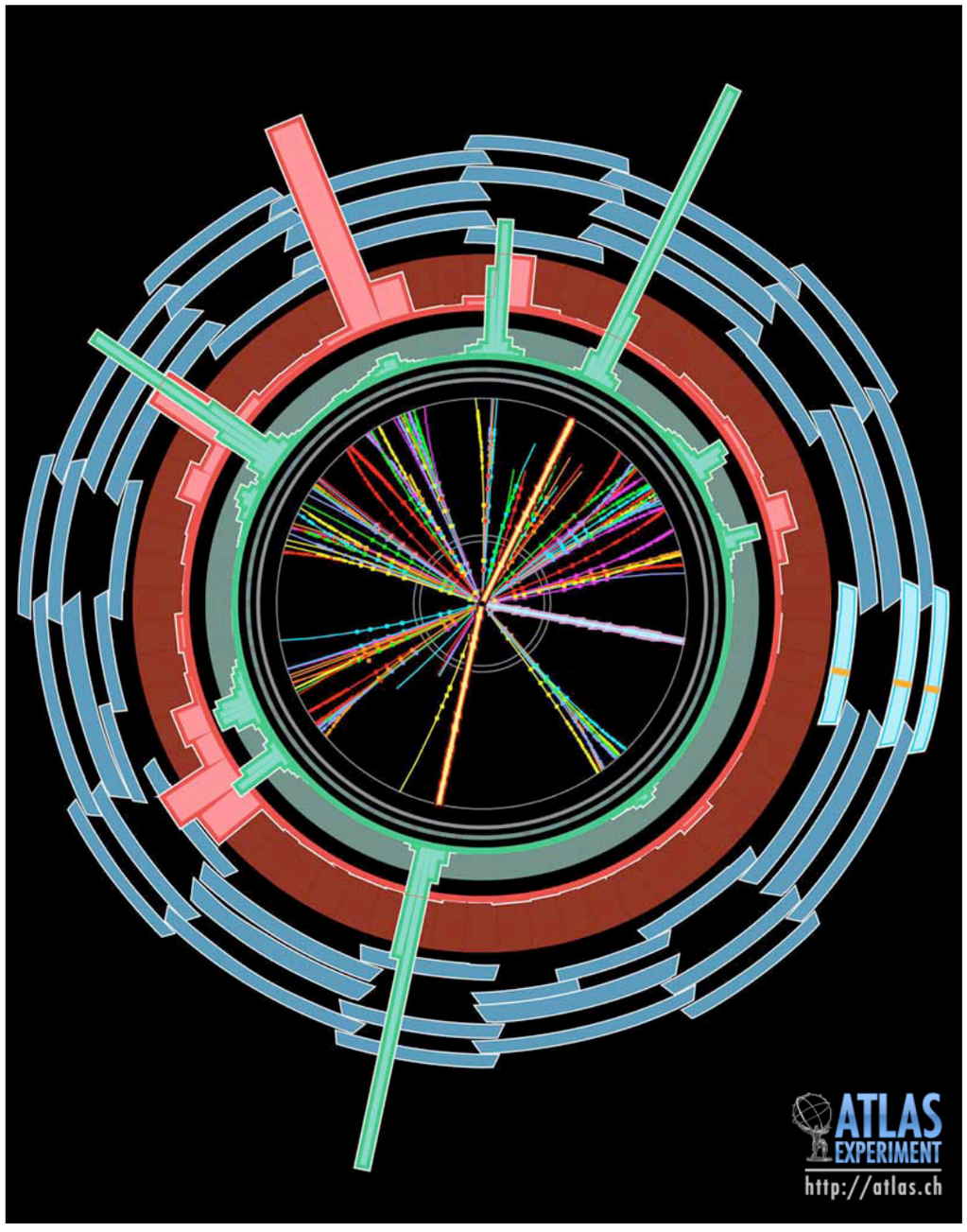
CMS
Compact Muon Solenoid

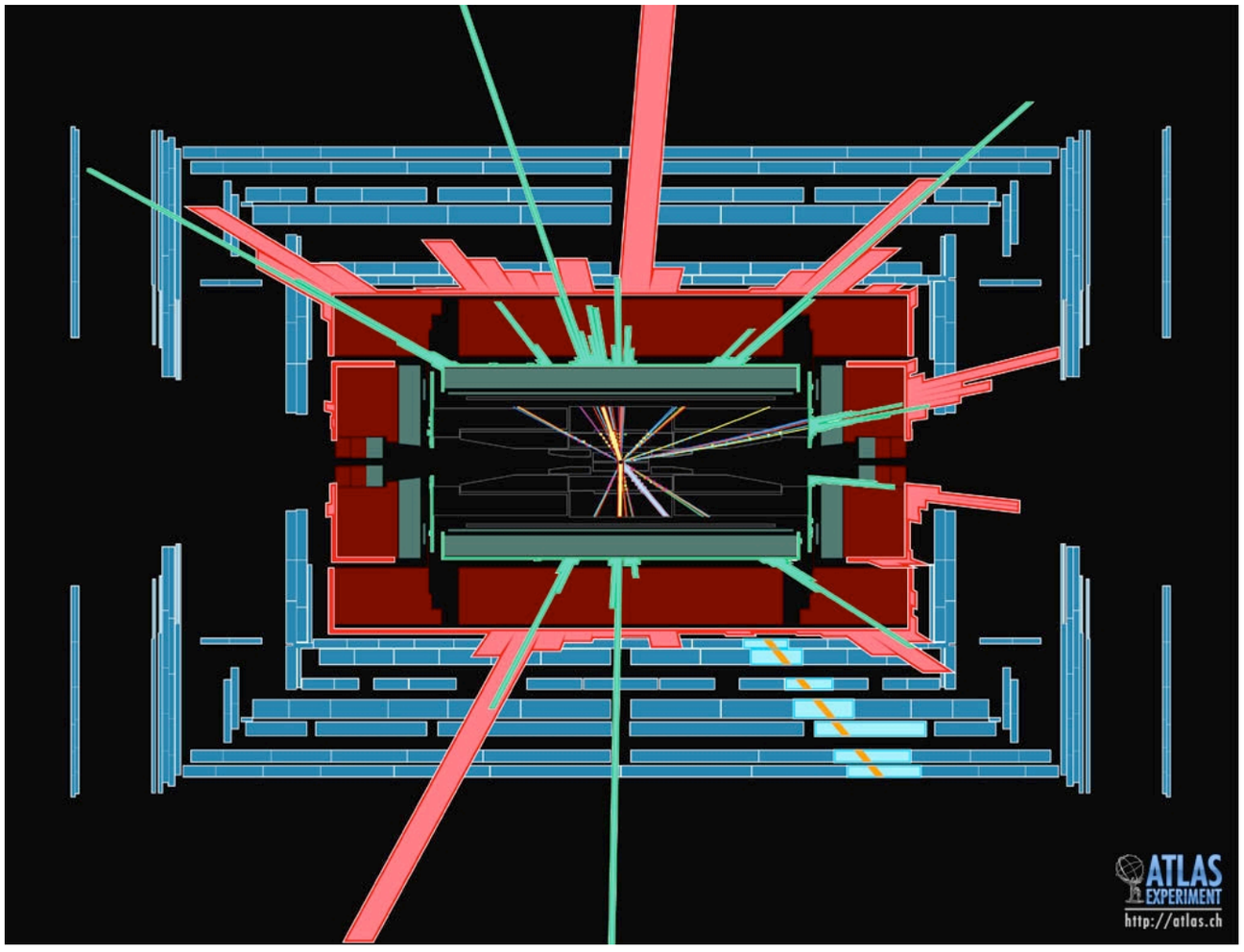
http://hands-on-cern.physto.se/ani/acc_lhc_atlas/lhc_atlas.swf






ATLAS
Detector characteristics
Width: 44m
Diameter: 22m
Weight: 7000t
CERN AC - ATLAS V1997
Muon Detectors
Electromagnetic Calorimeters
Solenoid
Forward Calorimeters
End Cap Toroid
Barrel Toroid
Inner Detector
Hadronic Calorimeters
Shielding


ATLAS
EXPERIMENT
http://atlas.ch


ATLAS
EXPERIMENT
http://atlas.ch

Other big questions for the Large Hadron Collider

Other big questions for the Large Hadron Collider

What was the Universe like just after the Big Bang?

Other big questions for the Large Hadron Collider

What was the Universe like just after the Big Bang?

How many dimensions are there?

Other big questions for the Large Hadron Collider

What was the Universe like just after the Big Bang?

How many dimensions are there?

Where is the anti-matter?

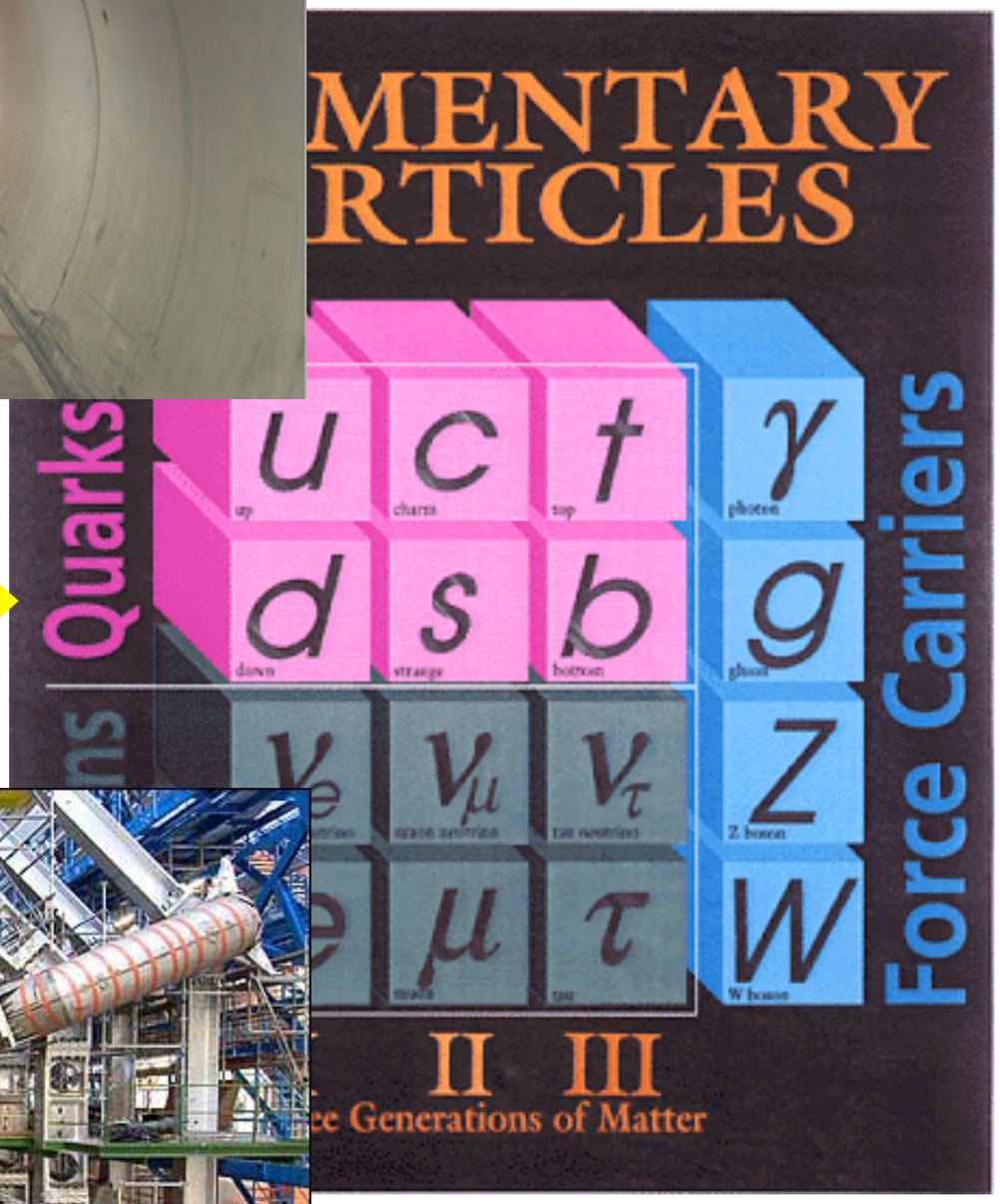
Other big questions for the Large Hadron Collider

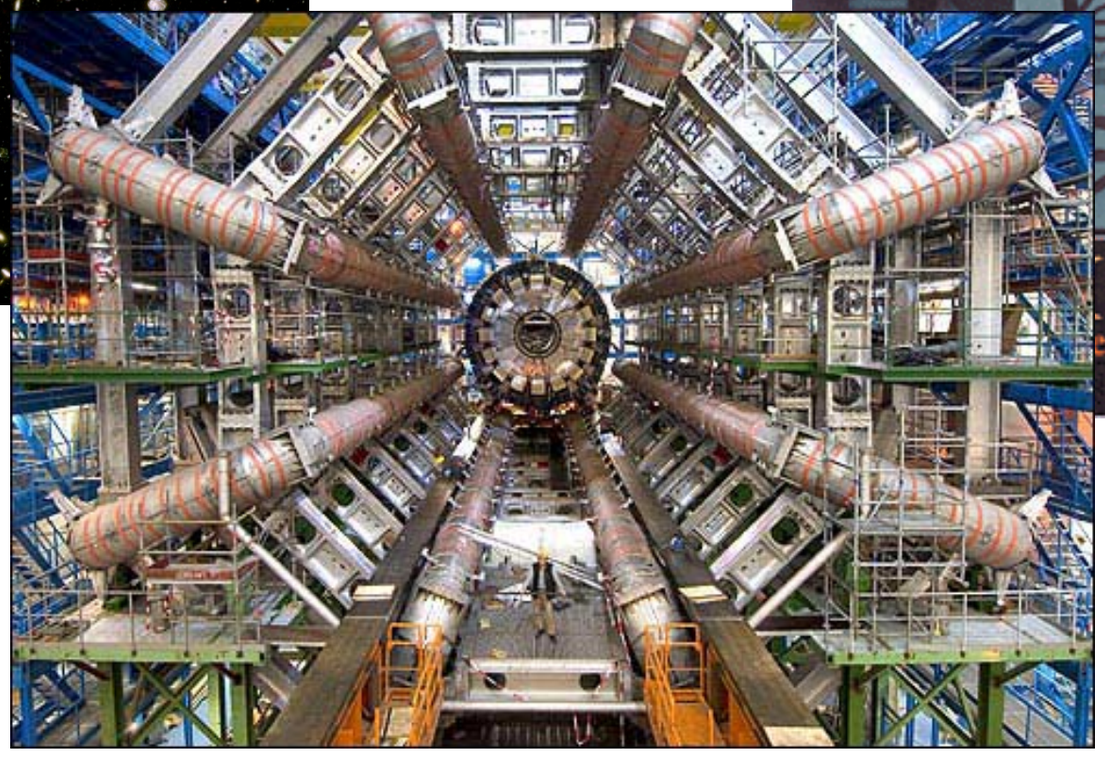
What was the Universe like just after the Big Bang?

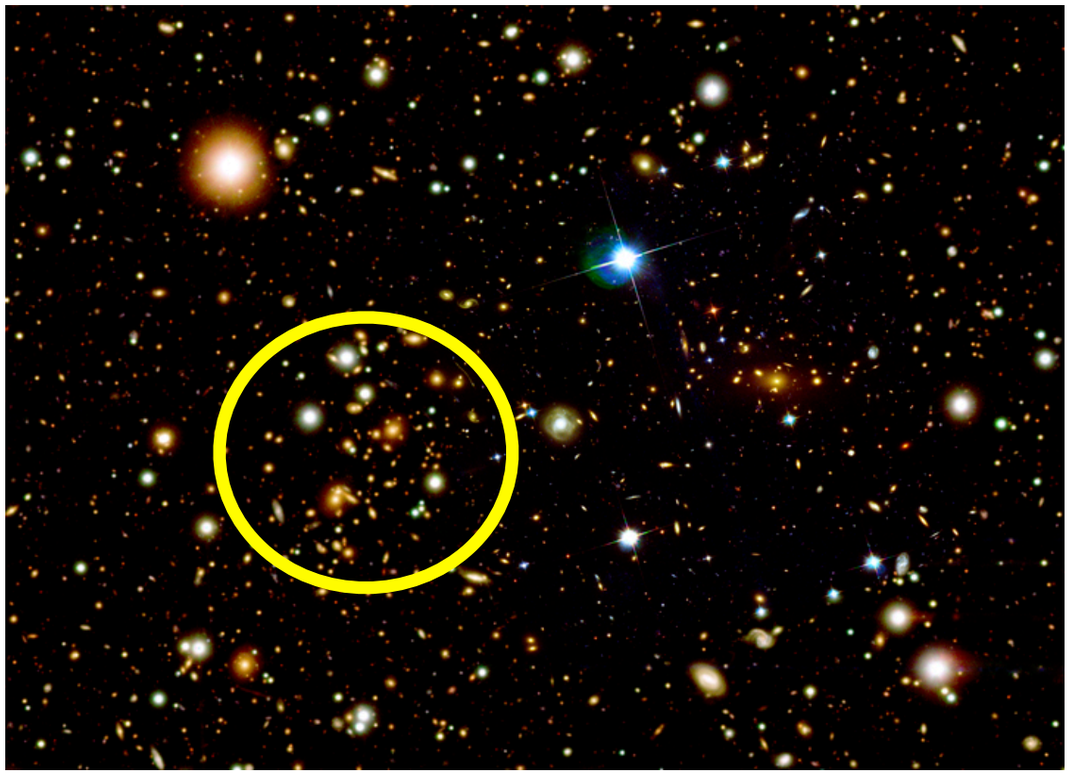
How many dimensions are there?

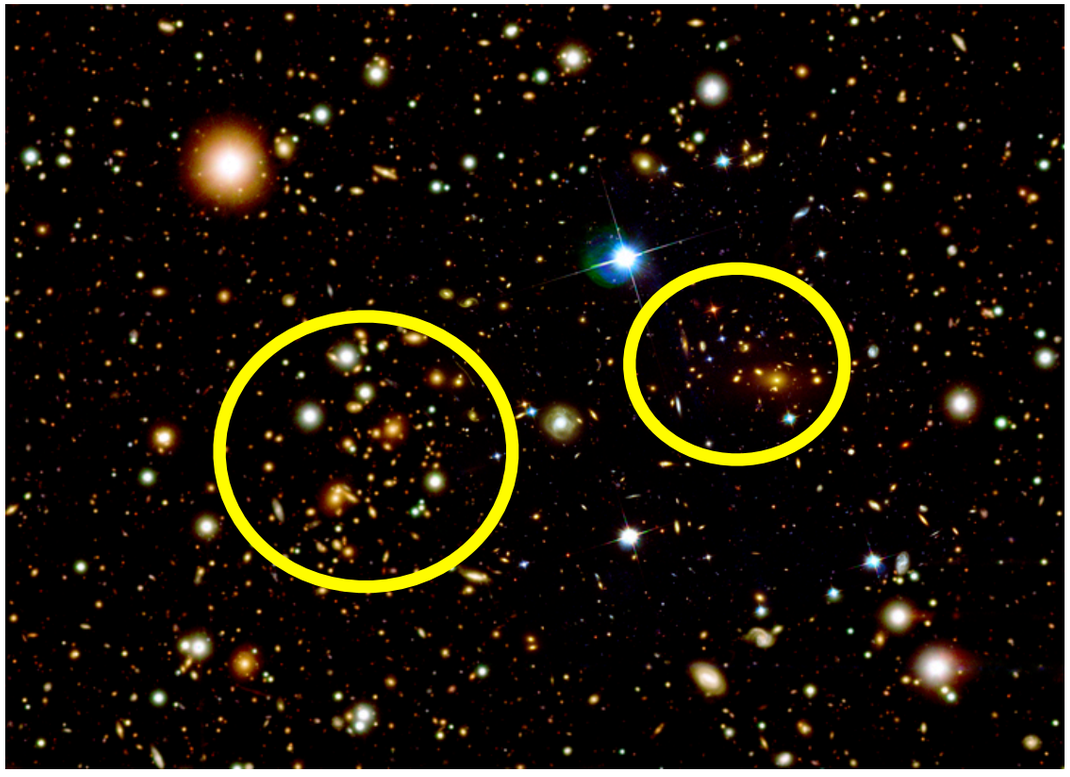
Where is the anti-matter?

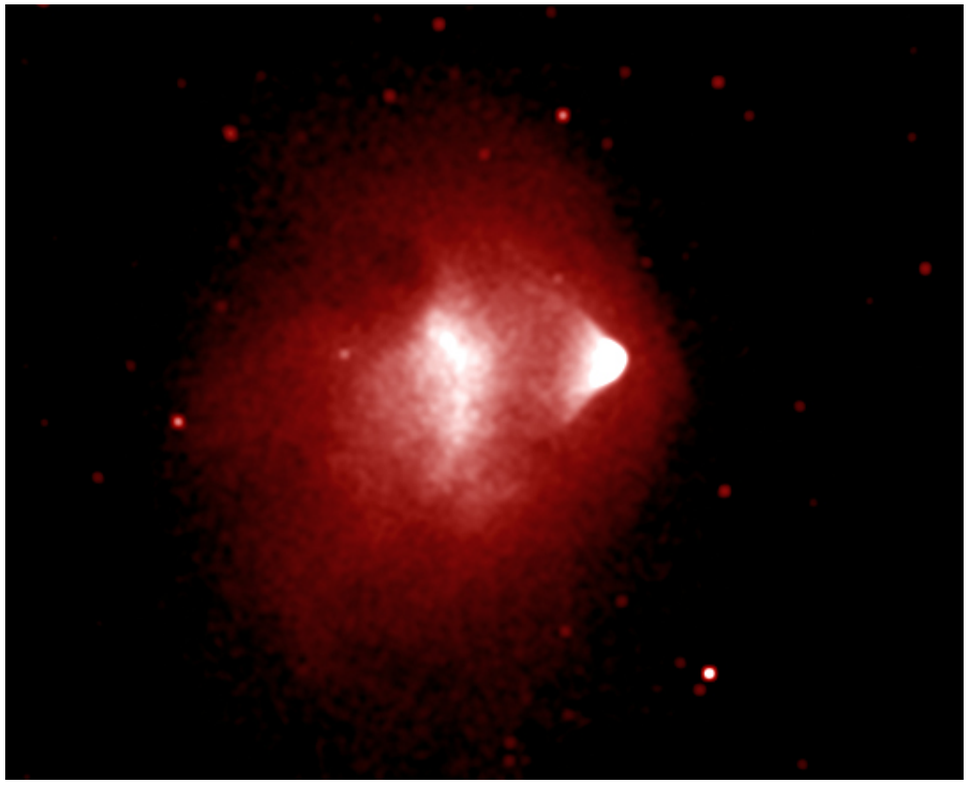
How do particles get their mass?

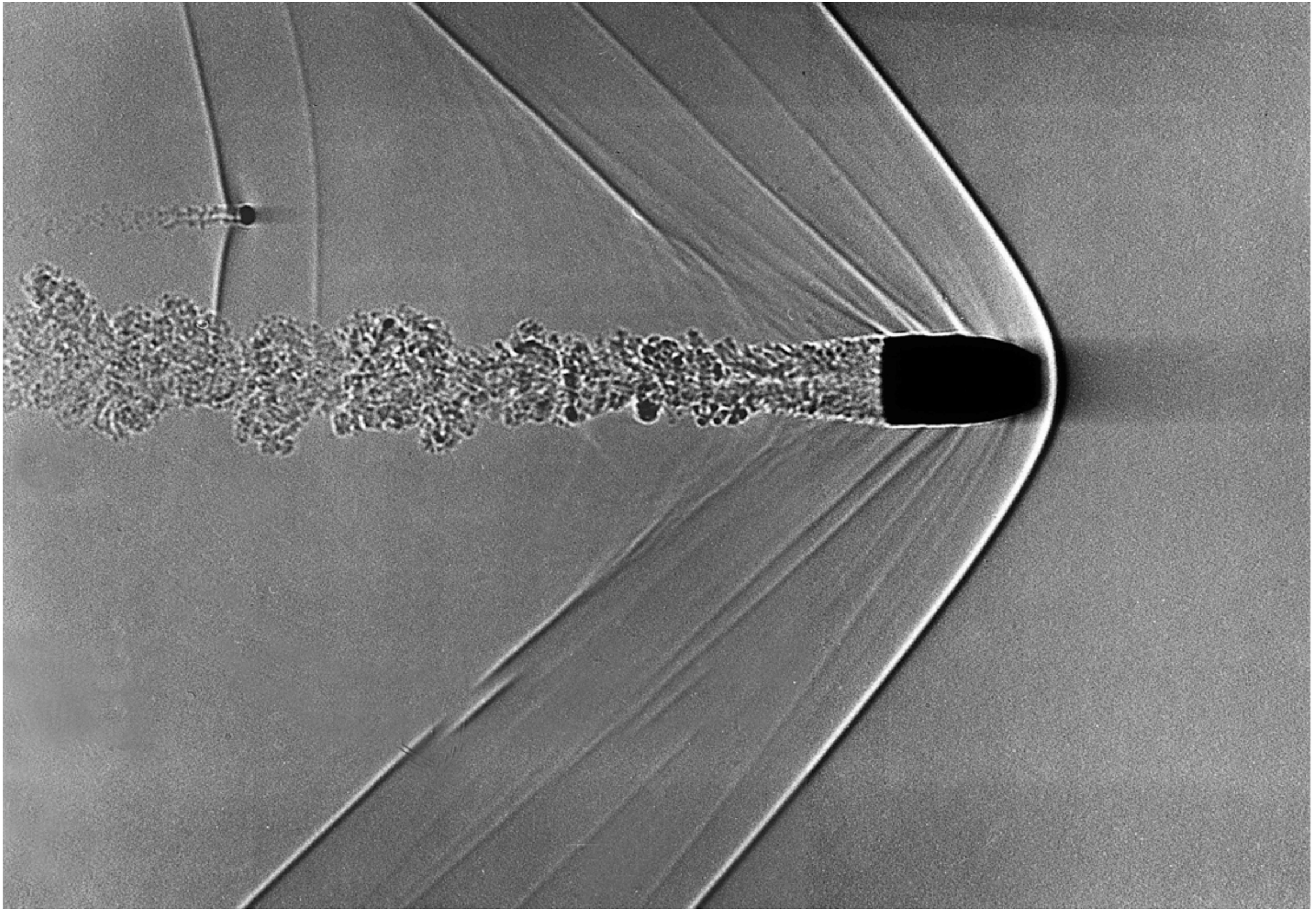

MENTARY
RTICLES
Quarks
u
up
c
charm
t
top
γ
photon
d
down
s
strange
b
bottom
g
gluon
ν_e
ν_μ
muon neutrino
ν_τ
tau neutrino
Z
Z boson
e
μ
muon
τ
tau
W
W boson
Force Carrie
II
III
ee Generations of Matter

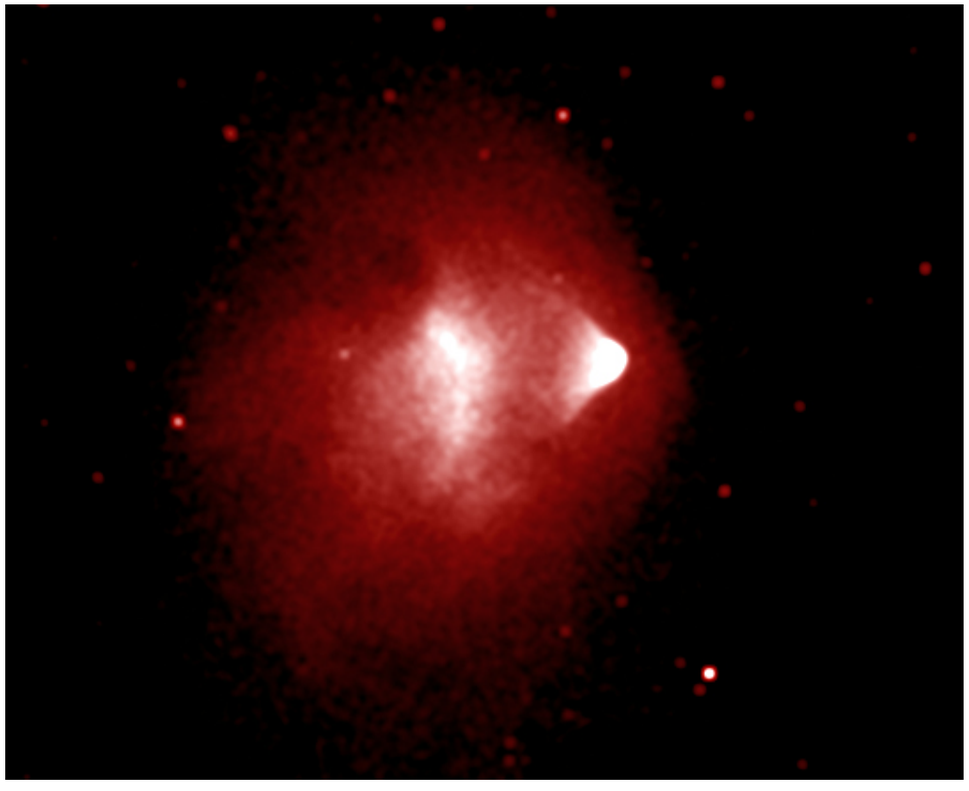


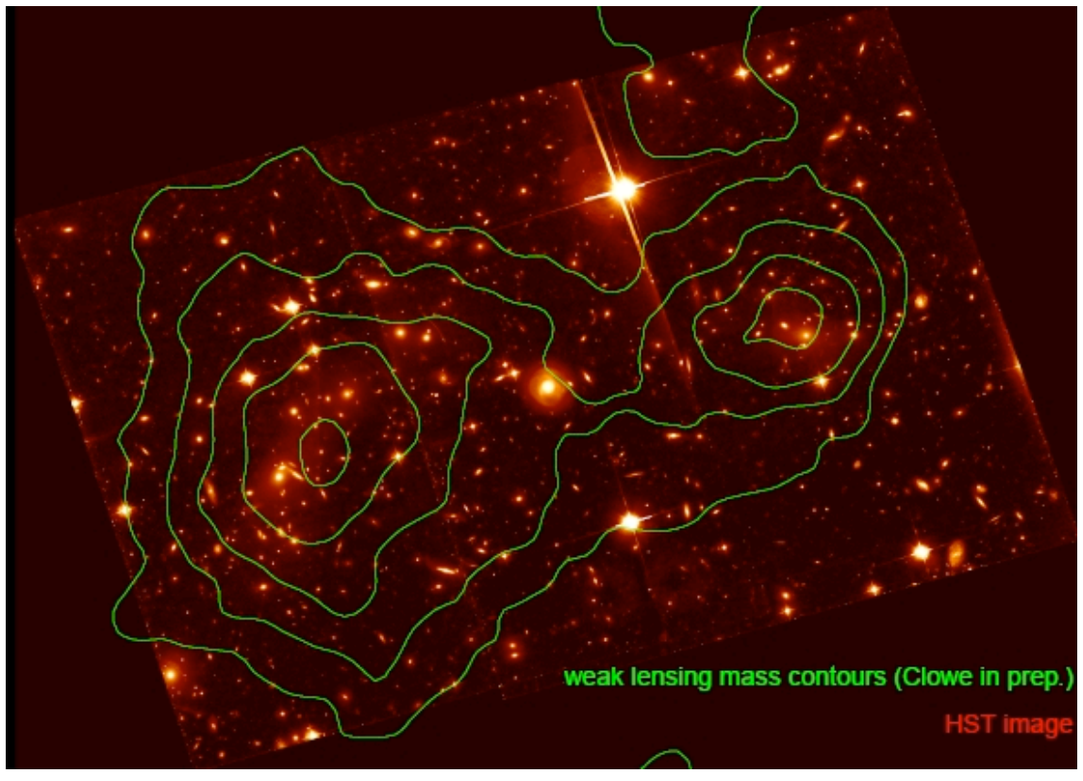


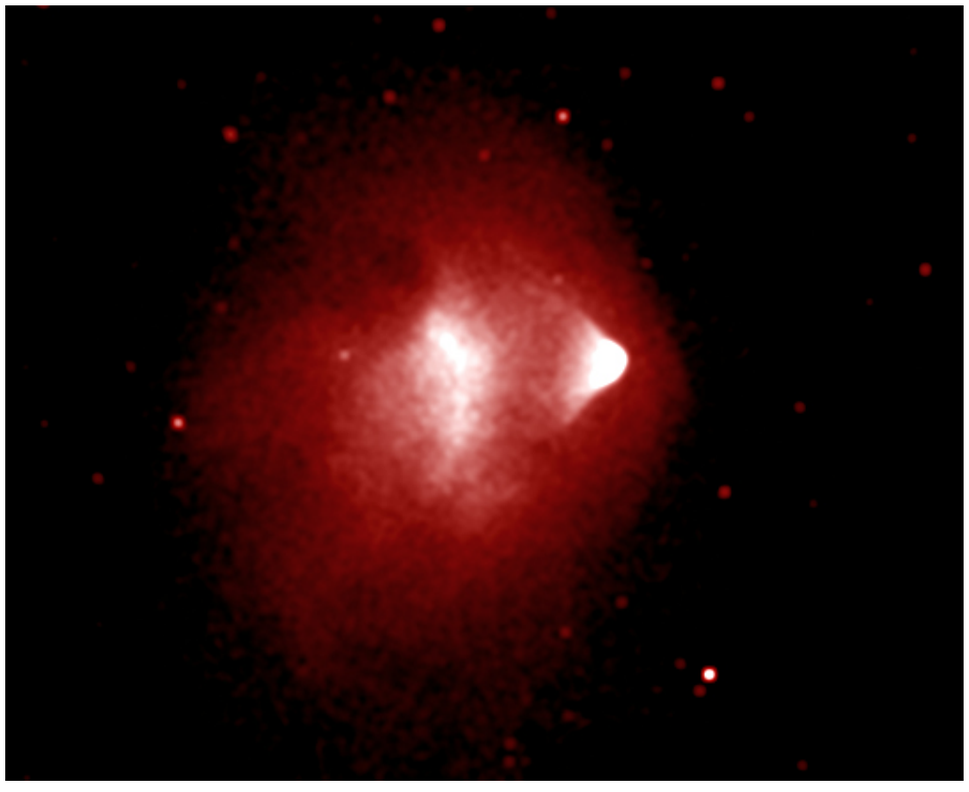


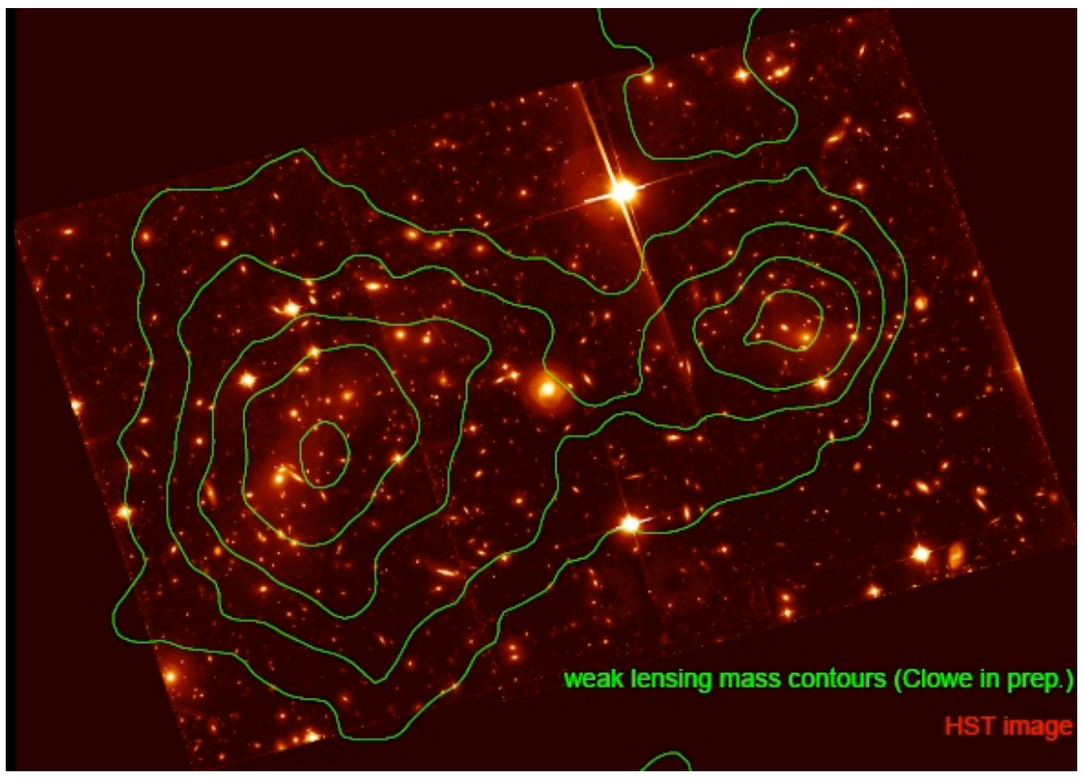







weak lensing mass contours (Clowe in prep.)
HST image

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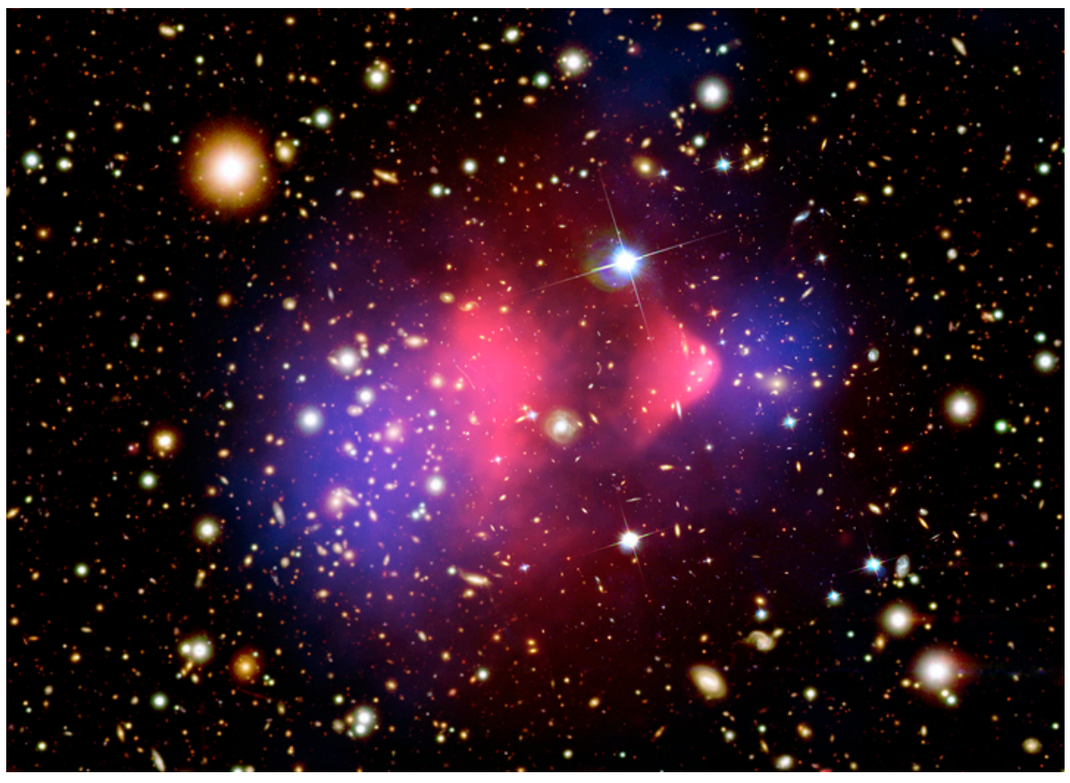
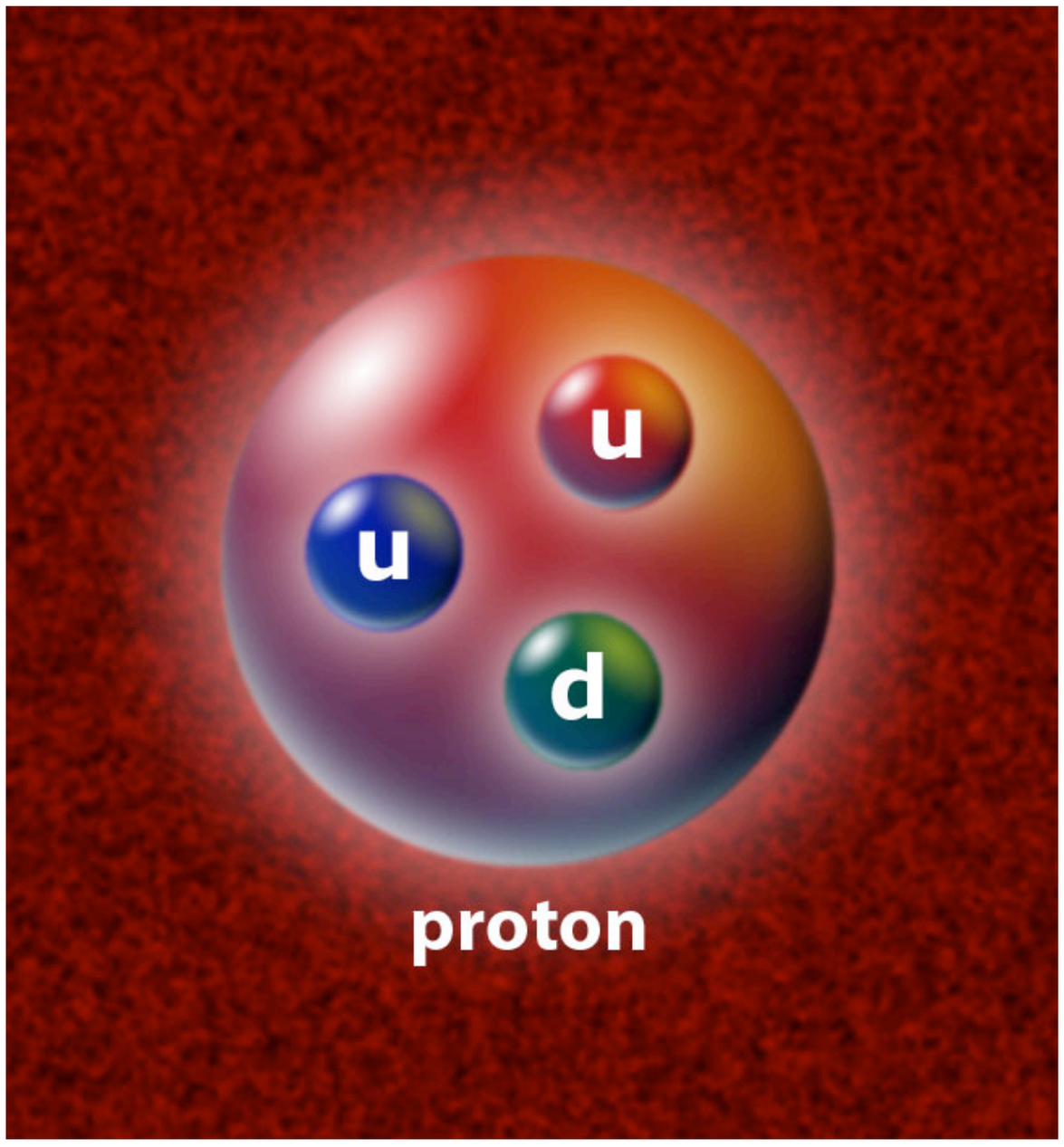
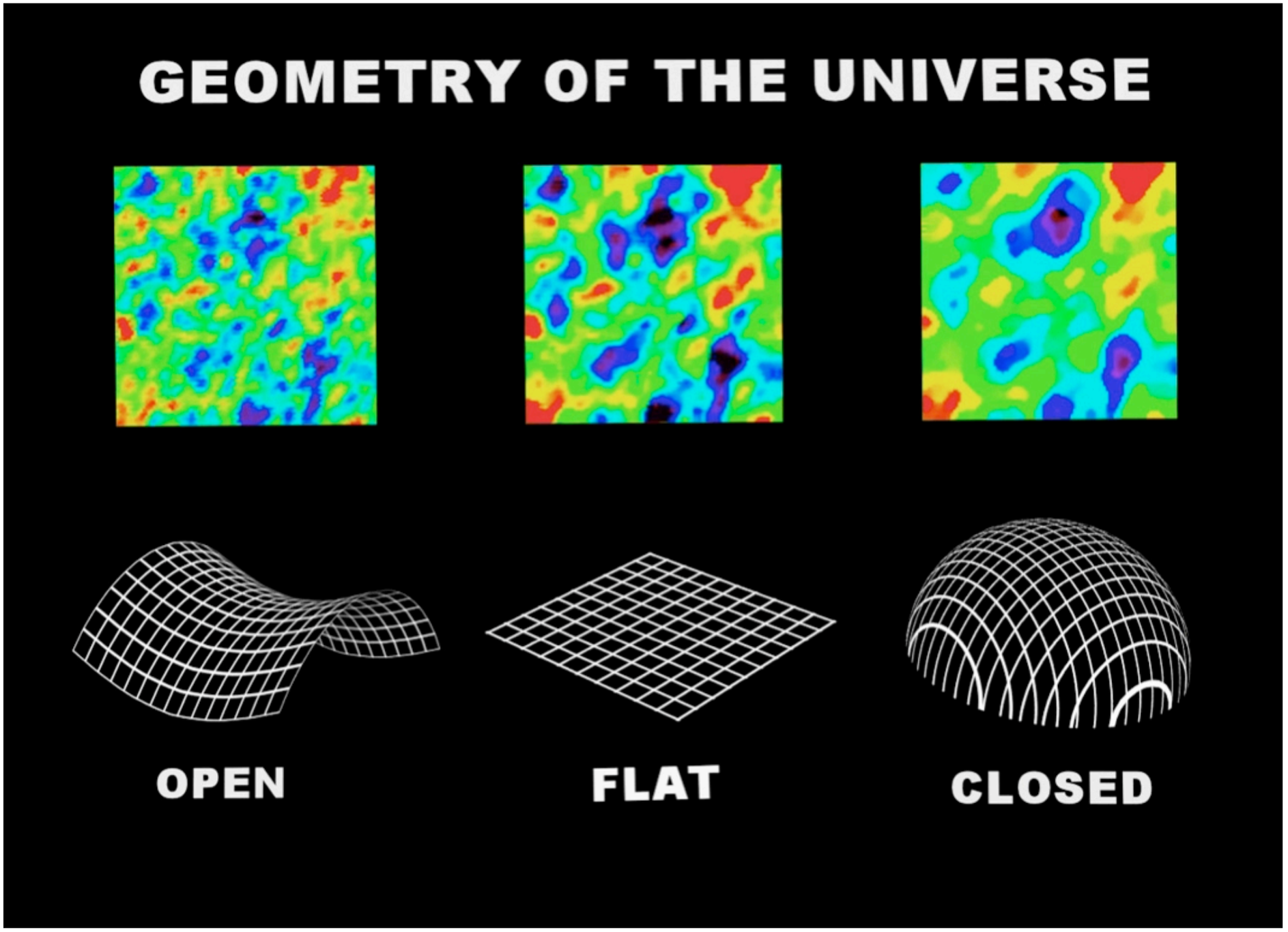




a proton: ~ 10^{-15} m


GEOMETRY OF THE UNIVERSE
OPEN
FLAT
CLOSED