KAVLI IPMU INSTITUTE FOR THE PHYSICS AND MATHEMATICS OF THE UNIVERSE

東京大学 THE UNIVERSITY OF TOKYO

Quantum Universe

Hitoshi Murayama (Berkeley & Kavli IPMU)

IFAE 25th anniversary, July 7, 2017

THE UNIVERSITY OF CALIFORNIA BERKELEY 1868 LET THERE BE LIGHT

BERKELEY CENTER FOR THEORETICAL PHYSICS

BERKELEY LAB

physicists asks simple and profound questions

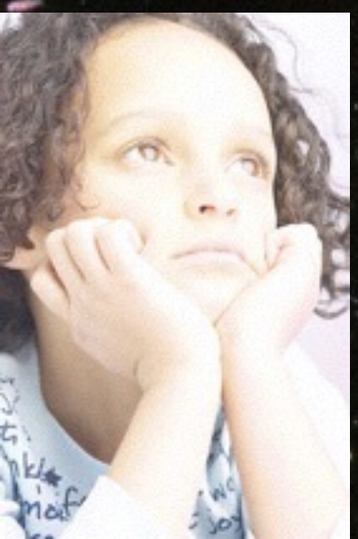
How did the Universe begin?

What is its fate?

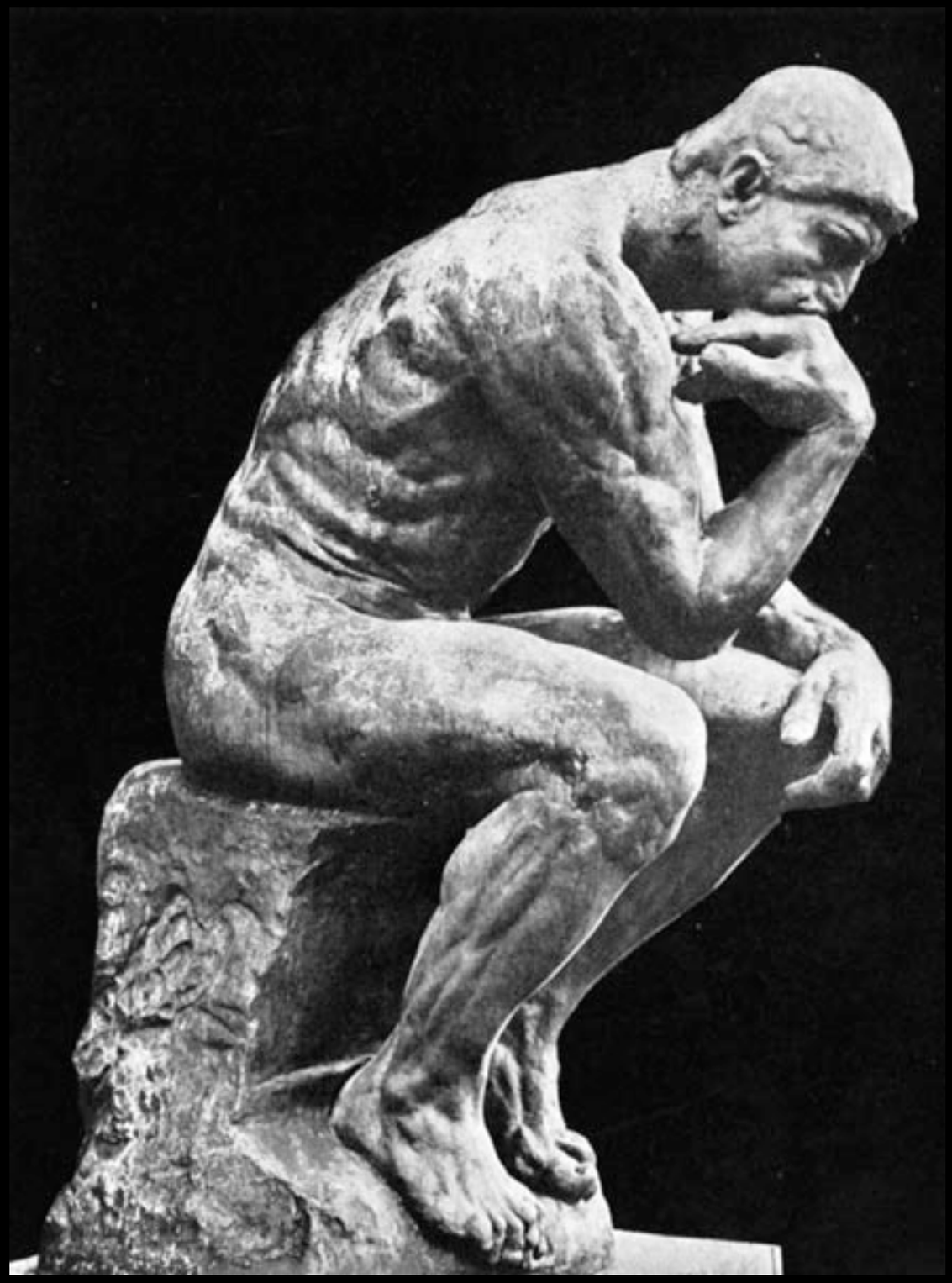
What is it made of?

What are its basic laws?

Where do we come from?

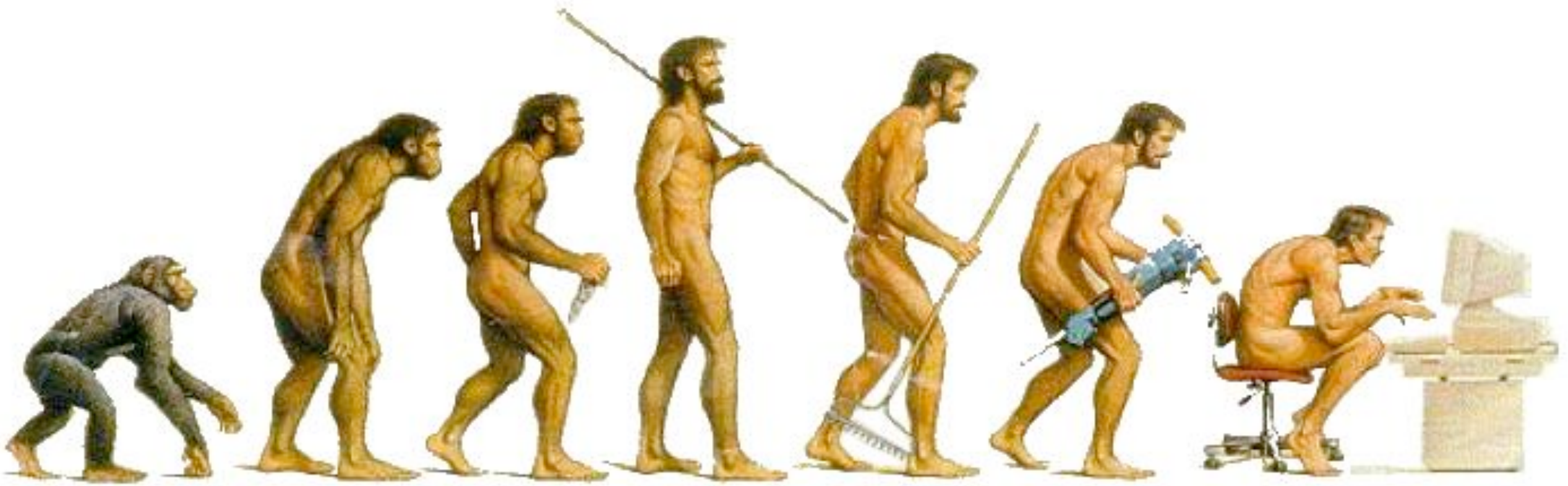


Religions



Philosophy

Evolutionary biology



DANIEL CARDLE 2003

TMT
100’ tall and wide

LHC
27km all around

Andromeda
2.3 million light years

HSC team
Subaru
telescope

cluster of galaxies
2.1 billion light year

Abell 2218

Galaxy Cluster MACS J1149+2223

galaxy @ 13.3 billion light years

High-Redshift Galaxy MACS1149-JD

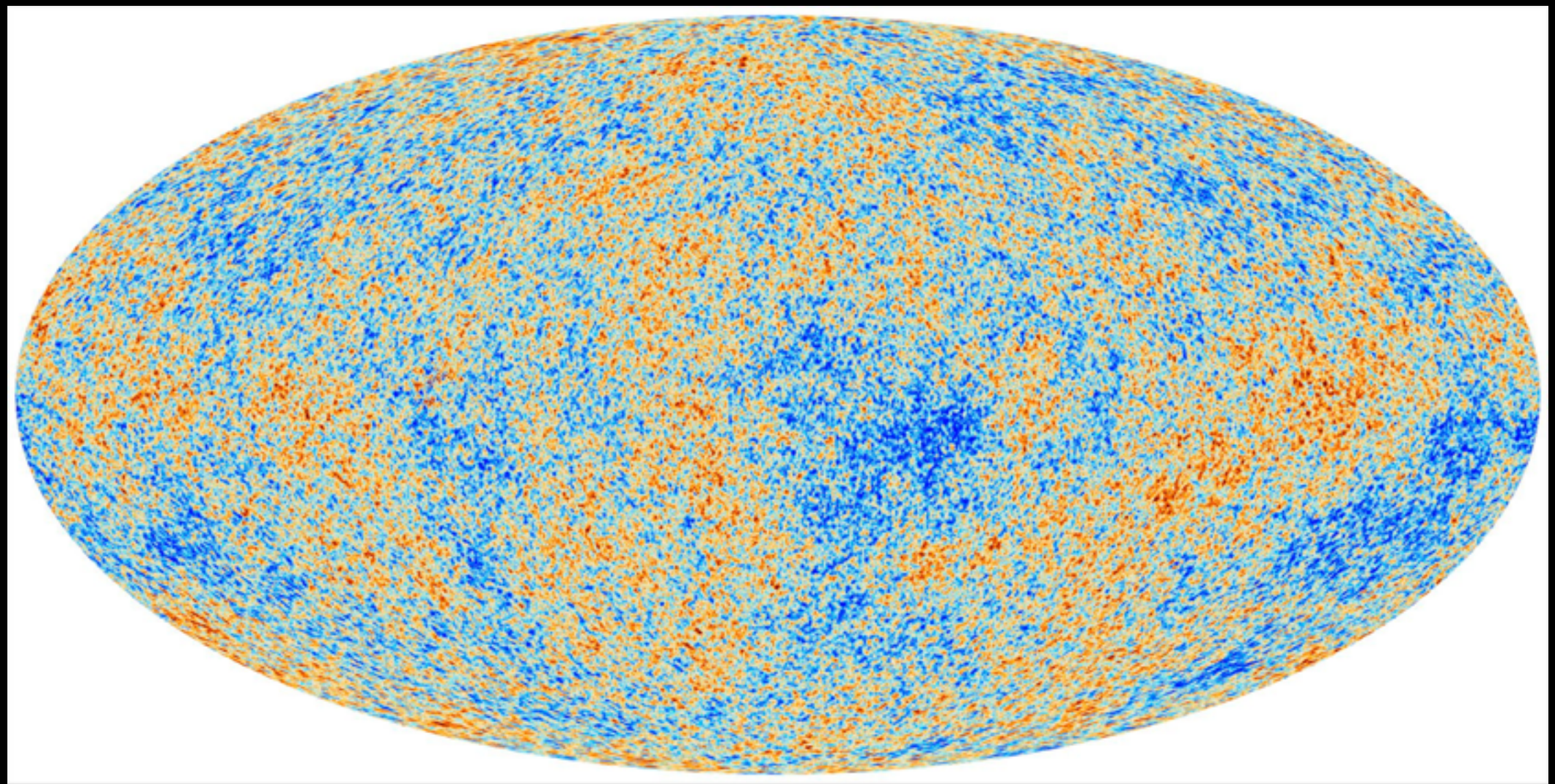
A Distant Gravitationally-Lensed Galaxy at Redshift = 9.6

Hubble Space Telescope • ACS • WFC3

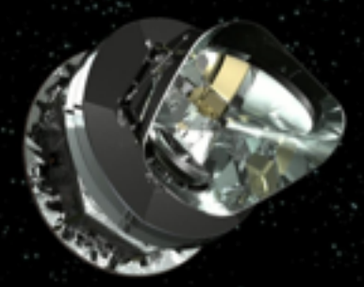
NASA / ESA / STScI/ J. Hora (Harvard-Smitsonian CfA)

ssc2012-12a

“Wall” @ 13.8 Blyrs



You can never “see” beyond this wall
with a telescope




Campbell's
CONDENSED
PARIS INTERNATIONAL EXPOSITION
1900
PARTICLE
SOUP

History of the Universe

3min

380Kyrs

Accelerators
LHC
Tevatron
RHIC

high-energy cosmic rays

Inflation

BIG BANG

possible dark matter relicts

accelerators

telescope

PARTICLE SOUP

t 10^-44 10^-37 s
T 10^32 10^28
E 10^19 10^15

10^-10 s
10^15
10^2

10^-5 s
10^12
10^-1

10^2 s
10^9
10^-4

3x10^5 y
3000
3x10^-10

10^9 y

Today

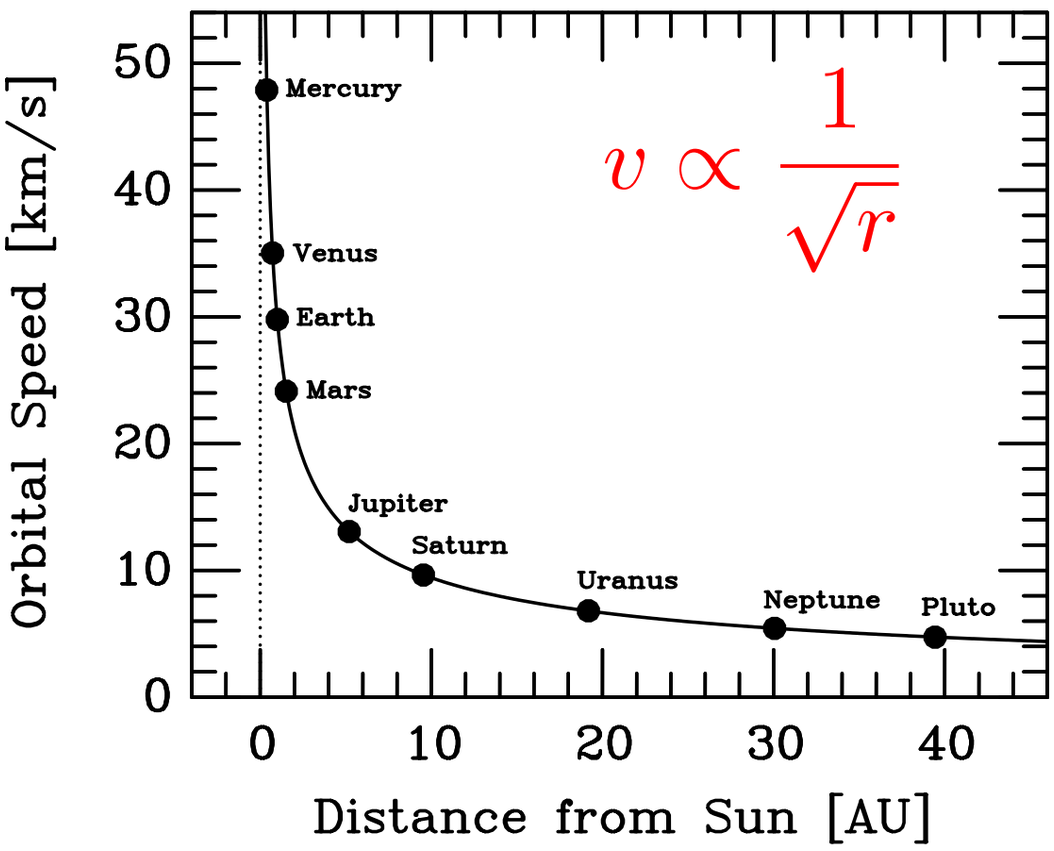
Key:
- q quark
- g gluon
- e electron
- μ muon τ tau
- ν neutrino
- W, Z bosons
- meson
- baryon
- ion
- atom
- photon
- galaxy
- star
- black hole

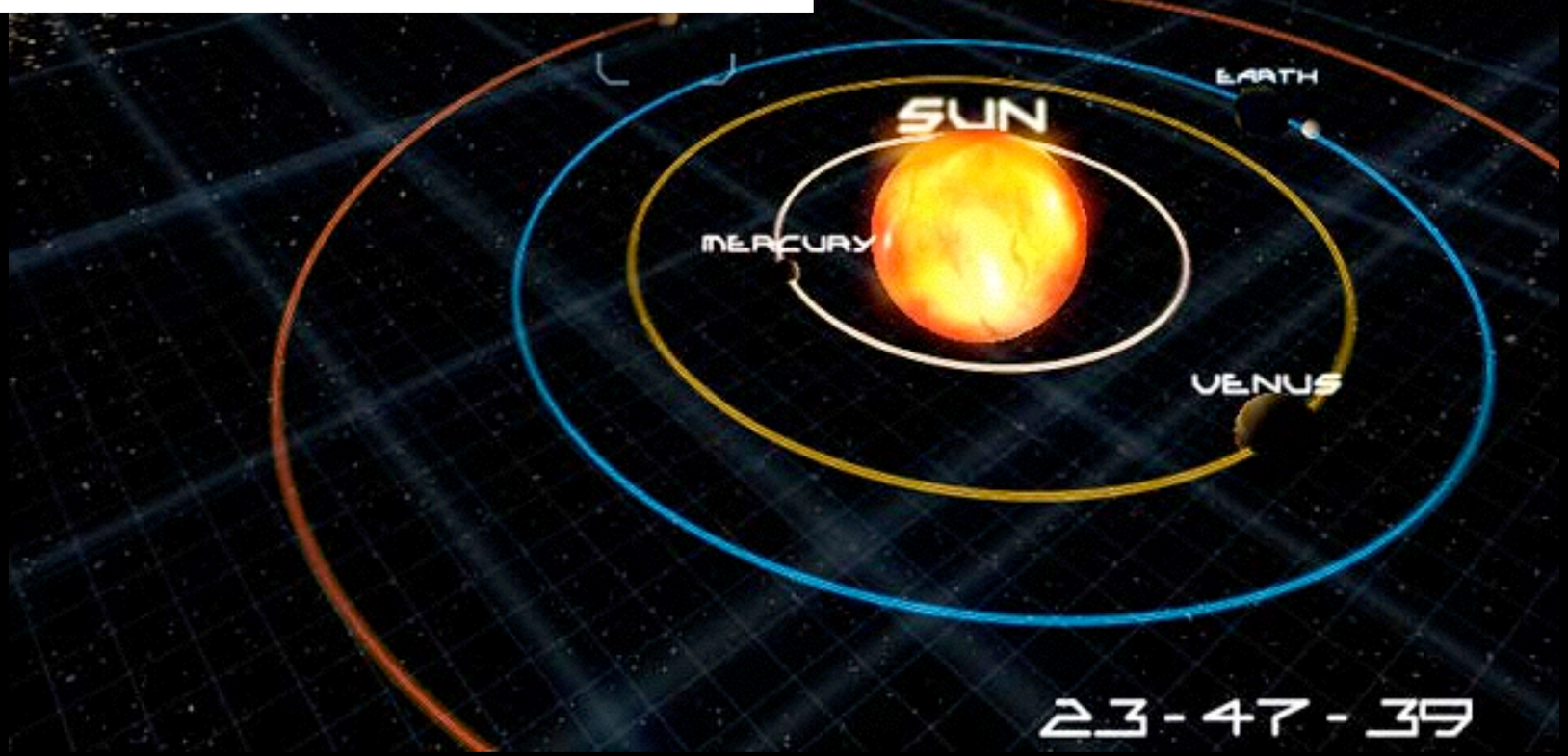
Particle Data Group, L

Big Bang predicts H:He ~ 3:1
agrees with observations

Dark Matter

solar system

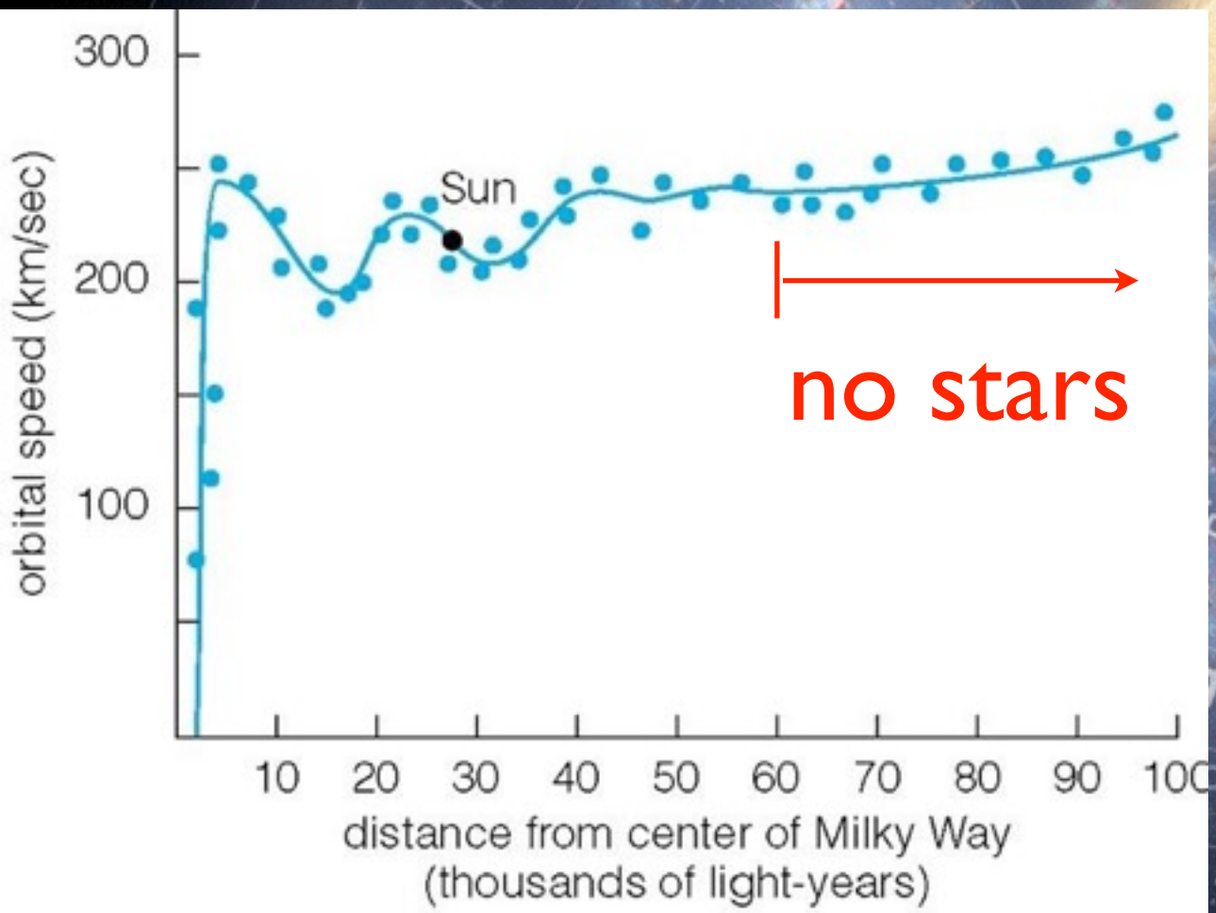




Earth revolves around the Sun at 30 km/s

a hundred billion stars

solar system revolves at 220 km/s
what is pulling us inside?



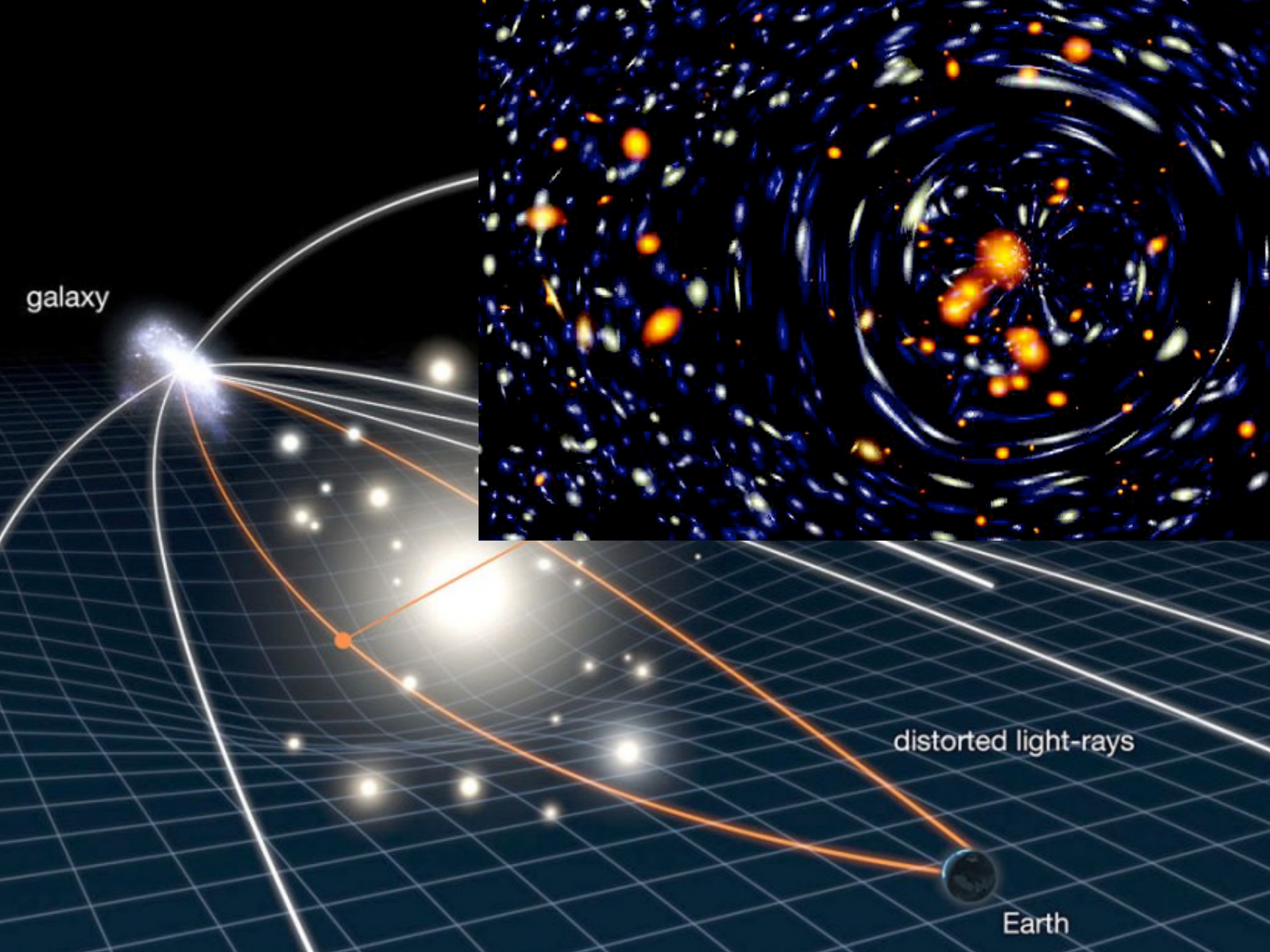
no stars

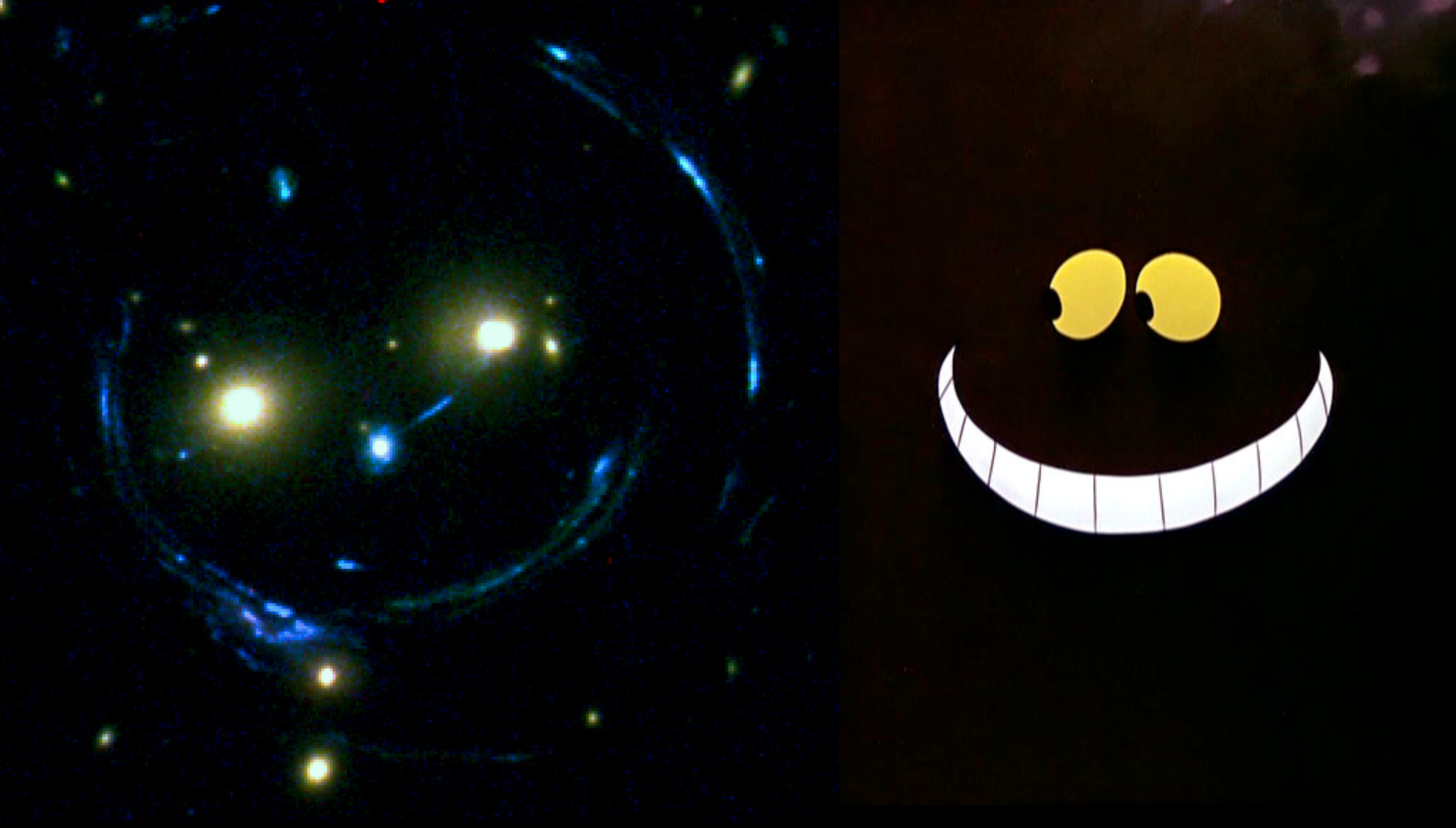
28,000 lyrs

Scutum-Centaurus Arm
Sagittarius Arm
Far 3kpc Arm
Galactic Bar
Norma Arm
Near 3kpc Arm
Sun
75,000 ly
60,000 ly
45,000 ly
30°
330°
60°
300°
270°
240°

cluster of galaxies

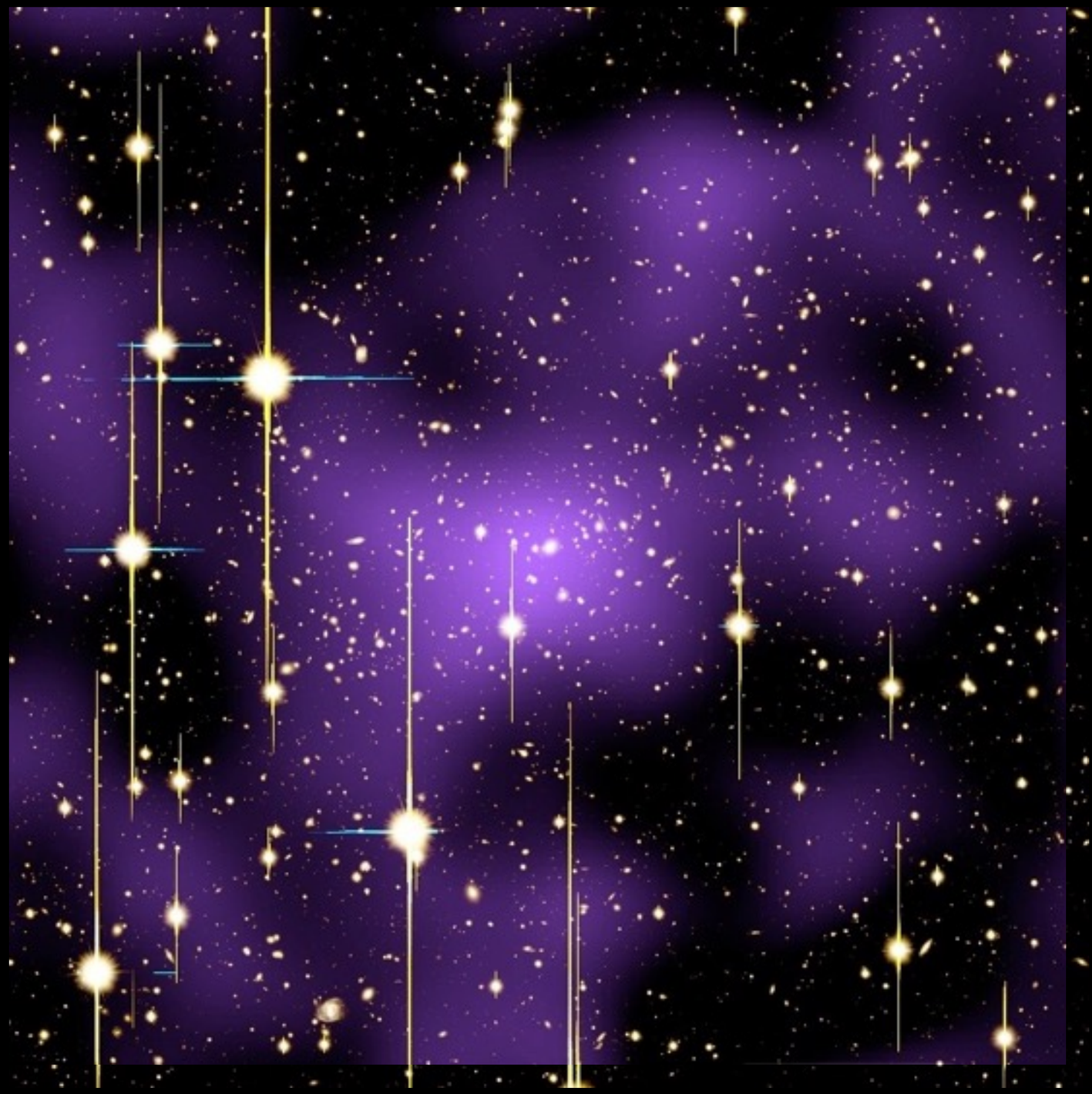
Abell 2218
2.1B lyrs


galaxy
distorted light-rays
Earth



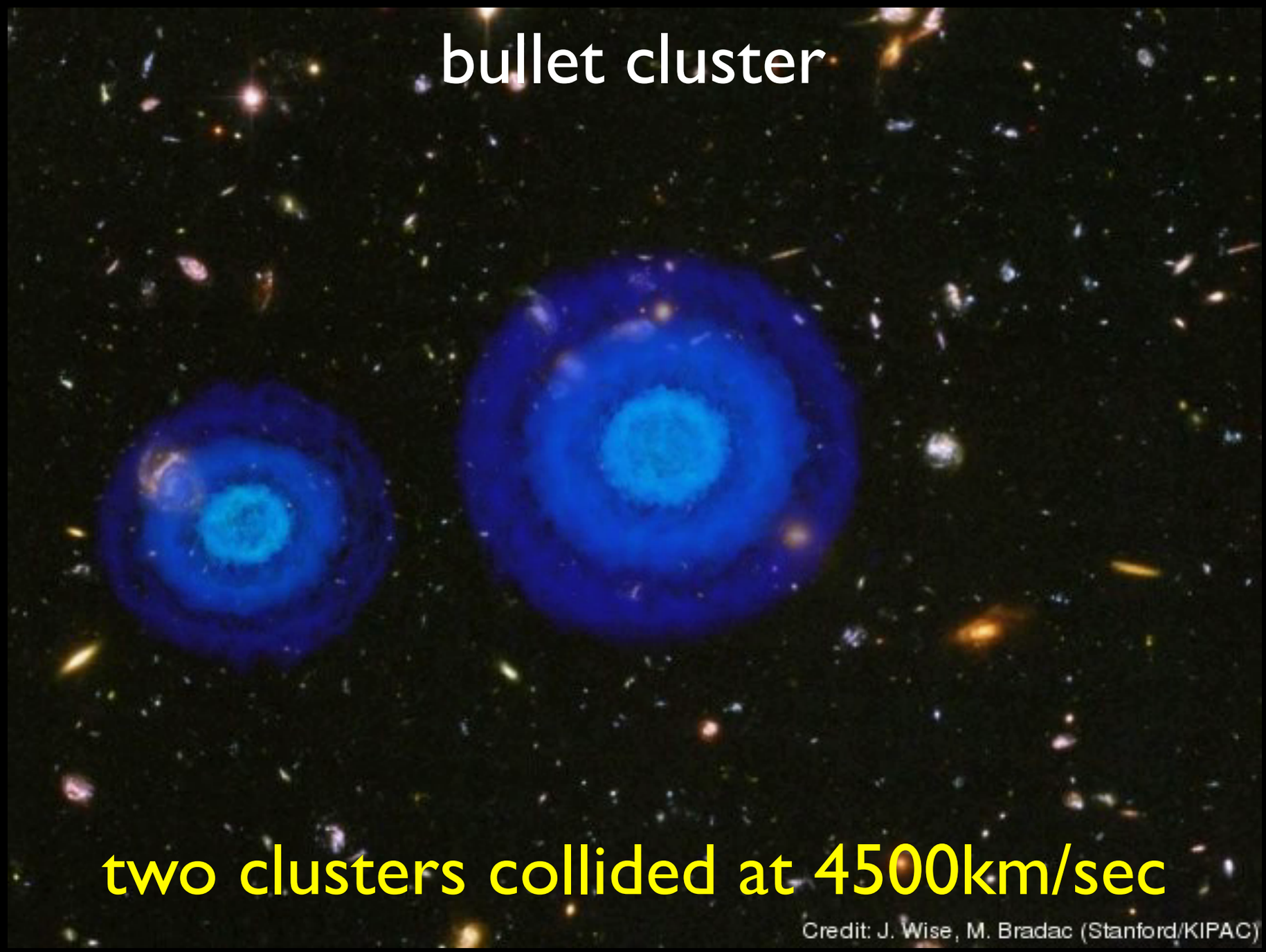
Cheshire cat

image invisible dark matter



more than 80% of matter in the Universe is not atoms

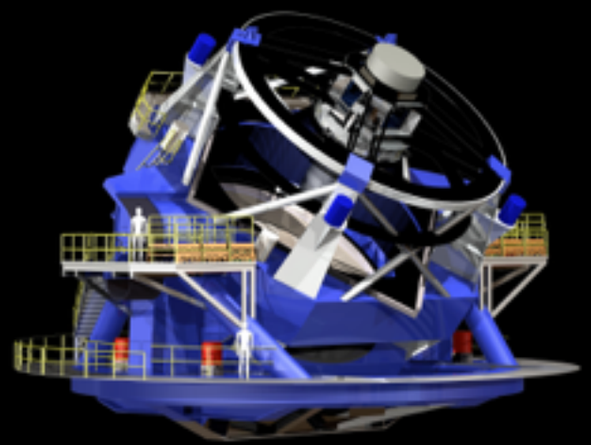
Good not to be here



4B lyrs away

Dark Matter

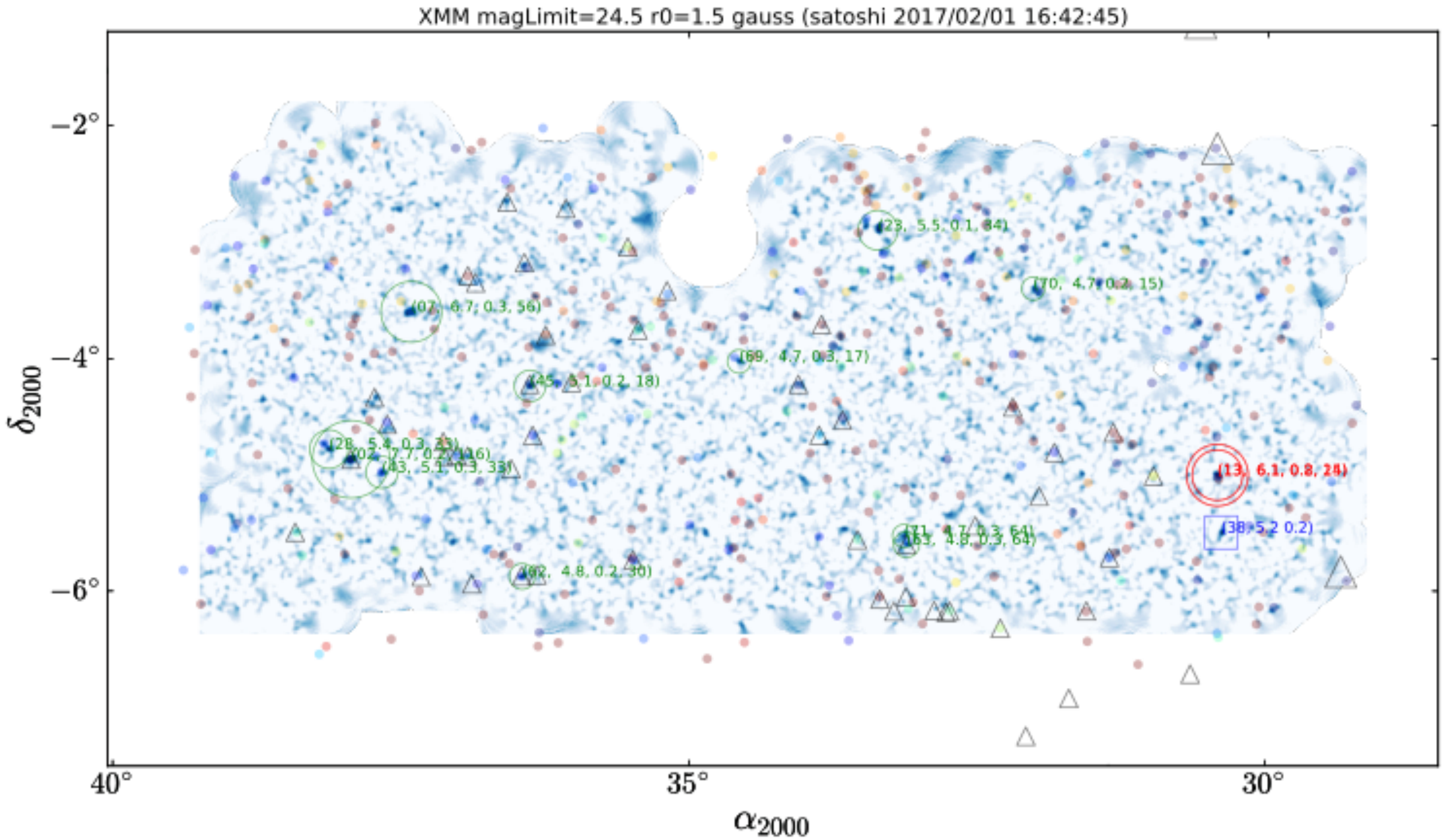
DES mass map

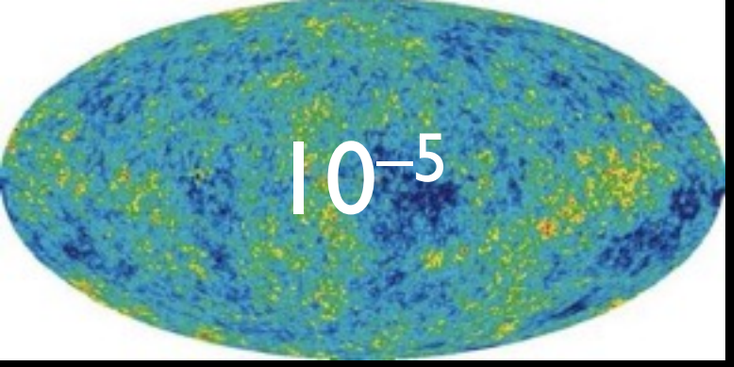


LSST

Large-scale map of dark matter

~100 square degrees
will cover x10 by 2019





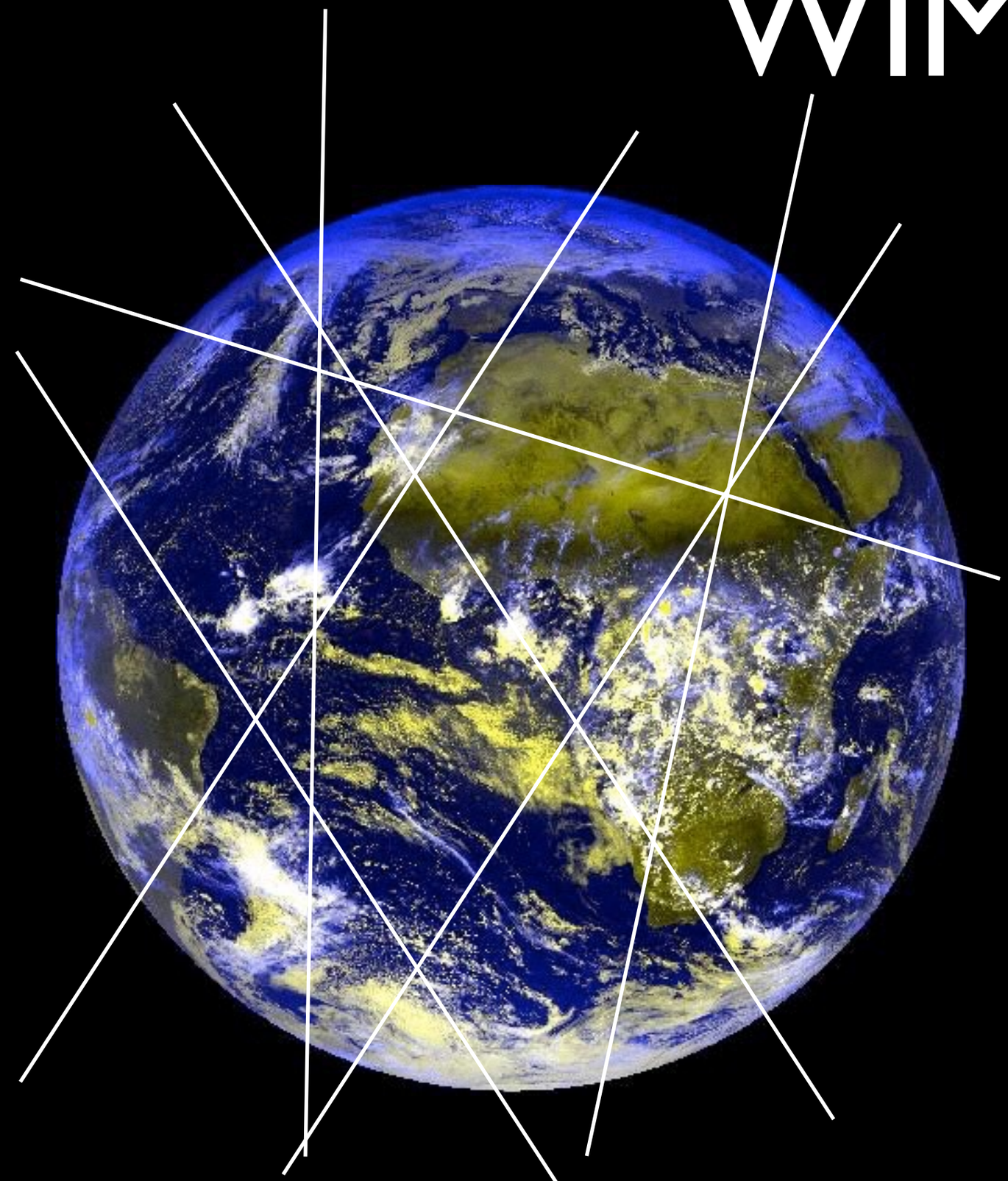
Dark Matter is our Mom

without dark matter

with dark matter

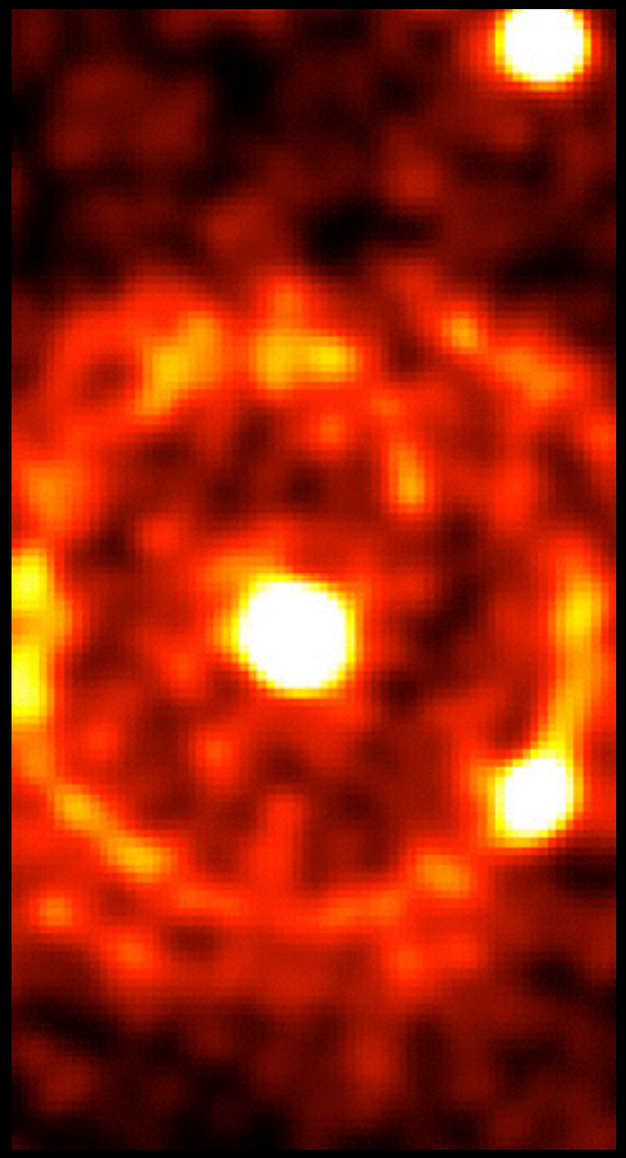
Reenacting the Big Bang with Cal Marching Band

WIMPs



- It is probably WIMP (Weakly Interacting Massive Particle)
- Stable heavy particle produced in early Universe, left-over from near-complete annihilation

MAGIC, CTA



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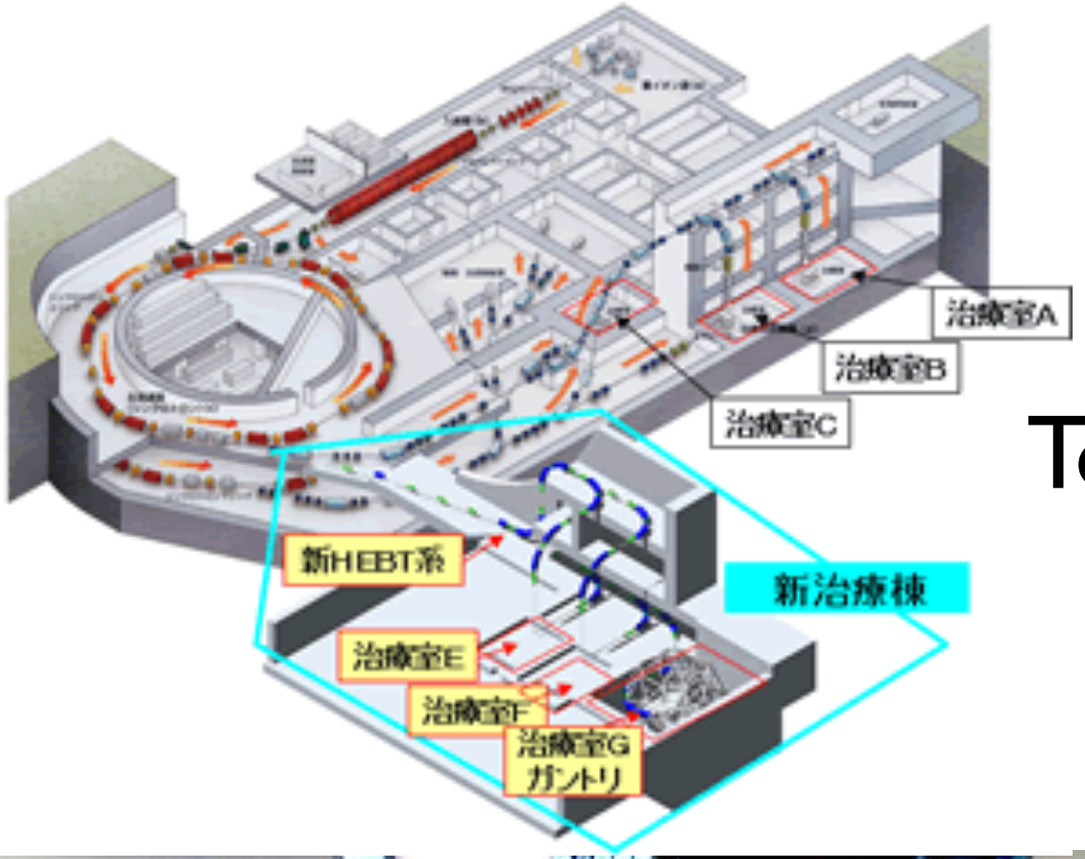
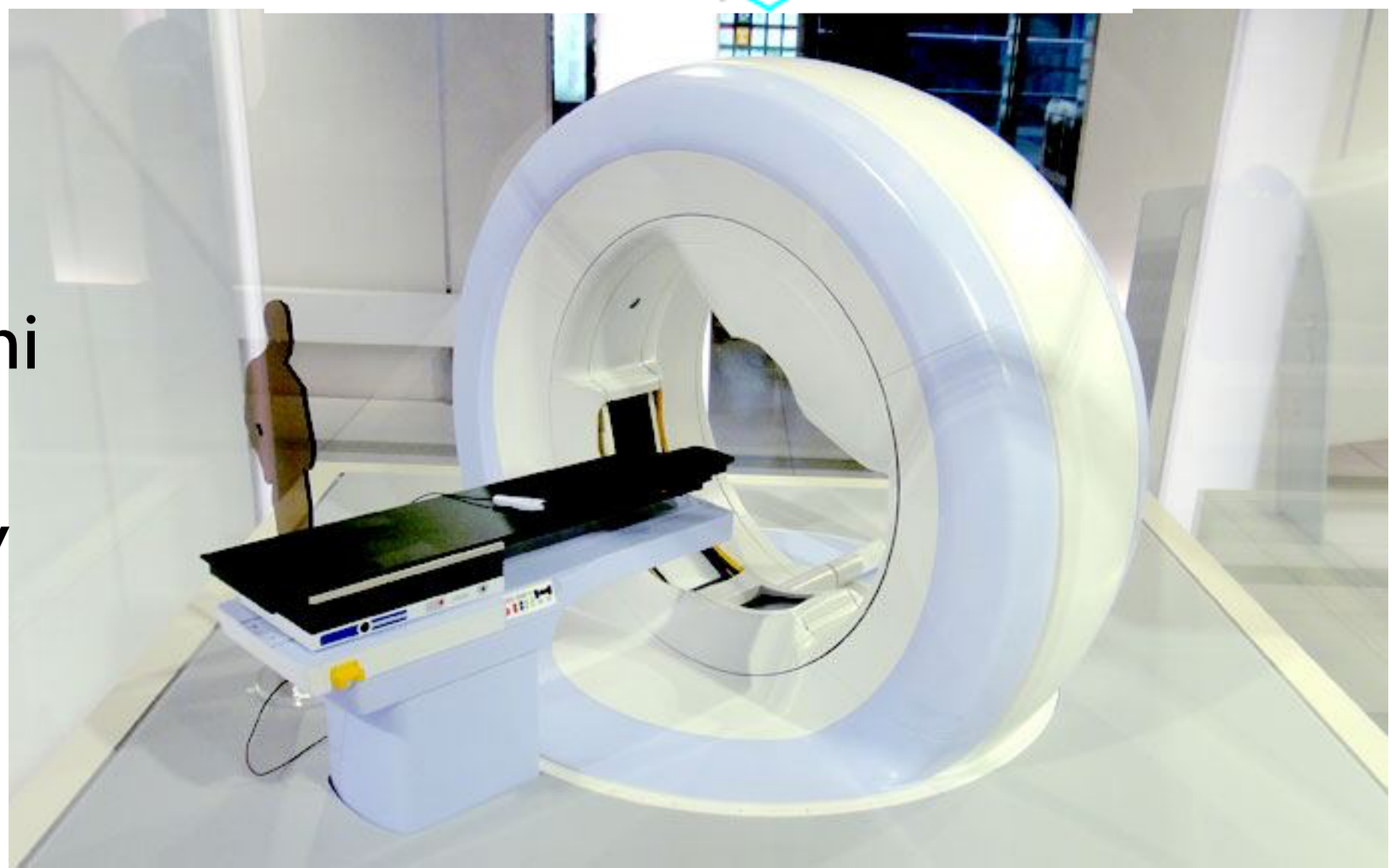
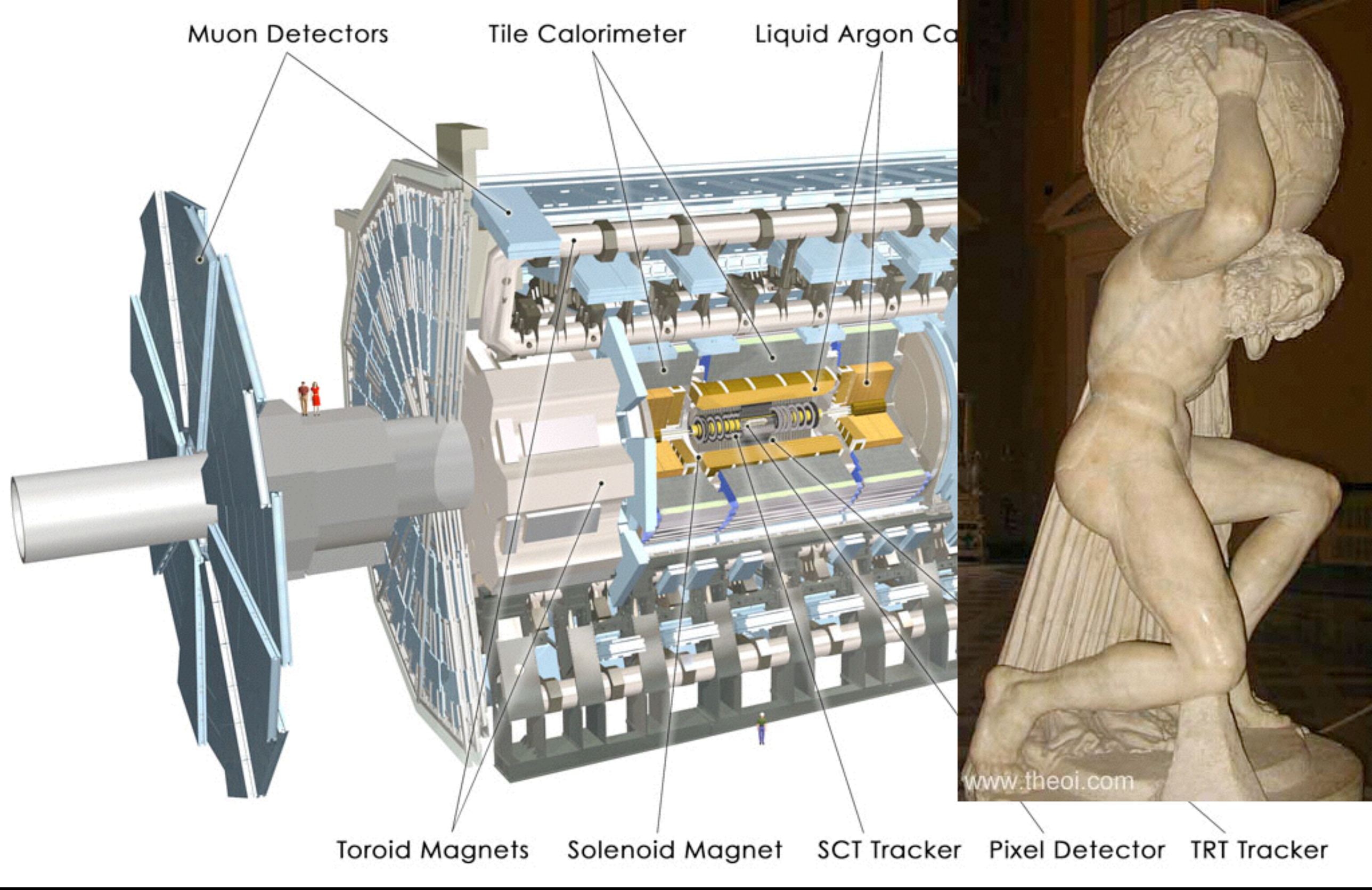
radiation therapy



Toshiba

Mitsubishi Heavy Industry

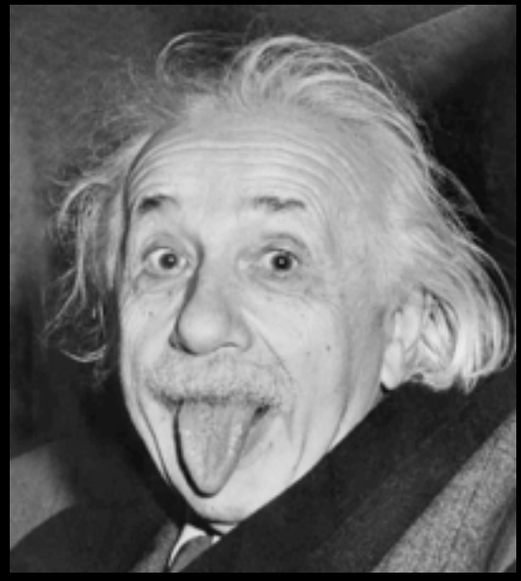



Muon Detectors
Tile Calorimeter
Liquid Argon Co
Toroid Magnets
Solenoid Magnet
SCT Tracker
Pixel Detector
TRT Tracker
www.theoi.com

ATLAS detector

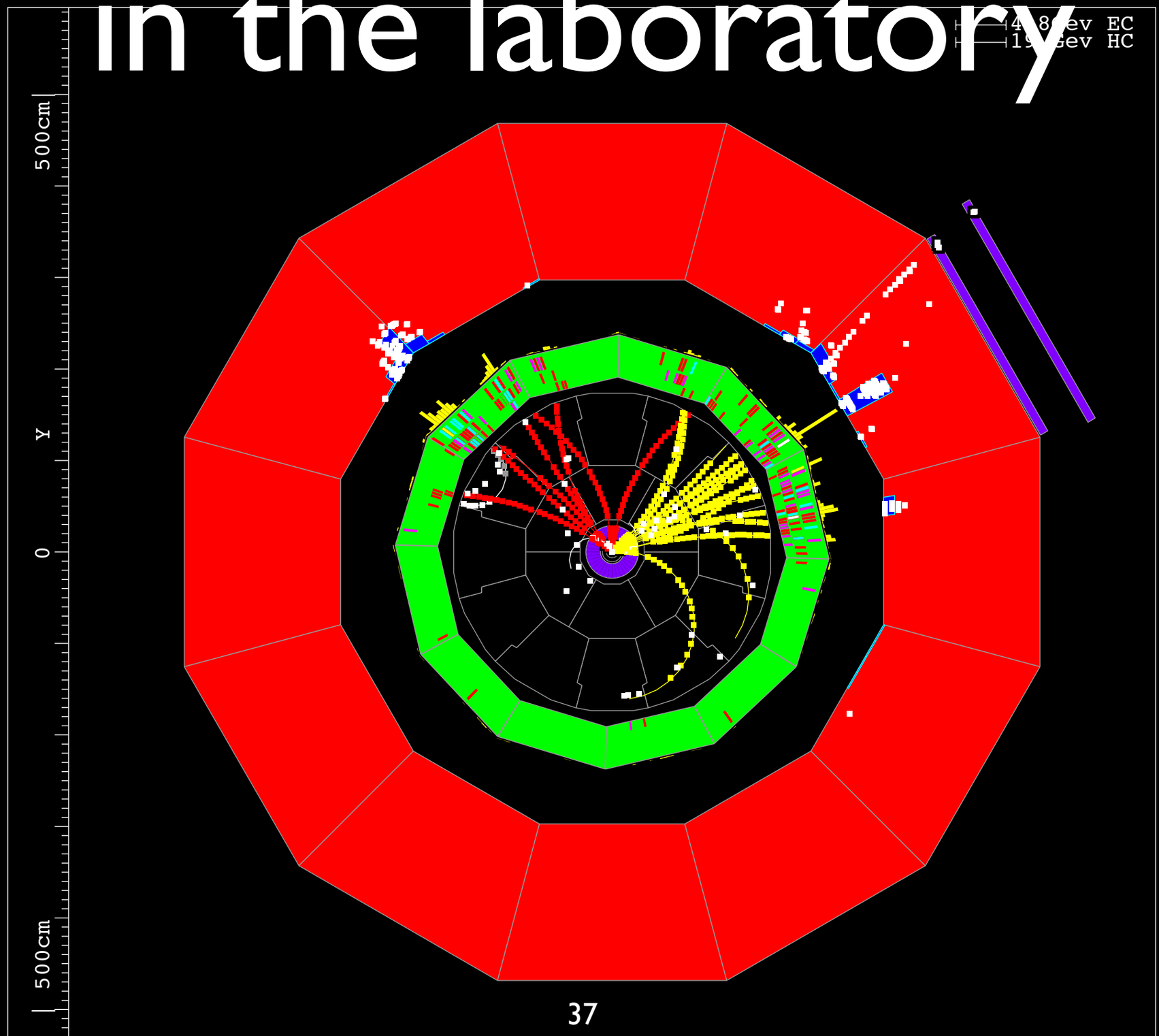
Berlioz "*Les Troyens*" in Valencia

Can we make it?



$E=mc^2$

Producing Dark Matter in the laboratory



History of the Universe

10⁻¹⁰ sec

380k yrs

13.8Bzyrs

high-energy cosmic rays

Inflation

BIG BANG

possible dark matter relicts

dark matter

telescope

cosmic microwave radiation visible

Today

t	10^{-44}	10^{-37} s		10^{-10} s		10^{-5} s		10^{2} s		3×10^{5} y		10^{9} y	12×10^{9} y (sec,yrs)
T	10^{32}	10^{28}		10^{15}		10^{12}		10^{9}		3000		15	2.7 (Kelvin)
E	10^{19}	10^{15}		10^{2}		10^{-1}		10^{-4}		3×10^{-10}		10^{-12}	2.3×10^{-13} (GeV)

Key:

- q quark
- g gluon
- e electron
- μ muon τ tau
- ν neutrino
- W, Z bosons
- qq̄ meson
- qqq baryon
- ion
- atom
- photon
- galaxy
- star
- black hole

Anti-matter

Irène

Frédéric Joliot-Curie

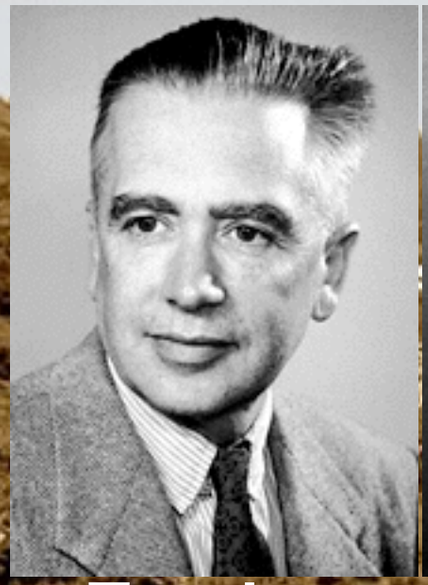
e−
electron

e+
positron

γ
photon

1933
first human-made anti-matter

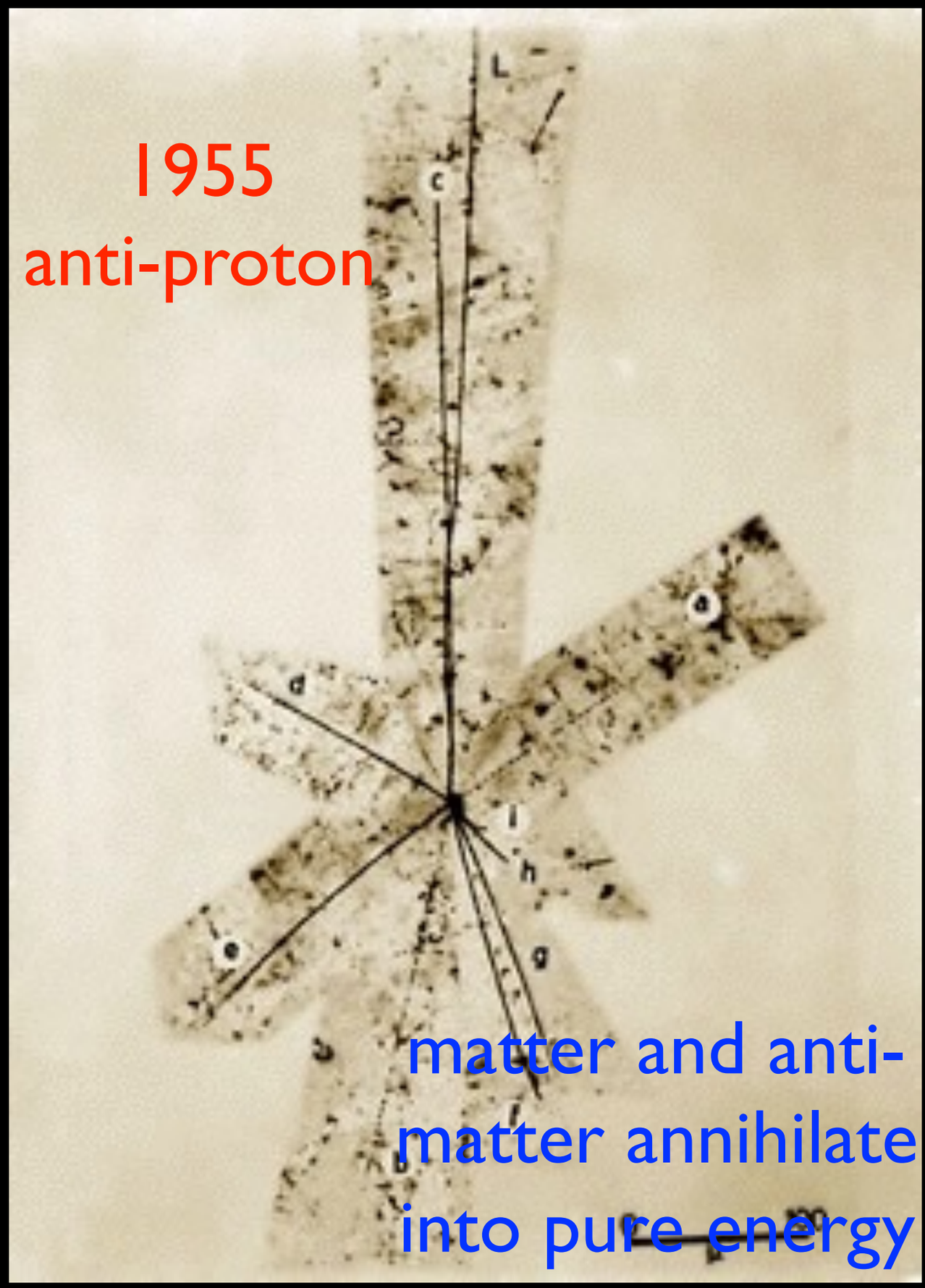
Berkeley



Emilio Owen

Segrè Chamberlain

1955
anti-proton

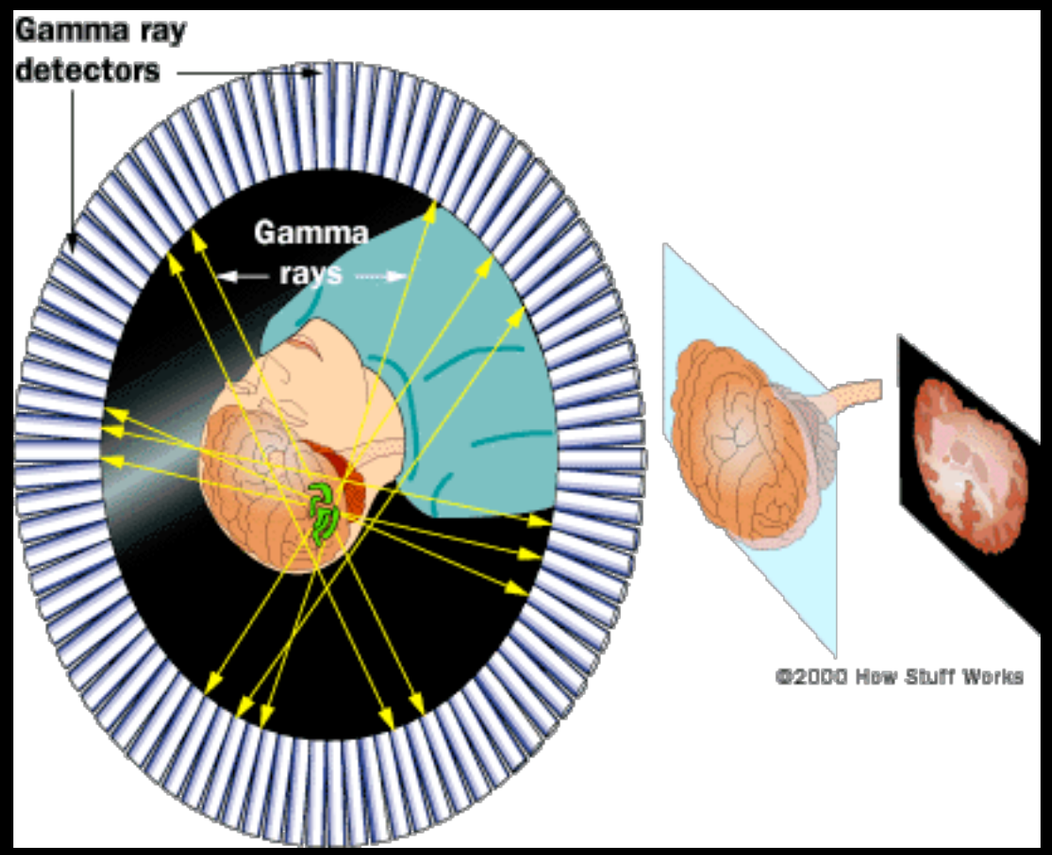


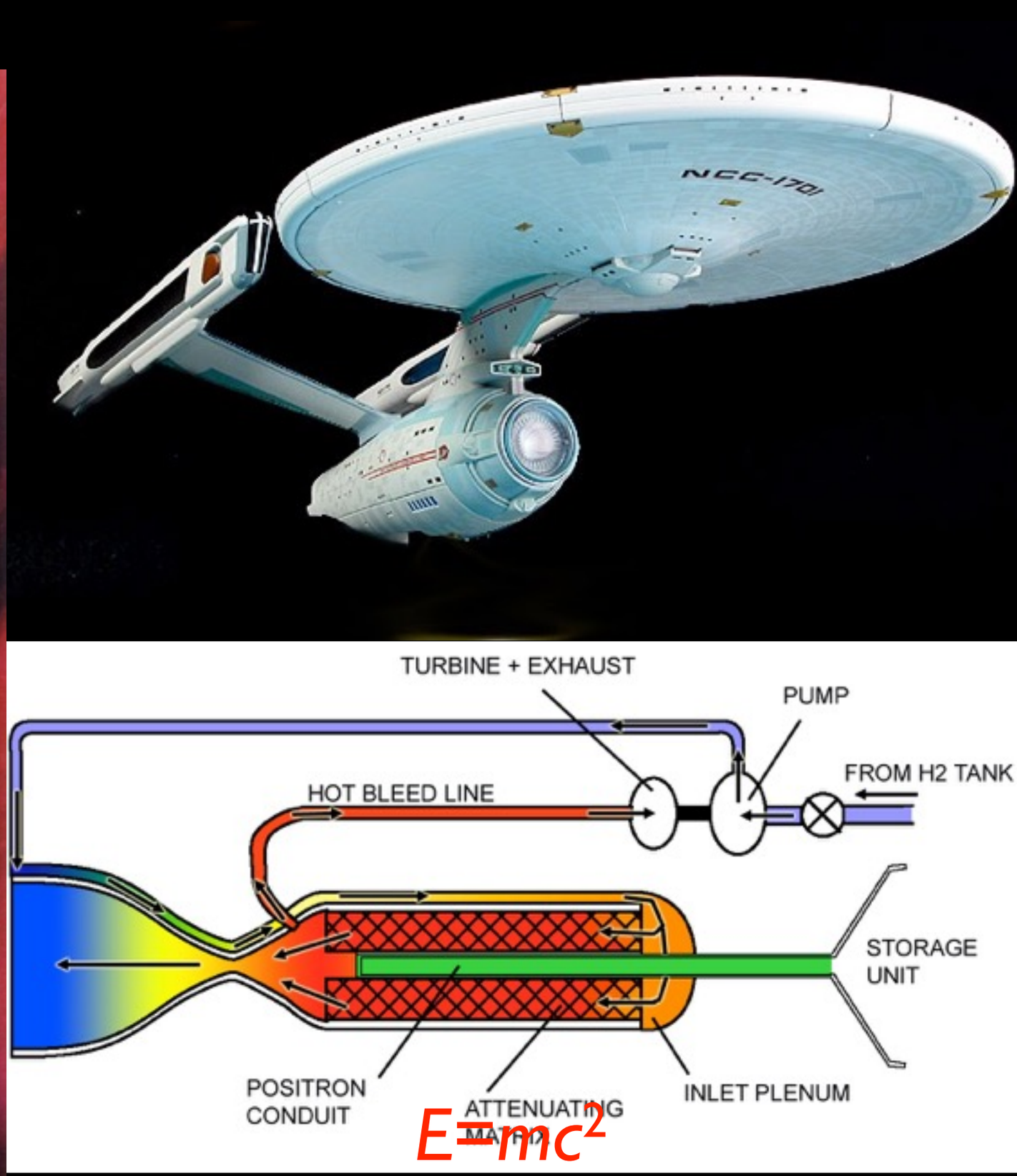
matter and anti-matter annihilate into pure energy

anti-matter at use

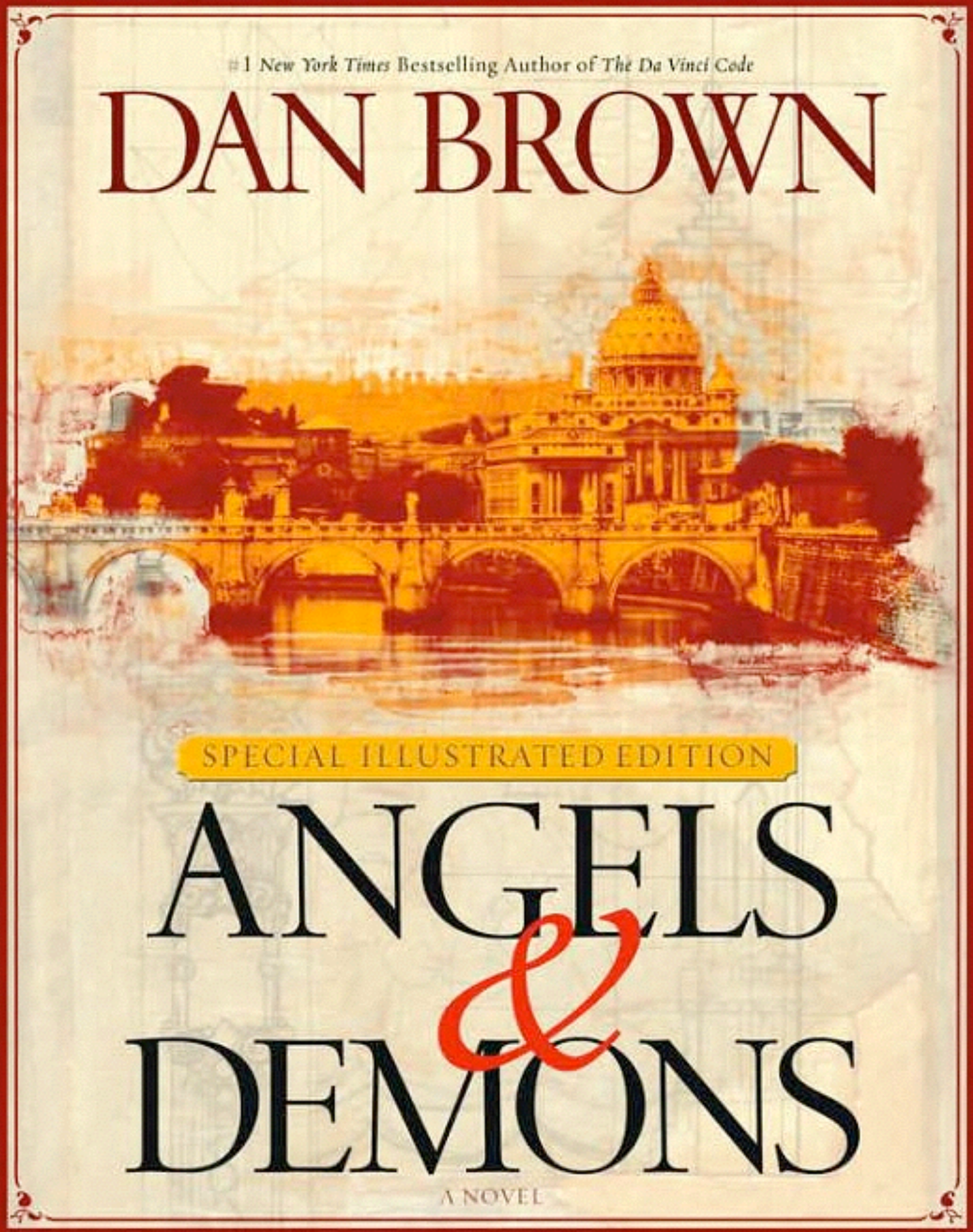
Positron Emission Tomography (PET)

Lawrence Berkeley
National Laboratory





300 million times more efficient than regular gasoline



- European Laboratory CERN
- A scientist produced a quarter gram of anti-matter without the knowledge of the Director General
- *falls into wrong hands!*

billion trillion trillion dollars


TOM HANKS
ANGELS & DEMONS
MAY 2009
REGISTER FOR UPDATES
WORLDWIDE RELEASE DATES
BASED ON THE BEST-SELLING NOVEL
BY THE AUTHOR OF
THE DA VINCI CODE

BASED ON THE BEST-SELLING NOVEL
BY THE AUTHOR OF

THE DAVINCI CODE

Early Universe

1,000,000,002

1,000,000,000

matter

anti-matter

Current Universe

2

•

us

matter *anti-matter*

We won! But *why*?

Beginning of Universe

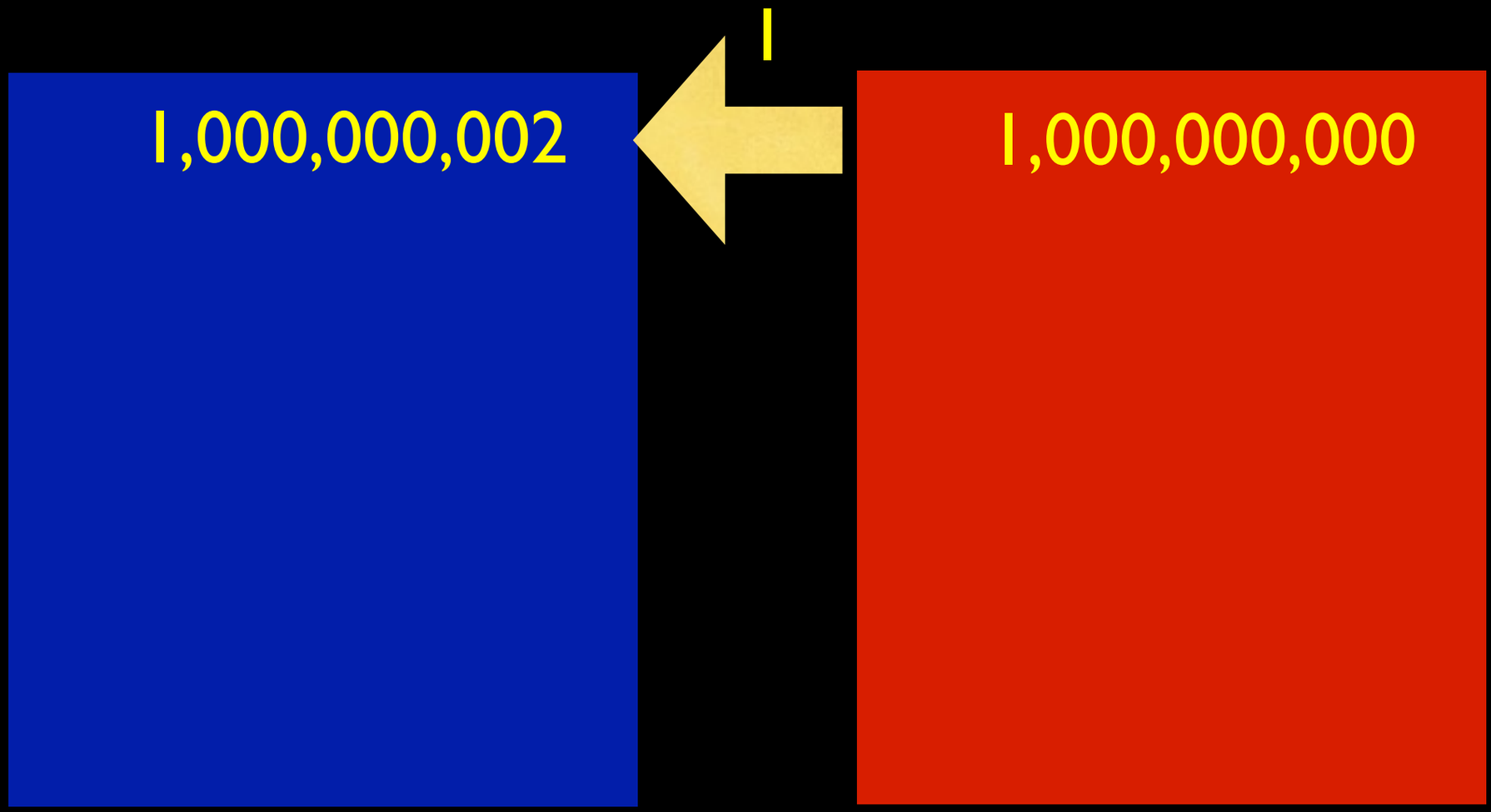
1,000,000,001

1,000,000,001

matter

anti-matter

fraction of second later



turned a billionth of anti-matter to matter

Universe Now

2

•

us

matter *anti-matter*

This must be how we survived the Big Bang!

How do we reshuffle matter & anti-matter?

$\bar{\nu} \rightarrow \nu$

How do we reshuffle matter & anti-matter?

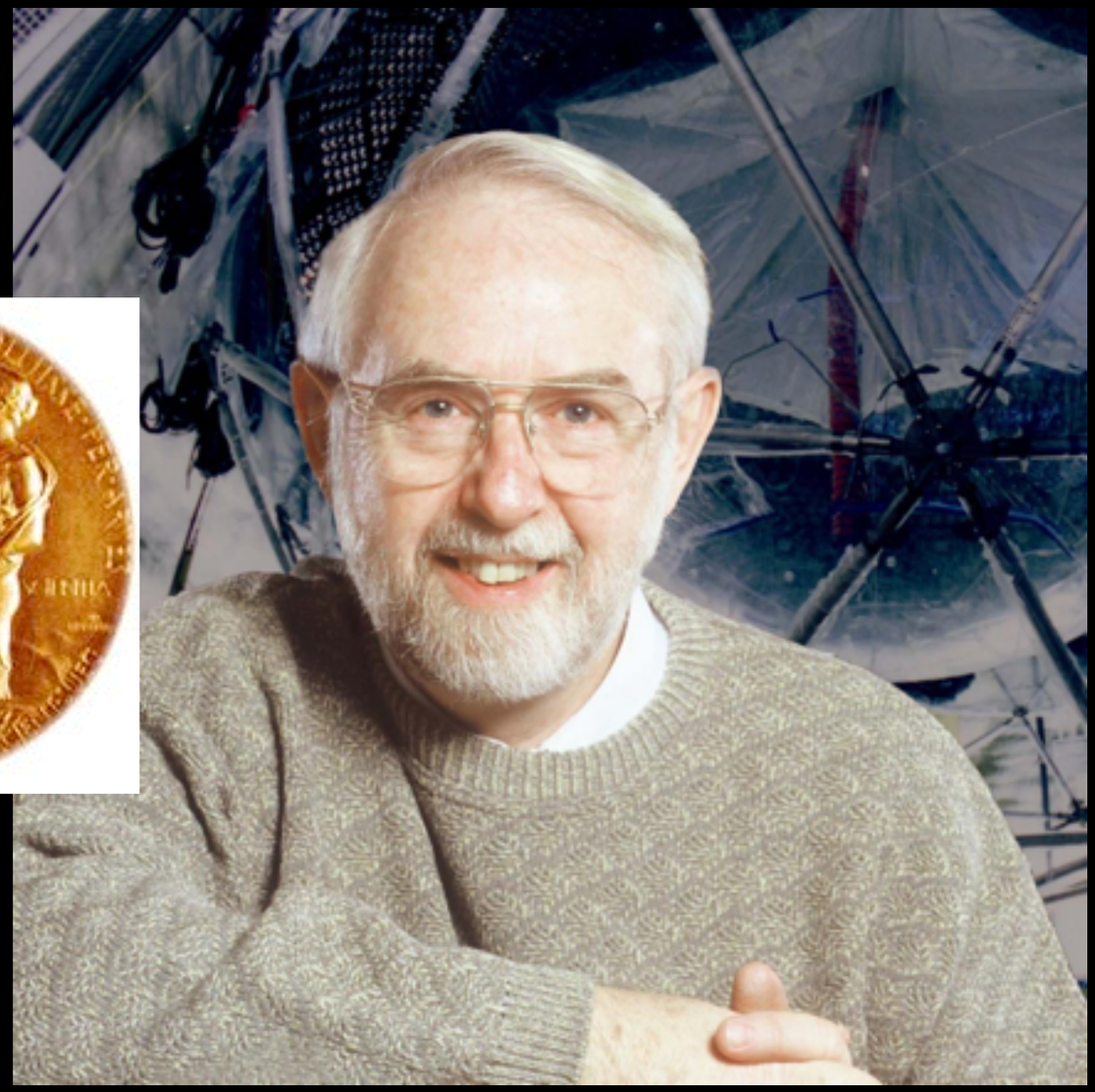
- neutrinos have no electric charge
- anti-neutrino may turn into neutrino

$$\bar{\nu} \rightarrow \nu$$

- neutrinos are our father?


Fukugita Yanagida

Neutrinos morph flavors



Nobel Prize in Physics 2015

Kajita (Super-K) can taste only strawberry, not chocolate

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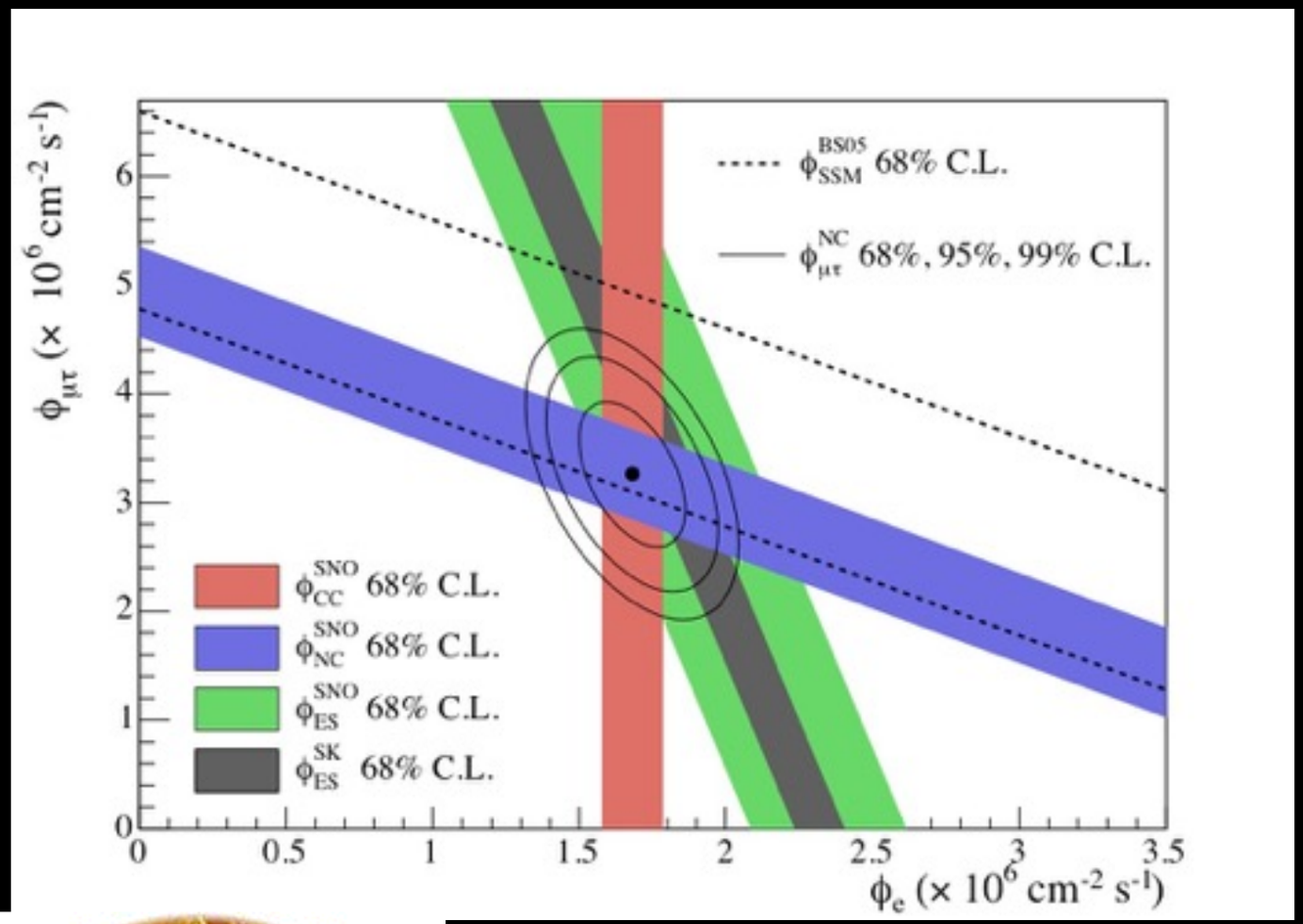
Kajita (Super-K) can taste only strawberry, not chocolate

Kajita (Super-K) can taste only strawberry, not chocolate

Kajita (Super-K) can taste only strawberry, not chocolate

He tastes only a half of the size!

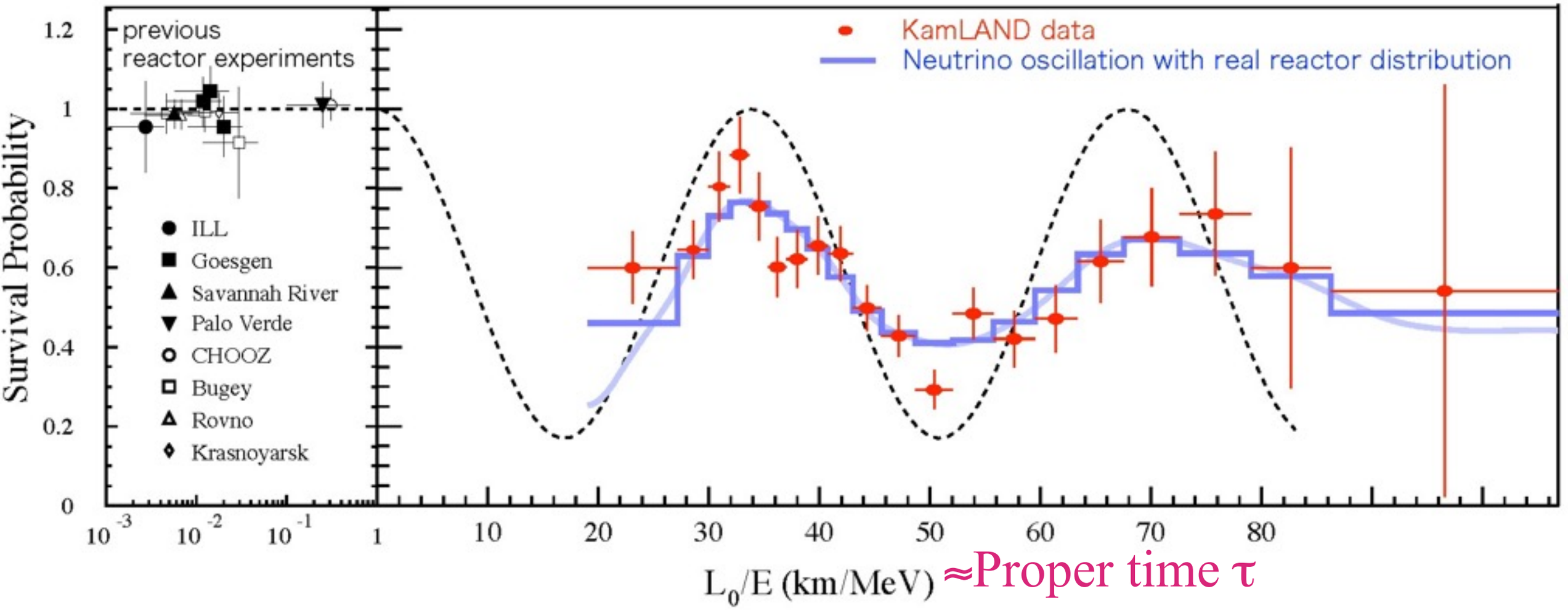
Solar Neutrinos



Flavor Transformation

KamLAND control room

KamLAND '08
neutrinos do oscillate!



L_0=180 km

Excitement

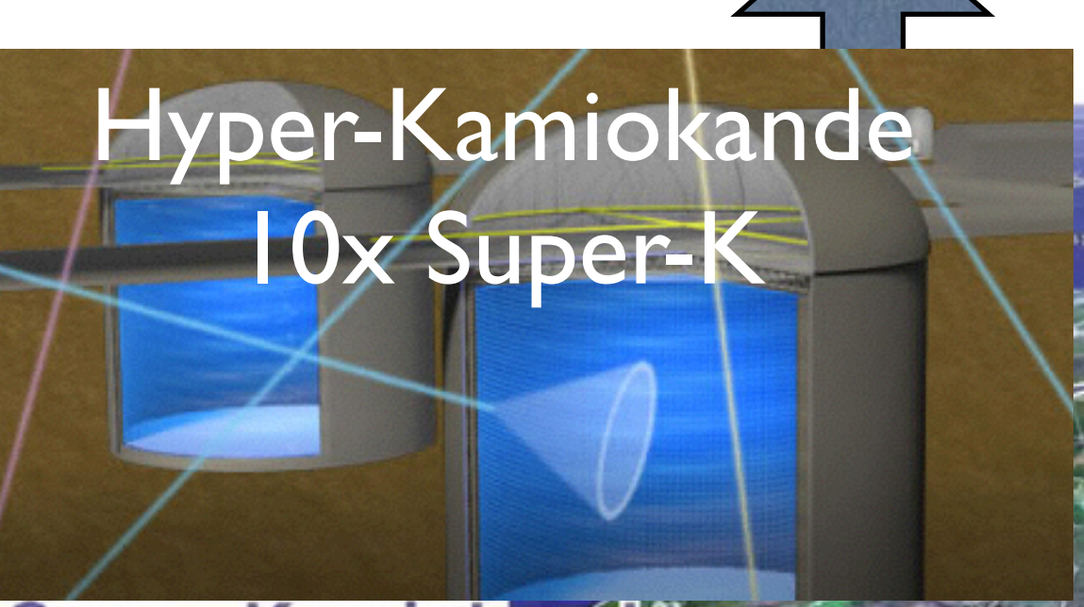
- CP violation in neutrino sector may be observable with conventional technique

$$P(\nu_\mu \to \nu_e) - P(\bar{\nu}_\mu \to \bar{\nu}_e) = -16 s_{12} c_{12} s_{13} c_{13}^2 s_{23} c_{23} \sin\delta \sin\frac{\Delta m^2_{12} L}{4E} - \sin\frac{\Delta m^2_{13} L}{4E} - \sin\frac{\Delta m^2_{23} L}{4E}$$

2002 KamLAND SNO

2012 Daya Bay

1998 Super-K



T2K hints

History of the Universe

10-26 seconds

10-10 sec

erators

on

high-energy cosmic rays

380k yrs

13.8Bzyrs

Inflation

BIG BANG

?

anti-matter

dark matter

possible dark matter relicts

cosmic microwave radiation visible

telescope

fate

t 10-44 10-37 s
T 10 32 10 28
E 10 19 10 15

10-10 s
10 15
10 2

10-5 s
10 12
10 -1

10 2 s
10 9
10 -4

3x10 5 y
3000
3x10 -10

10 9 y
15
10-12

12x10 9 y (sec,yrs)
2.7 (Kelvin)
2.3x10 -13 (GeV)

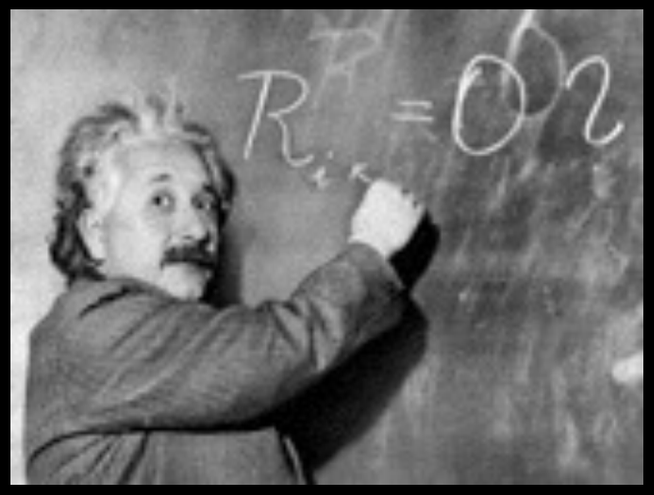
Today

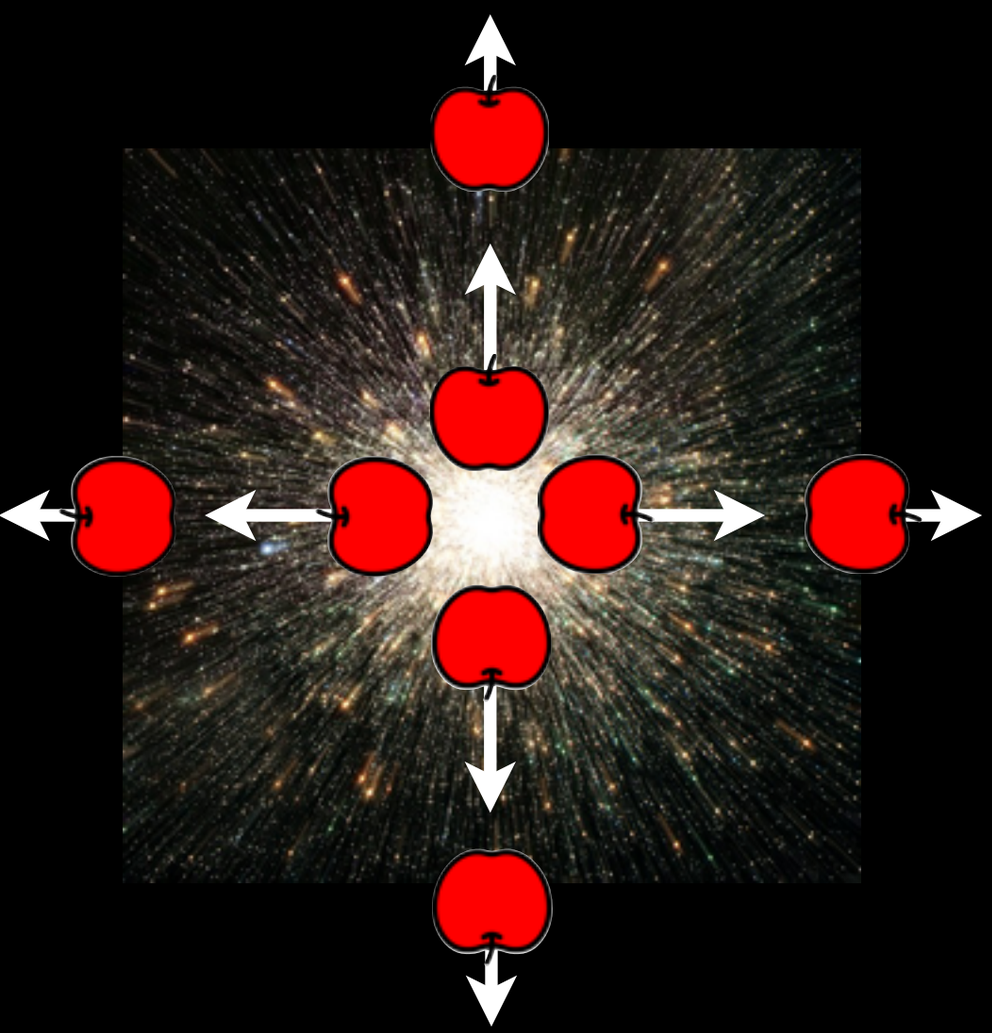
Key:

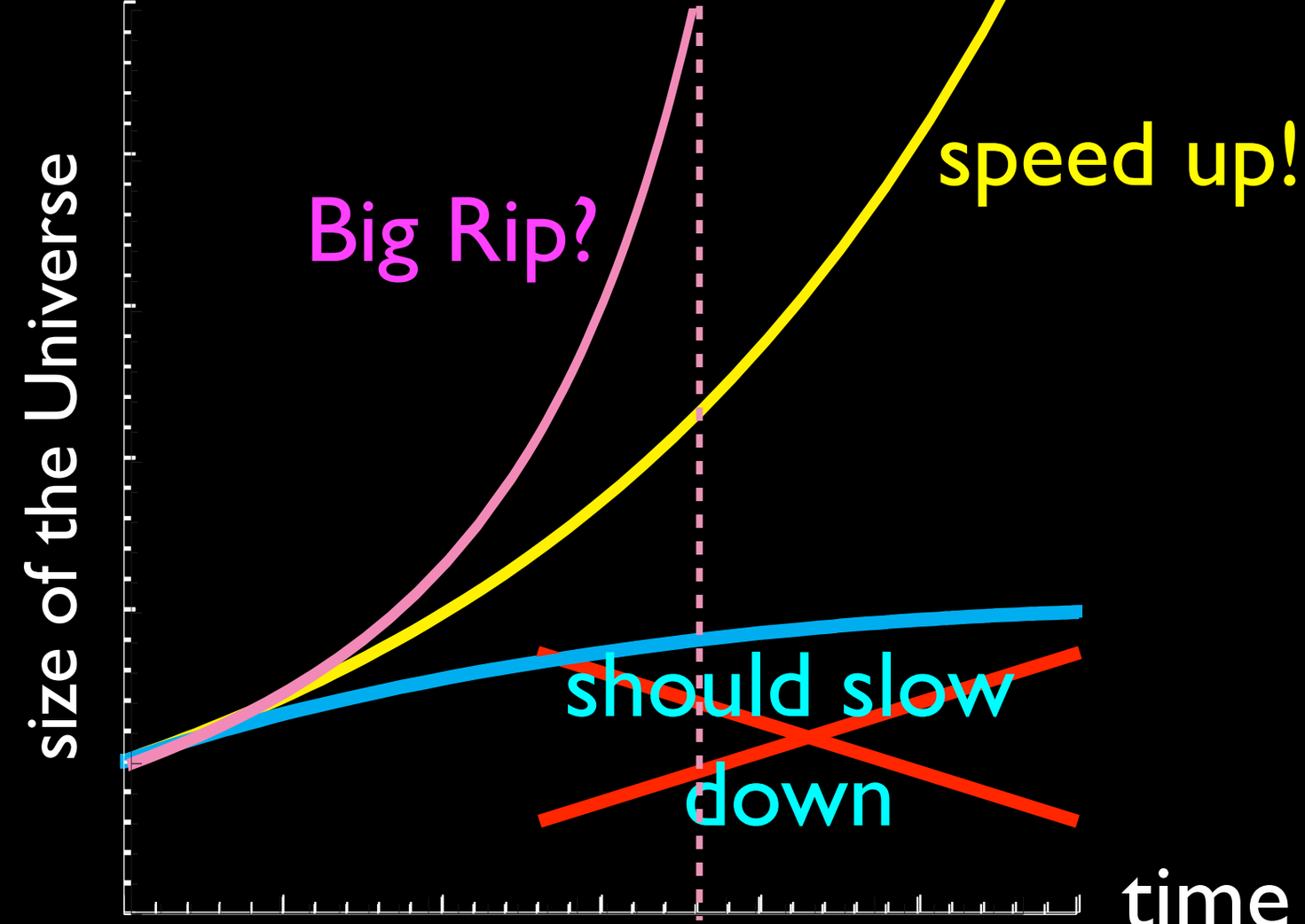
- W, Z bosons
- photon
- q quark
- meson
- galaxy
- g gluon
- baryon
- star
- e electron
- ion
- μ muon τ tau
- atom
- black hole
- ν neutrino

Fate of the Universe

Cosmic Expansion



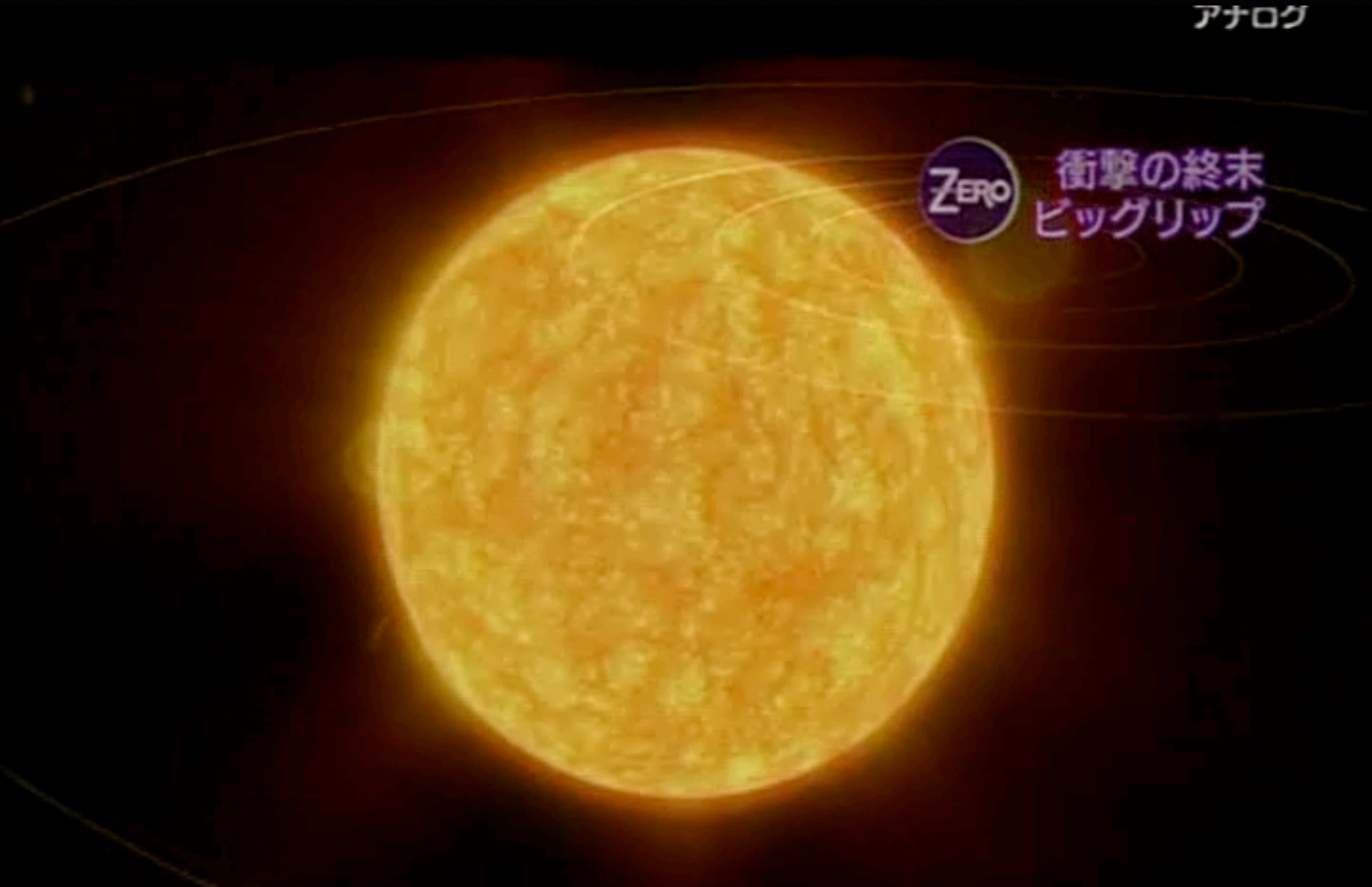




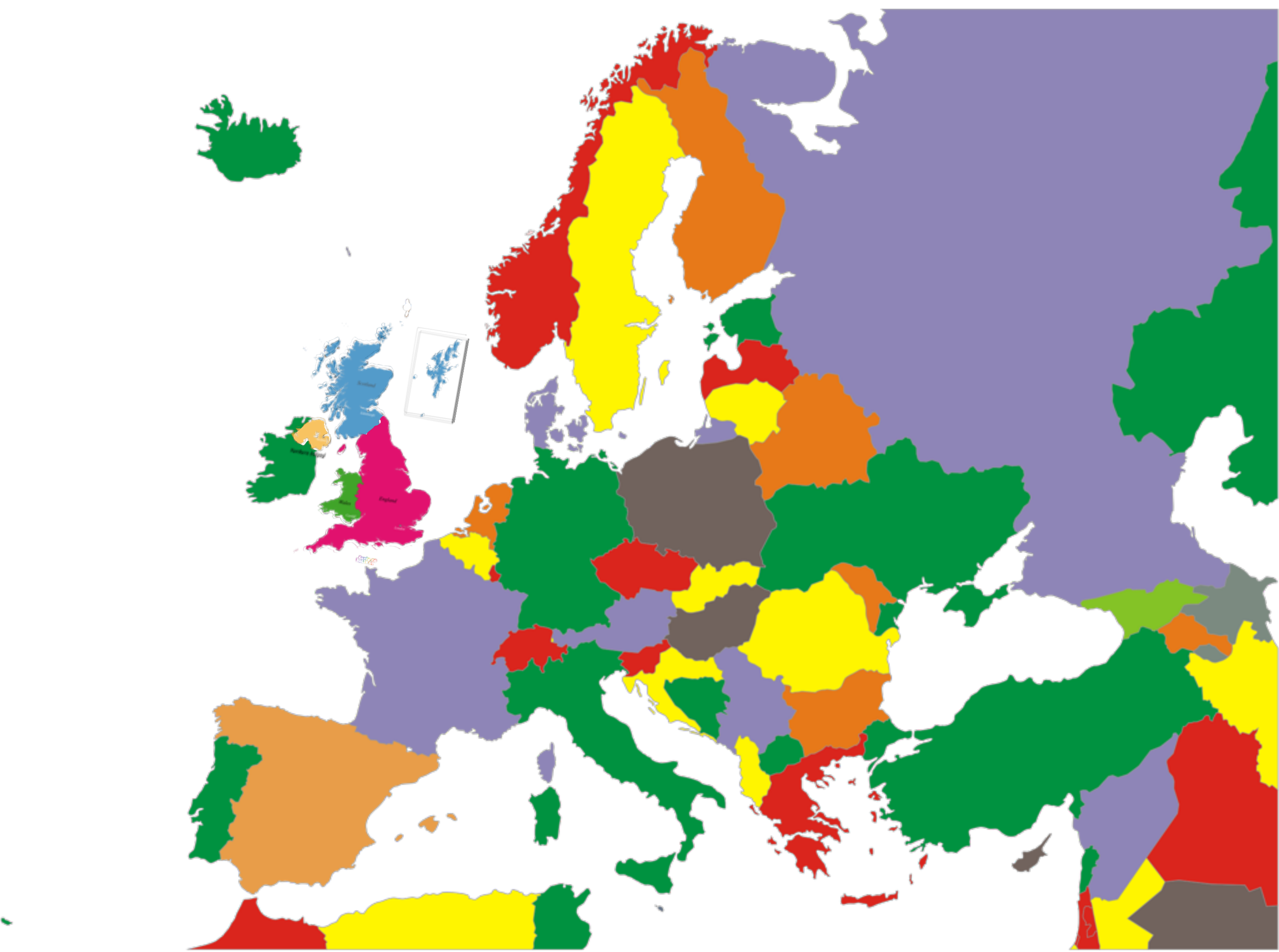
Gravity only pulls
Something is pushing the expansion
The biggest mystery in modern physics!

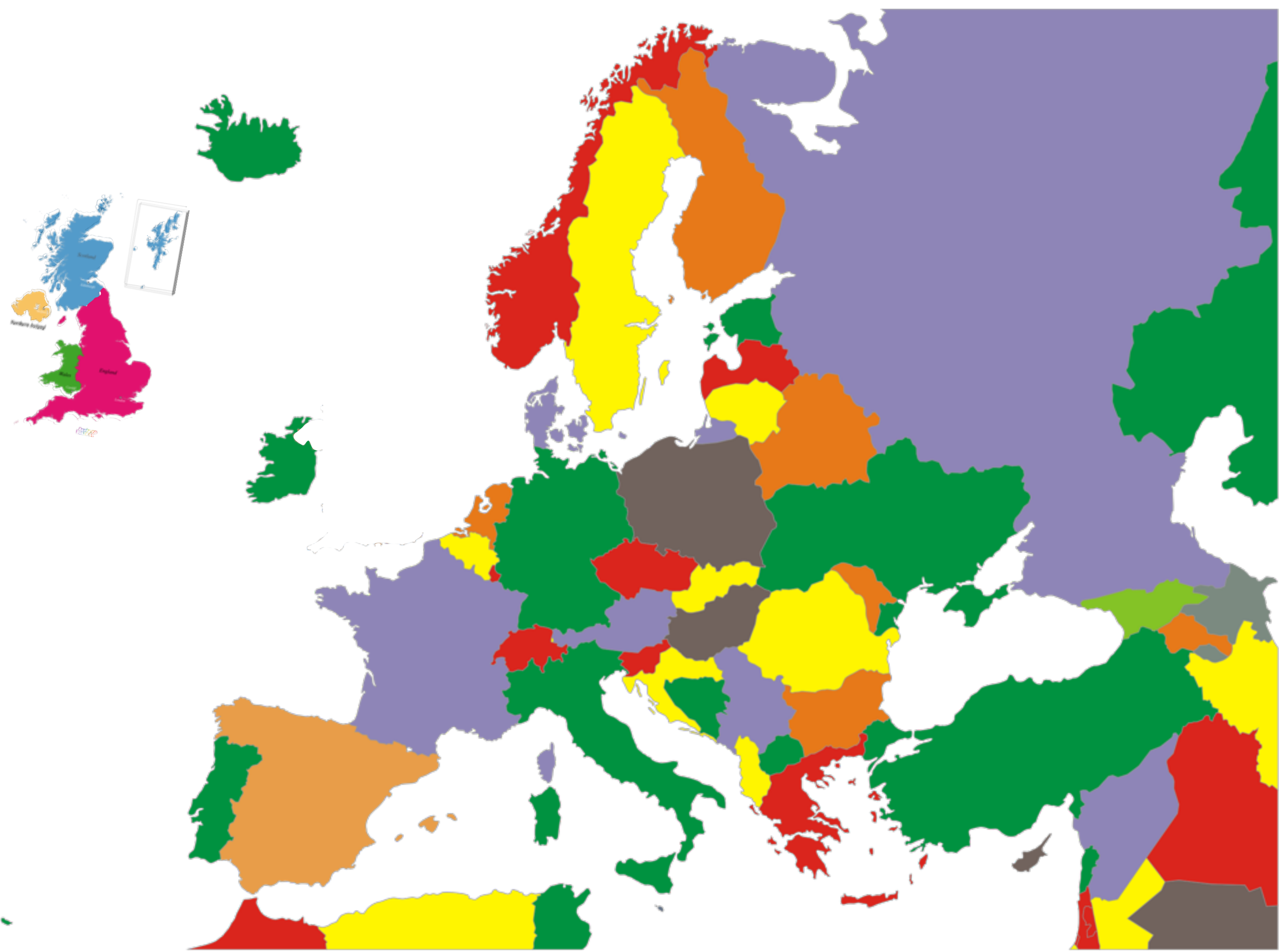
2011 Nobel Prize in Physics

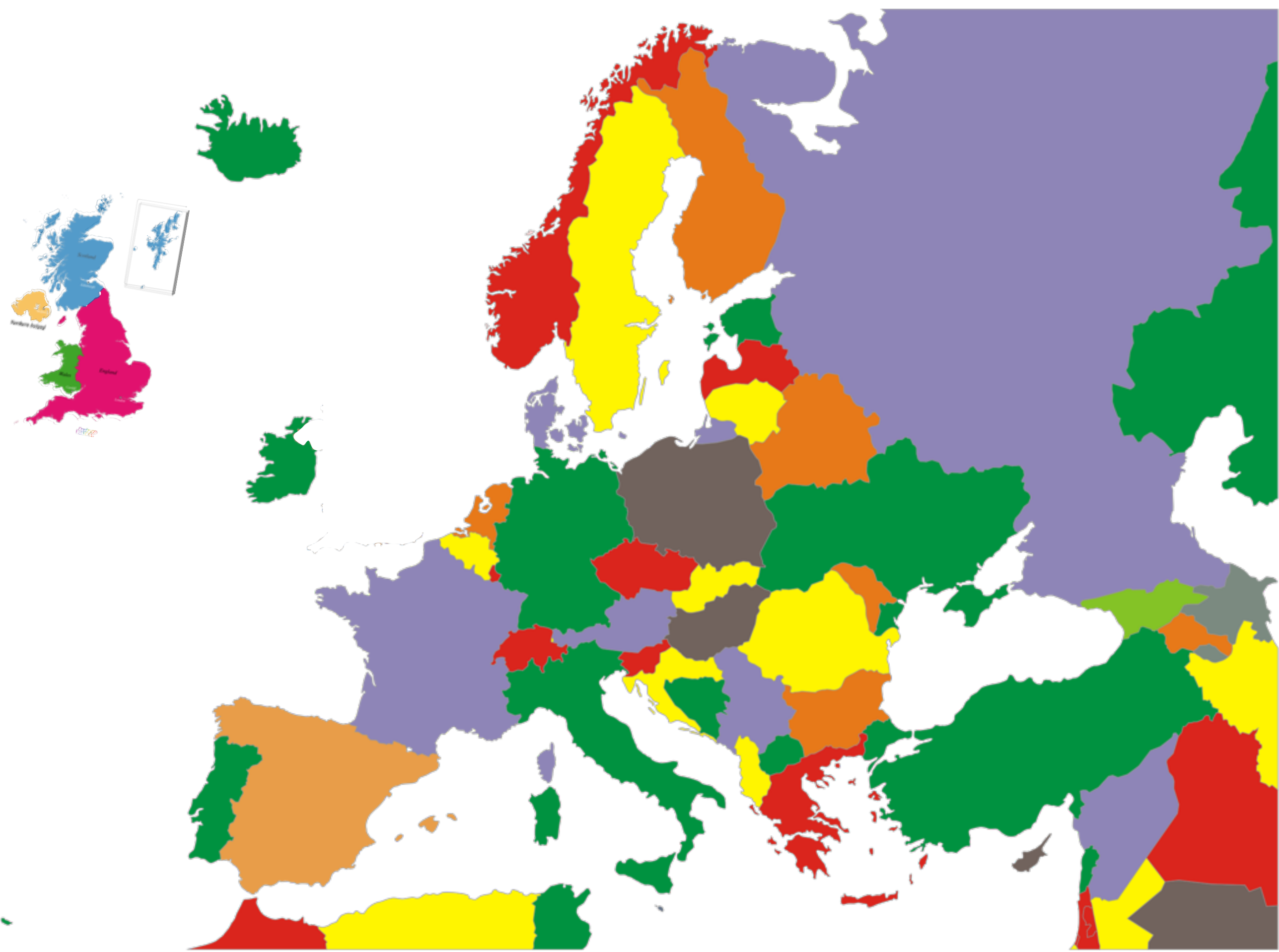
NHK Science Zero 2010.9.4

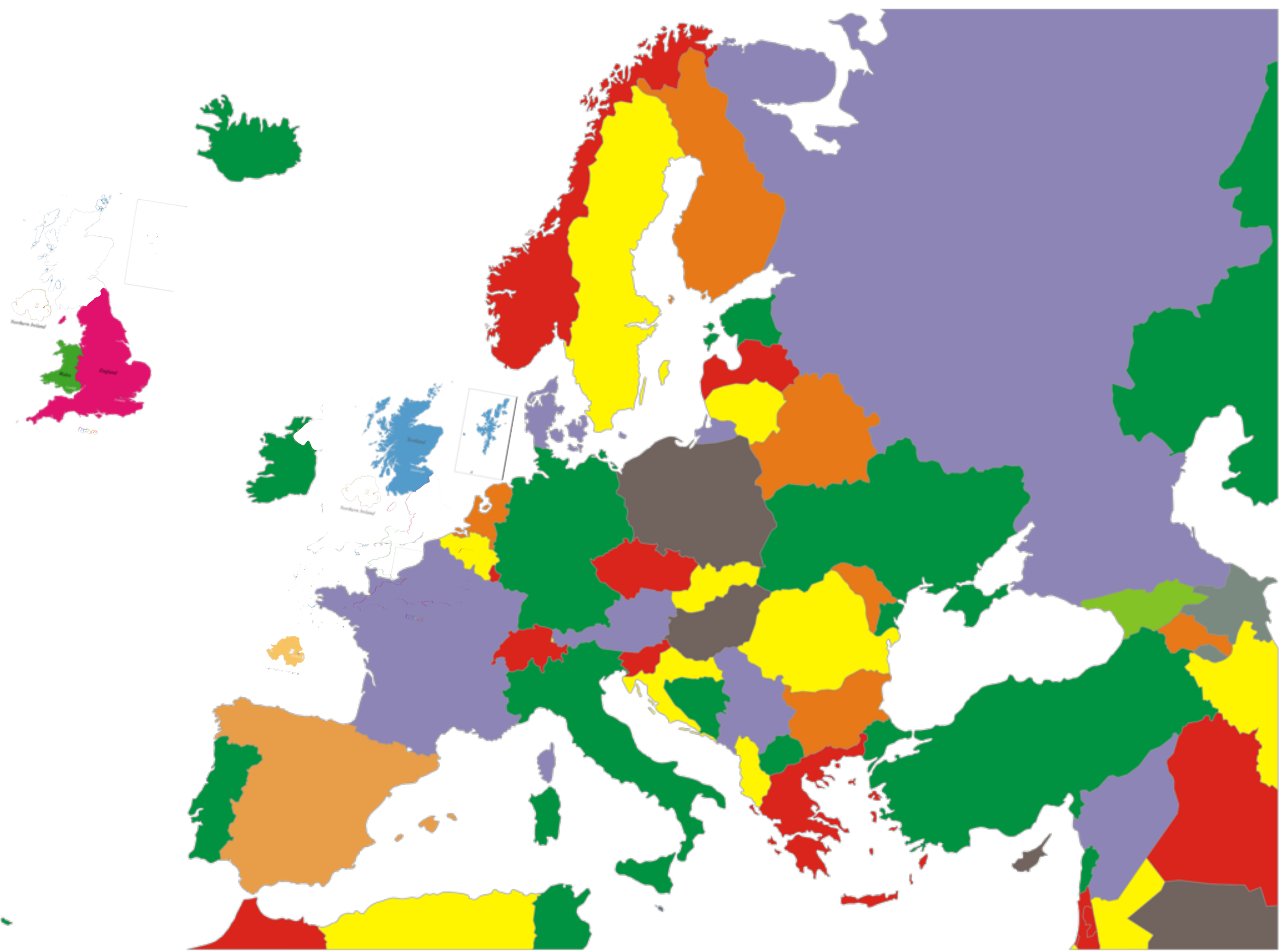


NHK Science Zero 2010.9.4

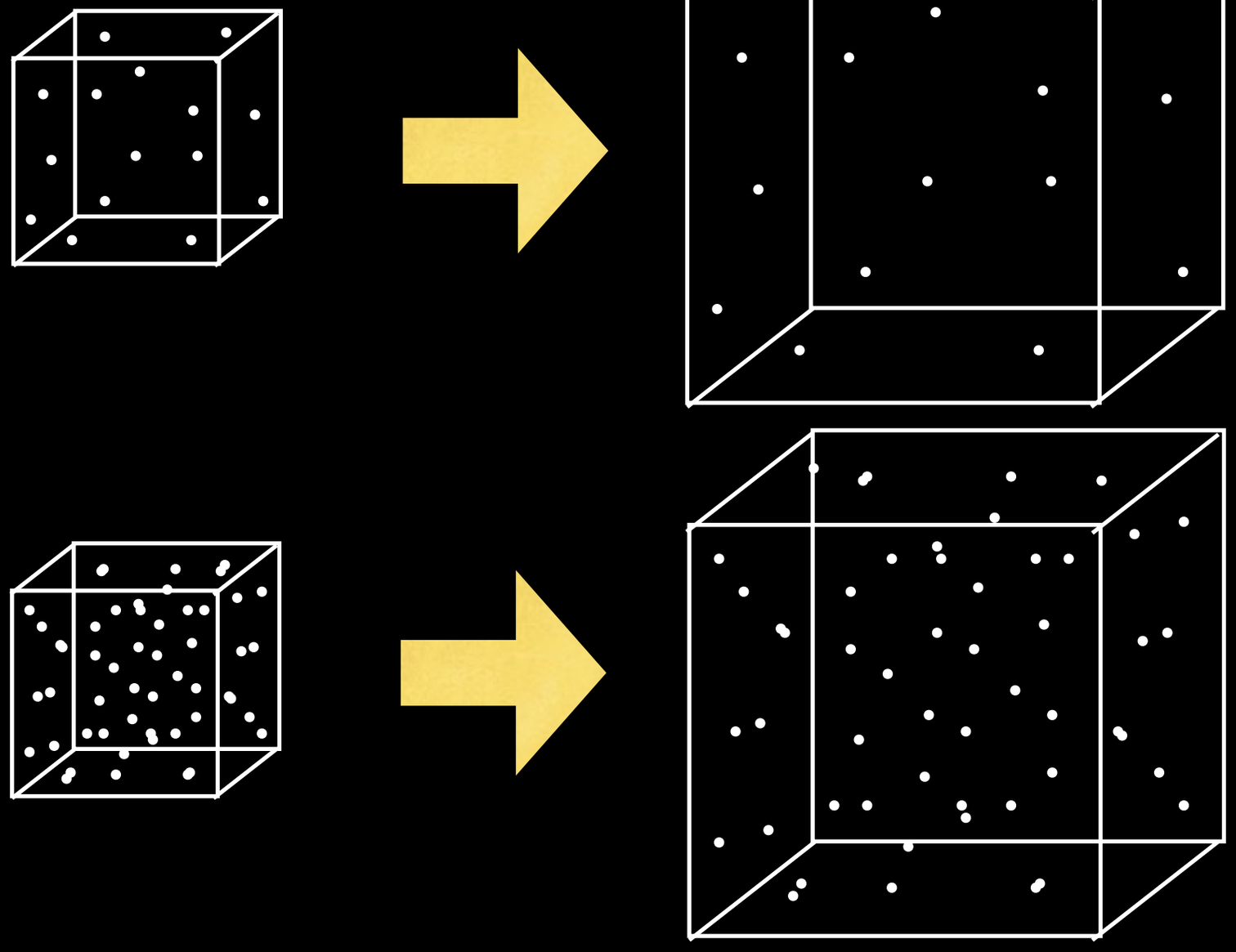

Scotland
Wales
England


Scotland
Northern Ireland
Wales
England


Scotland
Northern Ireland
Wales
England

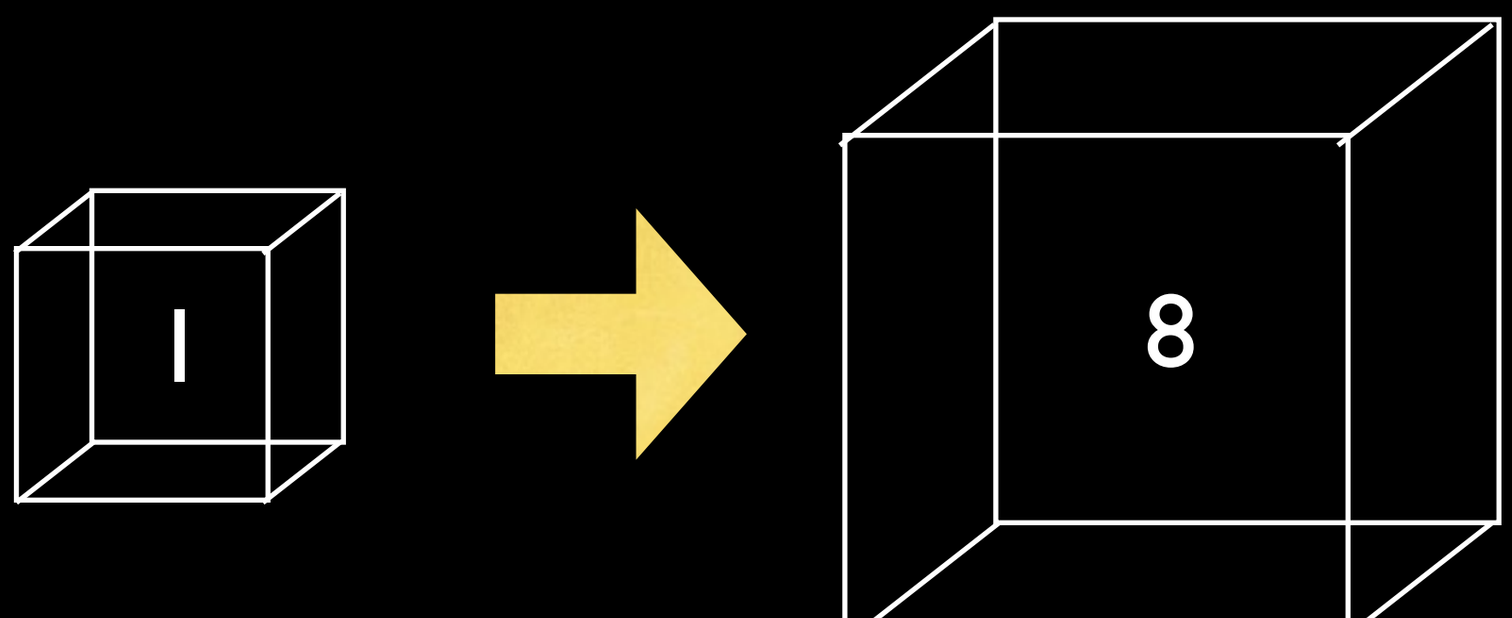

England
Wales

atoms
4%



dark
matter
23%

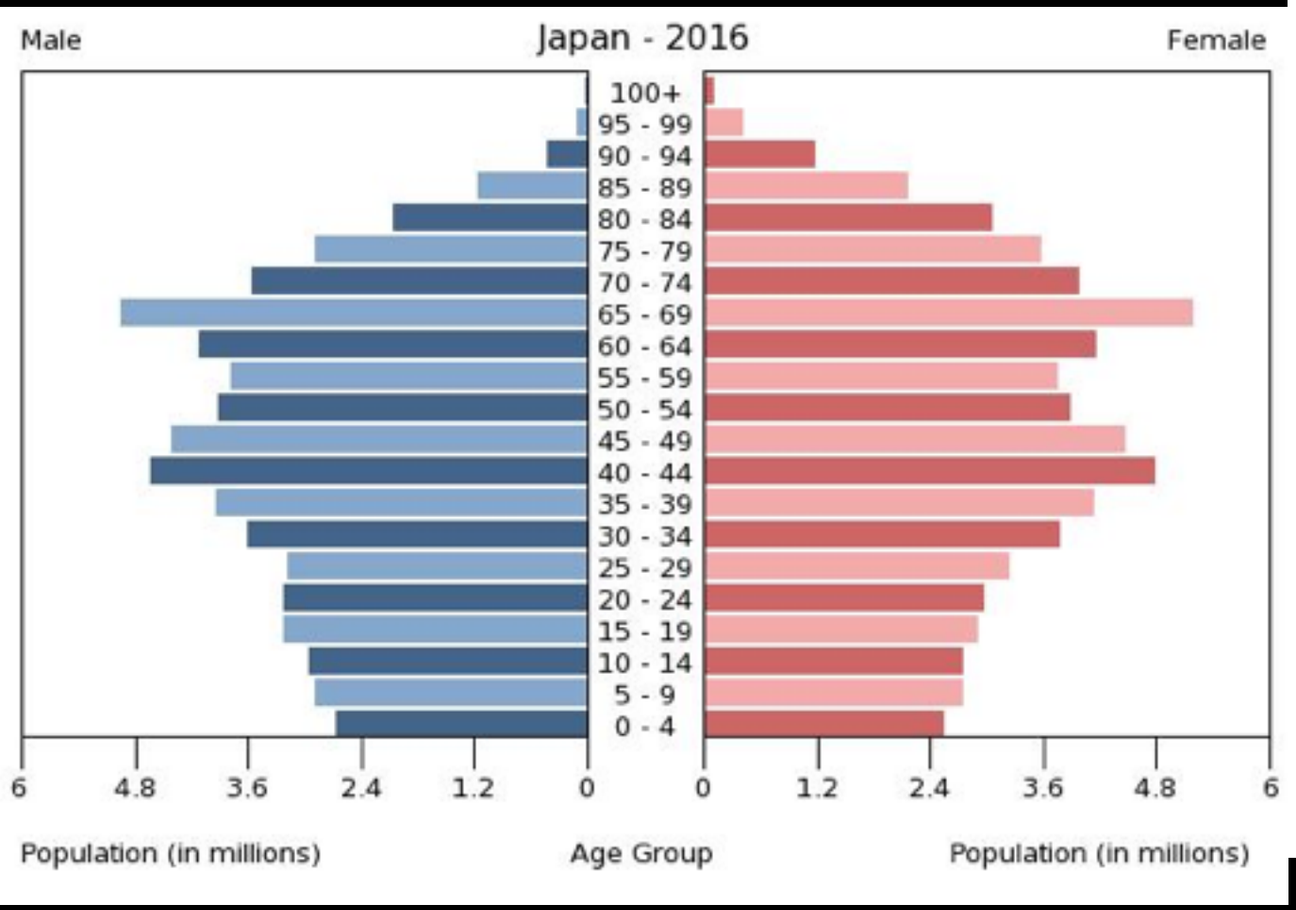
dark
energy
73%

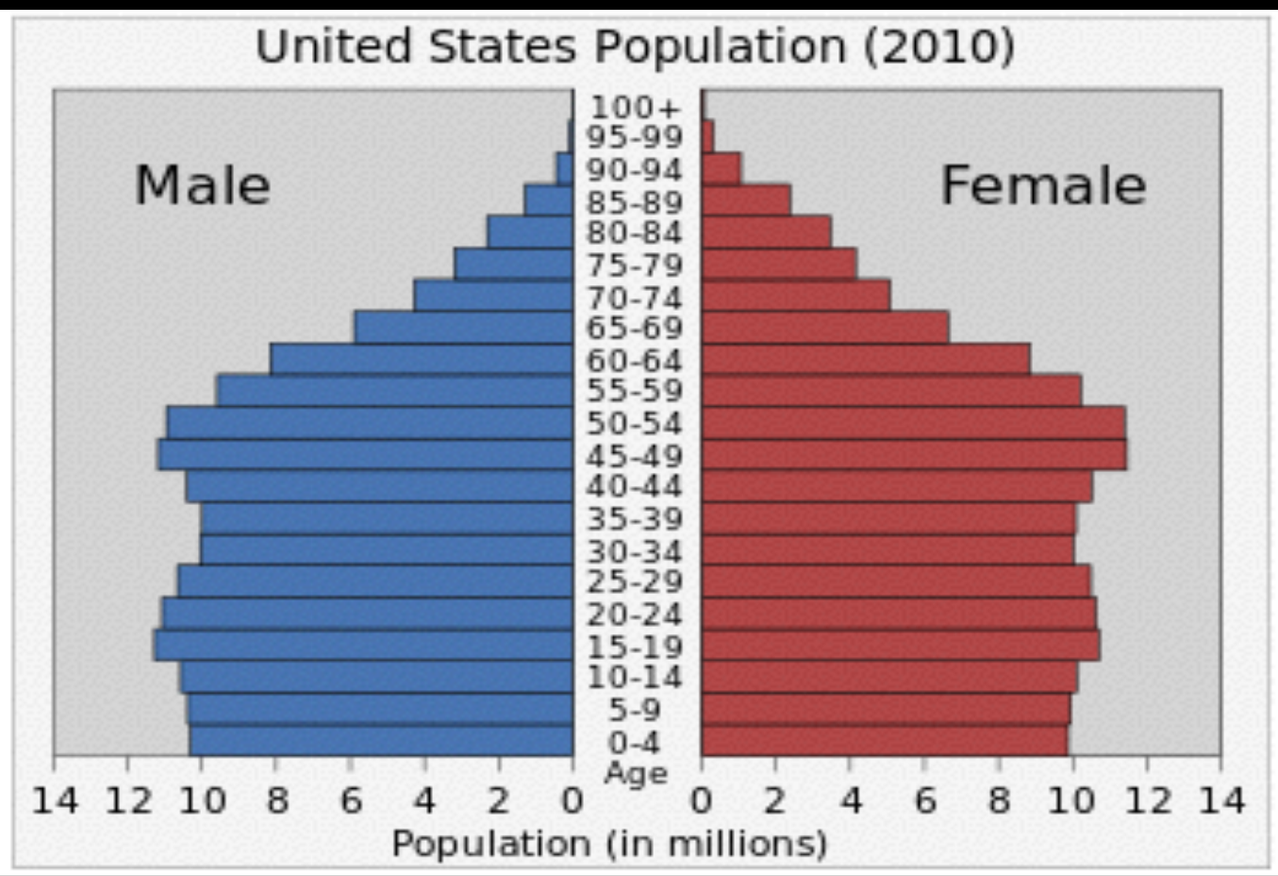


7? 9?

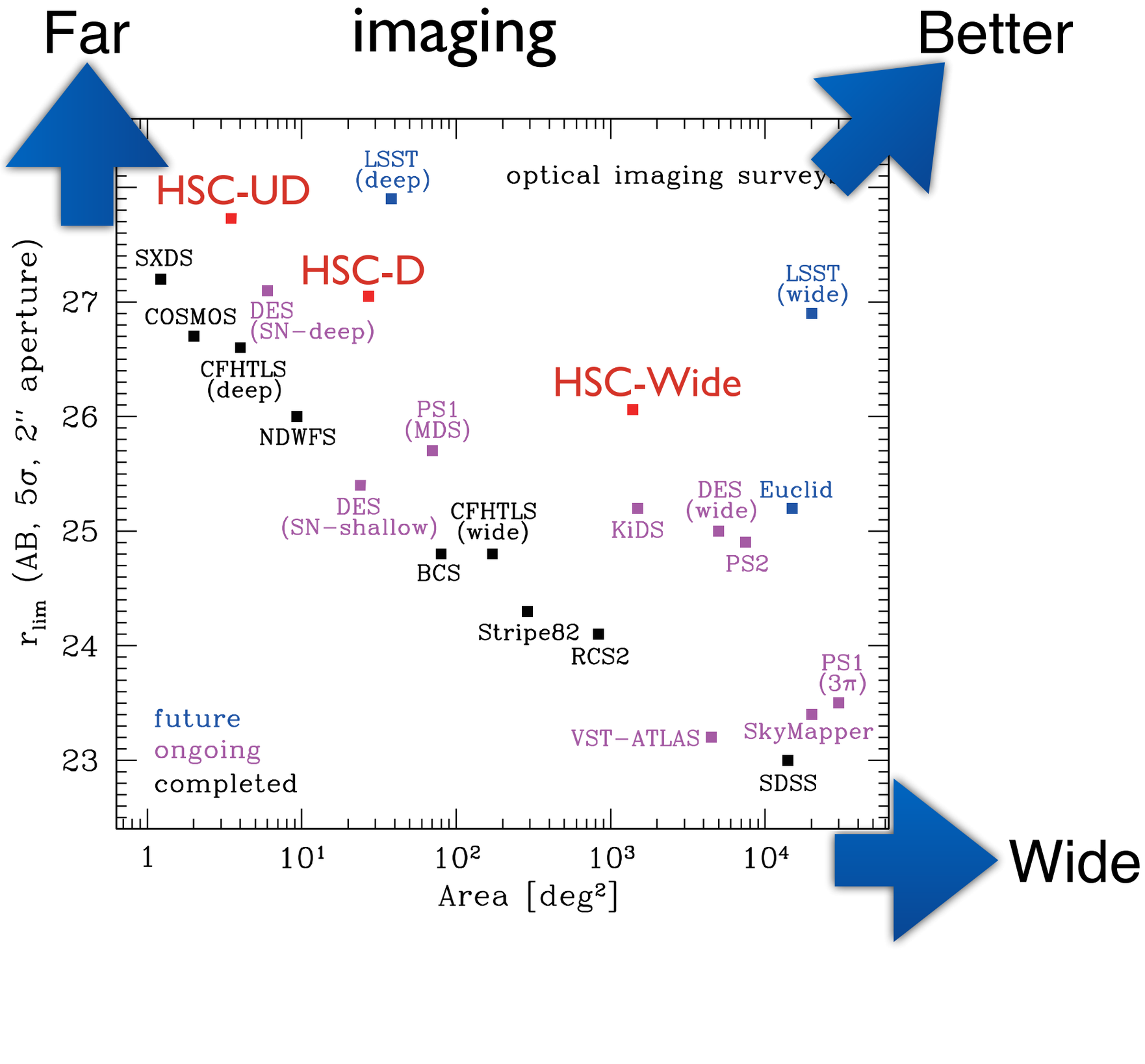
Need funding ASAP!

Need a *census* to understand our future

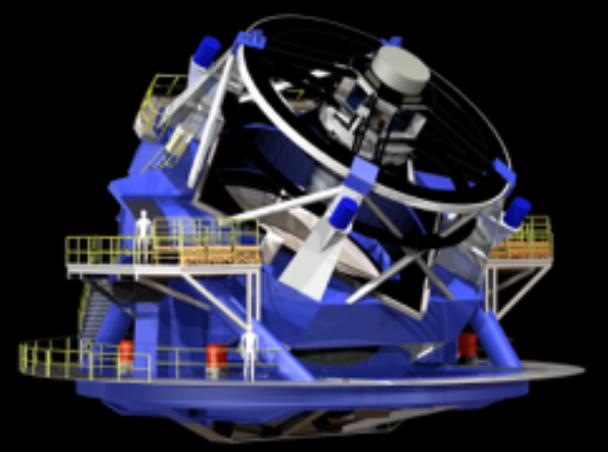




Far and Wide


Far
imaging
Better
HSC-UD
LSST (deep)
optical imaging survey
SXDS
HSC-D
LSST (wide)
COSMOS
DES (SN−deep)
CFHTLS (deep)
HSC-Wide
NDWFS
PS1 (MDS)
DES (SN−shallow)
CFHTLS (wide)
KiDS
DES (wide)
Euclid
PS2
BCS
Stripe82
RCS2
PS1 (3π)
future
ongoing
completed
VST−ATLAS
SkyMapper
SDSS
r_{lim} (AB, 5σ, 2" aperture)
27
26
25
24
23
1
10^1
10^2
10^3
10^4
Area [deg²]
Wide

DES, PAU, Euclid, LSST



LSST

physicists ask simple but profound questions

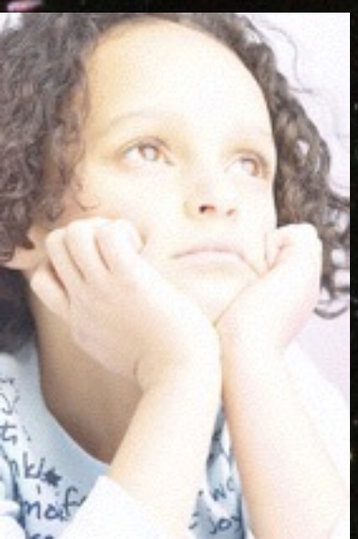
How did the Universe begin?

What is its fate?

What is it made of?

What are its basic laws?

Where do we come from?



Quantum
Universe

IFAE
physicists