The Universe

Composition?
Origin?

Rocky Kolb
Fermilab and the
University of Chicago

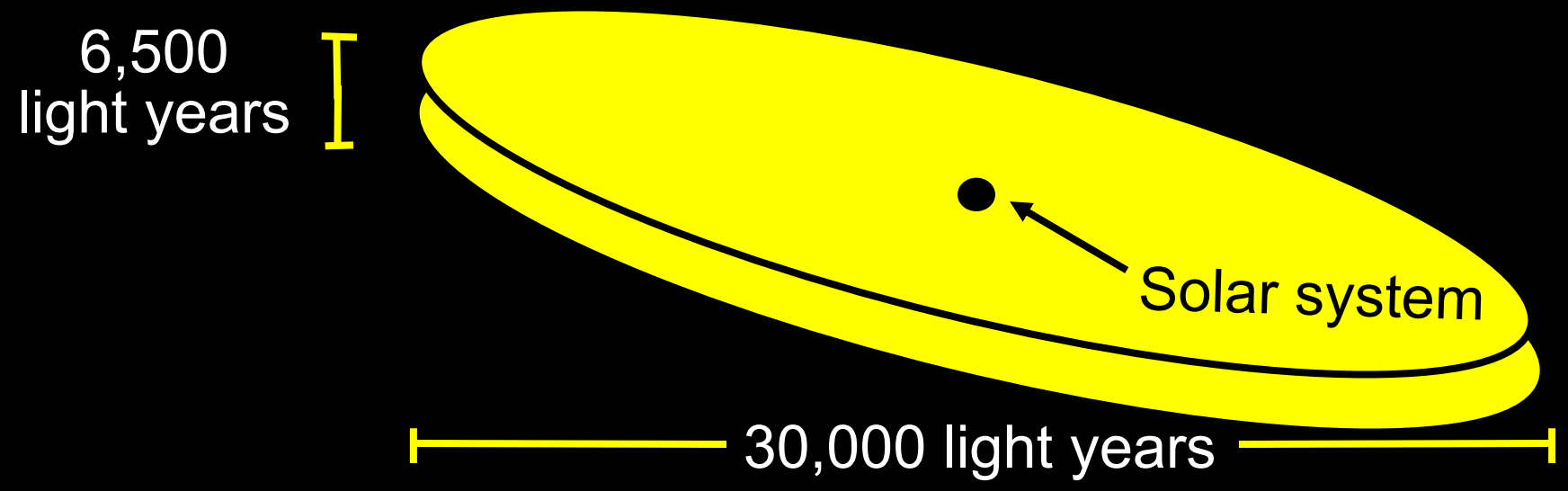
Cosmology 4000 years ago

Cosmology 1000 years ago

Cosmology 100 years ago

1) **Composition**: Starz' in the 'hood

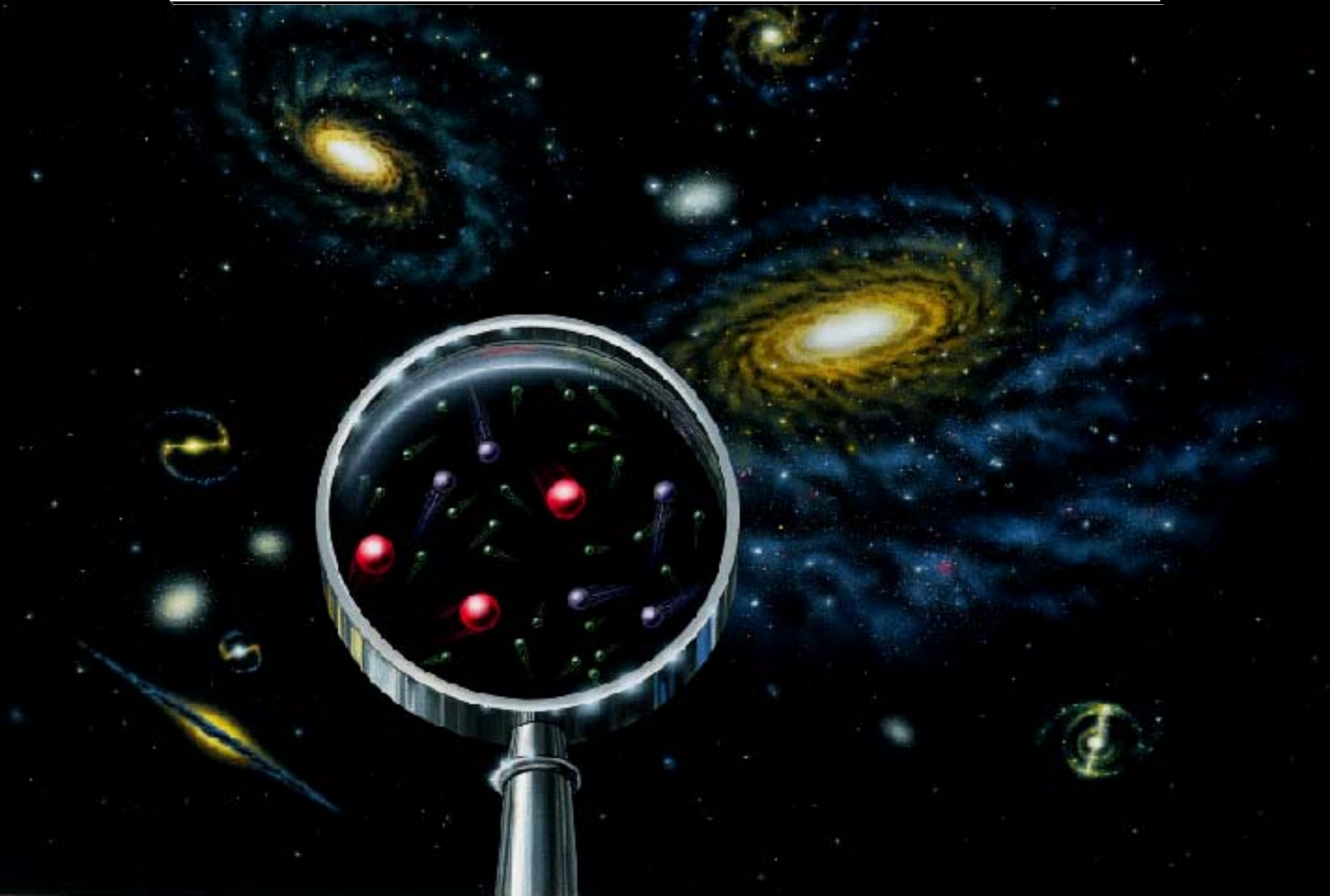
2) **Arrangement**:



3) **Origin**: ?

viale
dell'Astronomia
via
della Fisica

Inner space / Outer space

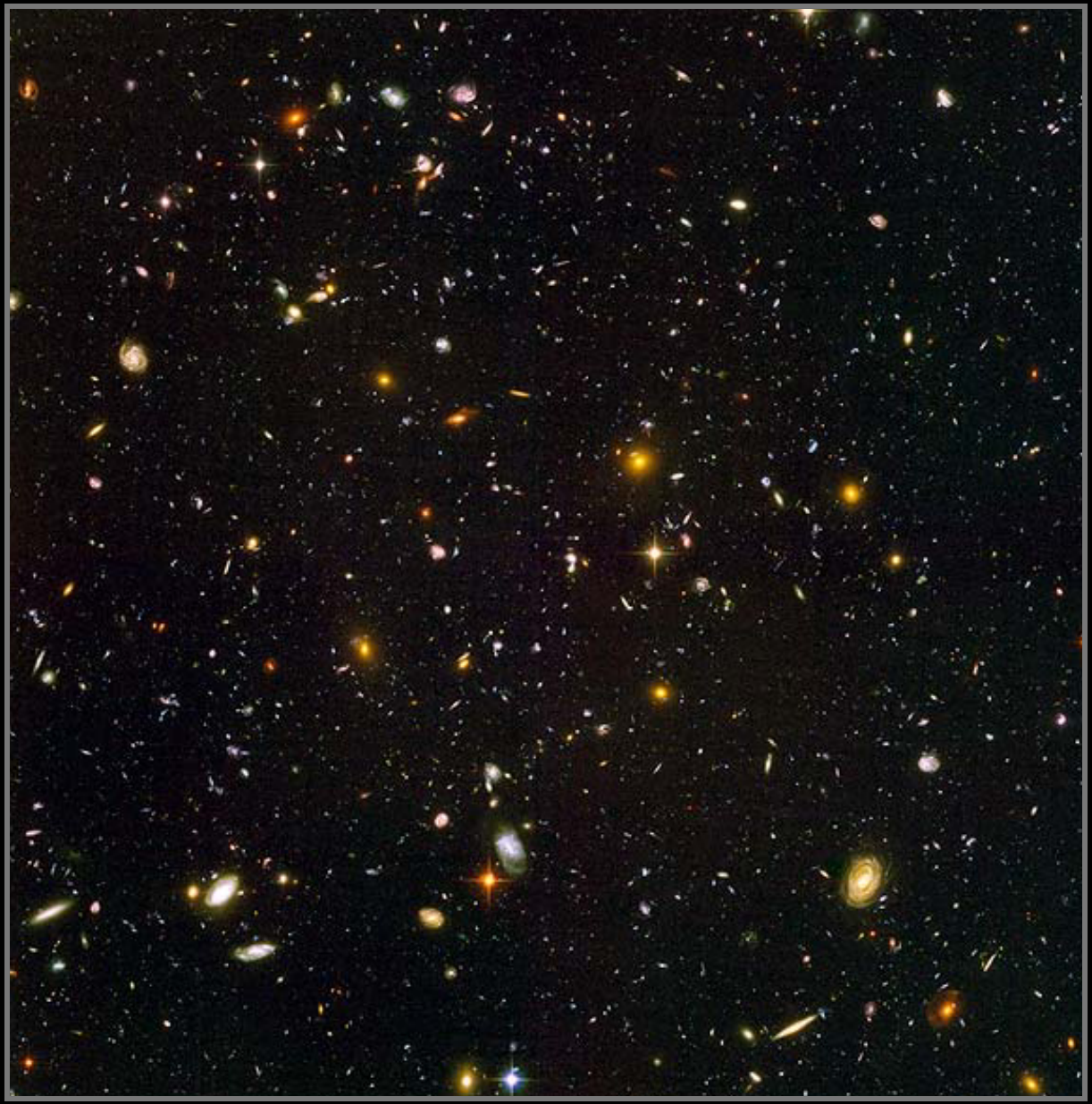


The Hubble Ultra Deep Field

UNIVERSE OF GALAXIES

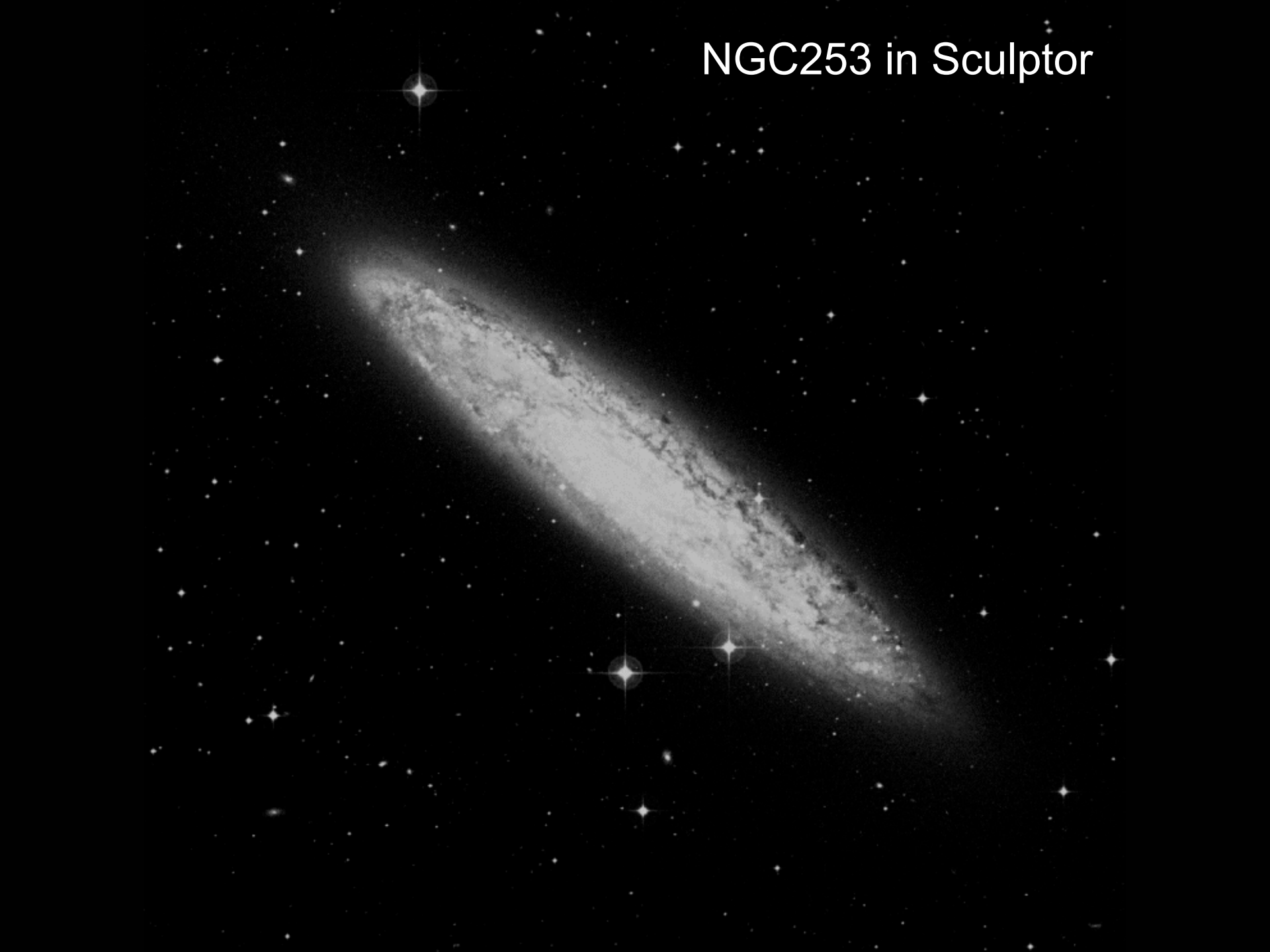
10,000 here →

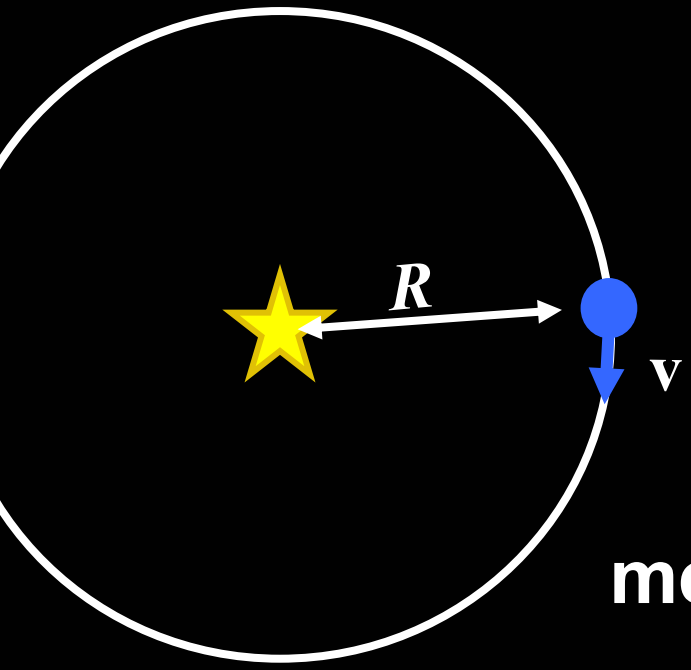
160 billion over entire sky



The visible universe

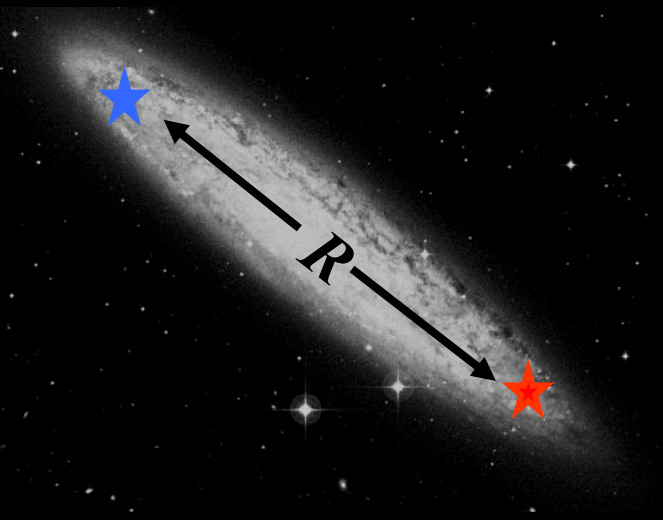
Galaxies


NGC253 in Sculptor



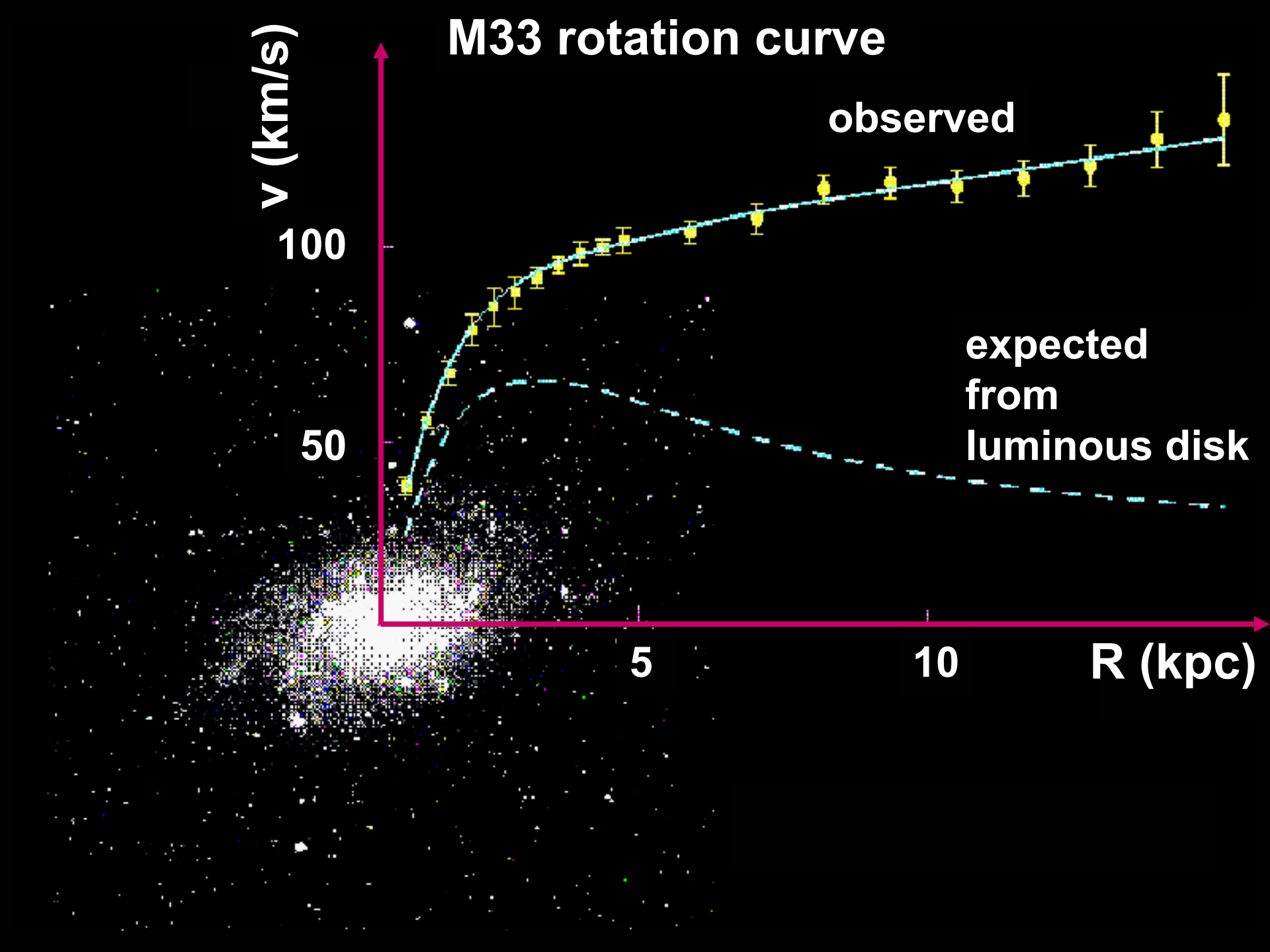
$$\frac{v^2}{R} = \frac{GM_{SUN}}{R^2}$$

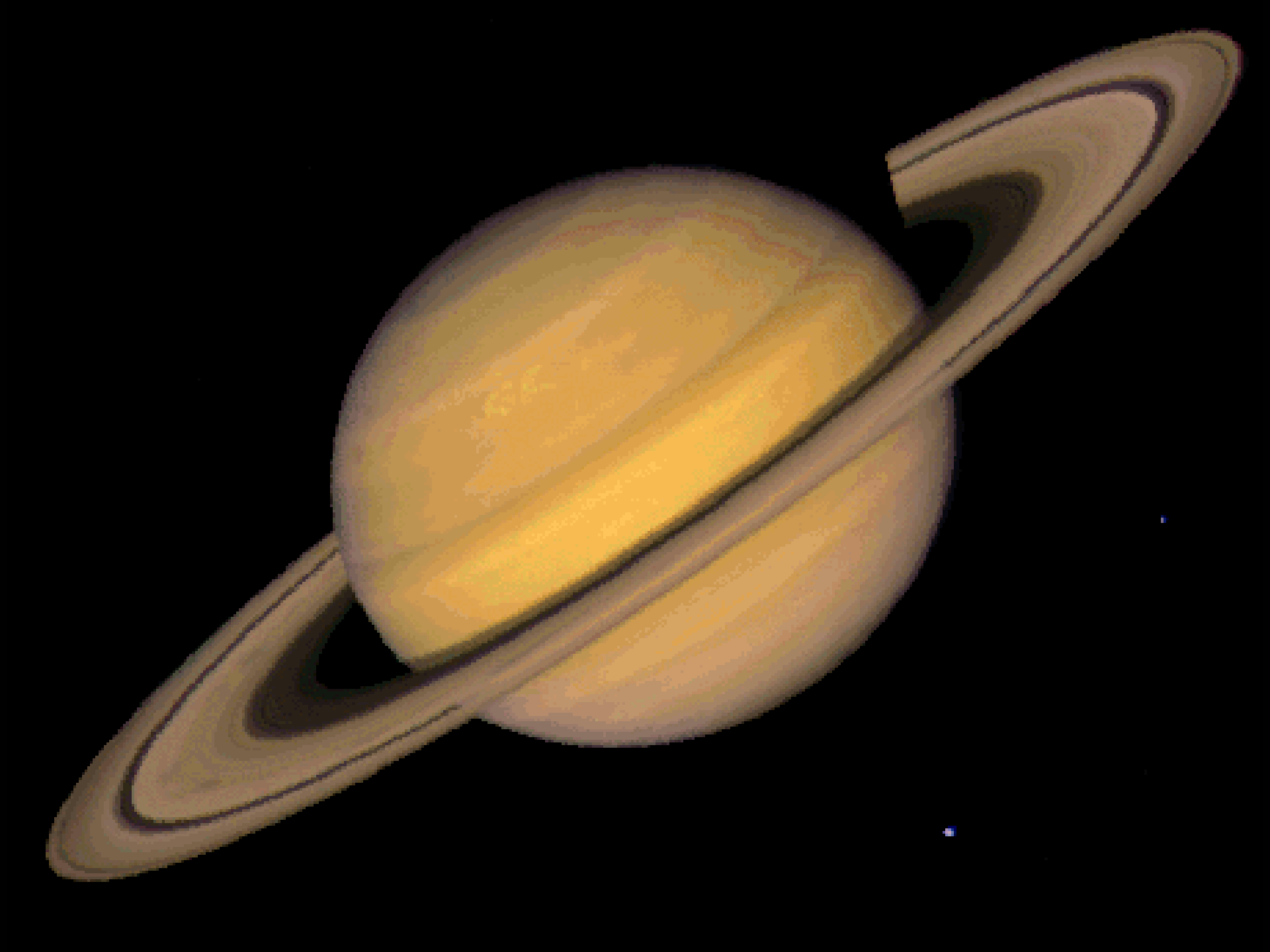
measure v & *R* → M_{SUN}

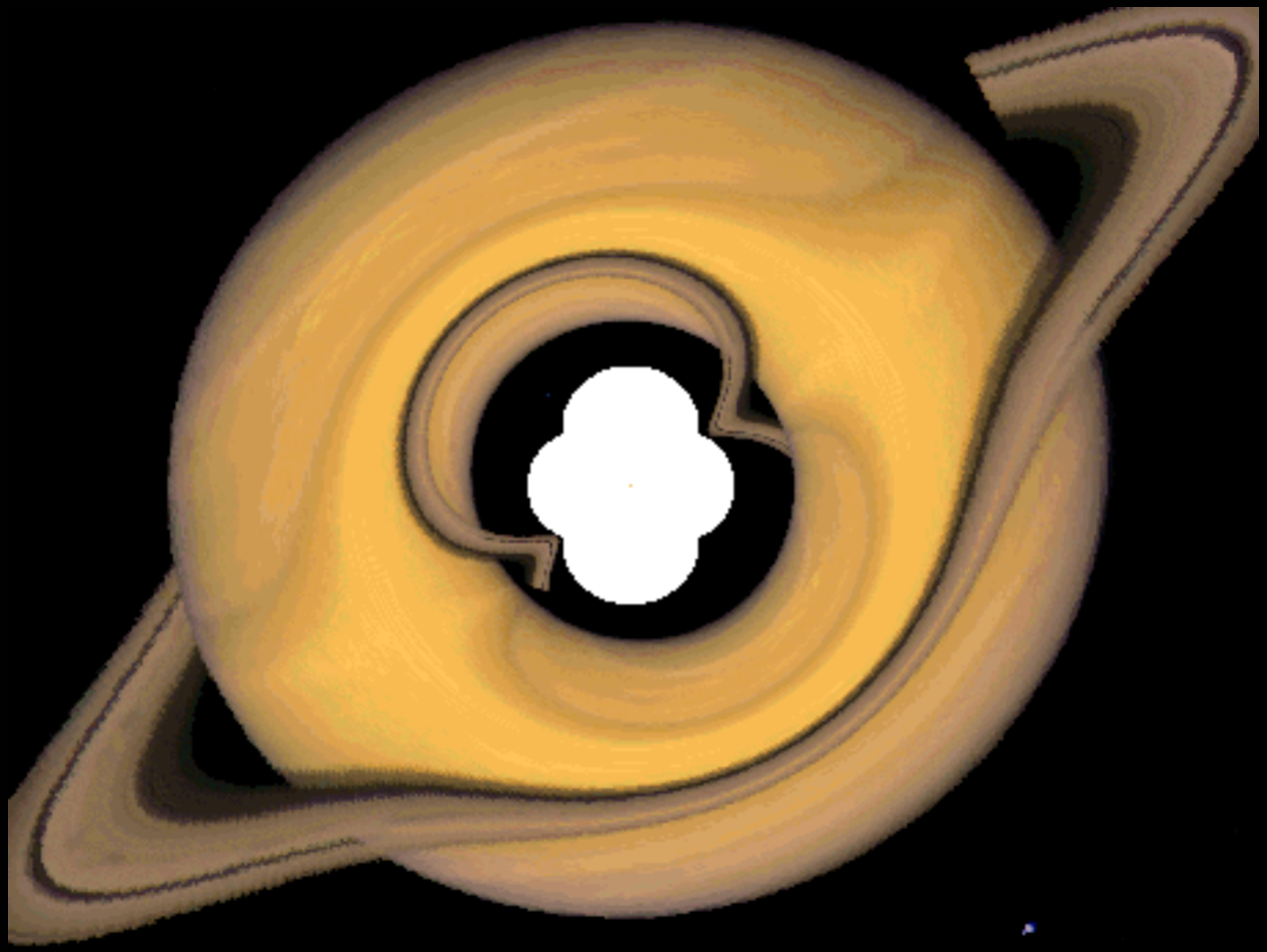


$$\frac{v^2}{R} = \frac{GM_{GALAXY}}{R^2}$$

measure v & *R* → M_{GALAXY}


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



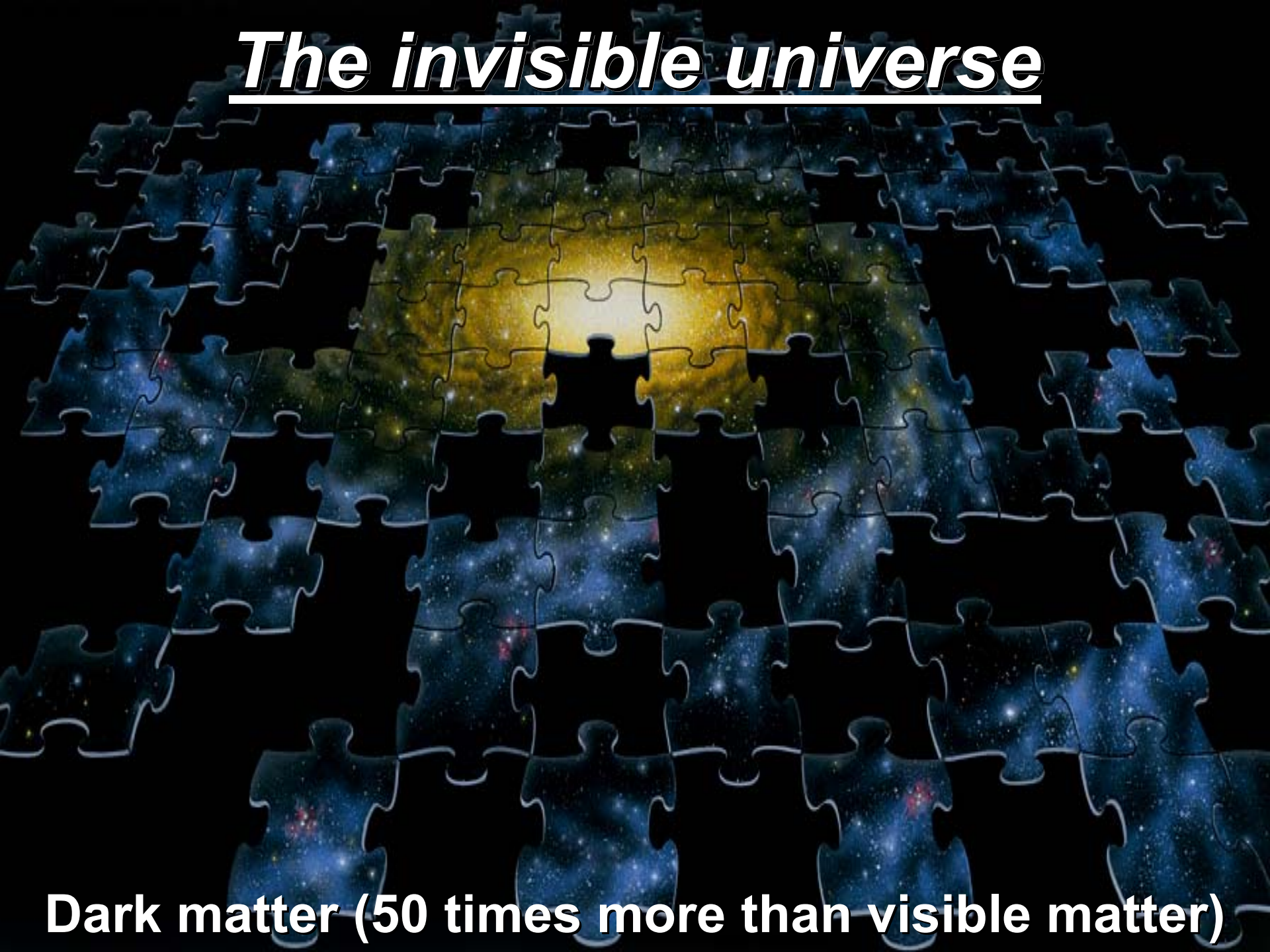


Gravitational Lens in Abell 2218 HST • WFPC2

PF95-14 • ST ScI OPO • April 5, 1995 • W. Couch (UNSW), NASA

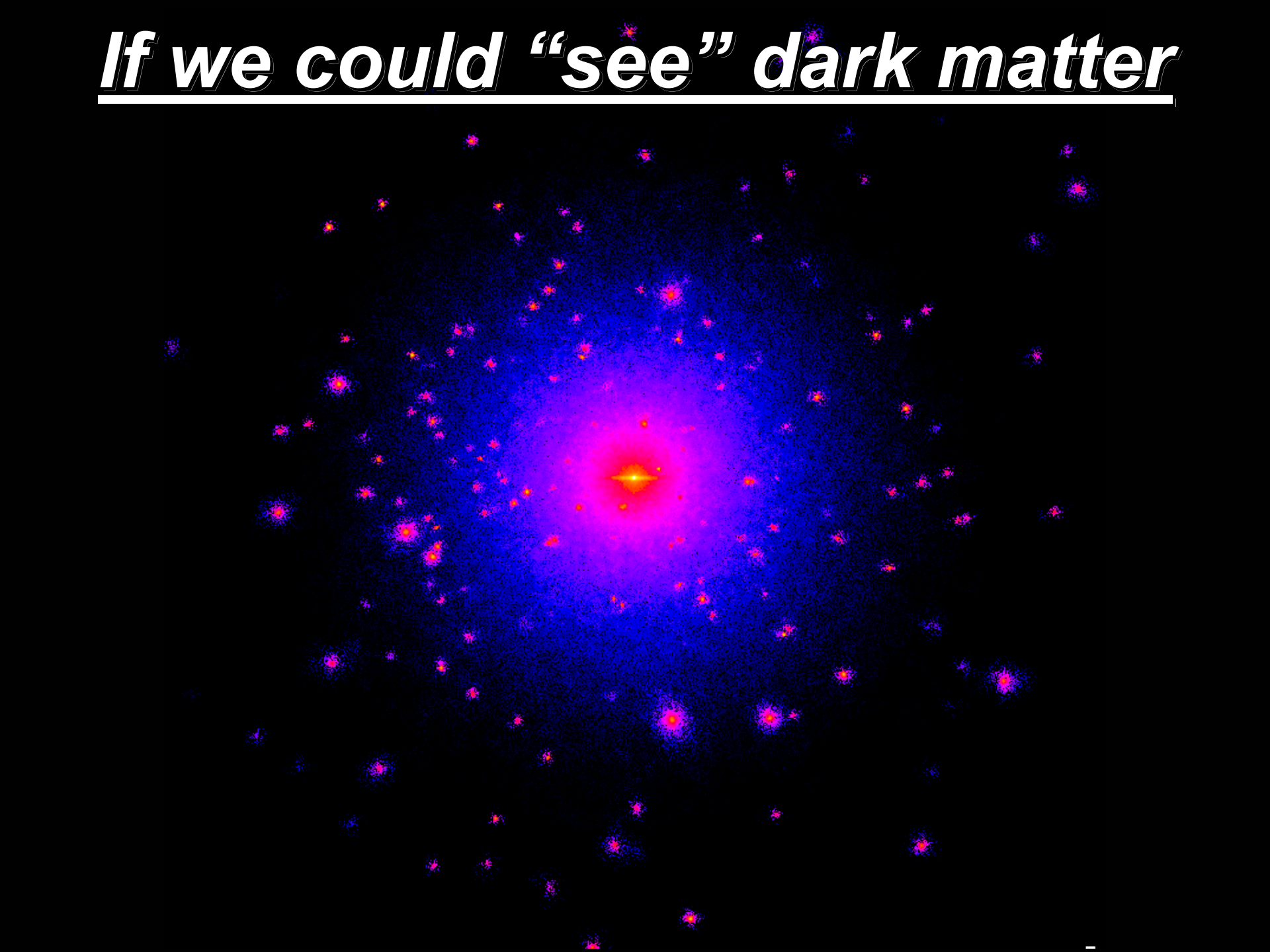
Gravitational Lens
Galaxy Cluster 0024+1654
Hubble Space Telescope • WFPC2

The invisible universe



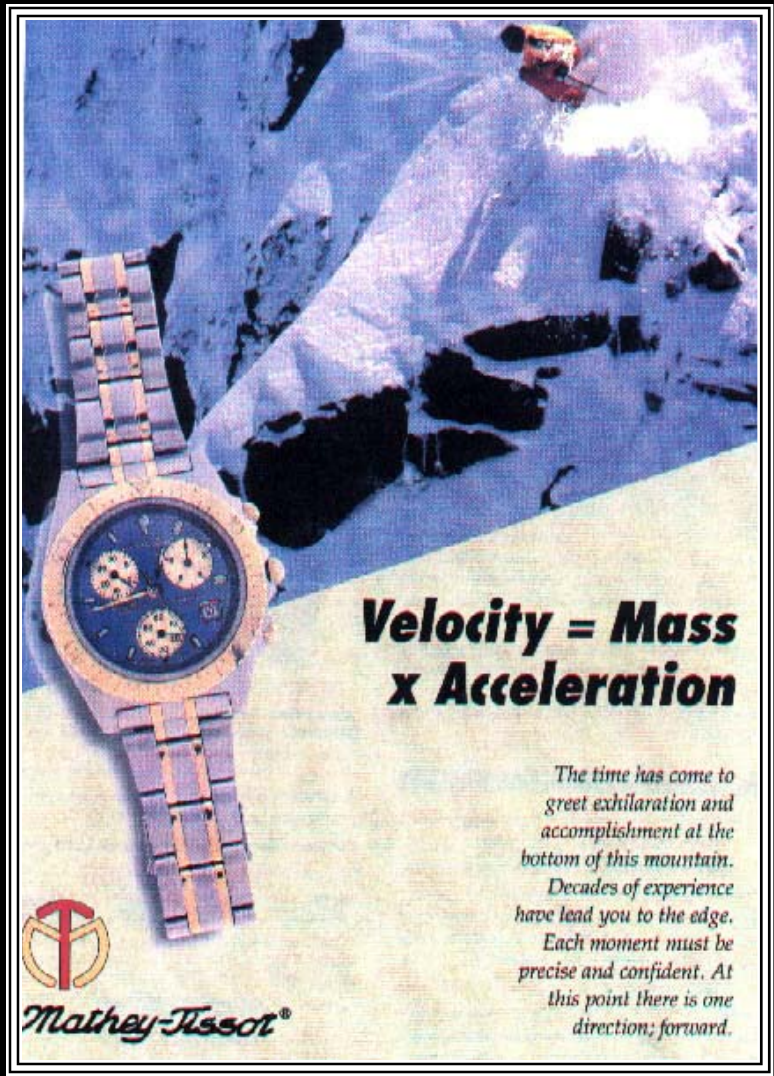
Dark matter (50 times more than visible matter)

If we could "see" dark matter



Dark matter?

- Modified Newtonian dynamics



Dark matter?

- Modified Newtonian dynamics
- Planets
- Mass disadvantaged stars

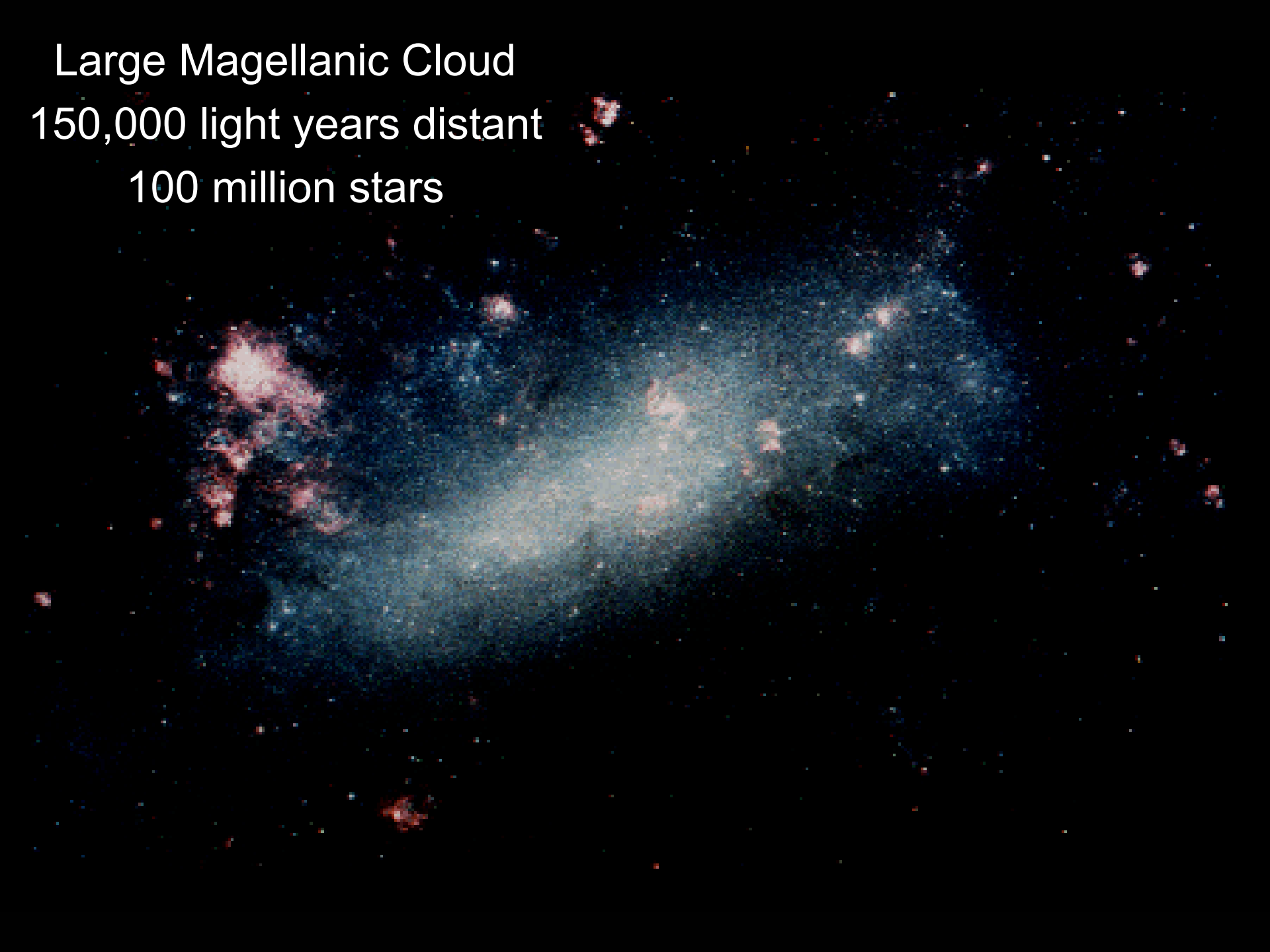
  brown red white
- Black holes

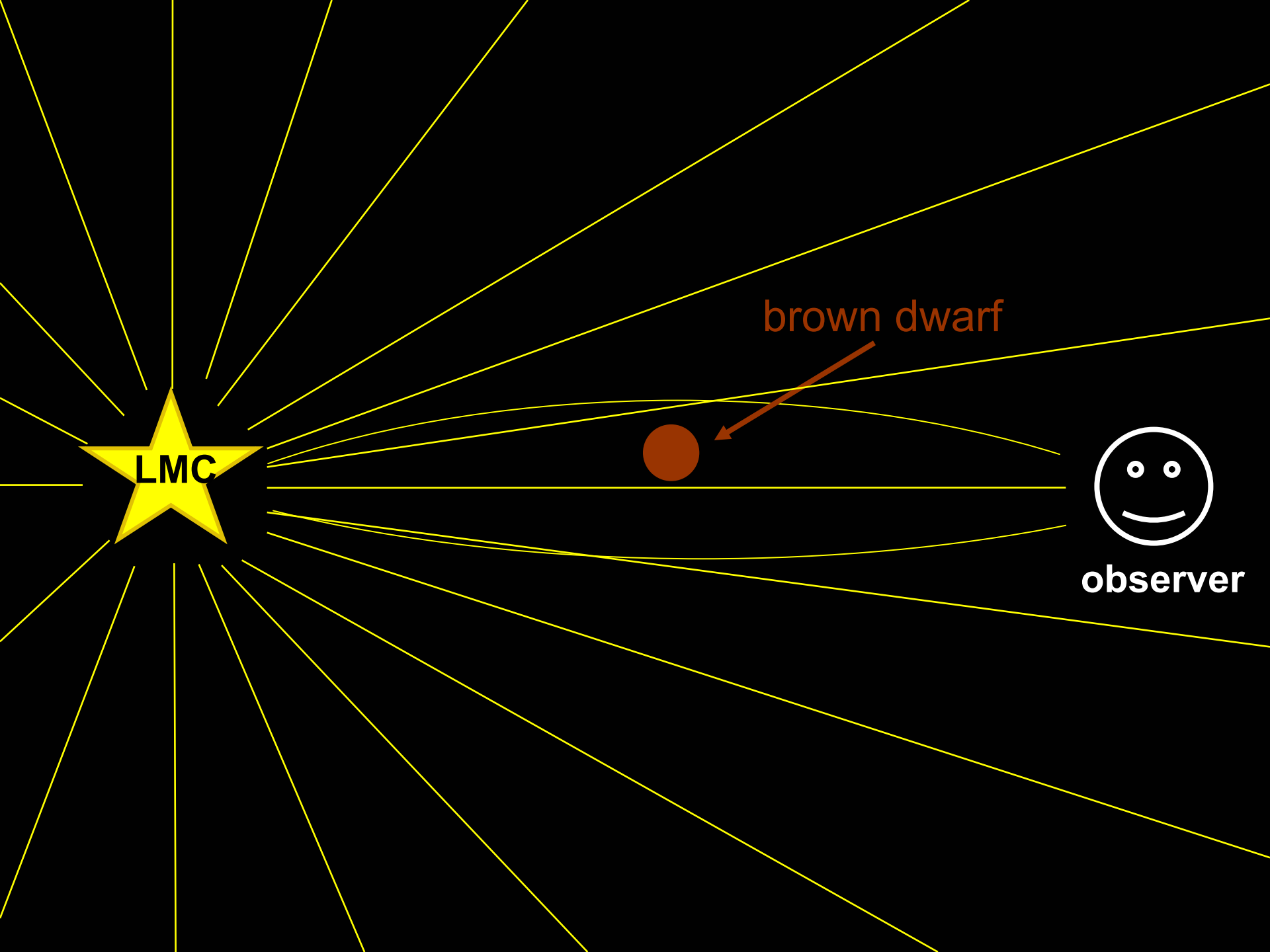
gravitational microlensing

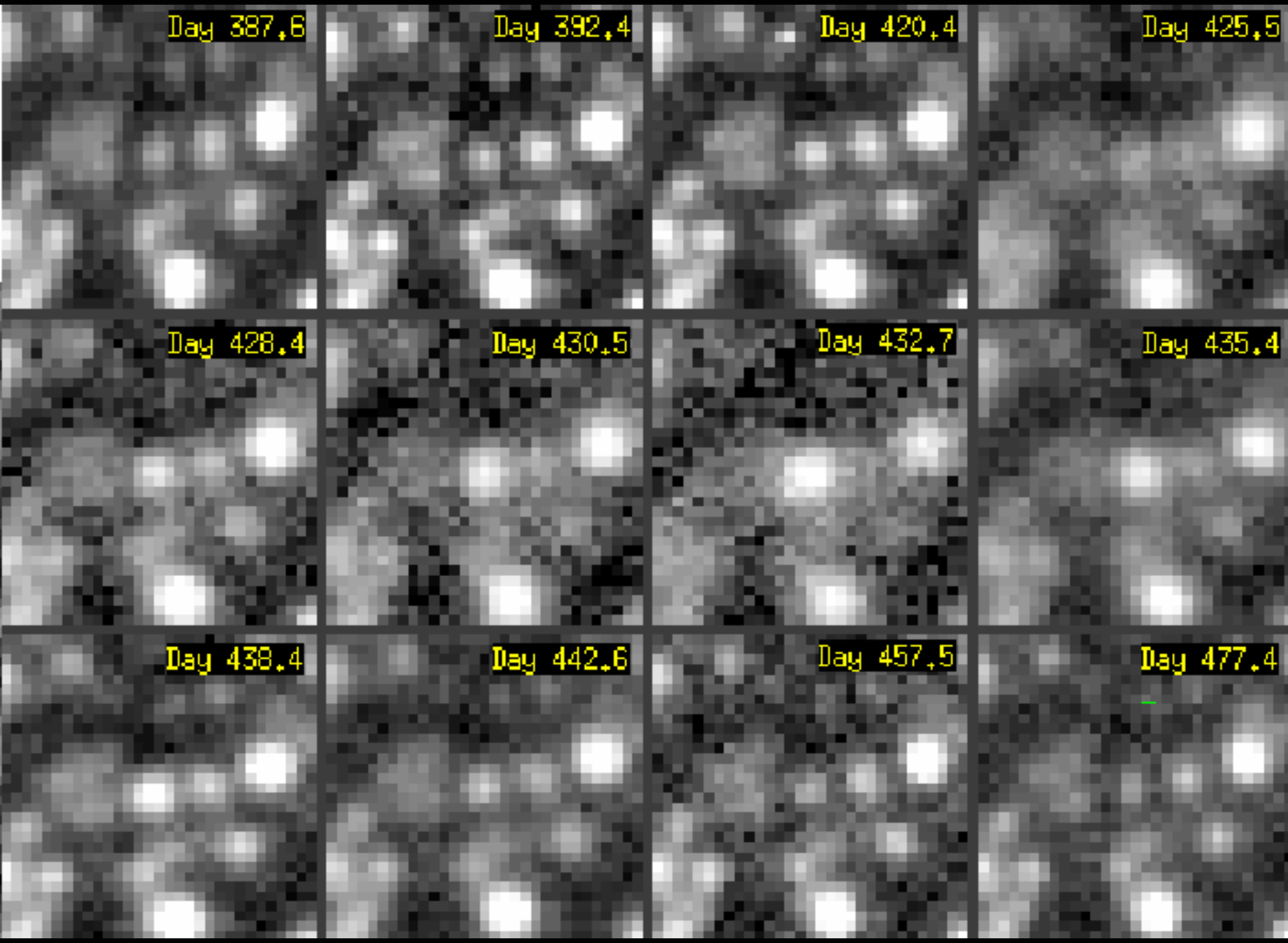
Large Magellanic Cloud

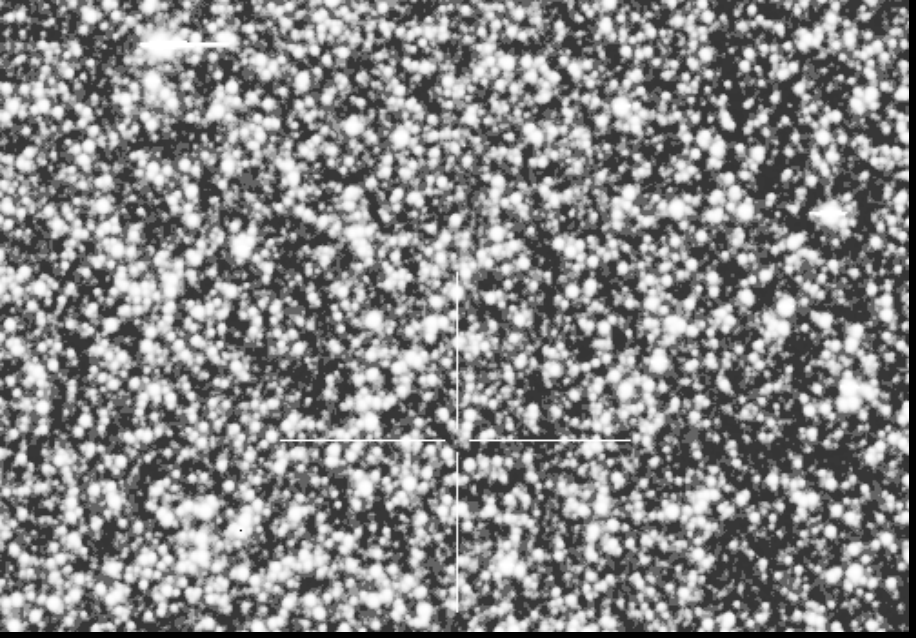
150,000 light years distant

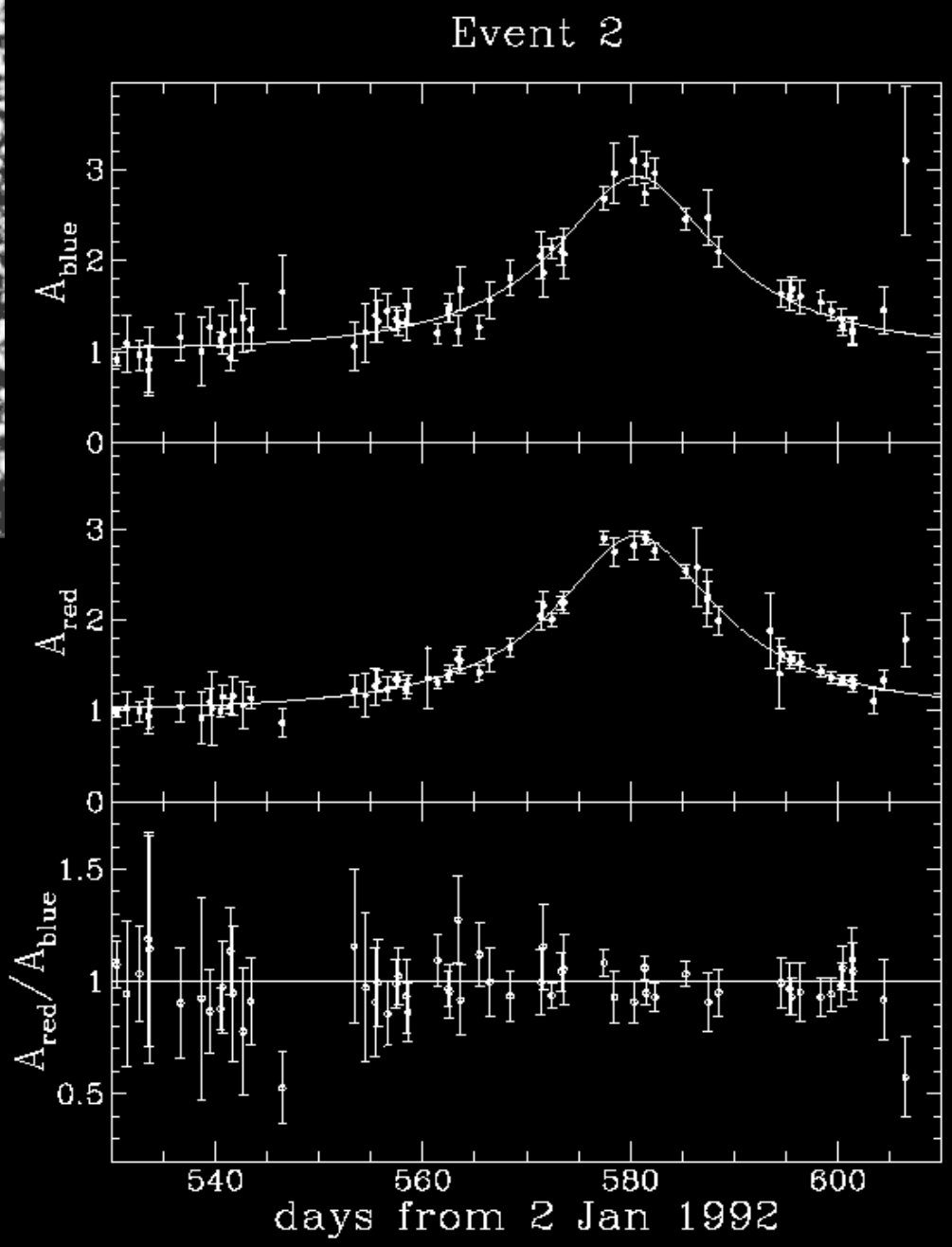
100 million stars




brown dwarf
LMC
observer


Day 387.6
Day 392.4
Day 420.4
Day 425.5
Day 428.4
Day 430.5
Day 432.7
Day 435.4
Day 438.4
Day 442.6
Day 457.5
Day 477.4



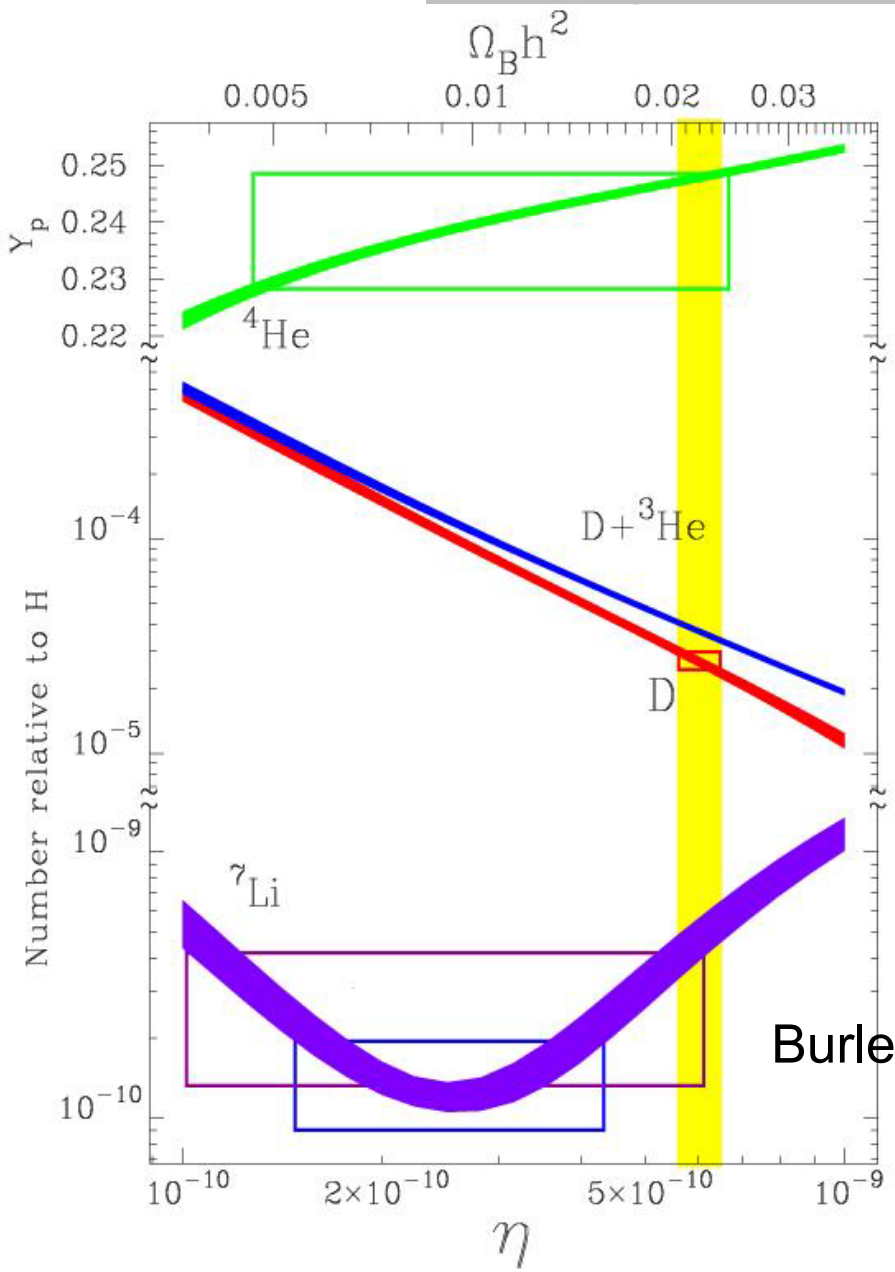

Event 2
A_{blue}
A_{red}
A_{red}/A_{blue}
0
1
2
3
0.5
1.5
540
560
580
600
days from 2 Jan 1992

Dark matter?

- Modified law of gravity
- Planets
- Mass disadvantaged stars

  brown red white
- Black holes
- Undiscovered new particle

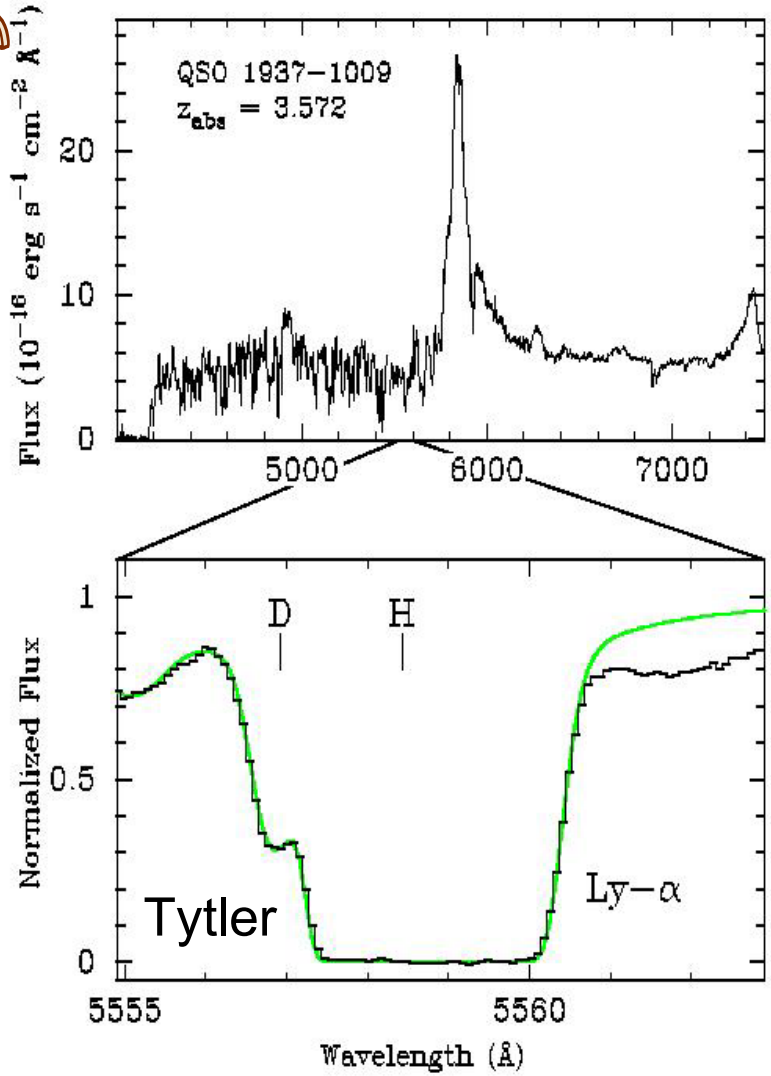
Baryons $\Omega_B h^2 \sim 0.02$



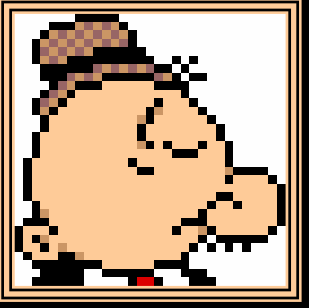
Burles et al.

Ly−α

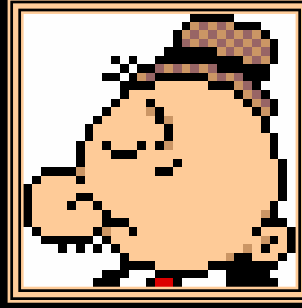
QSO 1937-1009



Tytler



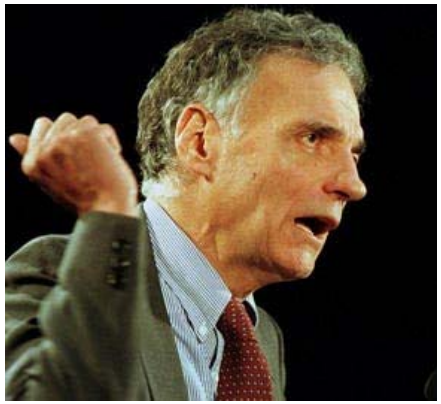
A WIMPY IDEA



- Most of the universe is *invisible*
- Dominated by the rest mass of an elementary particle
  - present in the primordial soup
  - massive
  - neutral
  - weakly interacting
  - slow
  - stable

WIMP

WIMPY candidates



Ralph Nadar

- neutrinos
- sterile neutrinos, gravitinos
- LSP (neutralino, axino, …)
- LKP (lightest Kaluza-Klein particle)
- axions, axion clusters
- solitons (Q-balls; B-balls; Odd-balls, Screw-balls….)
- supermassive wimpzillas

Mass range	
$10^{-6}\,\mathrm{eV}$ $(10^{-40}\,\mathrm{g})$	axions
$10^{-8}\,\mathrm{M}_{\odot}$ $(10^{25}\,\mathrm{g})$	axion clusters

Interaction strength range
Noninteracting: wimpzillas
Strongly interacting: B balls

Dark energy?

Space and time are related.

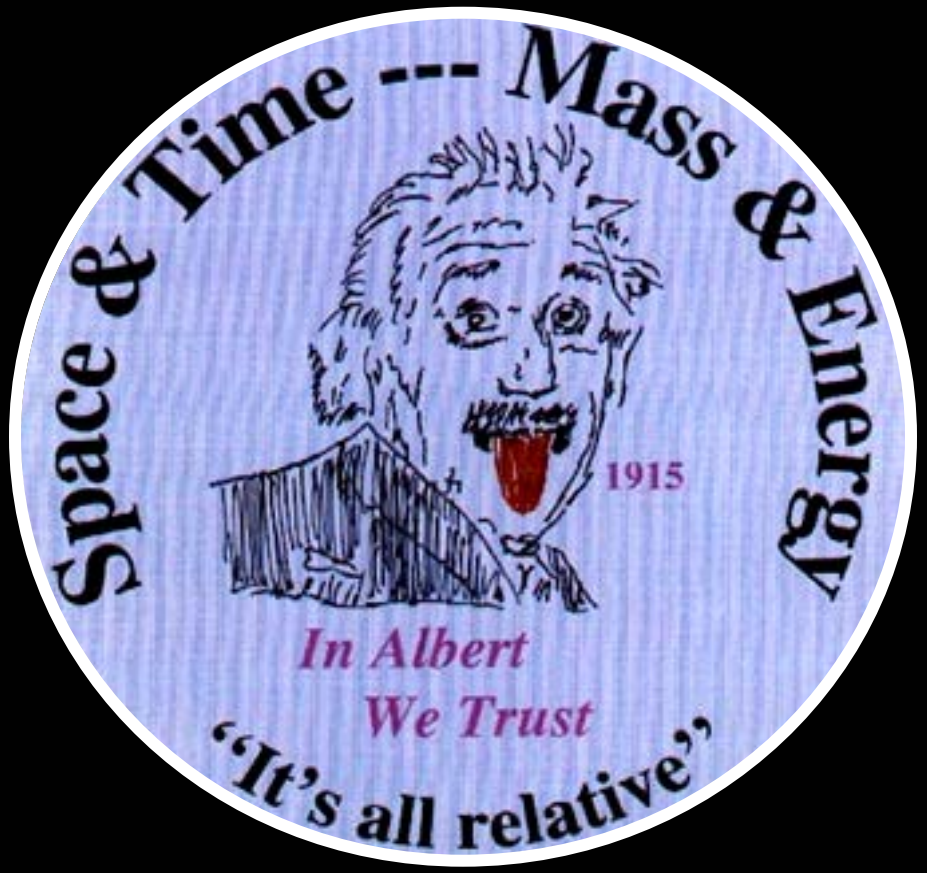
1905

Space is dynamical (curved, warped, bent).

1915

Empty space has a weight.

1917



the weight of space

Cosmological constant

(dark energy)

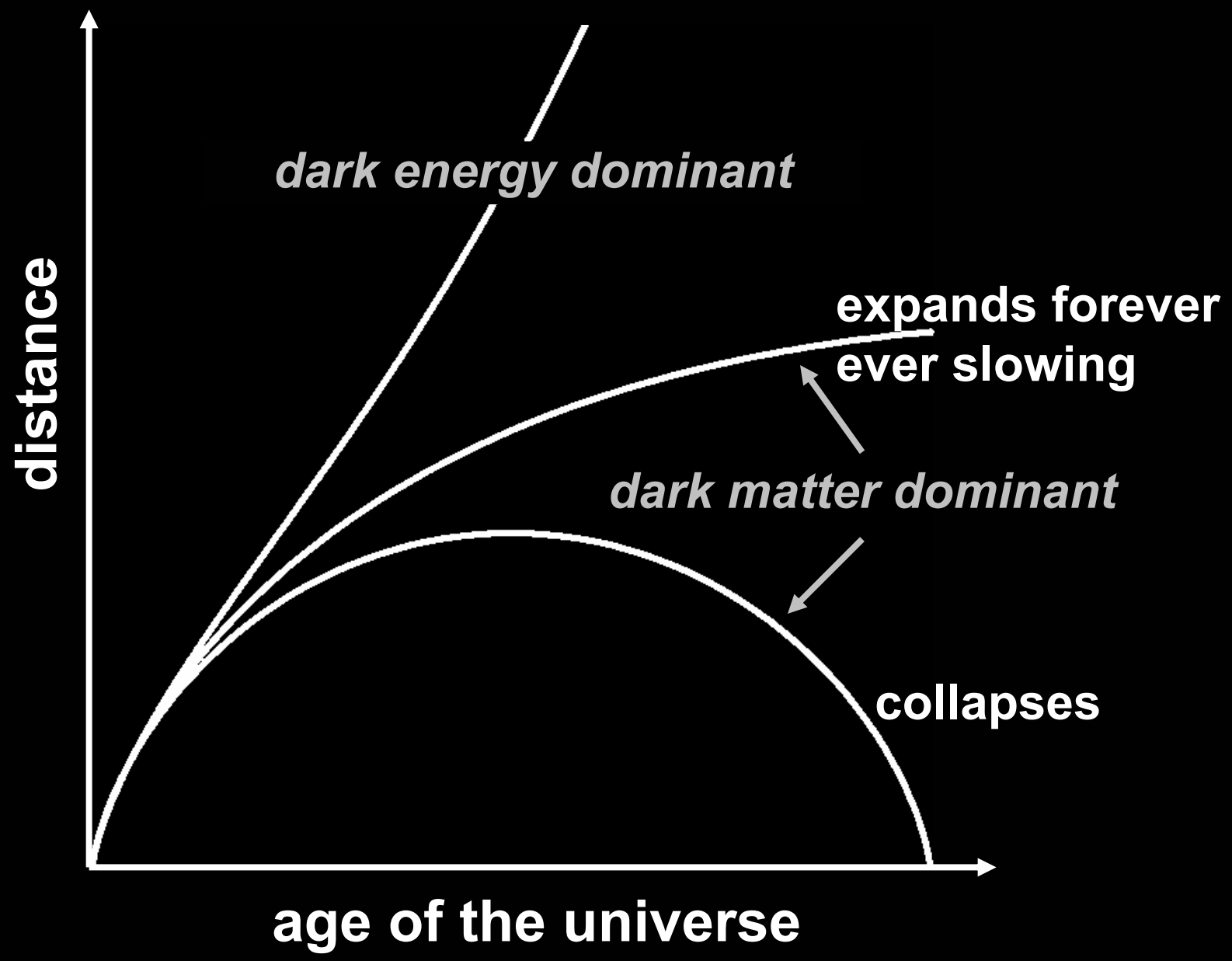
1917 Einstein proposed cosmological constant.

1929 Hubble discovered expansion of the universe.

1934 Einstein called it "my biggest blunder."

1998 Astronomers found evidence for it.

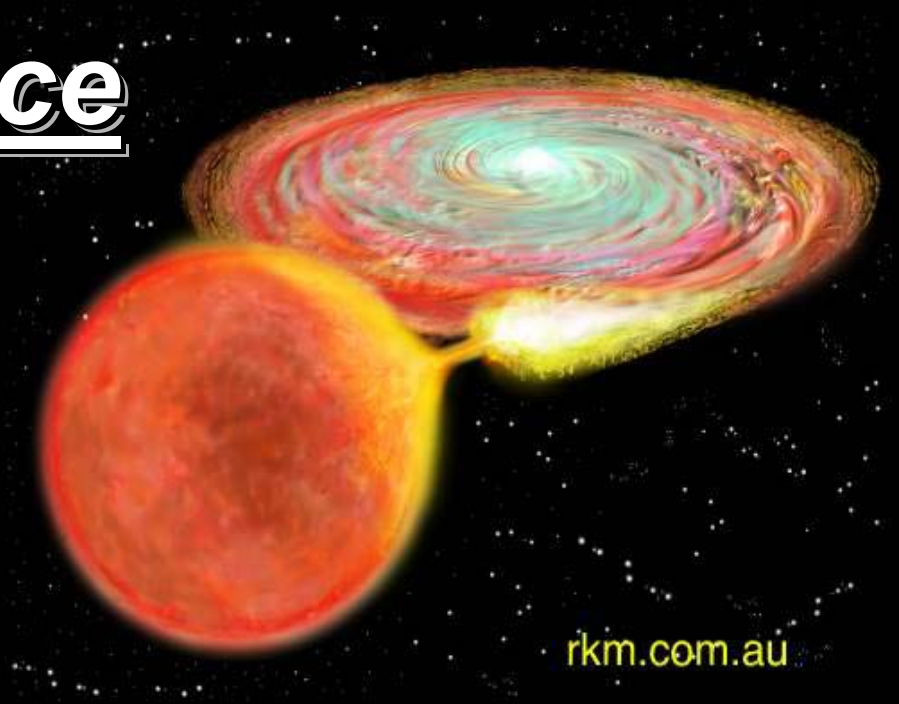
Cosmological constant (dark energy)



SN 1987A in the LMC

The weight of space

Supernovae



Cosmological constant (dark energy)

Mass density of space: $10^{-30}\,\mathrm{g\ cm^{-3}}$

The unbearable lightness of nothing!

Cosmo-illogical constant?

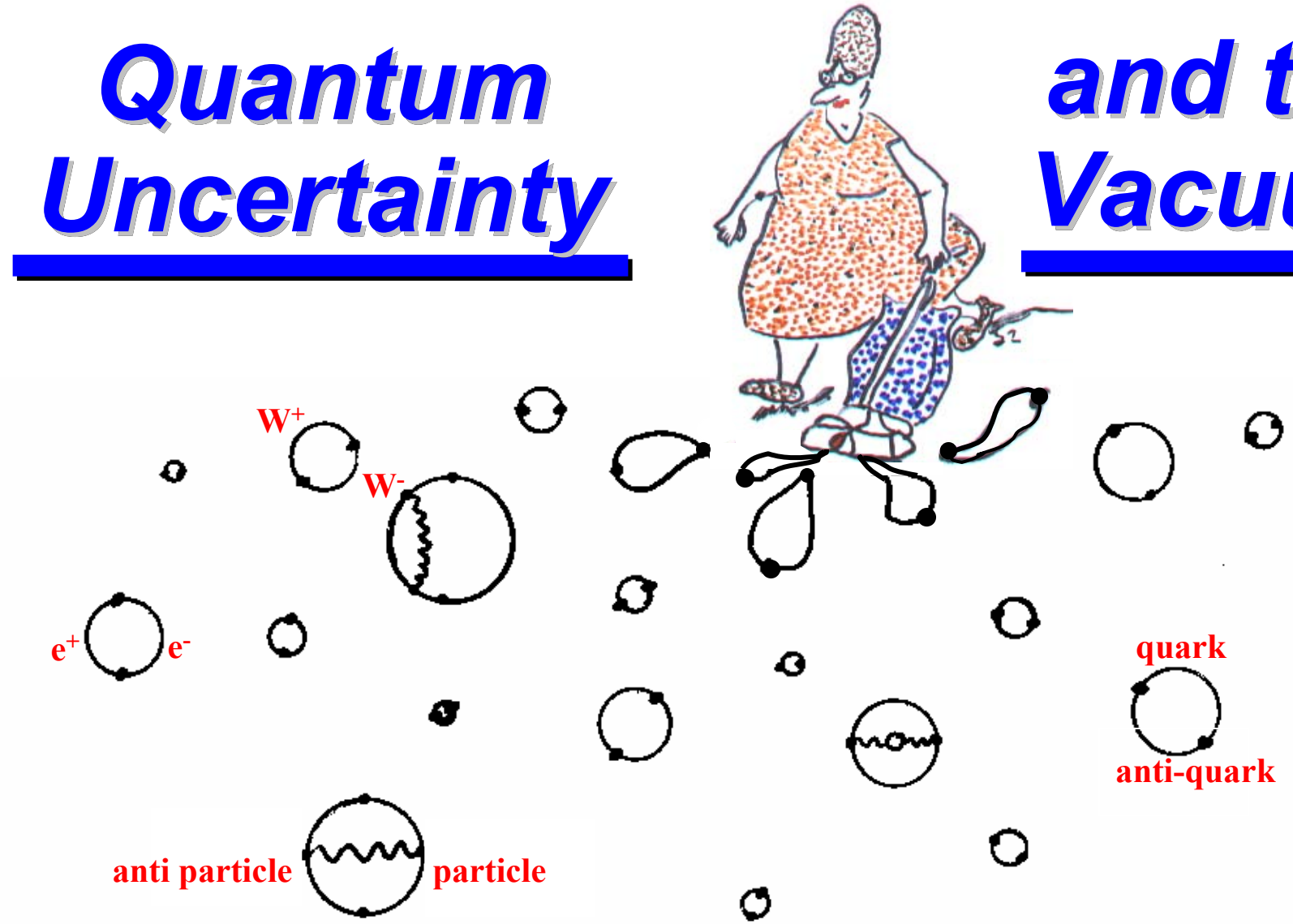
Much ado about nothing (the vacuum)

NOTHING is something!

NOTHING has energy!

NOTHING matters!

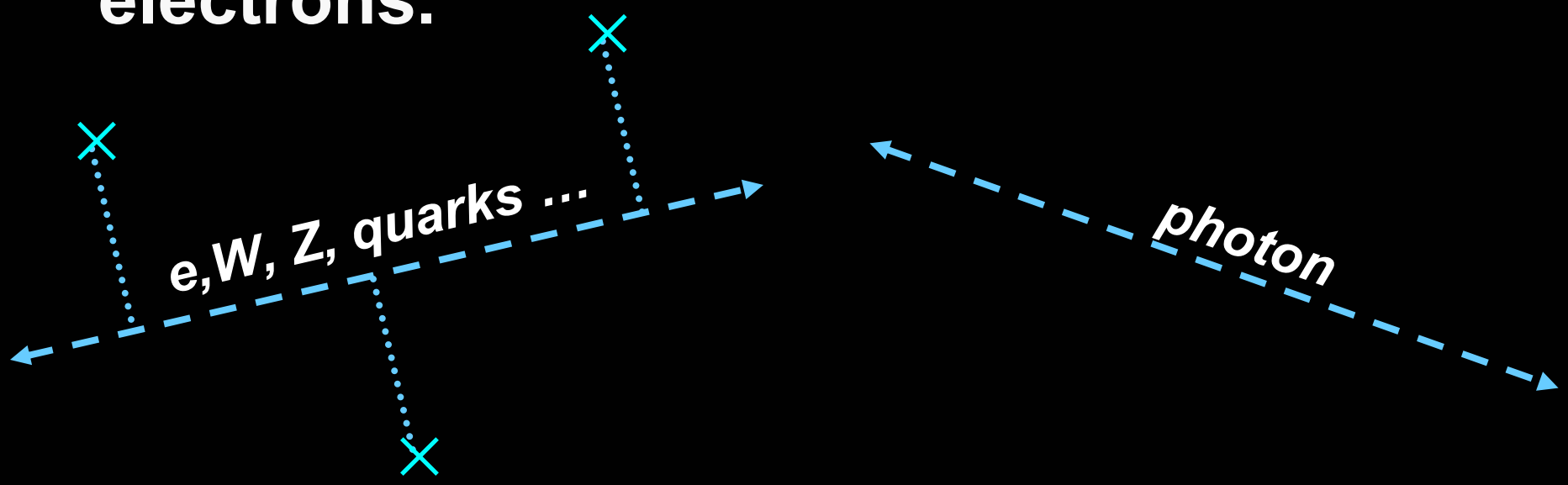
Quantum Uncertainty and the Vacuum



Nothing is something!

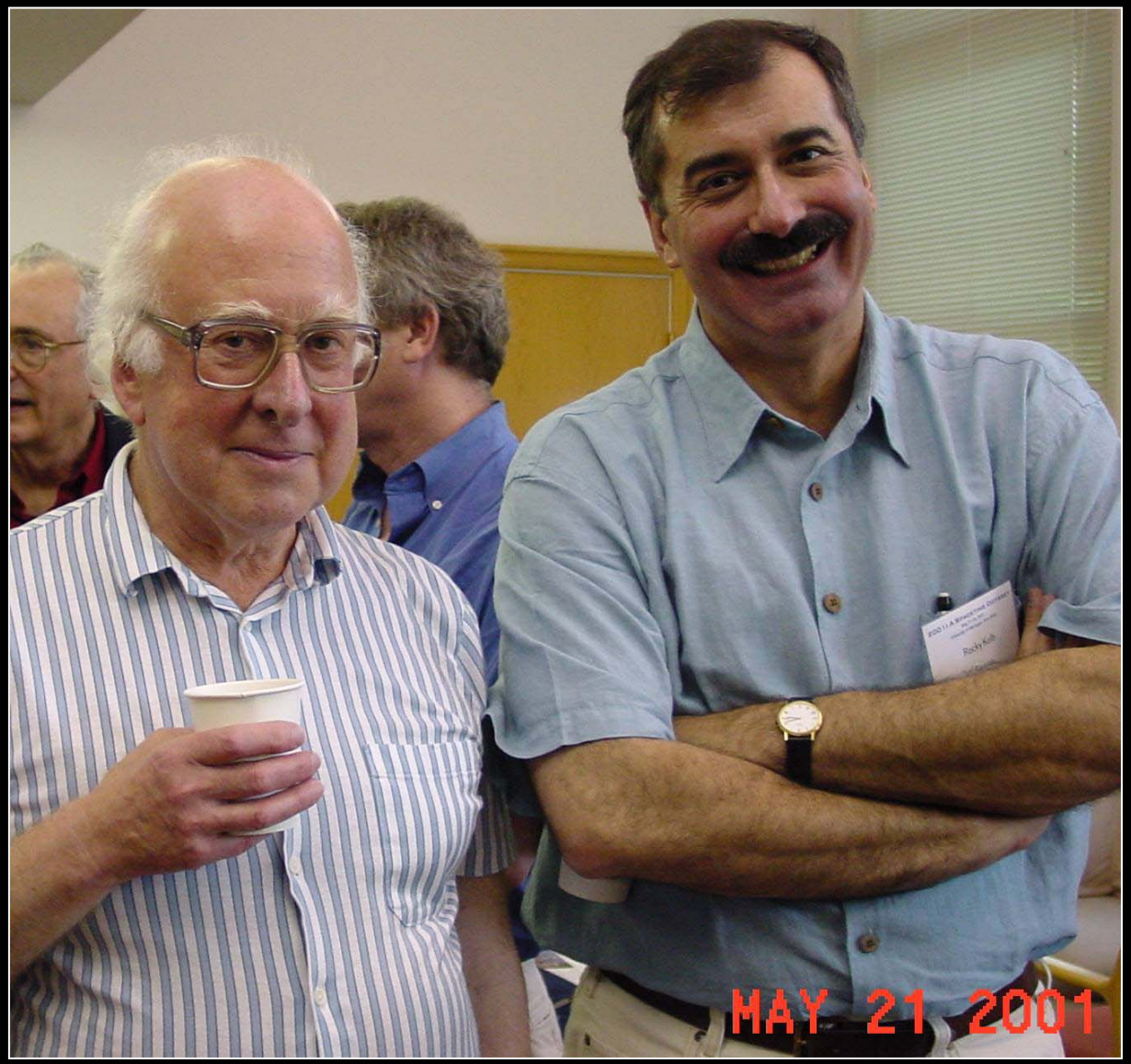
The Higgs potential

- The vacuum has a “Higgs potential”
- Interaction with the Higgs field potential gives mass to particles like quarks and electrons.

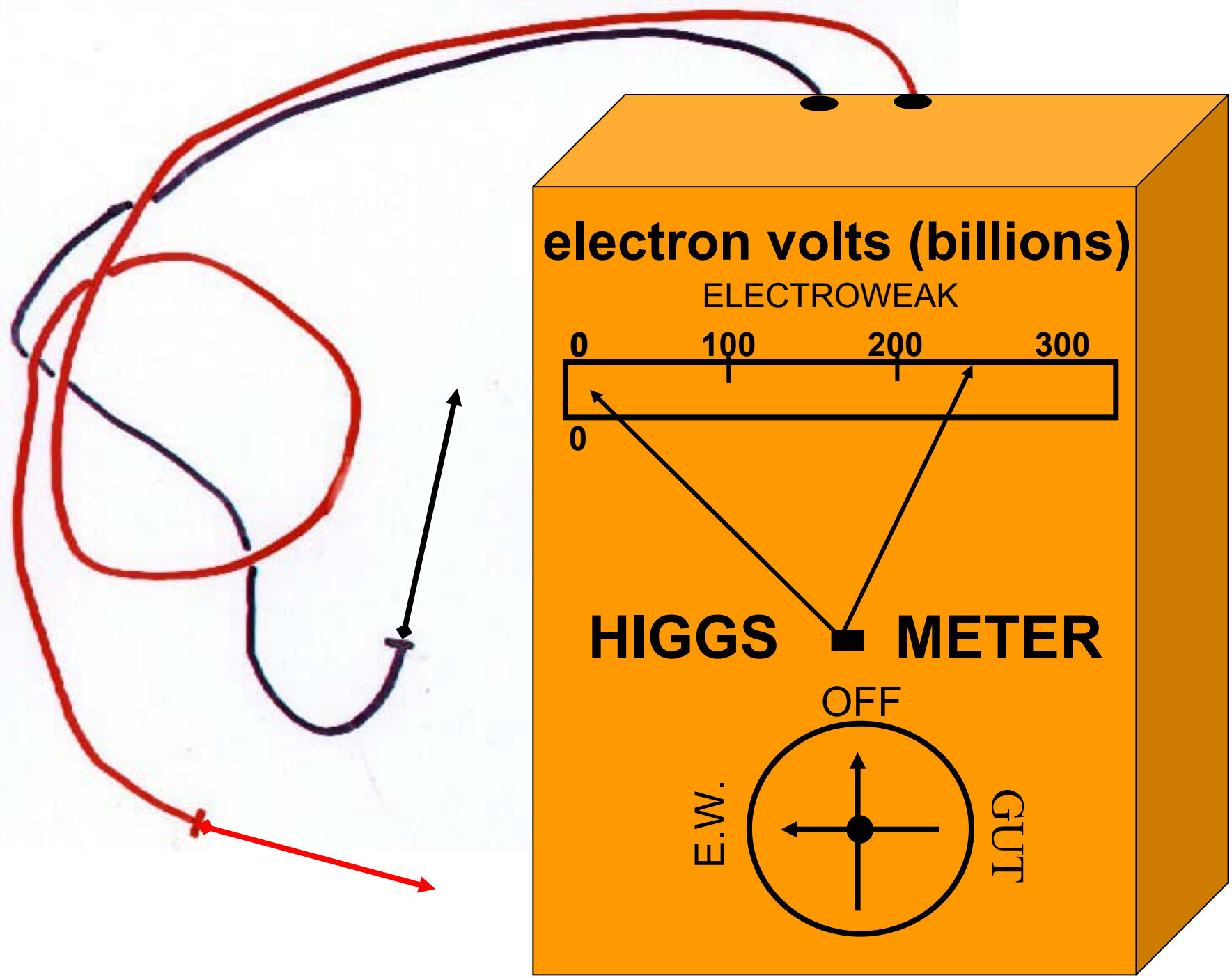


Nothing has energy:

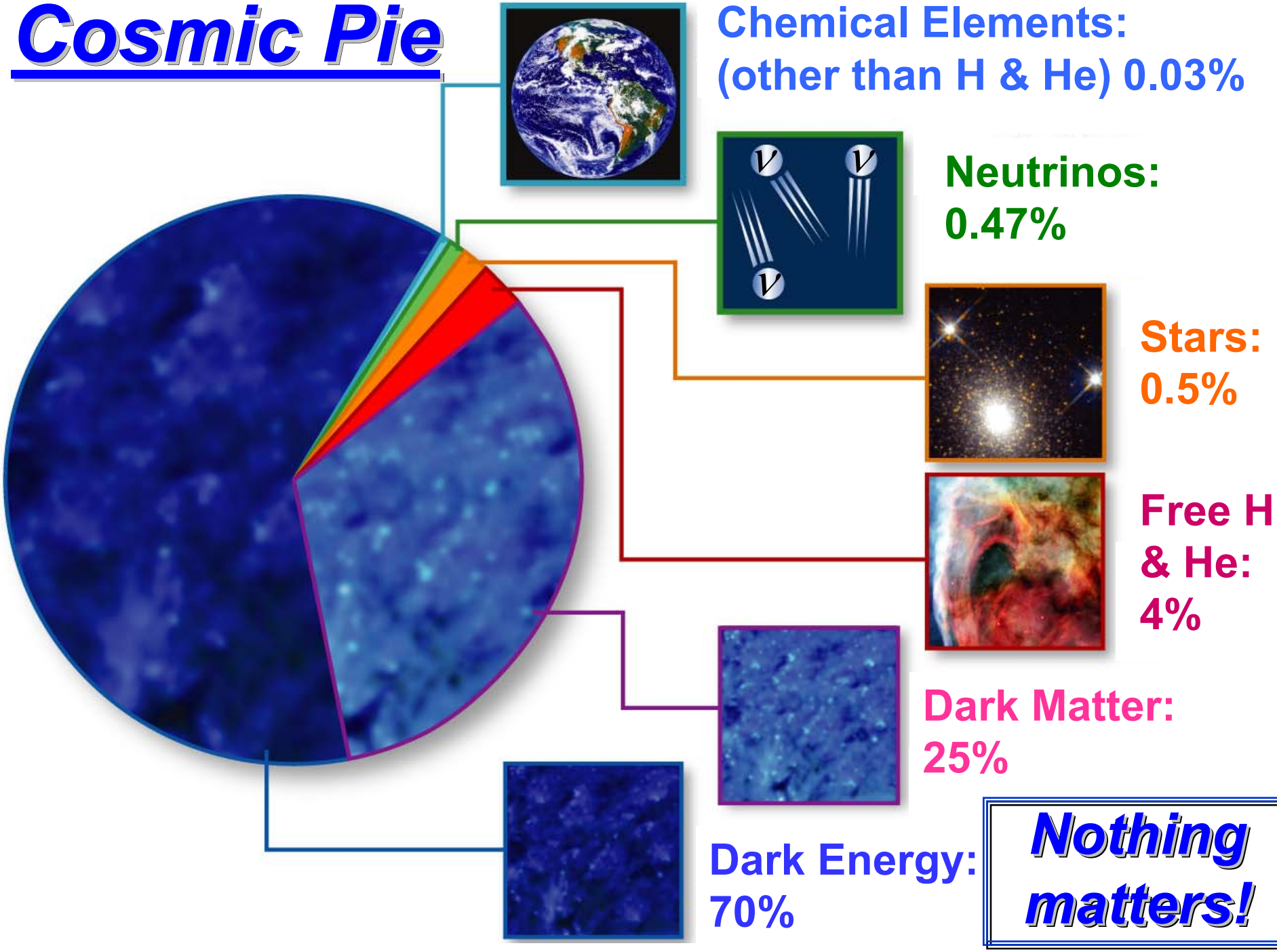
Rocky discovers Higgs!



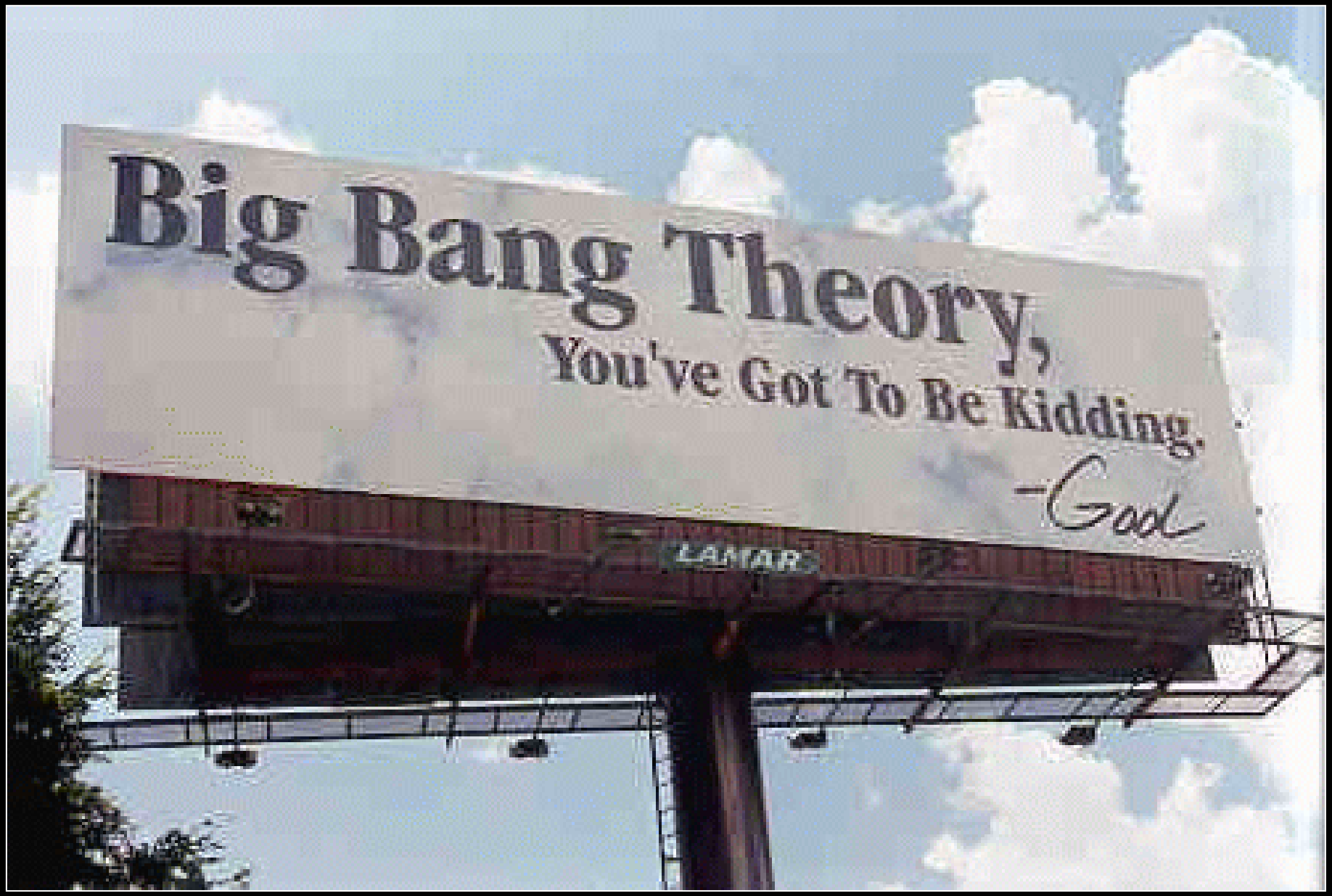
Prof. Peter Higgs


electron volts (billions)
ELECTROWEAK
0
100
200
300
0
HIGGS METER
OFF
E.W.
GUT

Cosmic Pie


Chemical Elements:
(other than H & He) 0.03%
Neutrinos:
0.47%
Stars:
0.5%
Free H
& He:
4%
Dark Matter:
25%
Dark Energy:
70%
Nothing
matters!

Origin



Space expands.

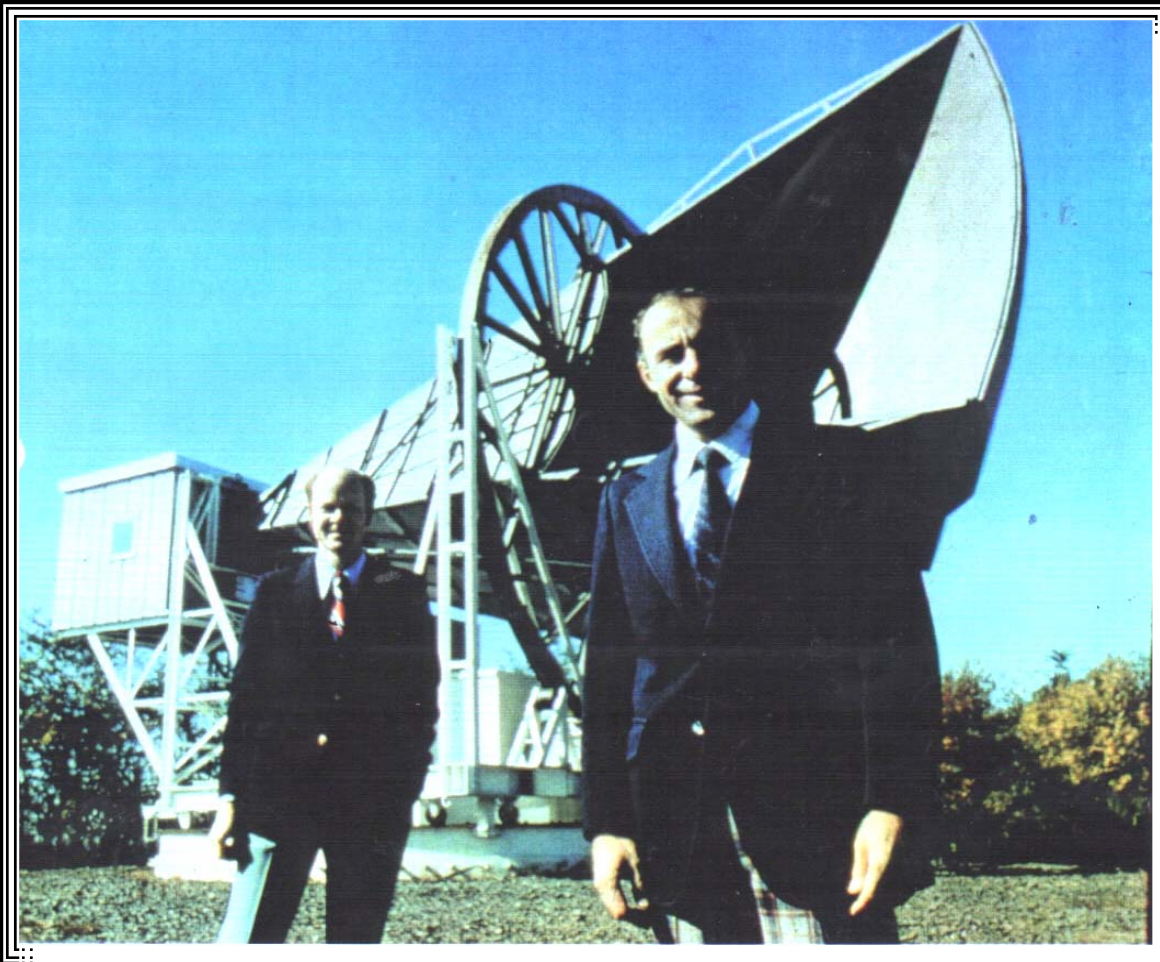
Edwin Hubble
1929

The University of Chicago

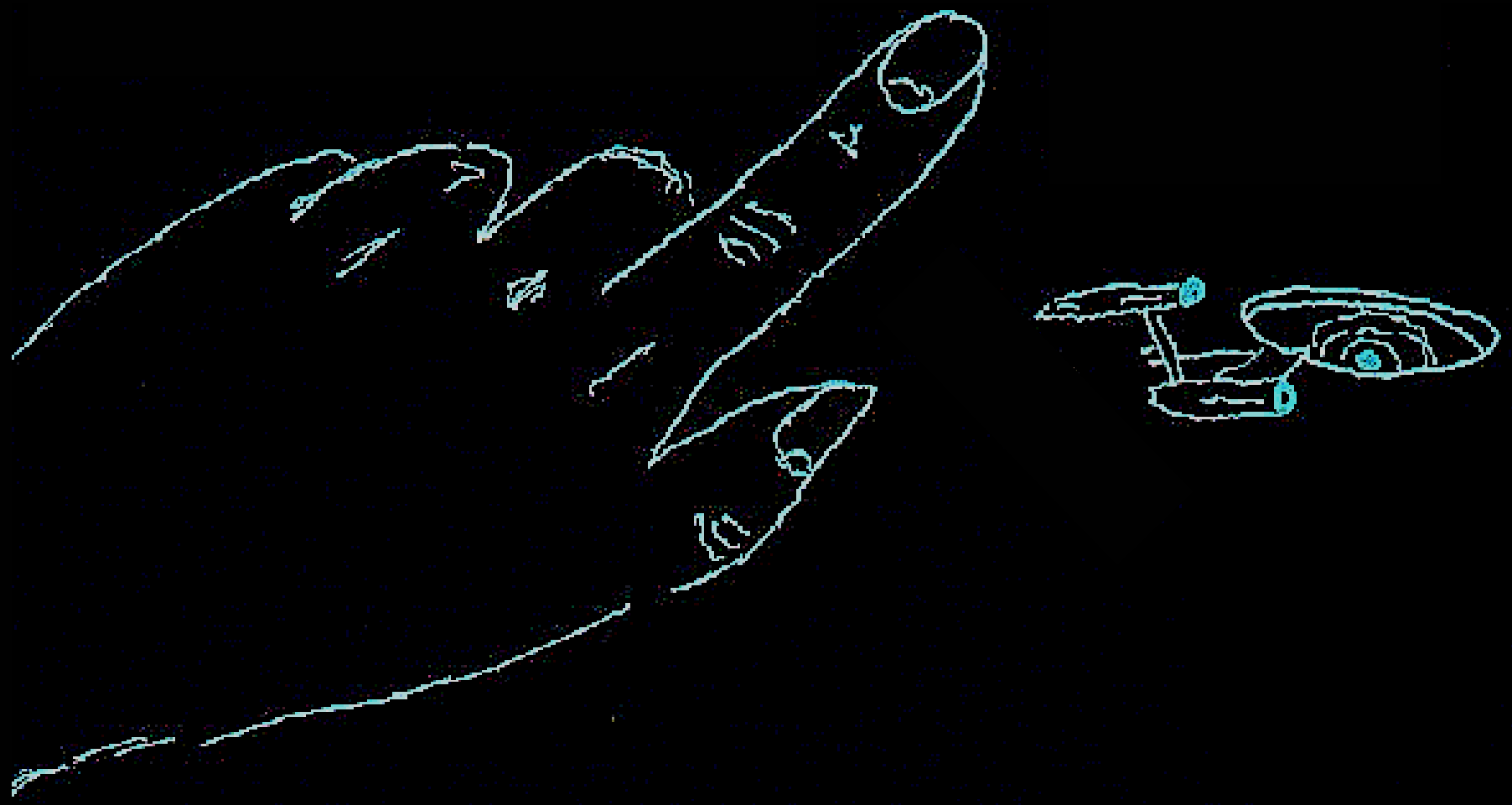
1909 National Champions

The universe
is radiant.

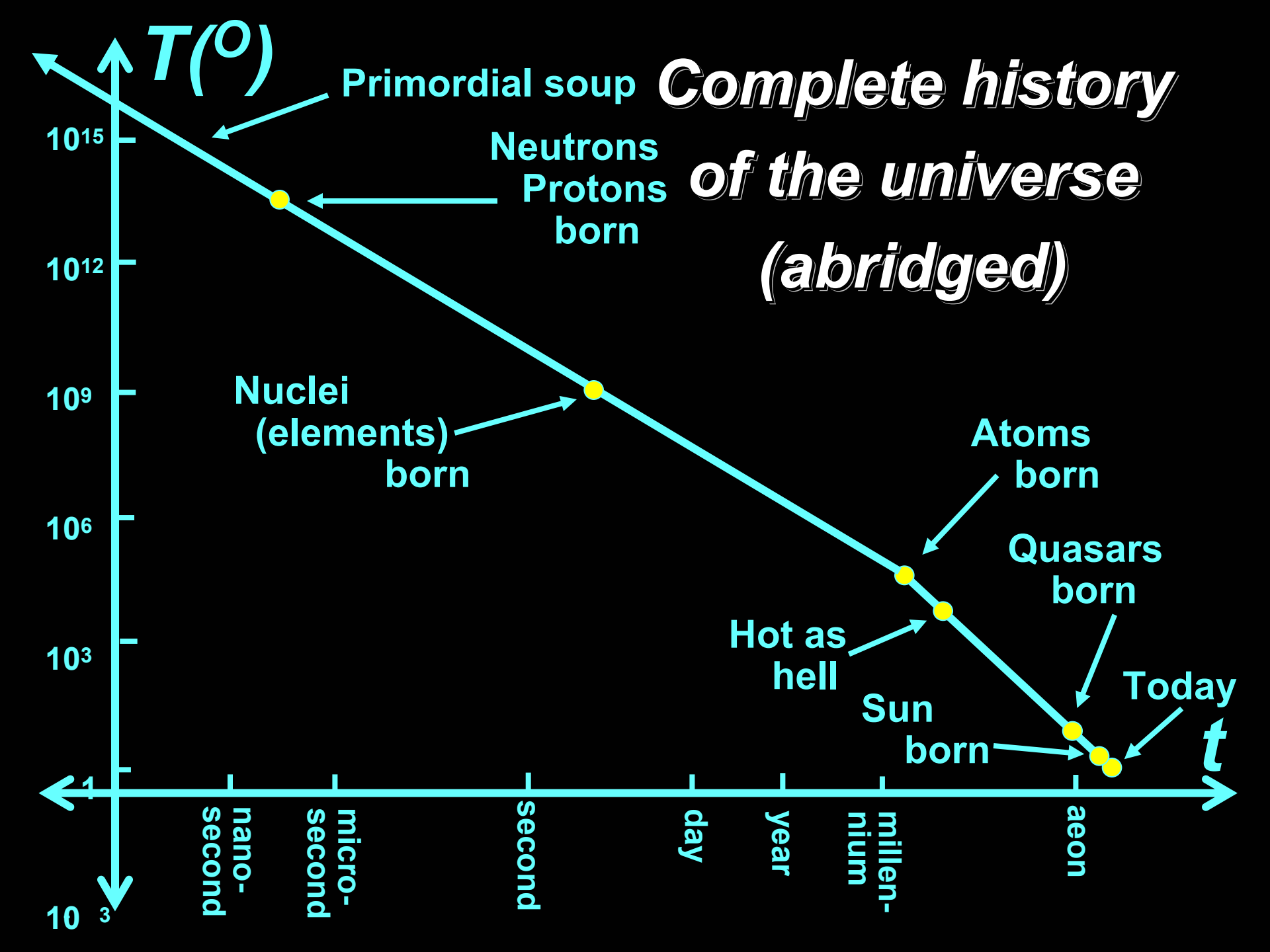
Arno Penzias
Robert Wilson
1965



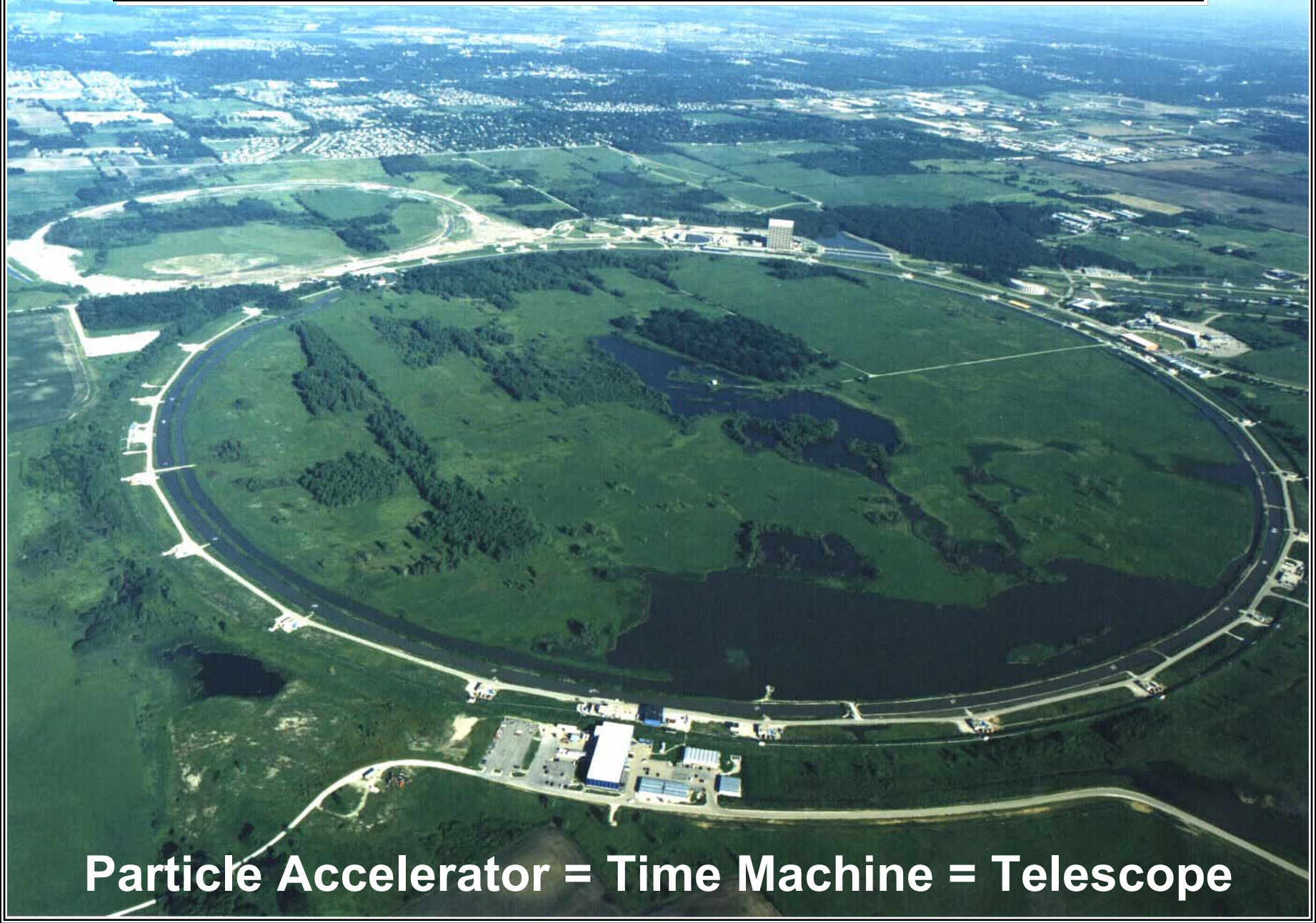
Cosmic background radiation



$$T \equiv 3K \equiv -454^{o}\ F$$


Complete history of the universe (abridged)
T(°)
Primordial soup
Neutrons Protons born
Nuclei (elements) born
Atoms born
Quasars born
Hot as hell
Sun born
Today
t
10^15
10^12
10^9
10^6
10^3
1
10^-3
nano-second
micro-second
second
day
year
millen-nium
aeon

Inner Space - The Quantum



Particle Accelerator = Time Machine = Telescope

Fermilab
Primordial
SOUP

Primordial soup

0.000 000 000 004 seconds AB

3,000,000,000,000,000°

CONDENSED

in one can } 50 Earth masses in matter
50 Earth masses in antimatter
+ extra mountain of matter

HOT

per serving } 10 billion years of total energy output of sun

INGREDIENTS

in every spoonful } every type of elementary particle

Primordial soup

KNOWN INGREDIENTS:

56% QUARKS

16% GLUONS (STRONG FORCE)

9% ELECTRON-LIKE PARTICLES

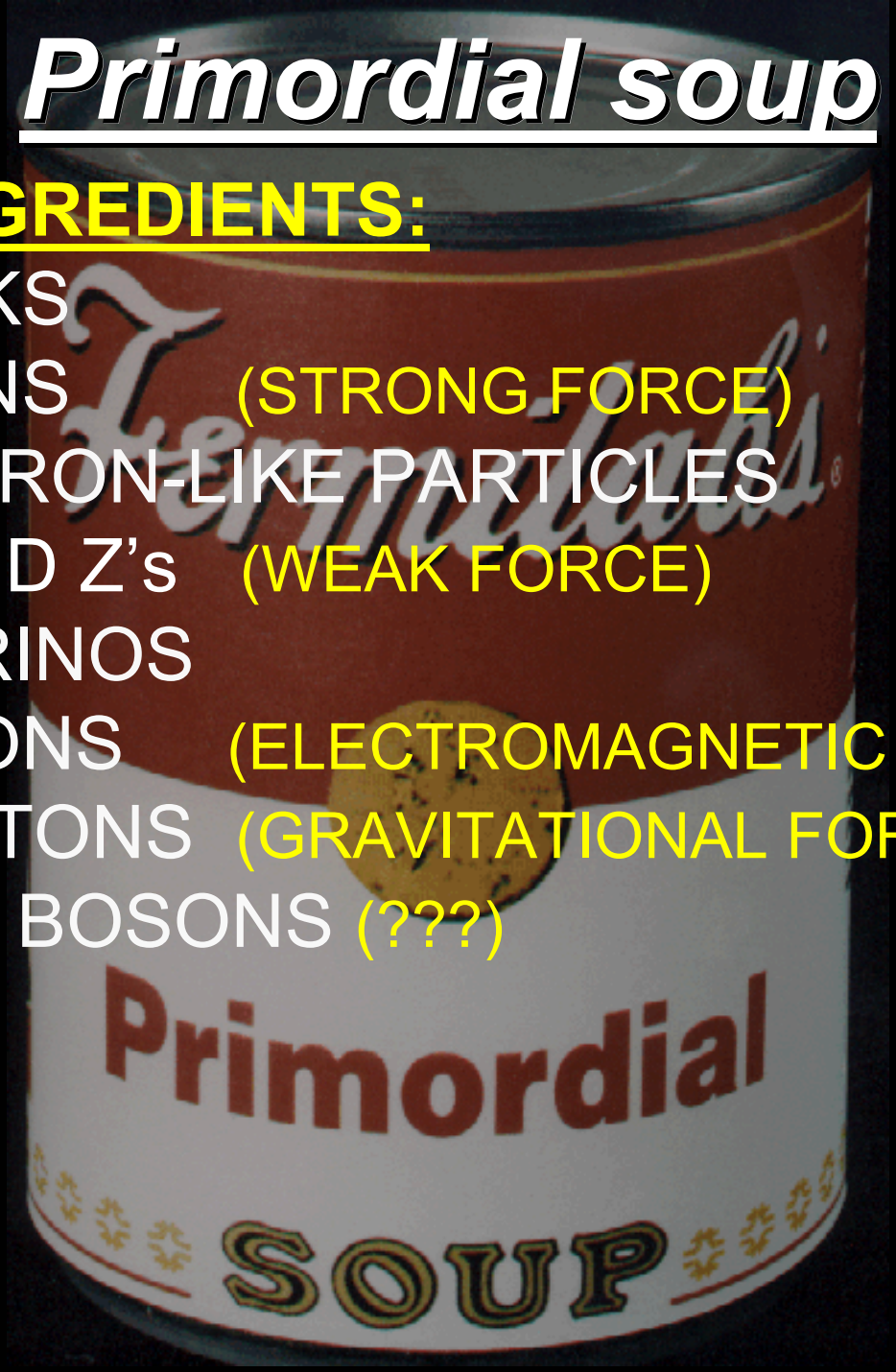
9% W's AND Z's (WEAK FORCE)

5% NEUTRINOS

2% PHOTONS (ELECTROMAGNETIC FORCE)

2% GRAVITONS (GRAVITATIONAL FORCE)

1% HIGGS BOSONS (???)



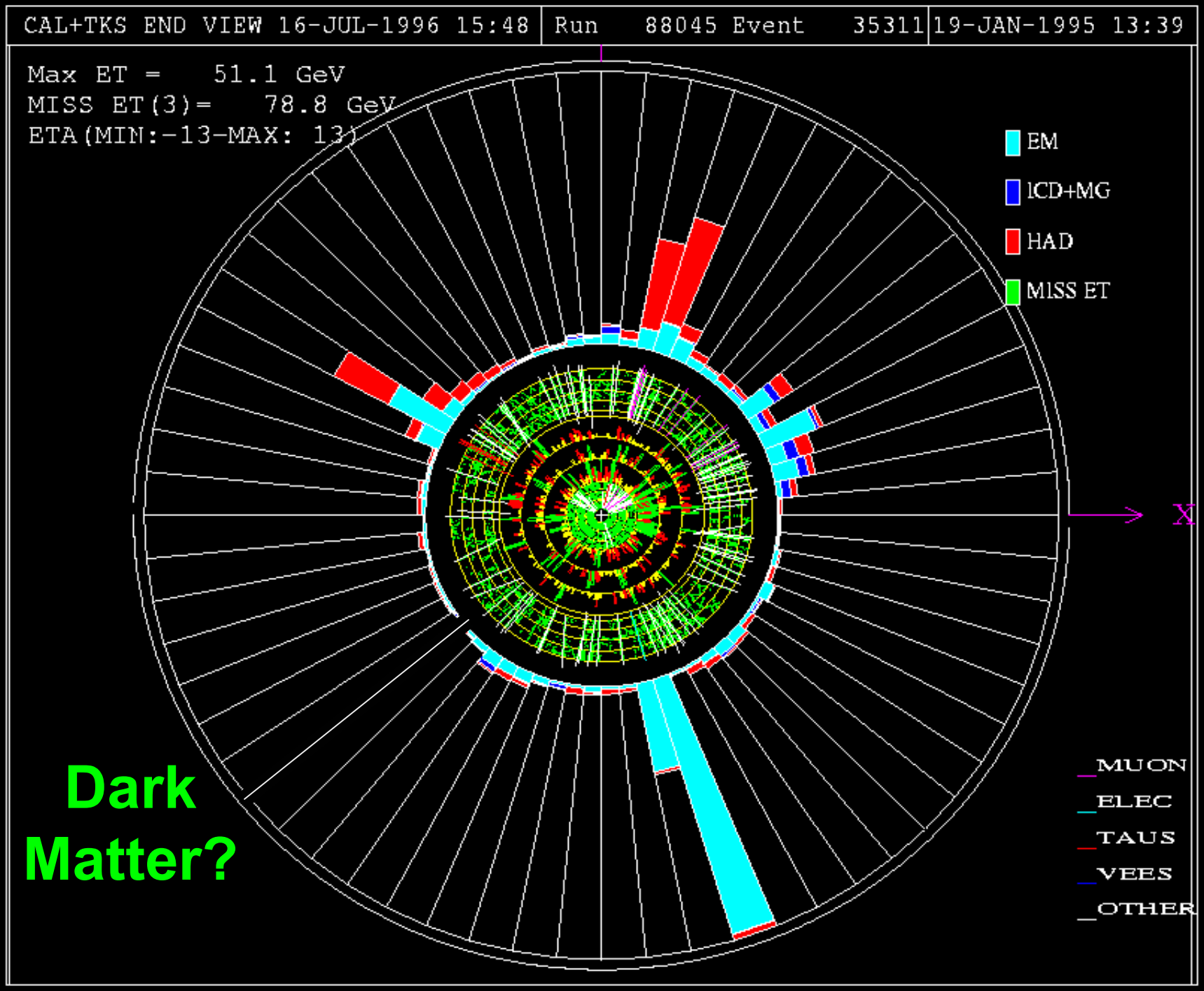
Primordial soup

KNOWN INGREDIENTS:

56% QUARKS
16% GLUONS (STRONG FORCE)
9% ELECTRON-LIKE PARTICLES
9% W's AND Z's (WEAK FORCE)
5% NEUTRINOS
2% PHOTONS (ELECTROMAGNETIC FORCE)
2% GRAVITONS (GRAVITATIONAL FORCE)
1% HIGGS BOSONS (???)

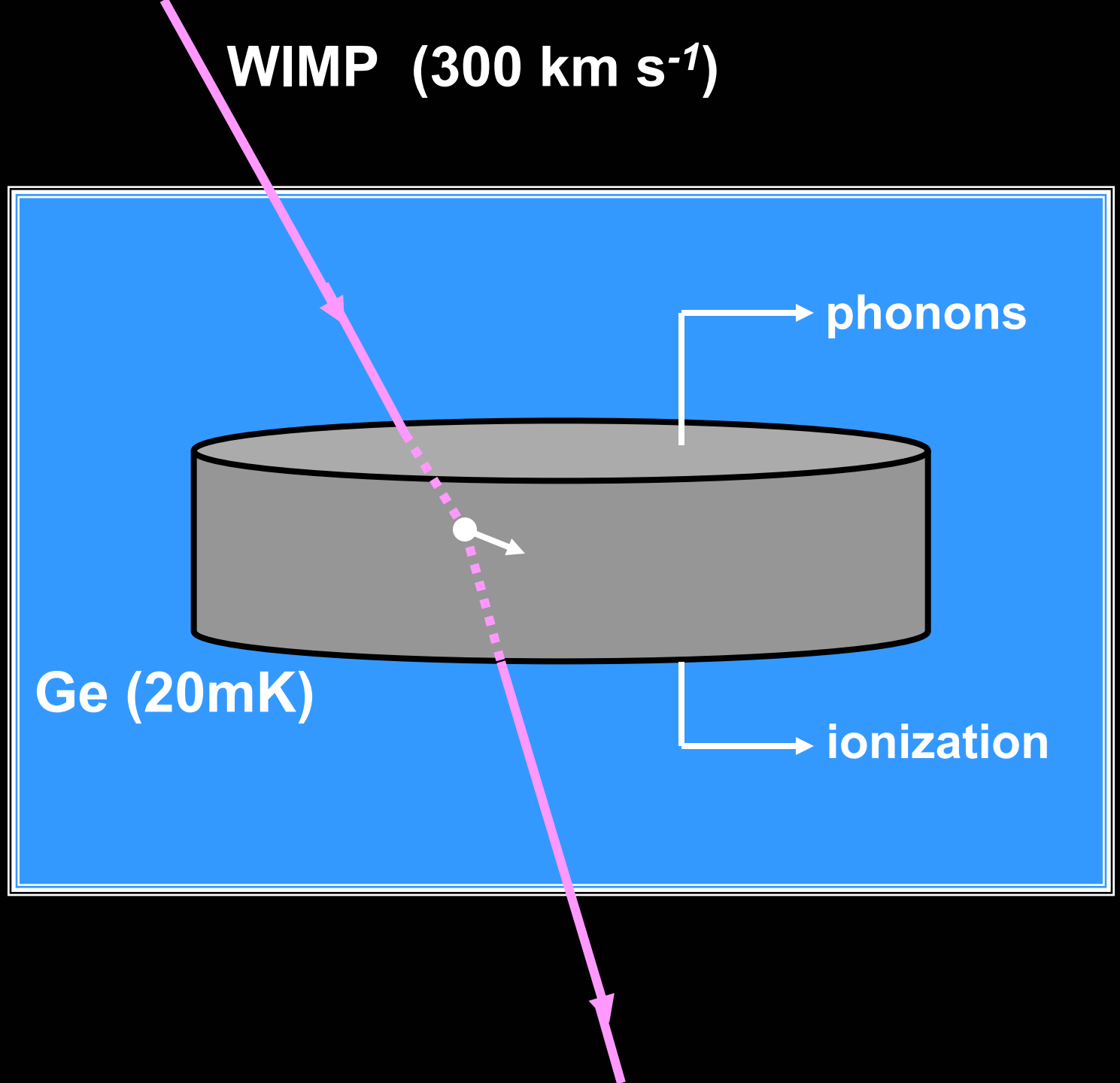
SECRET INGREDIENT:

DARK MATTER


CAL+TKS END VIEW 16-JUL-1996 15:48
Run 88045 Event 35311
19-JAN-1995 13:39
Max ET = 51.1 GeV
MISS ET(3)= 78.8 GeV
ETA(MIN:-13-MAX: 13)
EM
ICD+MG
HAD
MISS ET
X
MUON
ELEC
TAUS
VEES
OTHER
Dark Matter?

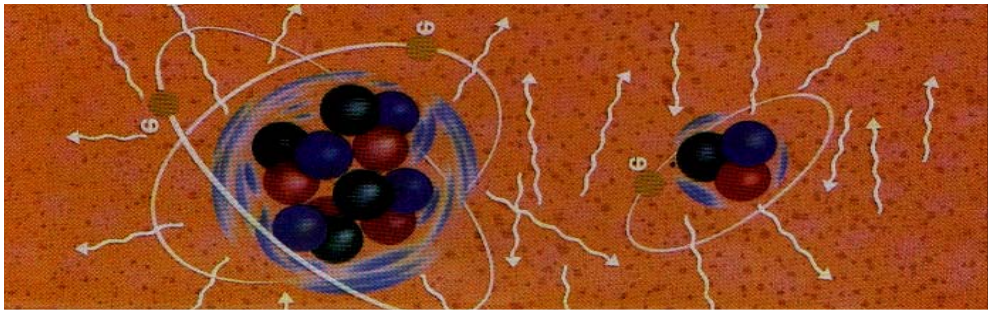
MINOS

also CERN → Gran Sasso


WIMP (300 km s-1)
phonons
Ge (20mK)
ionization

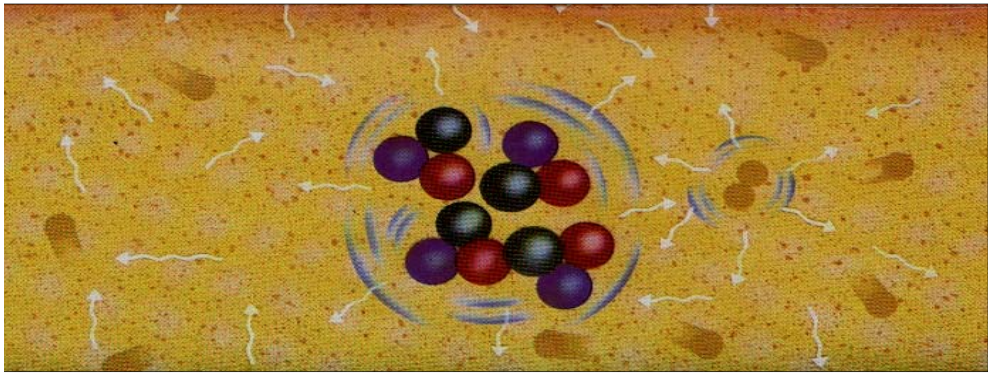
380,000 years

atoms form



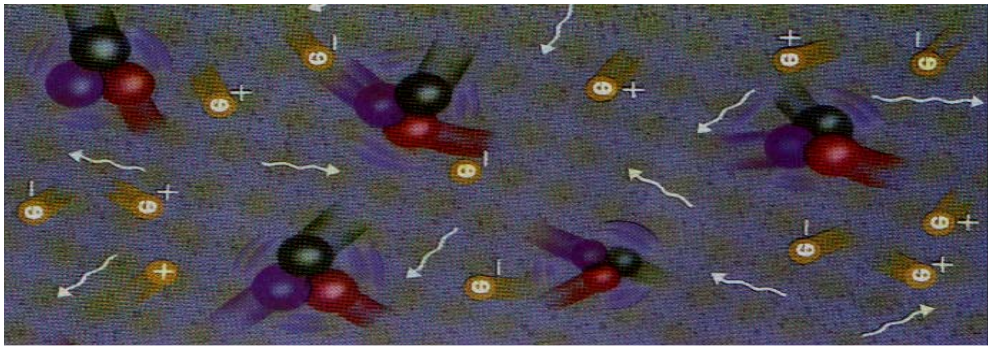
3 minutes

nuclei form



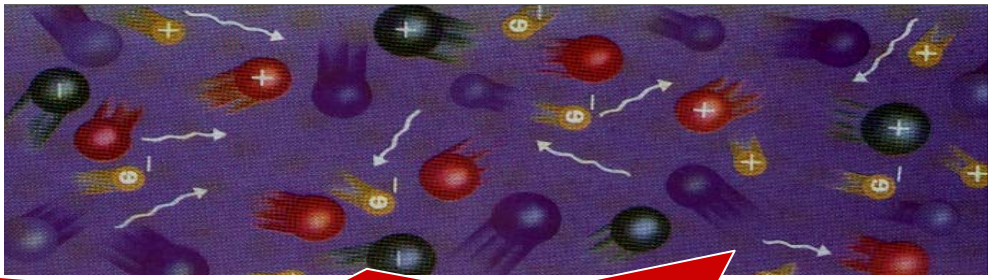
1-micro second

neutrons protons form



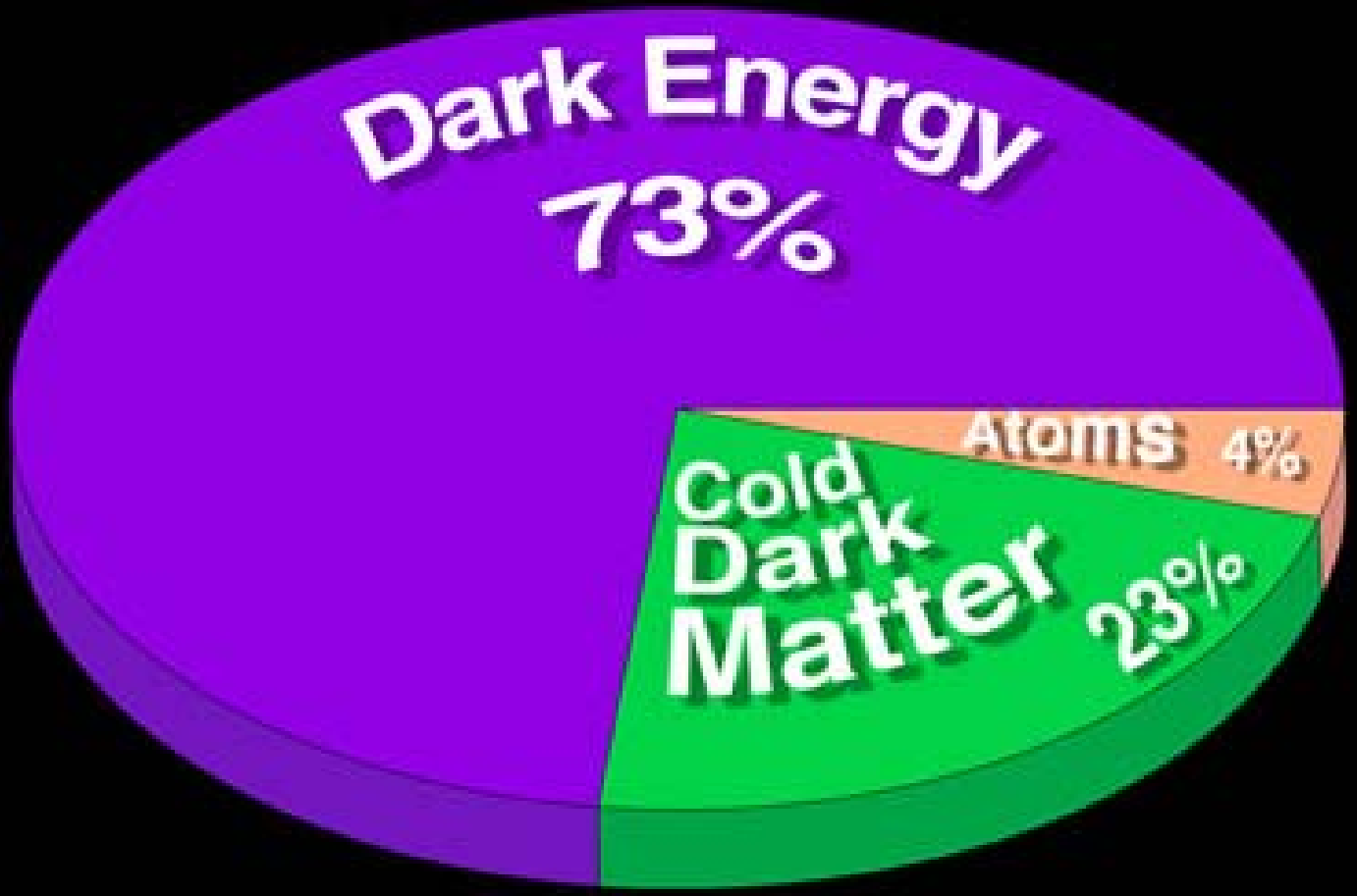
4-pico seconds

primordial soup



BANG!

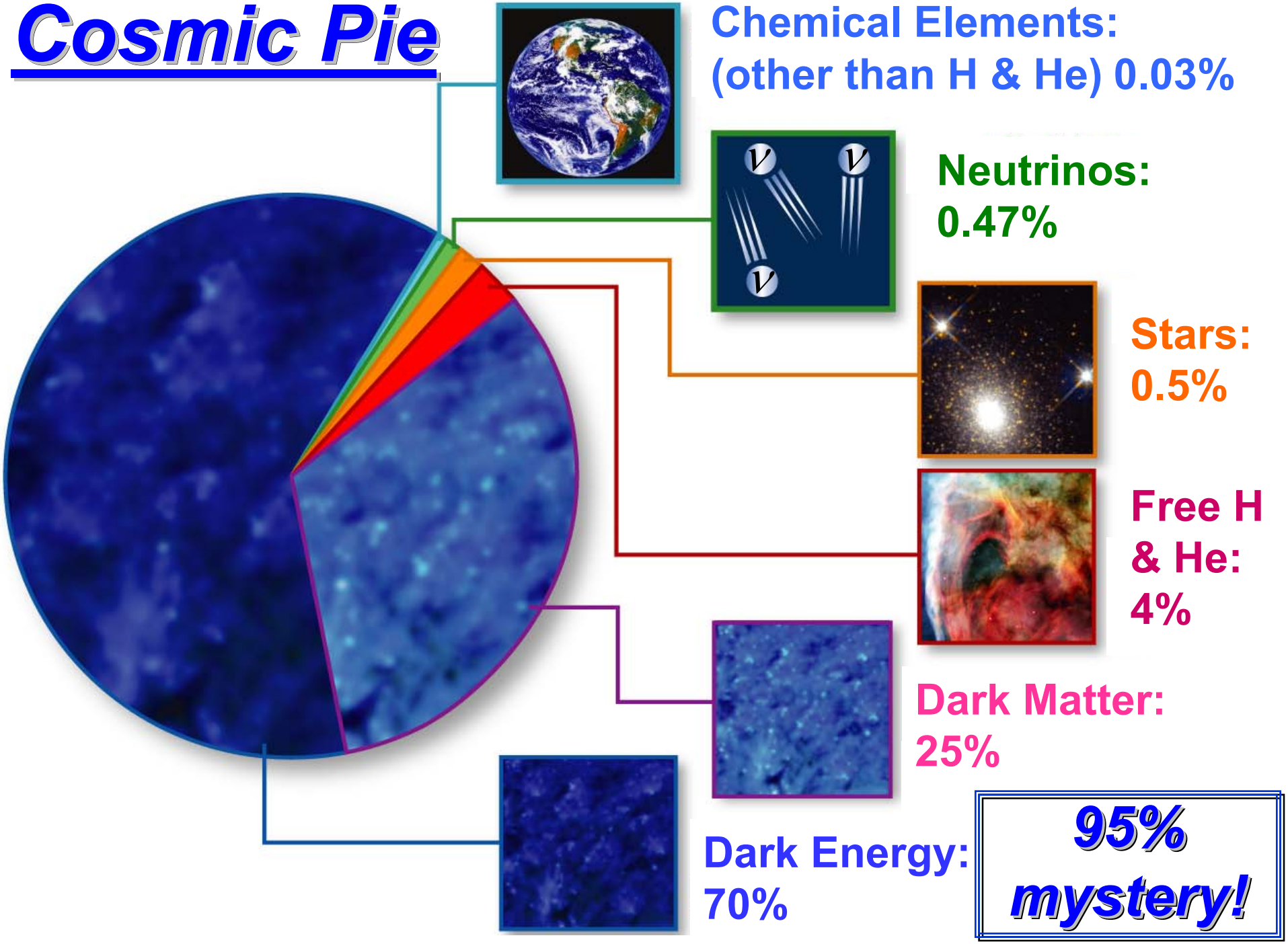
Mass-energy content

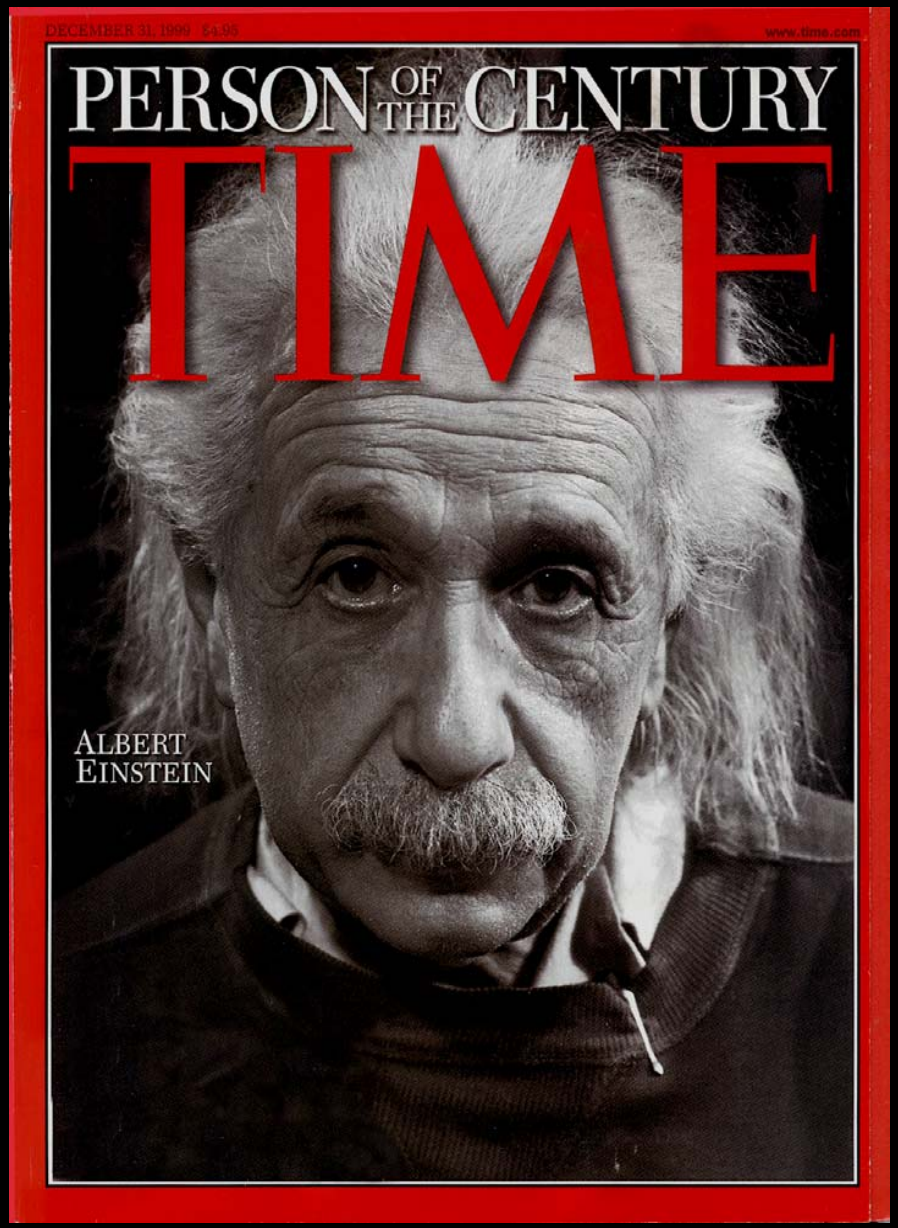


Mission accomplished …

… or premature jubilation?

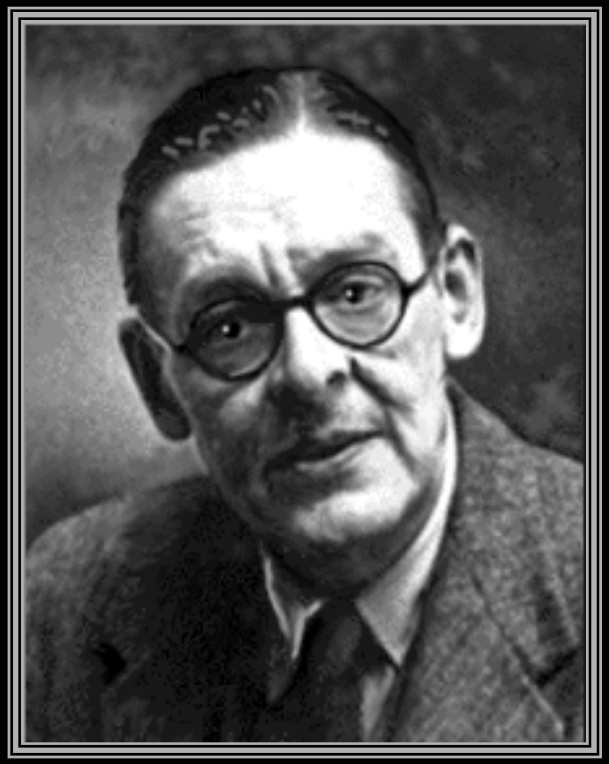
Cosmic Pie


Chemical Elements:
(other than H & He) 0.03%
Neutrinos:
0.47%
Stars:
0.5%
Free H
& He:
4%
Dark Matter:
25%
Dark Energy:
70%
95%
mystery!



"The most beautiful thing we can experience is the mysterious. It is the source of all true art and science. Those to whom this emotion is a stranger, . . . are as good as dead; their eyes are closed."

Albert Einstein

“We shall not cease from exploration
And the end of all our exploring
Will be to arrive where we started
And know the place for the first time.”

– T. S. Eliot