COSMOLOGIA.

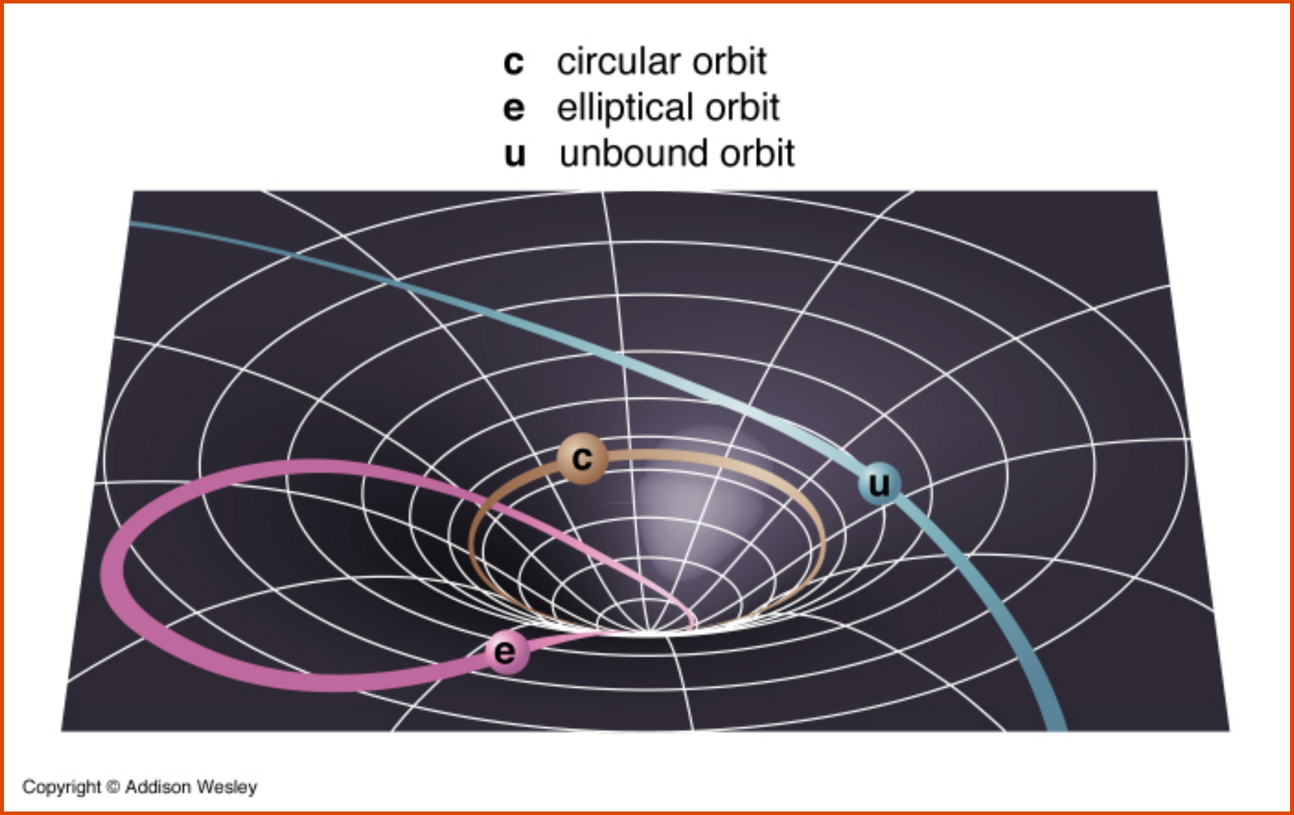
Dr. Yves Gaspar
Università Cattolica del Sacro Cuore
Dipartimento Matematica Fisica – Brescia
Ph.D. University of Cambridge (UK)

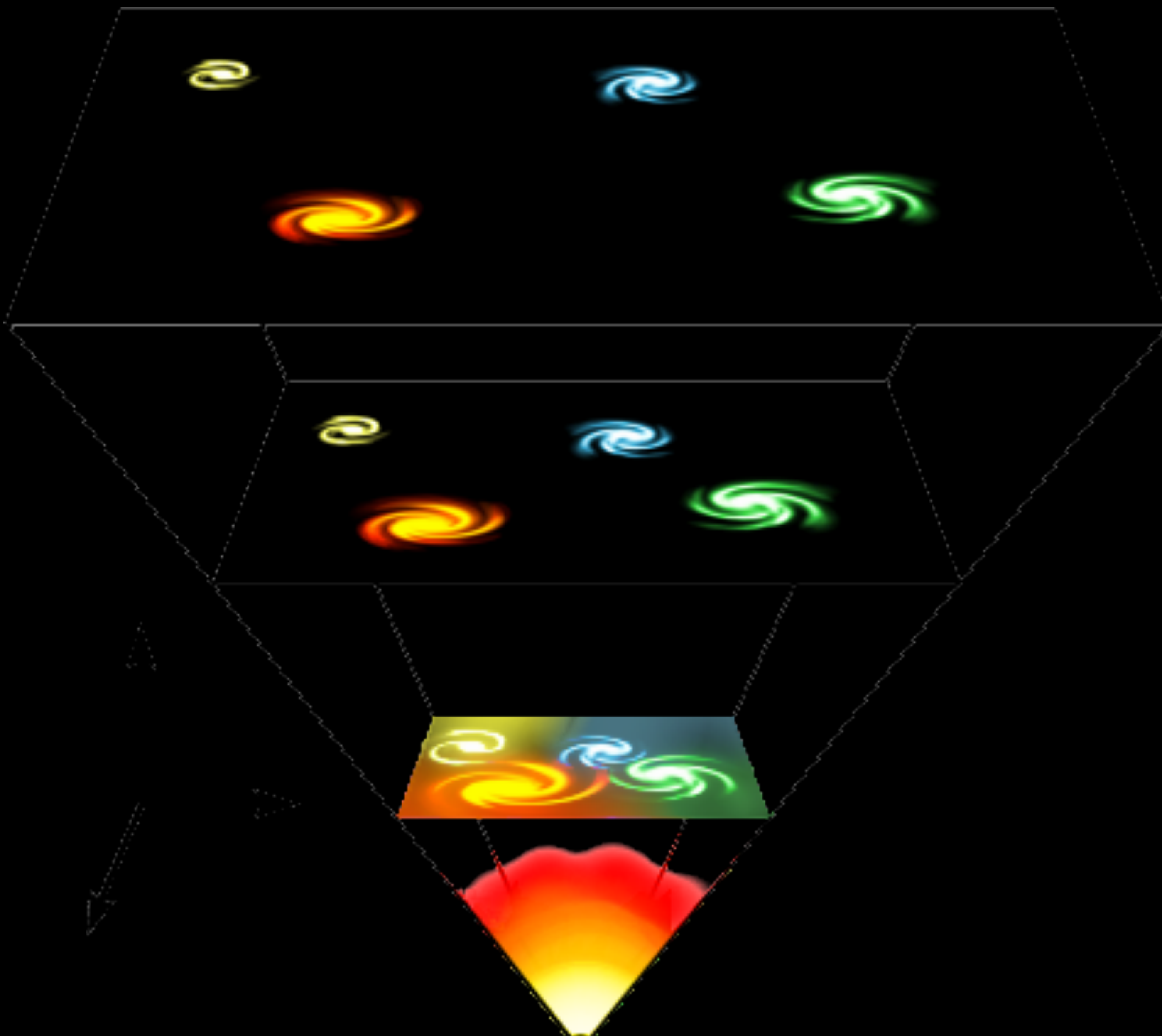
Equazioni di campo di Einstein

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

$$T^{\mu\nu} = \left(\rho + \frac{P}{c^2}\right)\,u^\mu\,u^\nu - P\,g^{\mu\nu}$$

Relatvità Generale – moto geodetico



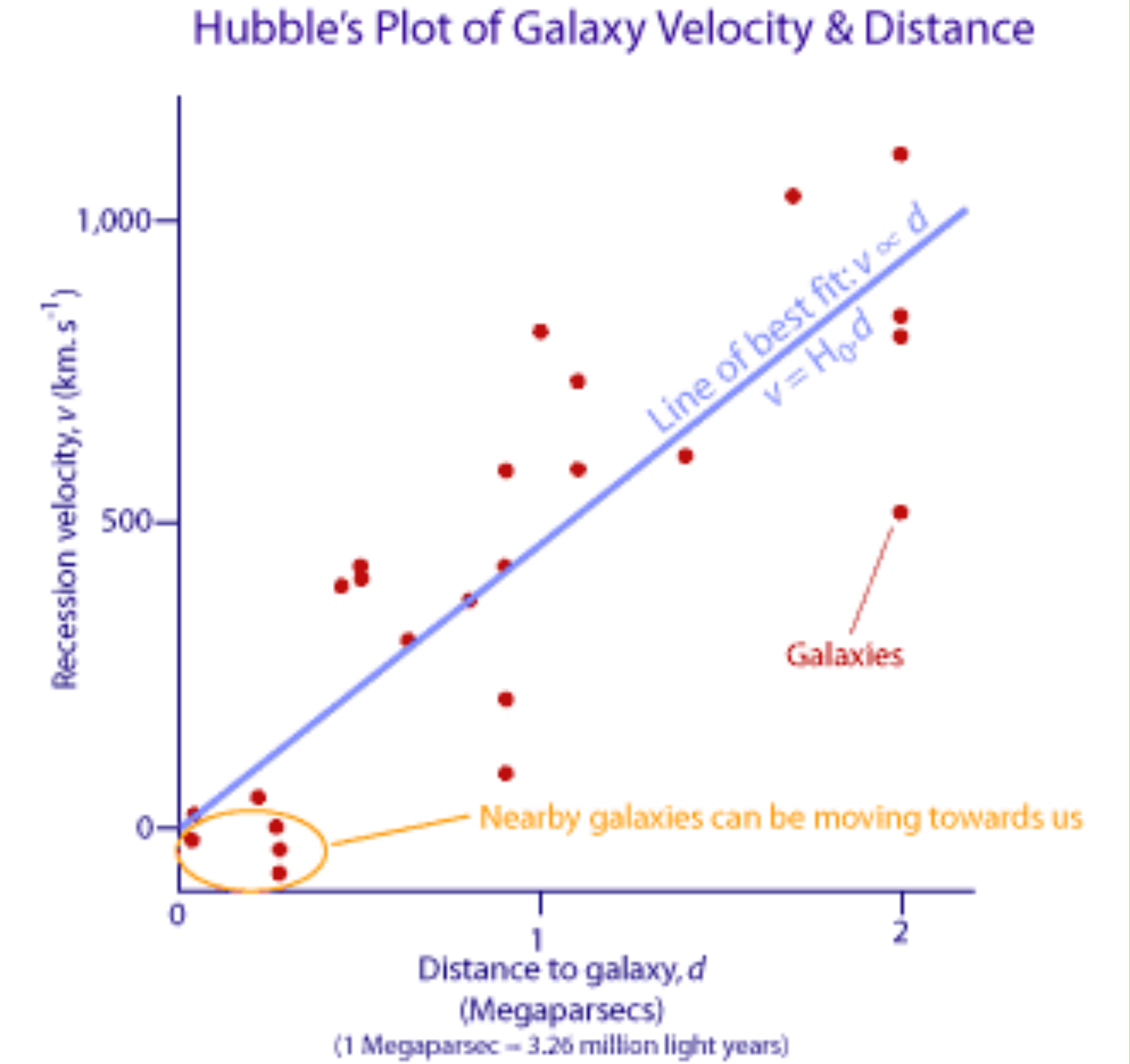


Georges Lemaître

Alexander Friedmann

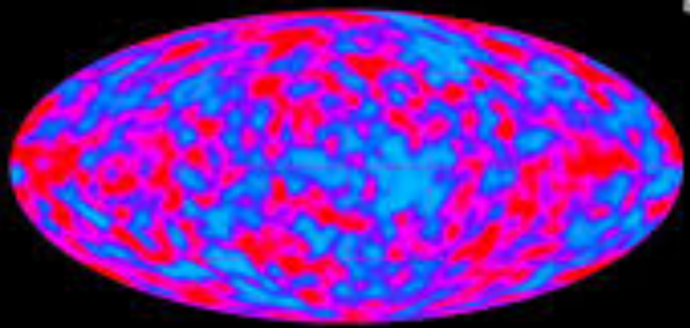
George Gamow

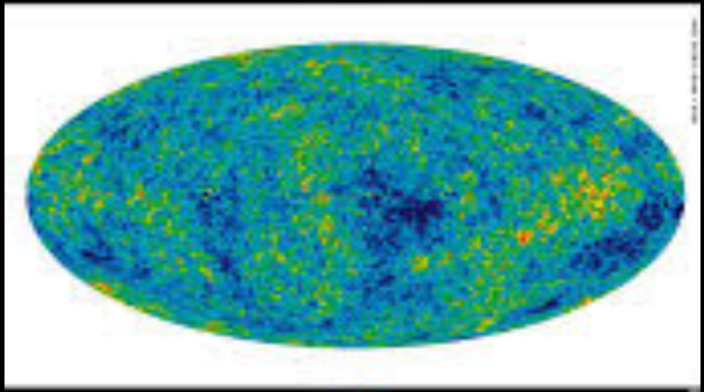
Vesto Slipher - Edwin Hubble

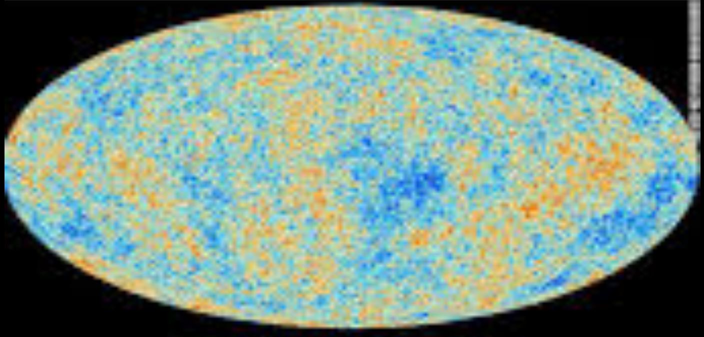

Hubble's Plot of Galaxy Velocity & Distance
1,000
500
0
Recession velocity, v (km.s⁻¹)
Line of best fit: v ∝ d
v = H₀d
Galaxies
Nearby galaxies can be moving towards us
0
1
2
Distance to galaxy, d
(Megaparsecs)
(1 Megaparsec = 3.26 million light years)

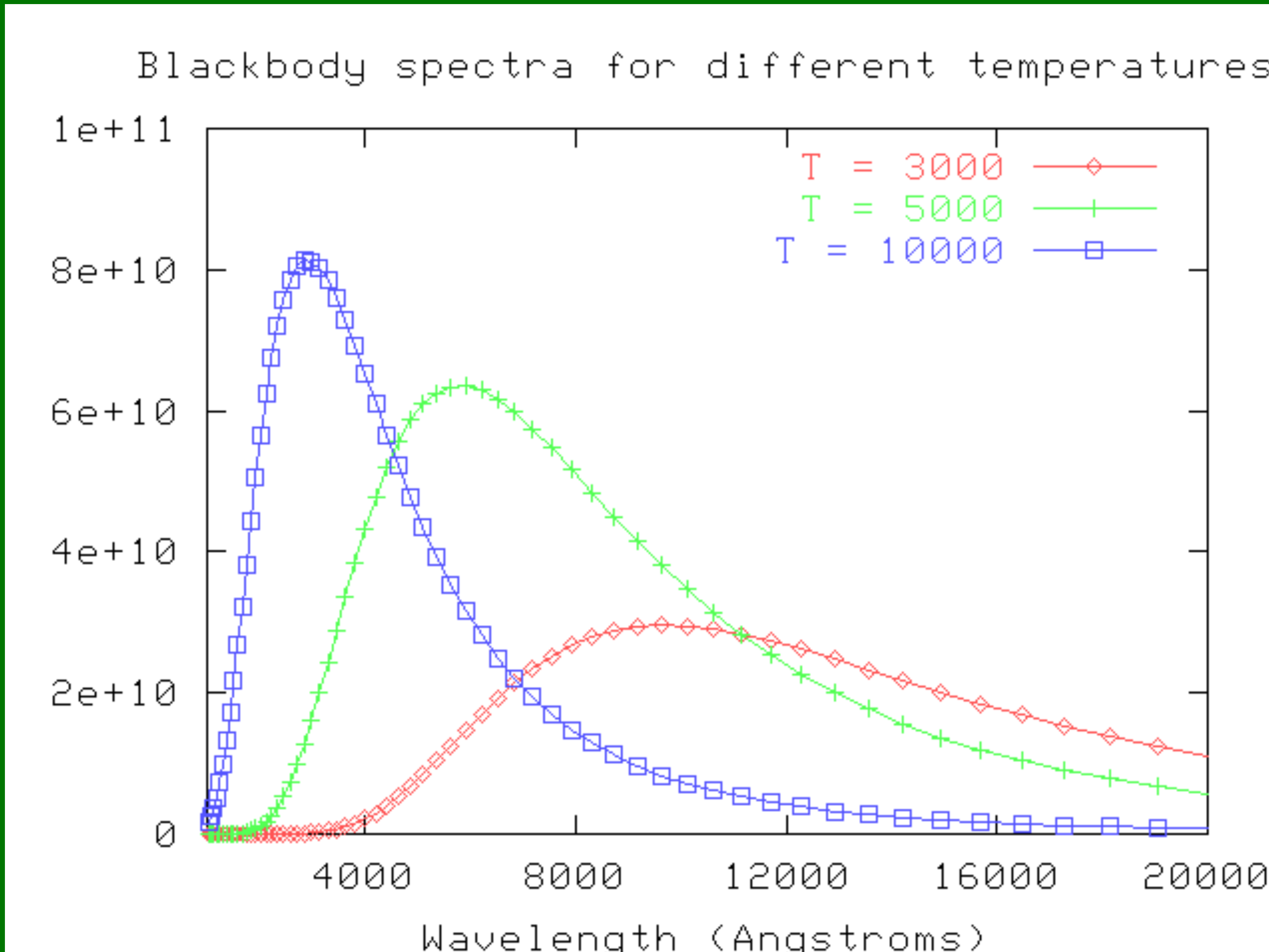
Arno Penzias – Robert Wilson

COBE - WMAP - PLANCK

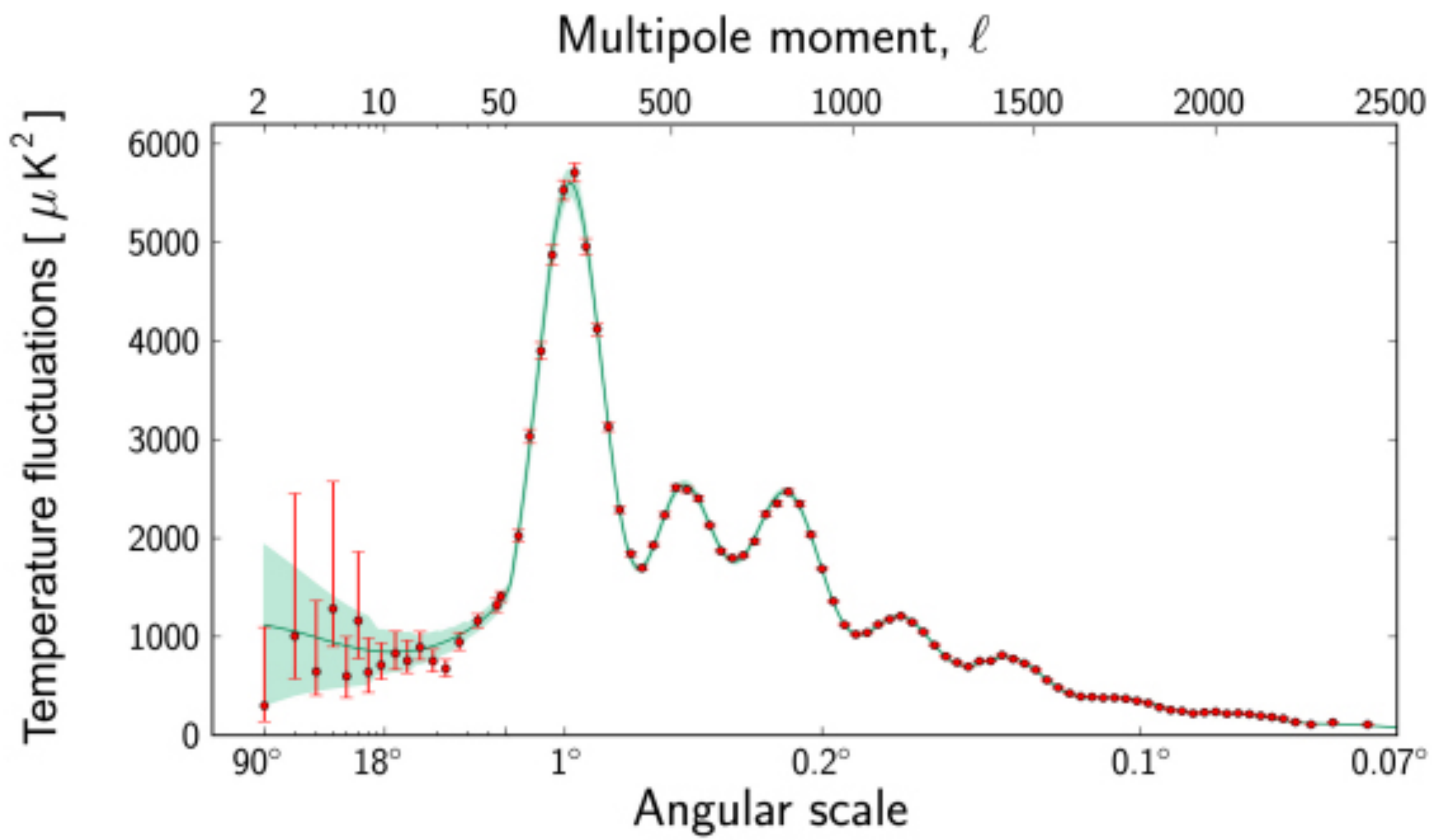


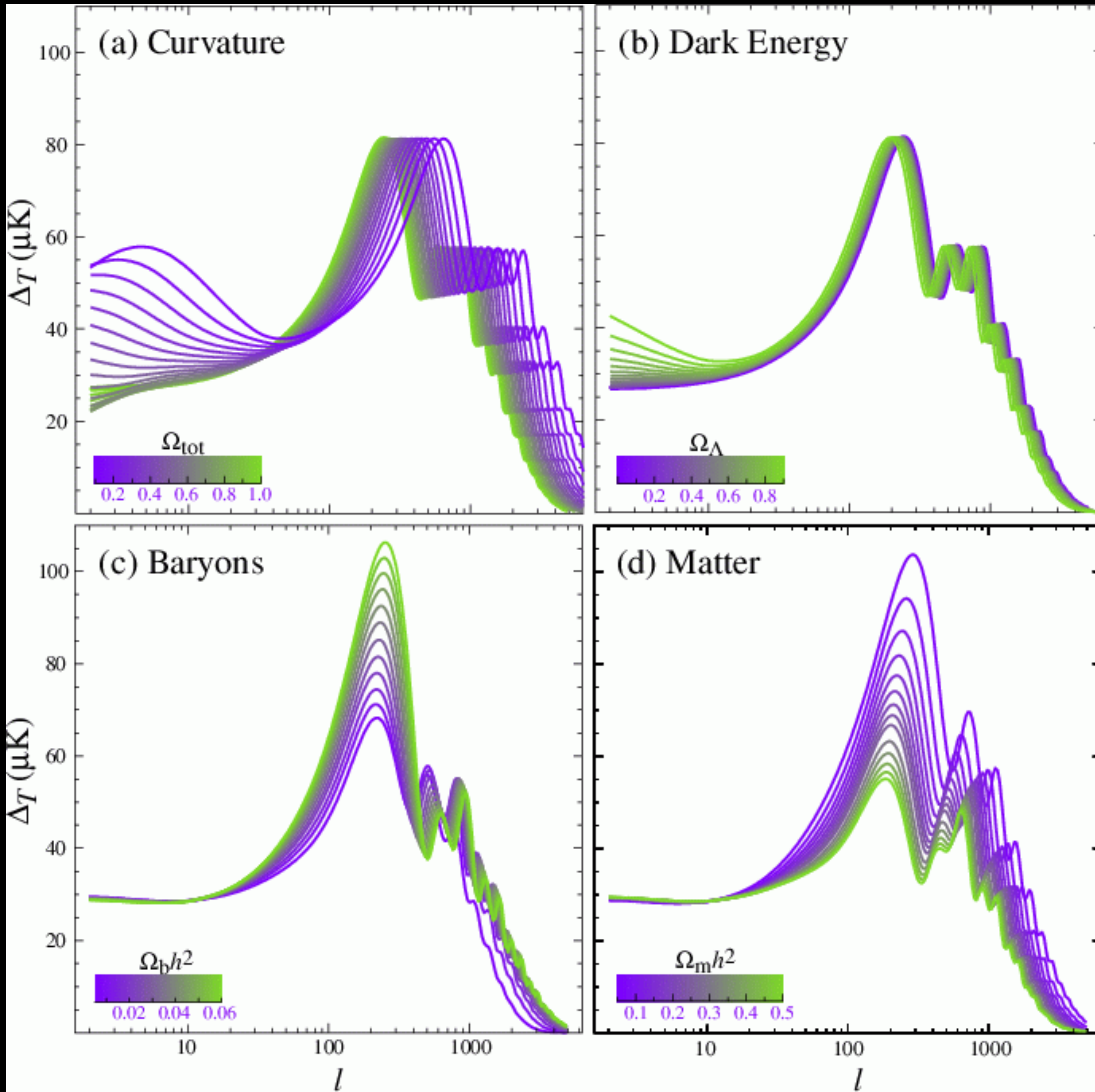




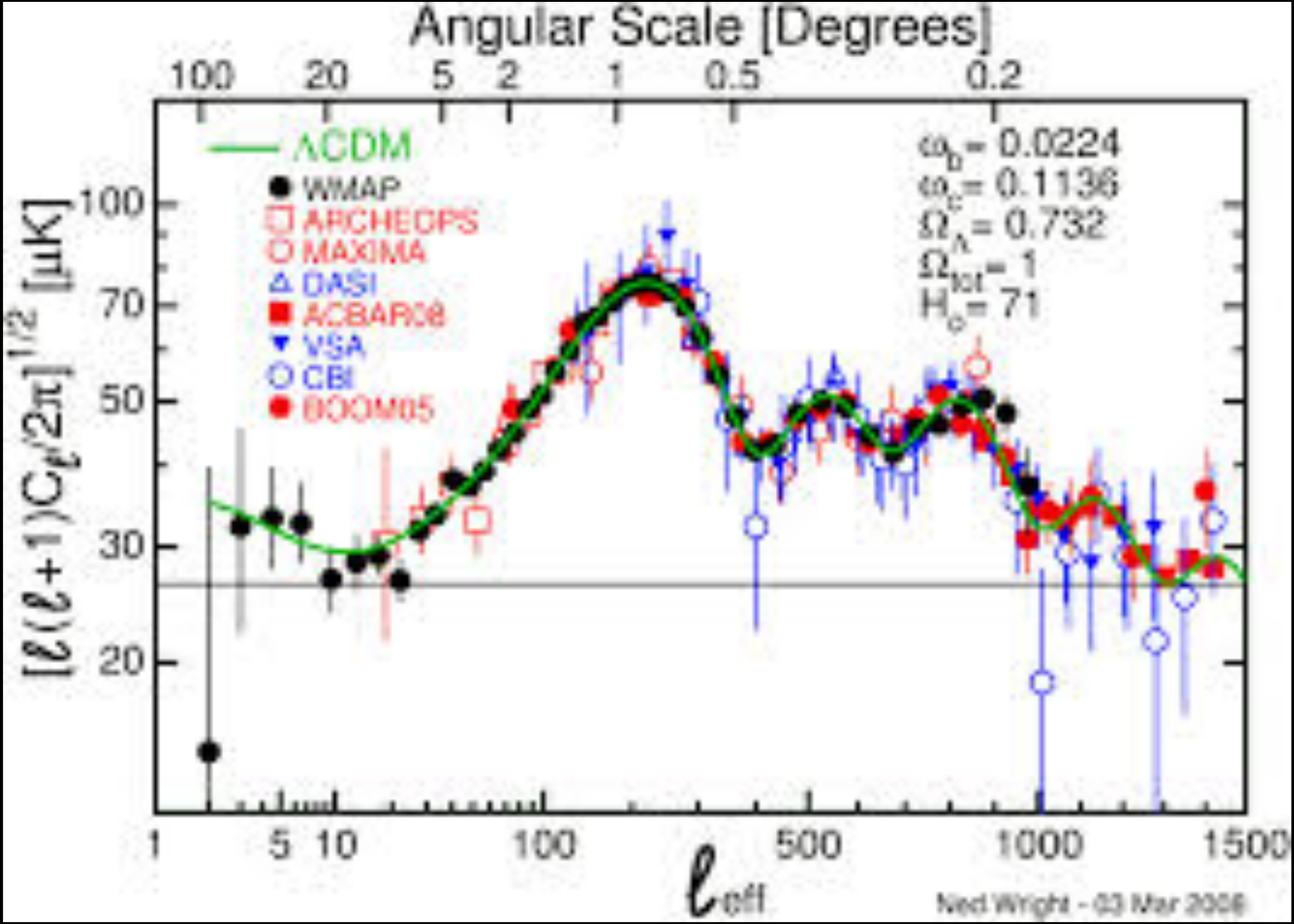

Blackbody spectra for different temperatures
1e+11
8e+10
6e+10
4e+10
2e+10
0
4000
8000
12000
16000
20000
Wavelength (Angstroms)
T = 3000
T = 5000
T = 10000

Power spectrum temperature fluctuations





(a) Curvature
(b) Dark Energy
(c) Baryons
(d) Matter
Δ_T (μK)
l
Ω_{tot}
0.2 0.4 0.6 0.8 1.0
Ω_Λ
0.2 0.4 0.6 0.8
$\Omega_b h^2$
0.02 0.04 0.06
$\Omega_m h^2$
0.1 0.2 0.3 0.4 0.5
20 40 60 80 100
10 100 1000



Angular Scale [Degrees]
100
20
5
2
1
0.5
0.2
ΛCDM
WMAP
ARCHEOPS
MAXIMA
DASI
ACBAR08
VSA
CBI
BOOM05
$\omega_b = 0.0224$
$\omega_c = 0.1136$
$\Omega_\Lambda = 0.732$
$\Omega_{tot} = 1$
$H_o = 71$
$[\ell(\ell+1)C_\ell/2\pi]^{1/2}$ [μK]
100
70
50
30
20
1
5
10
100
500
1000
1500
ℓ_{eff}
Ned Wright - 03 Mar 2006

Parametri cosmologici

$$H_0 = 70 \pm 5 \ \frac{\text{km}}{\text{sec Mpc}}$$

$$T_{CMB} = 2.725 \pm 0.002 \text{ K}$$

$$\Omega_b = 0.044 \pm 0.004$$

$$\Omega_M = 0.27 \pm 0.04$$

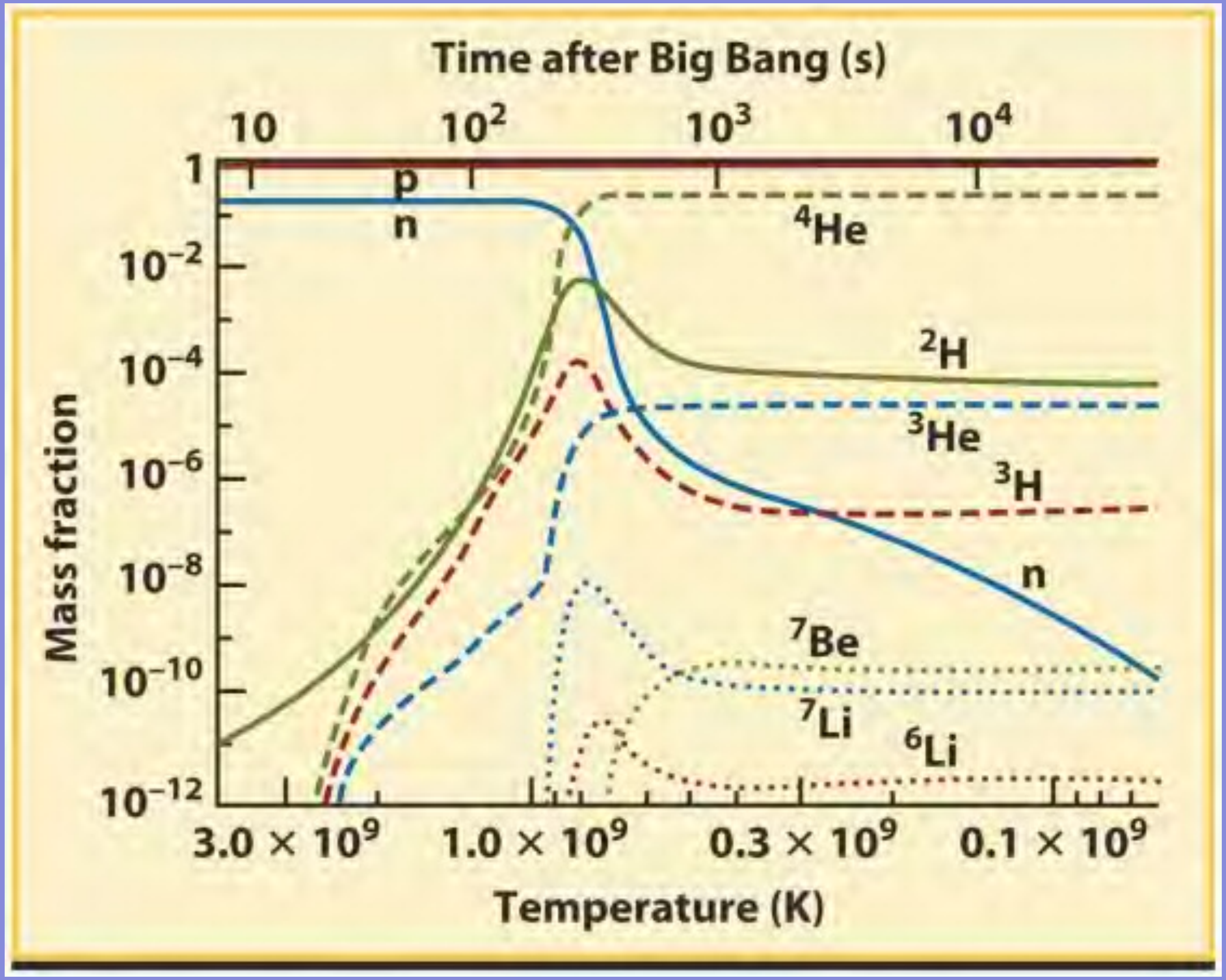
$$\Omega_\Lambda = 0.73 \pm 0.04$$

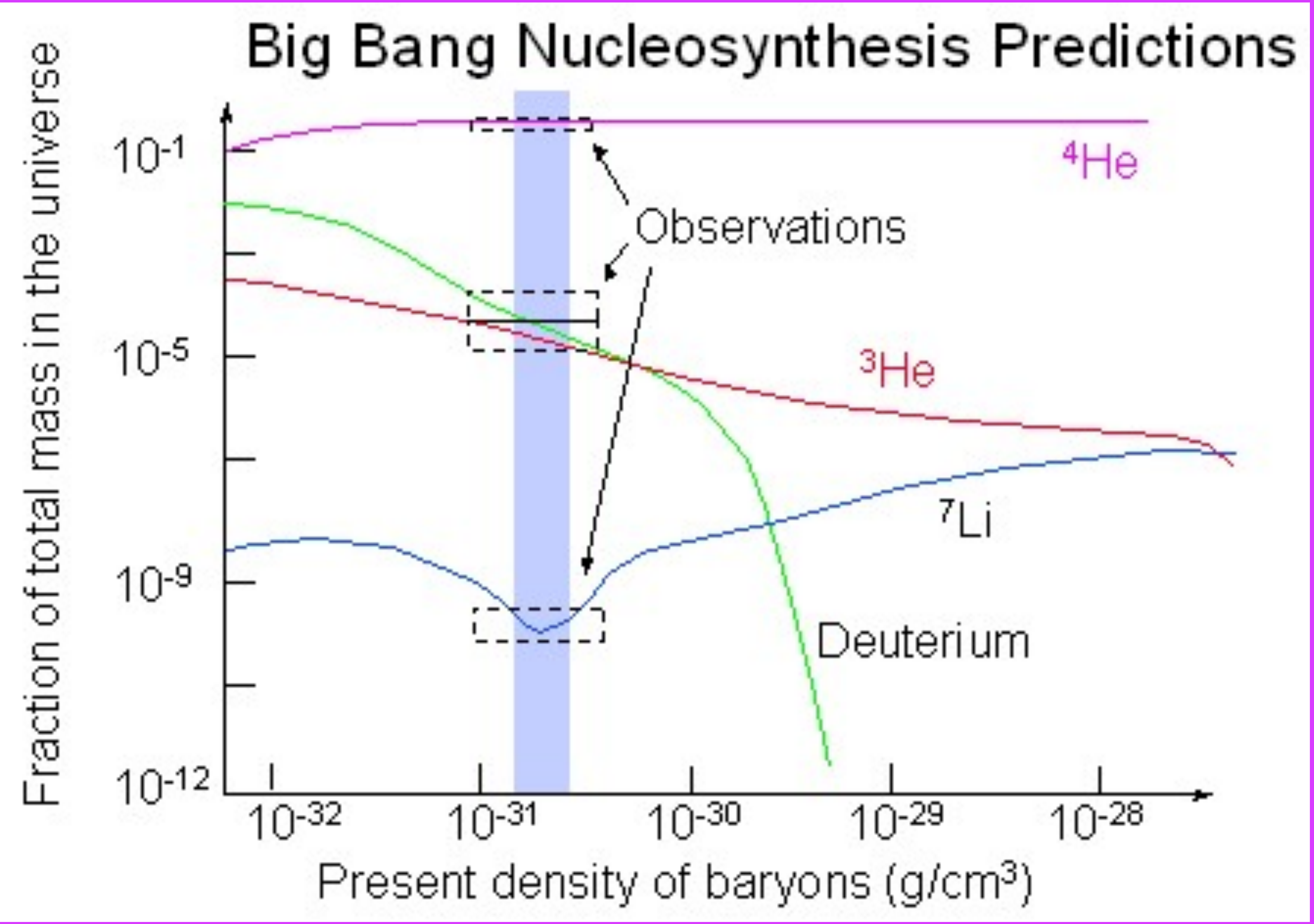
$$\Omega_0 = 1.02 \pm 0.02$$

$$t_0 = 13.7 \pm 0.2 \text{ Gyr}$$

$$q_0 \approx 0.5$$

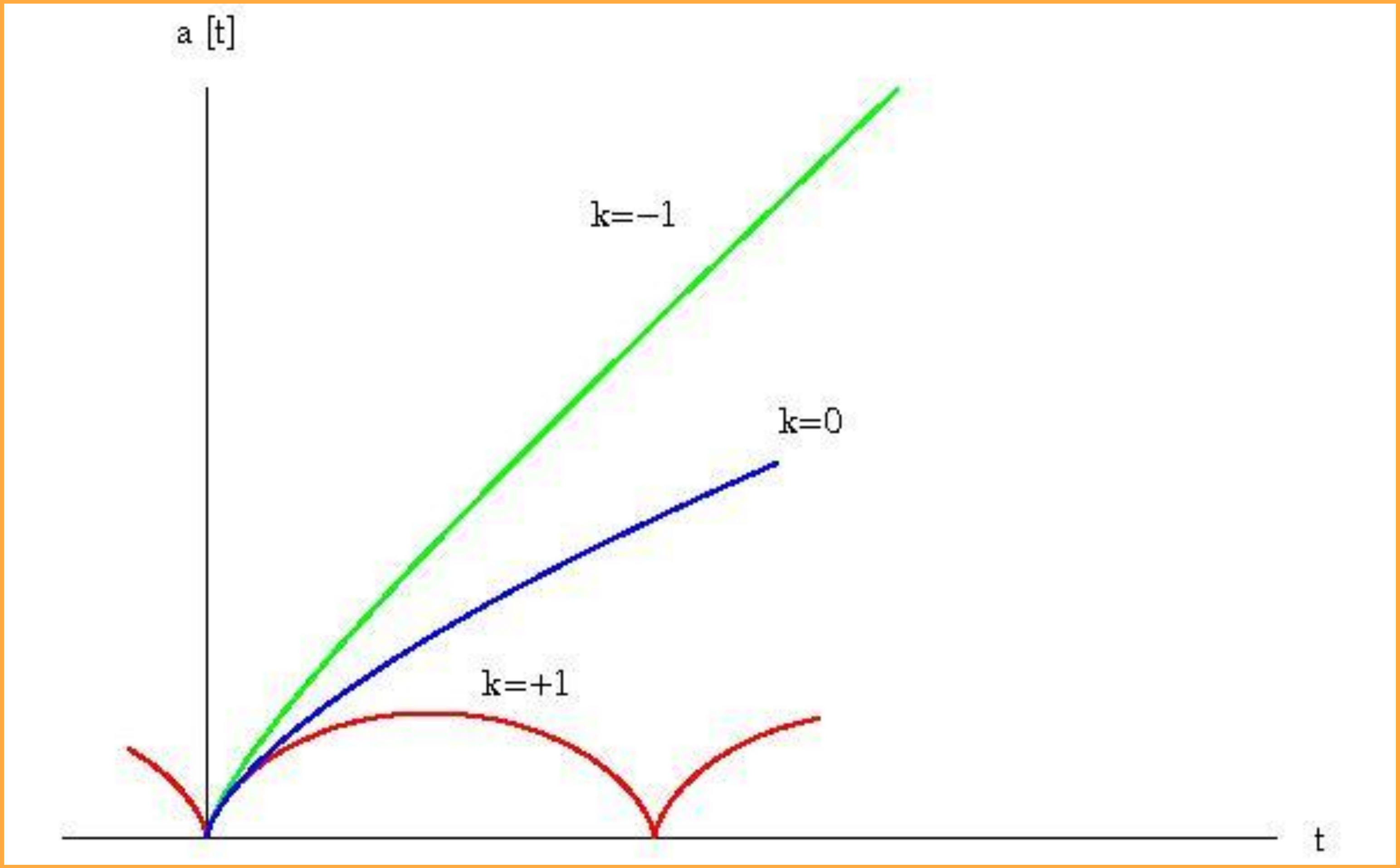
Nucleosintesi primordiale – “Deuterium Bottelneck”

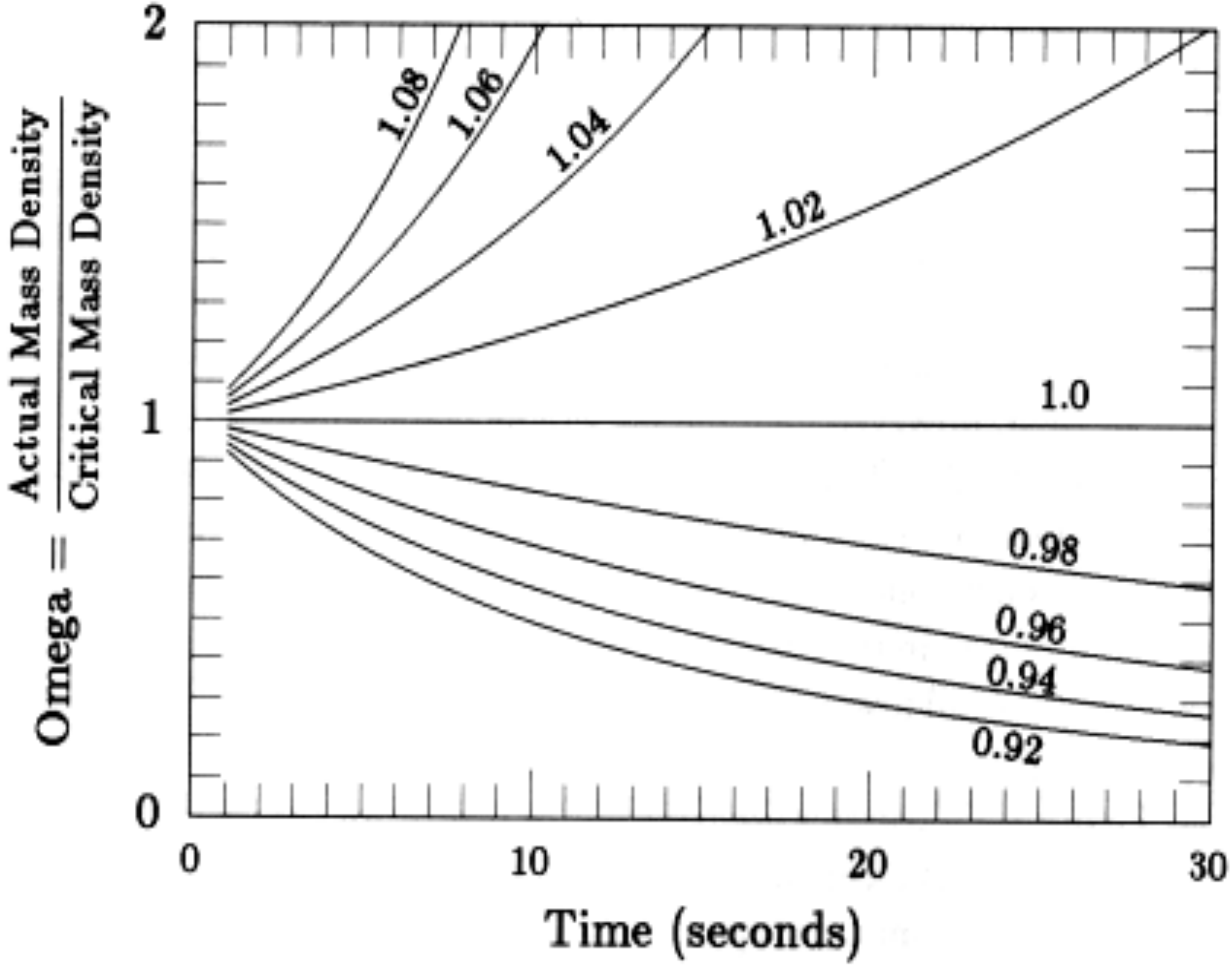




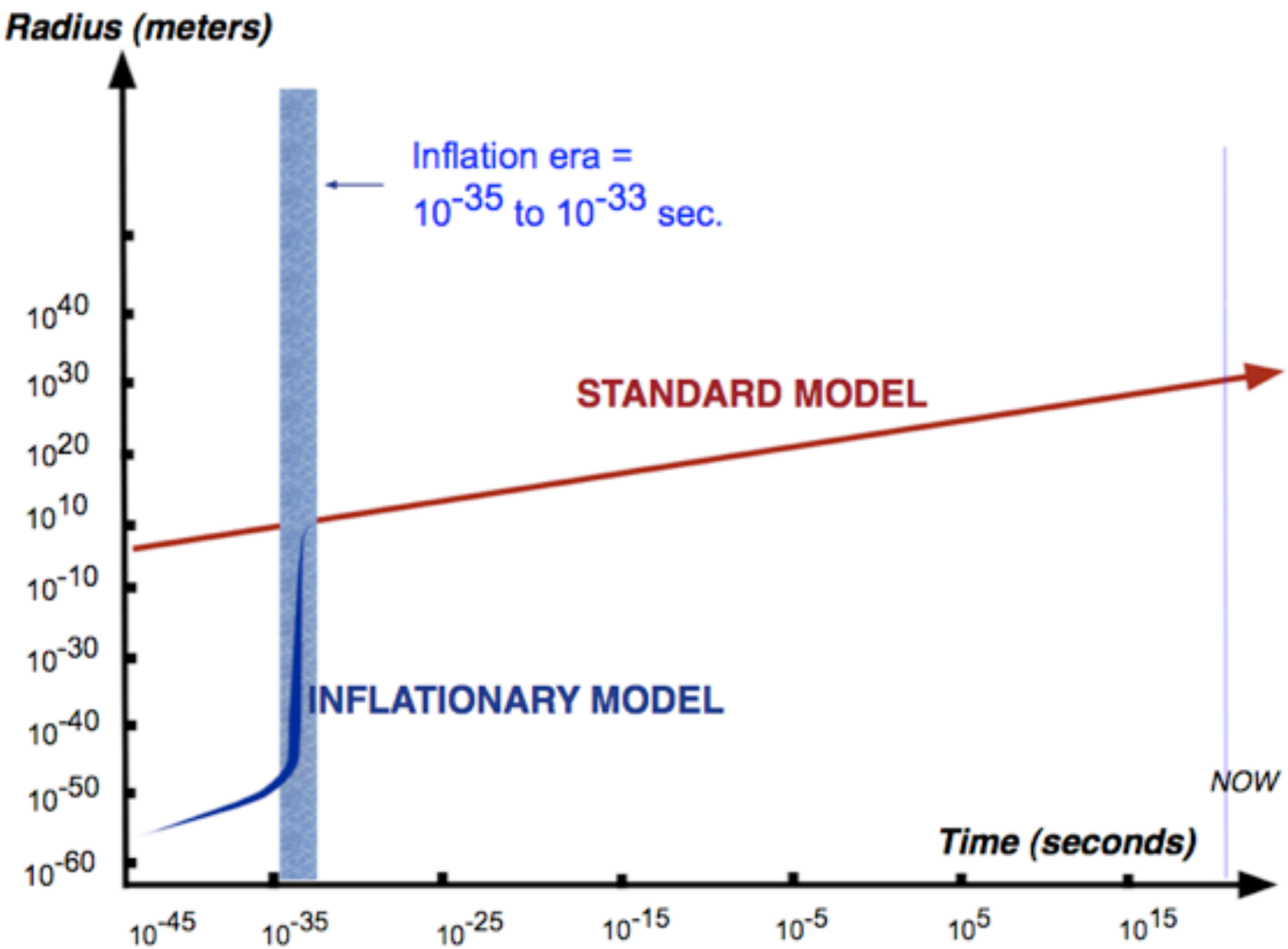
Big Bang Nucleosynthesis Predictions
Fraction of total mass in the universe
10-1
10-5
10-9
10-12
4He
Observations
3He
7Li
Deuterium
10-32
10-31
10-30
10-29
10-28
Present density of baryons (g/cm3)

Modelli Friedmann-Lemaître-Robertson-Walker (FLRW)





Omega = Actual Mass Density / Critical Mass Density
2
1
0
1.08
1.06
1.04
1.02
1.0
0.98
0.96
0.94
0.92
0
10
20
30
Time (seconds)



EXPANSION OF THE OBSERVABLE UNIVERSE

Interazioni fondamentali

a) Nucleare forte => gluoni

1

b) Nucleare debole => W,Z

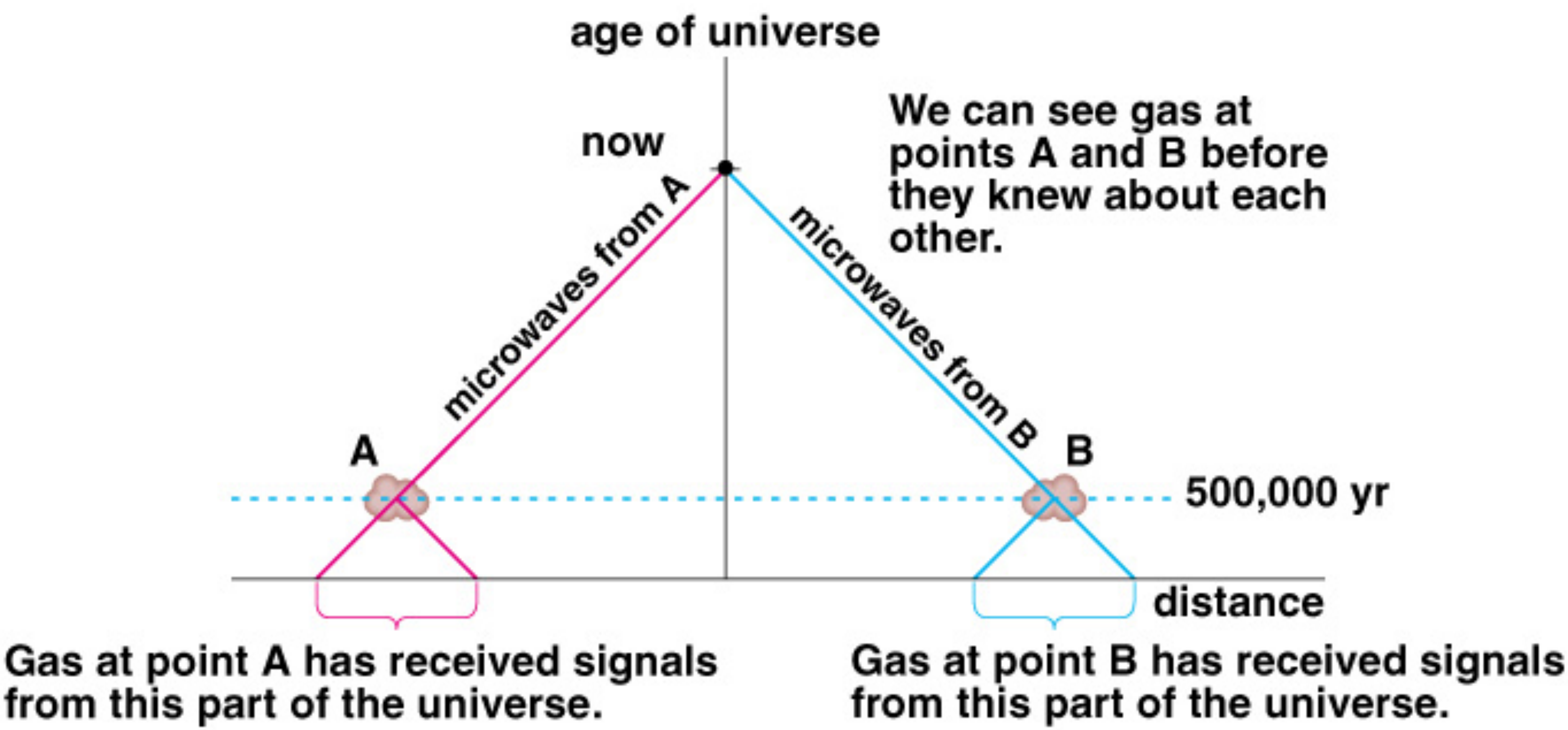
1/ 100.000

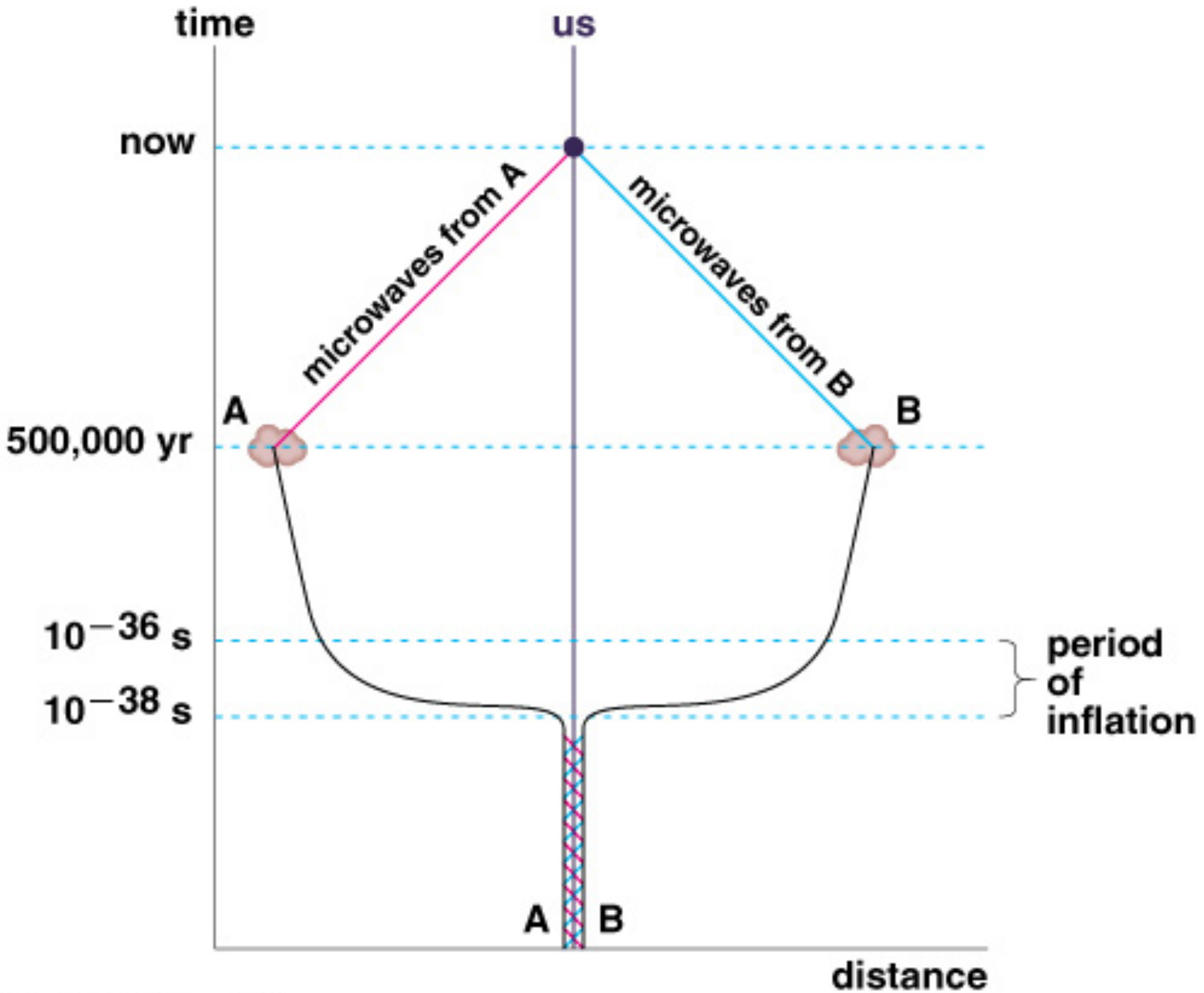
c) Elettromagnetica => fotone

1 / 137

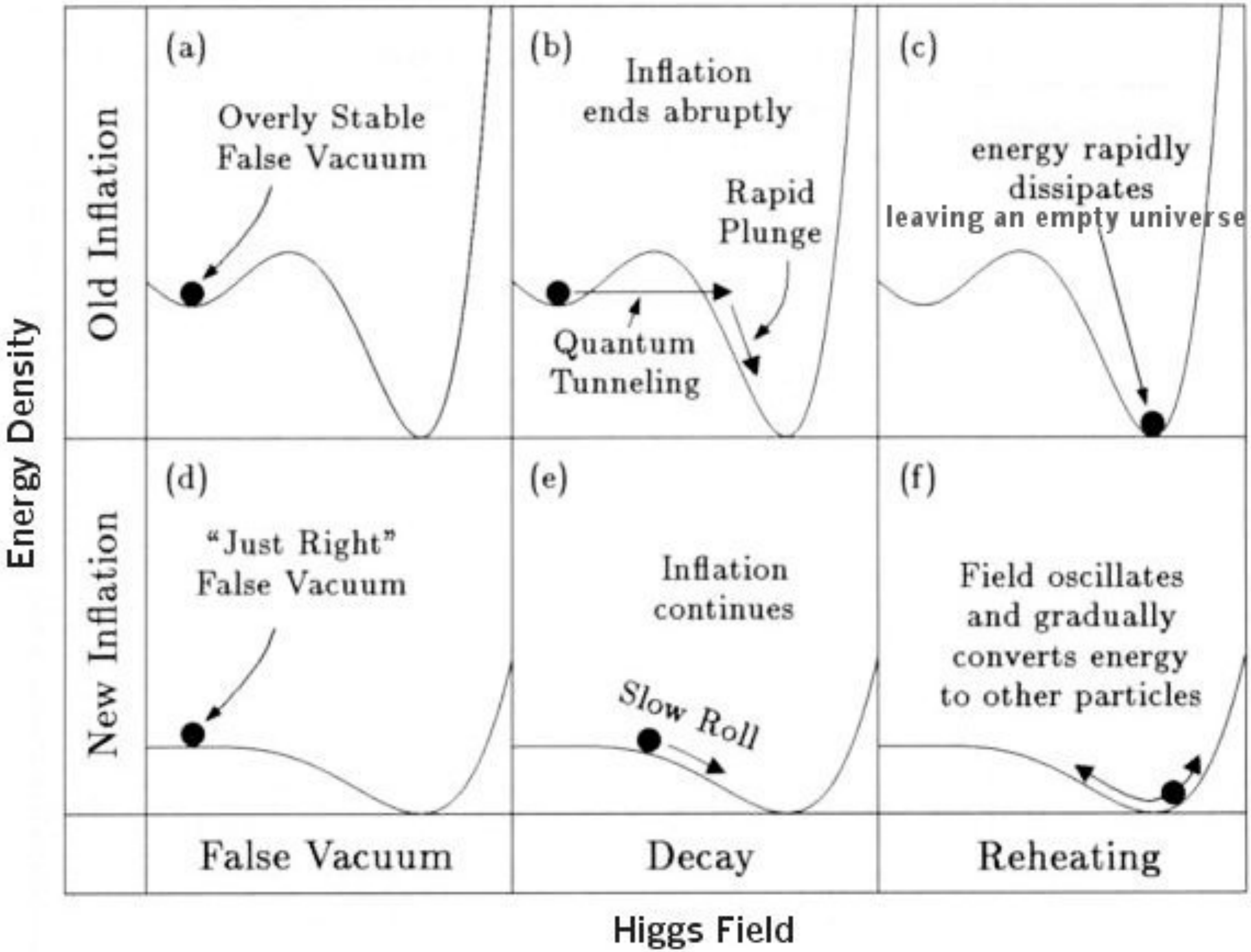
d) Gravitazione => gravitone (?)

1/1000000000000000000000000000000000000000


age of universe
now
We can see gas at points A and B before they knew about each other.
microwaves from A
microwaves from B
A
B
500,000 yr
distance
Gas at point A has received signals from this part of the universe.
Gas at point B has received signals from this part of the universe.



time
us
now
microwaves from A
microwaves from B
A
B
500,000 yr
10^{-36} s
10^{-38} s
period of inflation
A
B
distance


Energy Density
Old Inflation
New Inflation
(a)
Overly Stable
False Vacuum
(b)
Inflation
ends abruptly
Rapid
Plunge
Quantum
Tunneling
(c)
energy rapidly
dissipates
leaving an empty universe
(d)
"Just Right"
False Vacuum
(e)
Inflation
continues
Slow Roll
(f)
Field oscillates
and gradually
converts energy
to other particles
False Vacuum
Decay
Reheating
Higgs Field

Problemi dei modelli inflazionari: fine tuning ?

$$\varepsilon \equiv \frac{\Gamma_V}{H^4}$$

$\varepsilon \rangle 1 \quad \longrightarrow \quad$ infazione troppo breve

$\varepsilon \langle 1 \quad \longrightarrow \quad$ infazione non finisce

Problemi dei modelli inflazionari

- Sintonizzazione fine del self-coupling

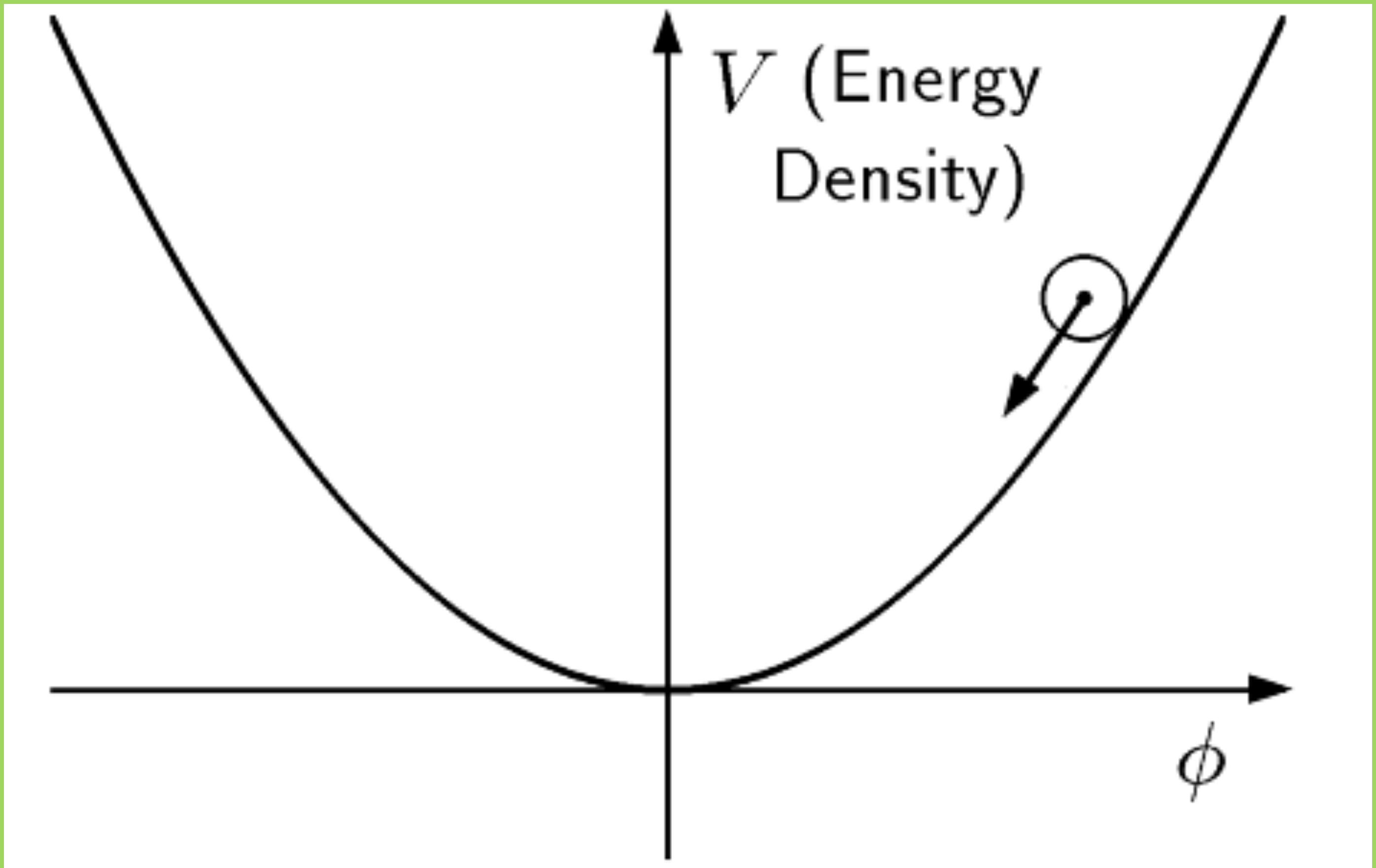
$$\lambda \langle 10^{-14}$$

- Piattezza del potenziale - modelli di Higgs.

- Condizione iniziale del campo intorno a

$\Phi = 0$.

Inflazione caotica

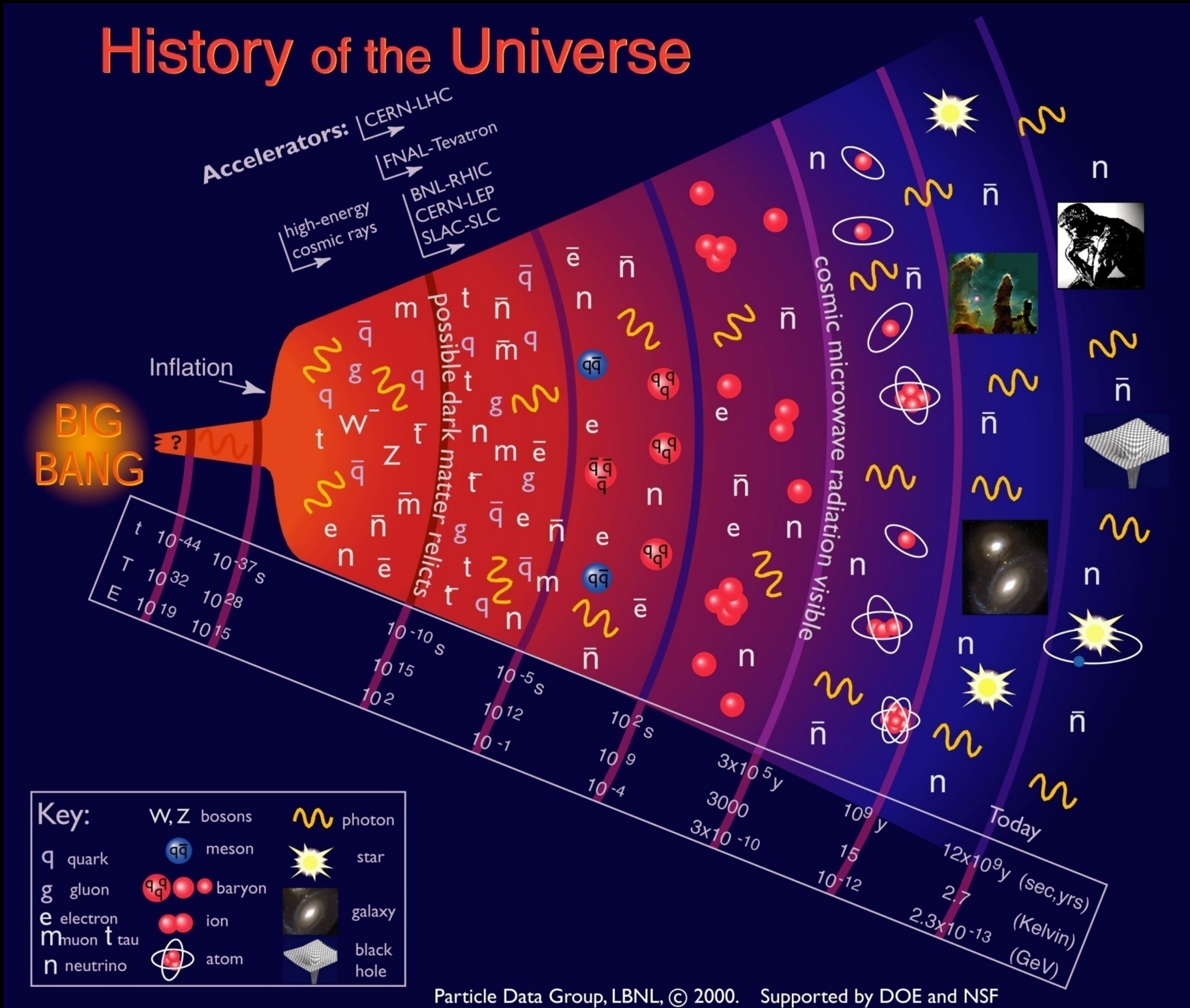


Problemi dei modelli inflazionari

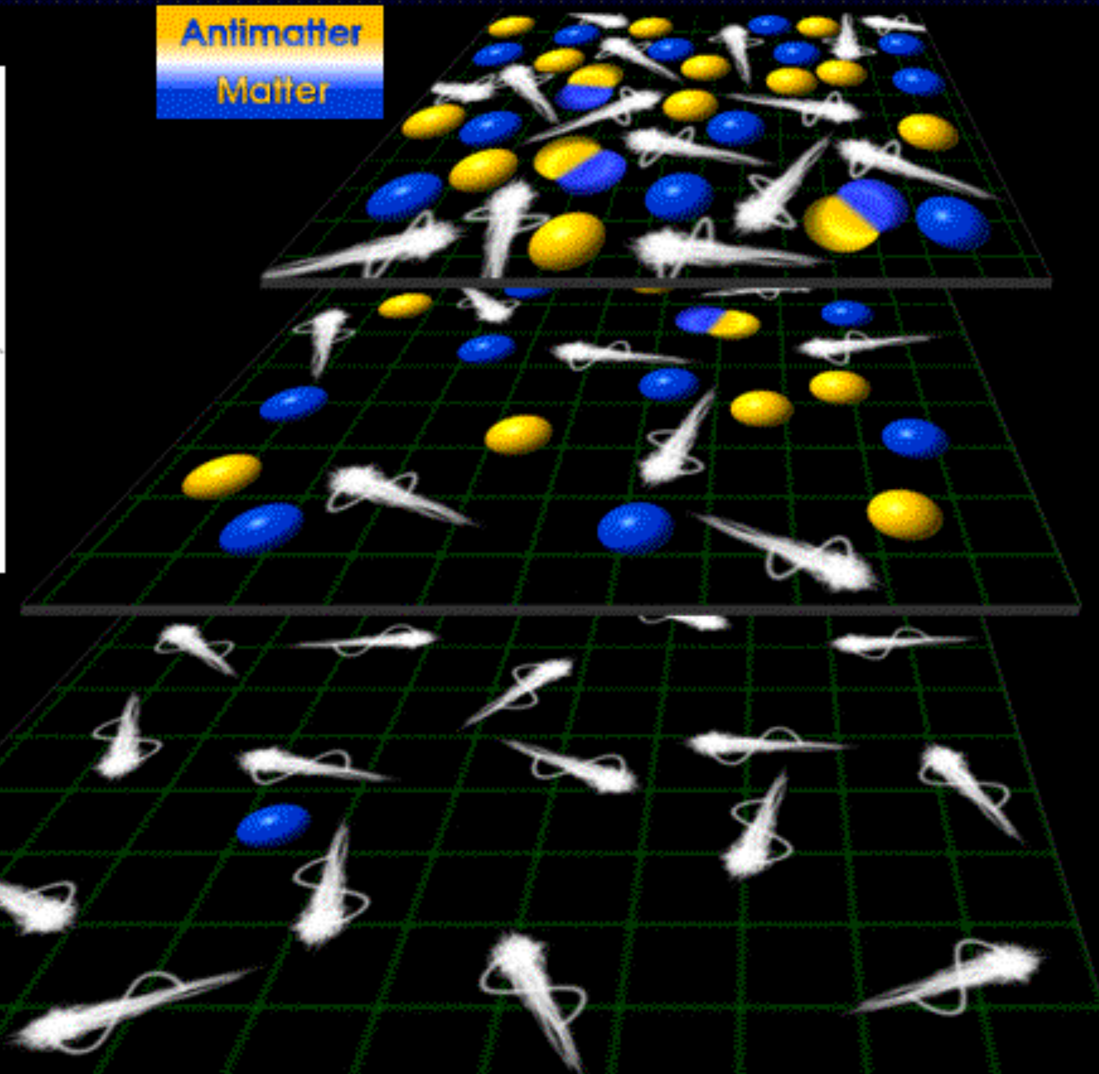
- “No - Hair theorem” generale in caso di spazi-tempi non-omogenei
- Il problema generale della costante cosmologica come energia del vuoto.
- Correzione dovute ad effetti di fisica planckiana o trans-planckiana
- Problemi termodinamici
- Natura del campo “inflatone”
- Il problema della singolarità iniziale permane

BICEPII - Polarizzazione del CMBR

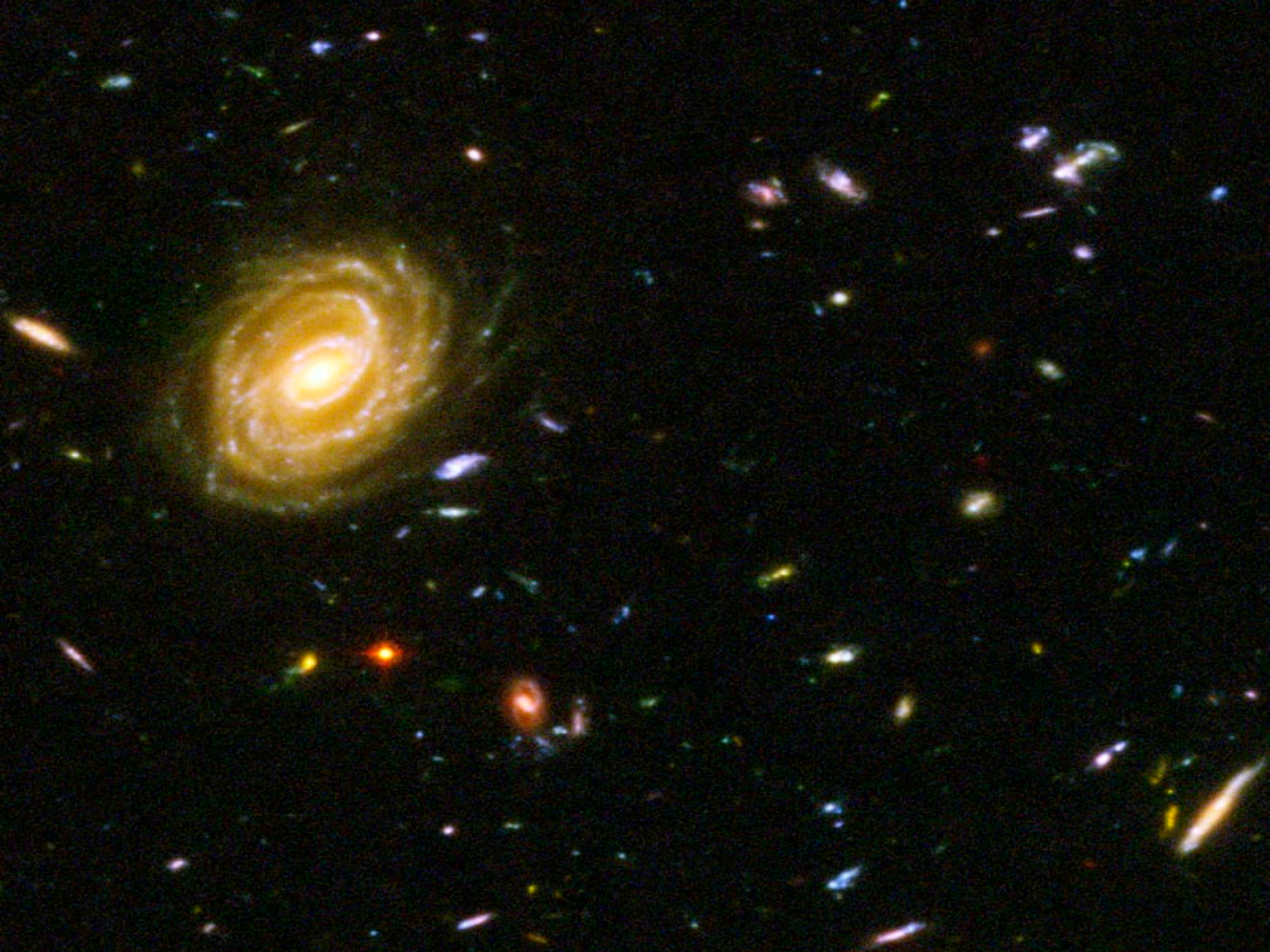
Background Imaging of Cosmic Extragalactic Polarization

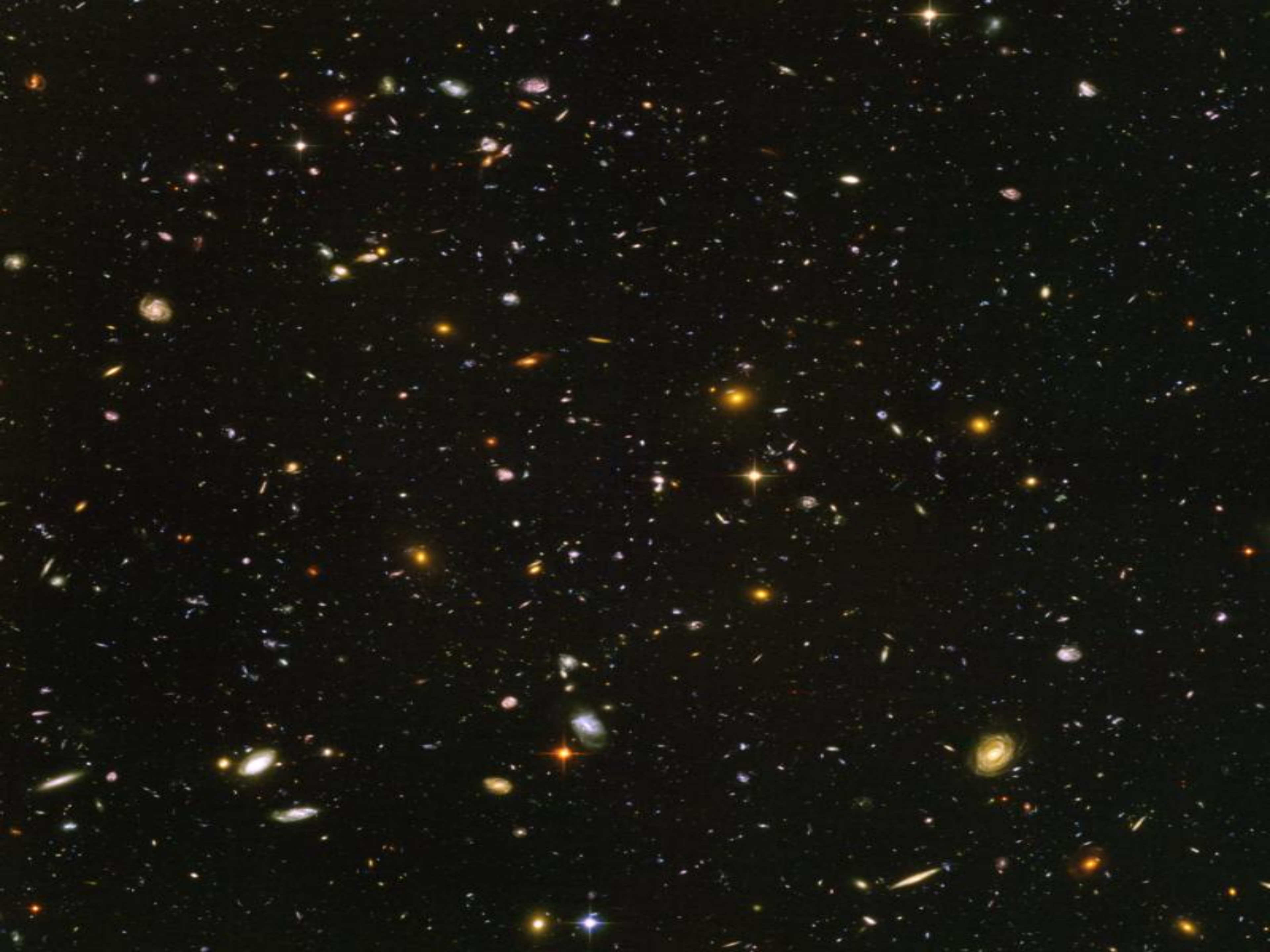

History of the Universe
Accelerators:
CERN-LHC
FNAL-Tevatron
BNL-RHIC
CERN-LEP
SLAC-SLC
high-energy cosmic rays
Inflation
BIG BANG
possible dark matter relicts
cosmic microwave radiation visible
t 10^-44 10^-37 s
T 10^32 10^28
E 10^19 10^15
10^-10 s
10^15
10^2
10^-5 s
10^12
10^-1
10^2 s
10^9
10^-4
3x10^5 y
3000
3x10^-10
10^9 y
15
10^-12
Today
12x10^9 y (sec,yrs)
2.7 (Kelvin)
2.3x10^-13 (GeV)
Key:
q quark
g gluon
e electron
m muon
t tau
n neutrino
W, Z bosons
meson
baryon
ion
atom
photon
star
galaxy
black hole
Particle Data Group, LBNL, © 2000. Supported by DOE and NSF

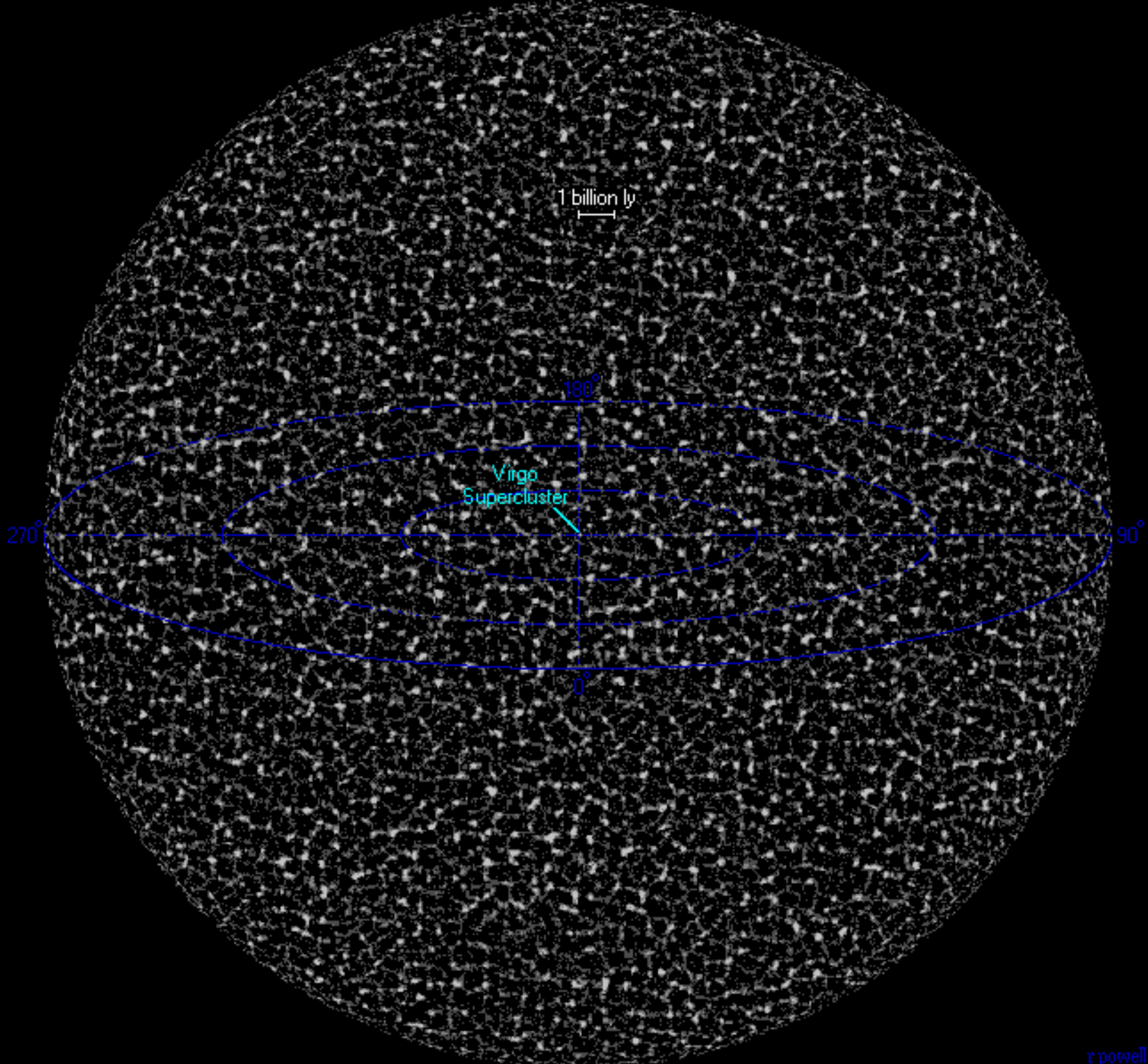
Matter-Antimatter Asymmetry of the Universe



Strutture cosmiche.

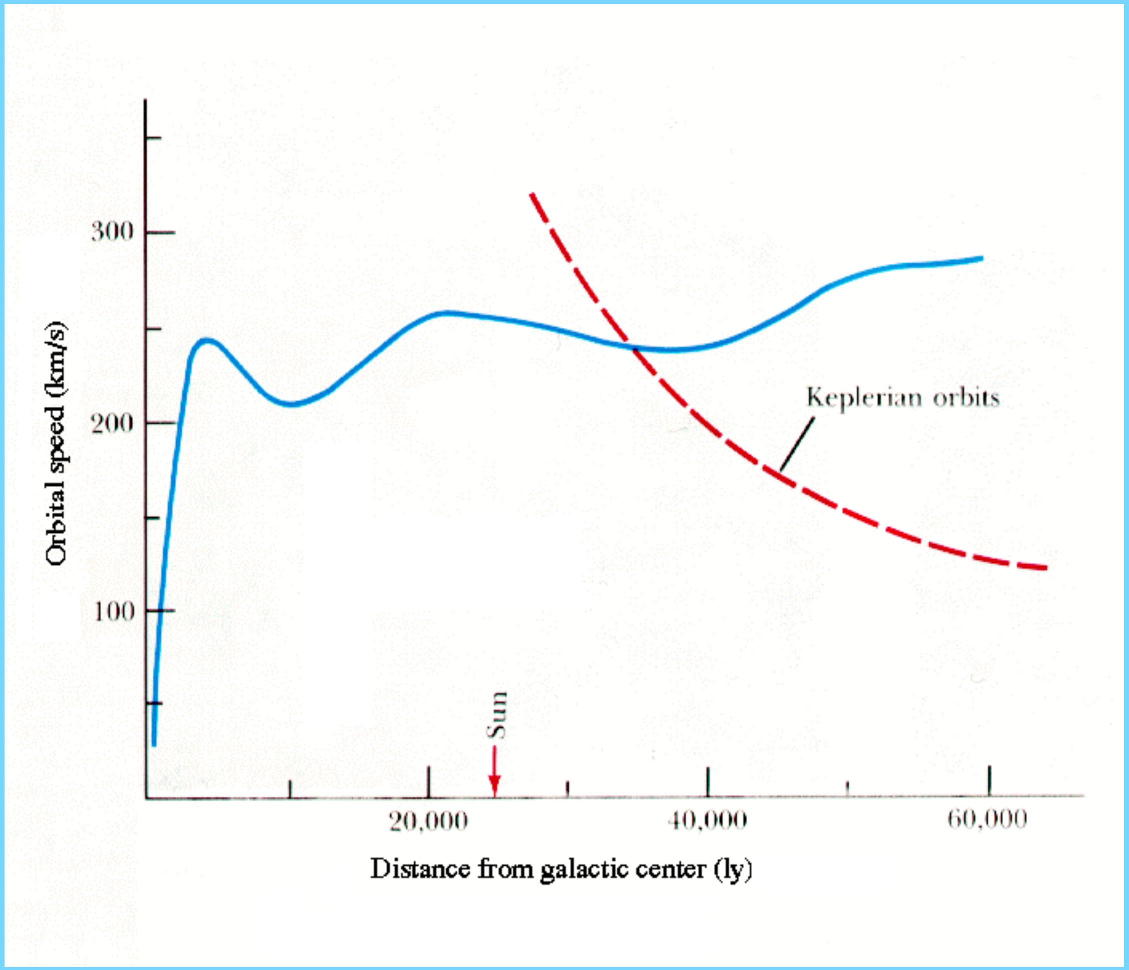


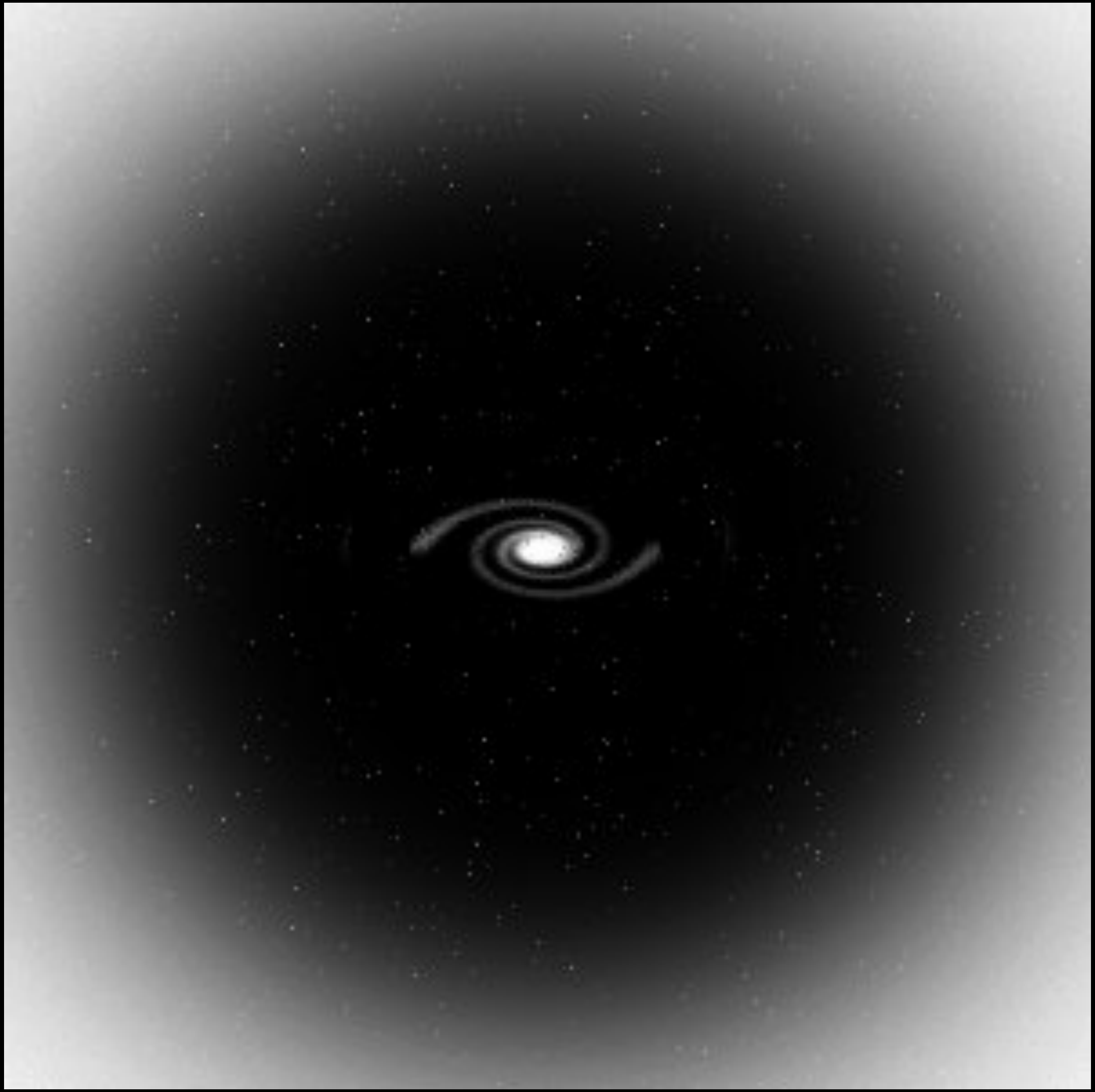




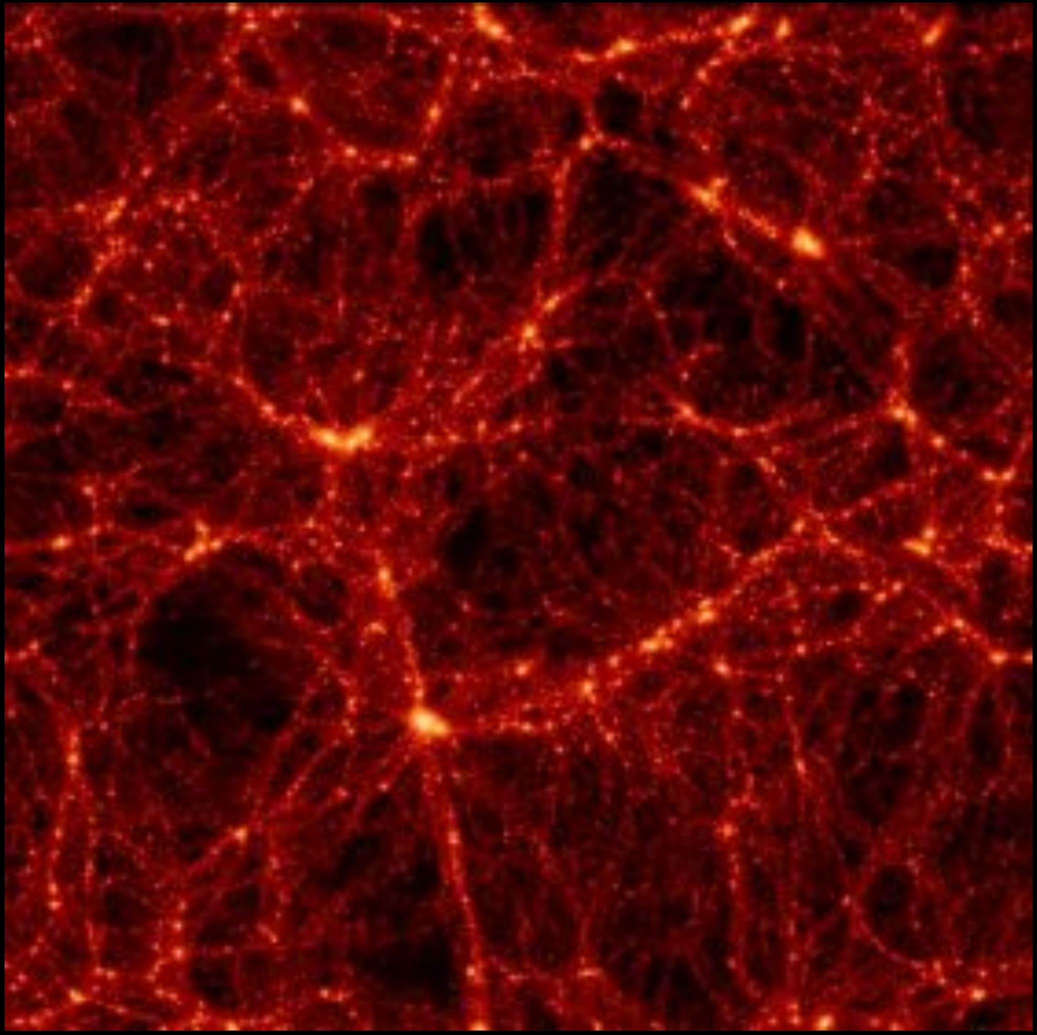
1 billion ly
180°
Virgo
Supercluster
270°
90°
0°
r powell

Il problema della materia oscura



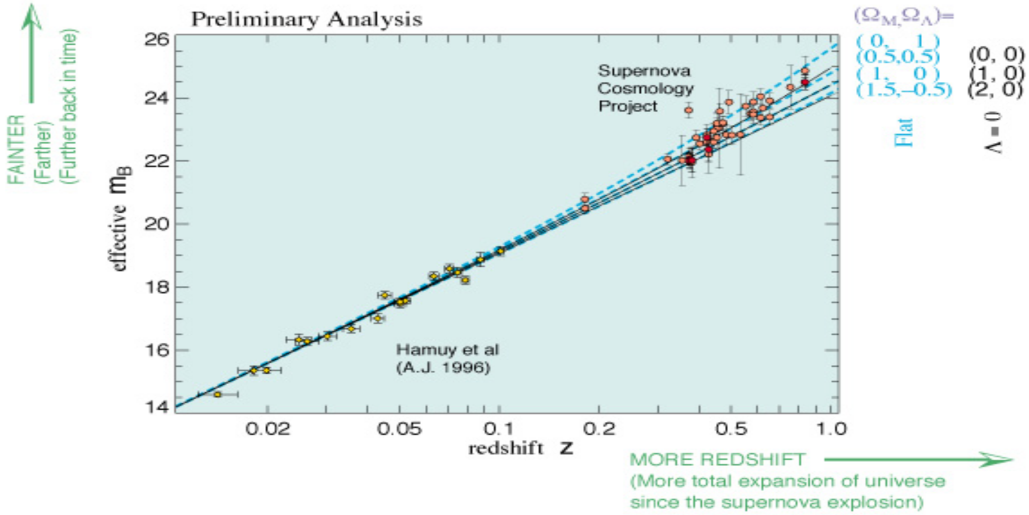


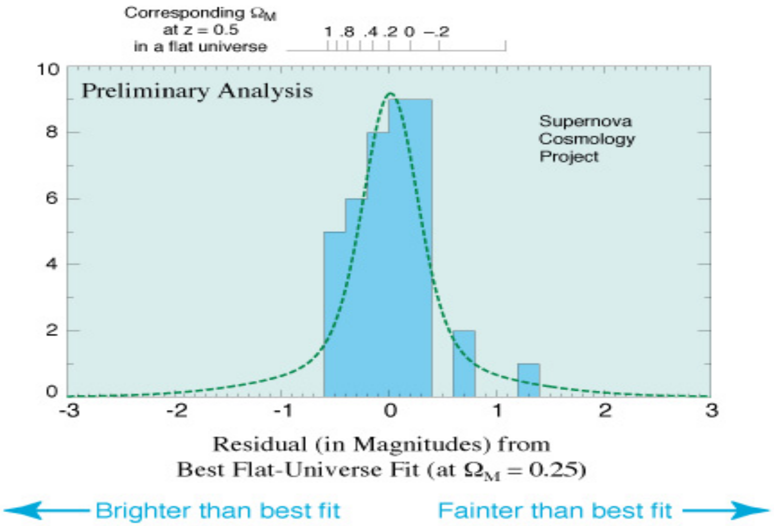
Max Planck Millenium Simulation



Accelerazione cosmica - energia oscura : Adam *Riess*, Saul *Perlmutter* and Brian *Schmidt*

Hubble Plots



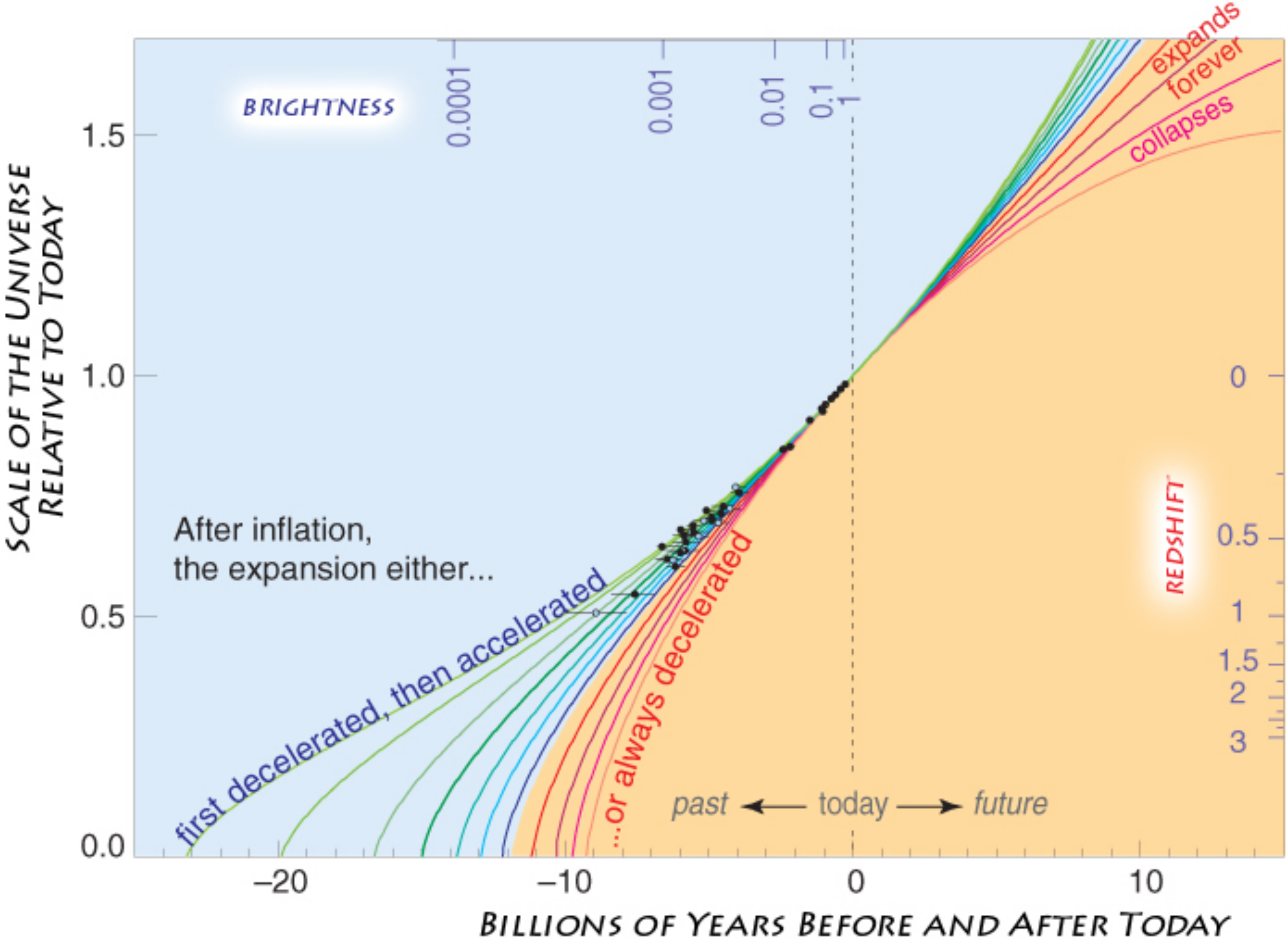


The Hubble diagram with the data from the supernovae already published (Perlmutter et al, Ap.J., 1997, with the supernovae at z ~ 0.4, and Perlmutter et al., Nature, 1998, with the supernova at z = 0.83) show as dark red circles with black outlines, and the next 35 supernovae shown as lighter red circles. The four dashed blue curves show the locus expected for a flat universe for four values of Ω_M (listed at right), and the three solid black curves are for a $\Lambda = 0$ universe. The lower plot is a histogram of residuals from the best fit values:

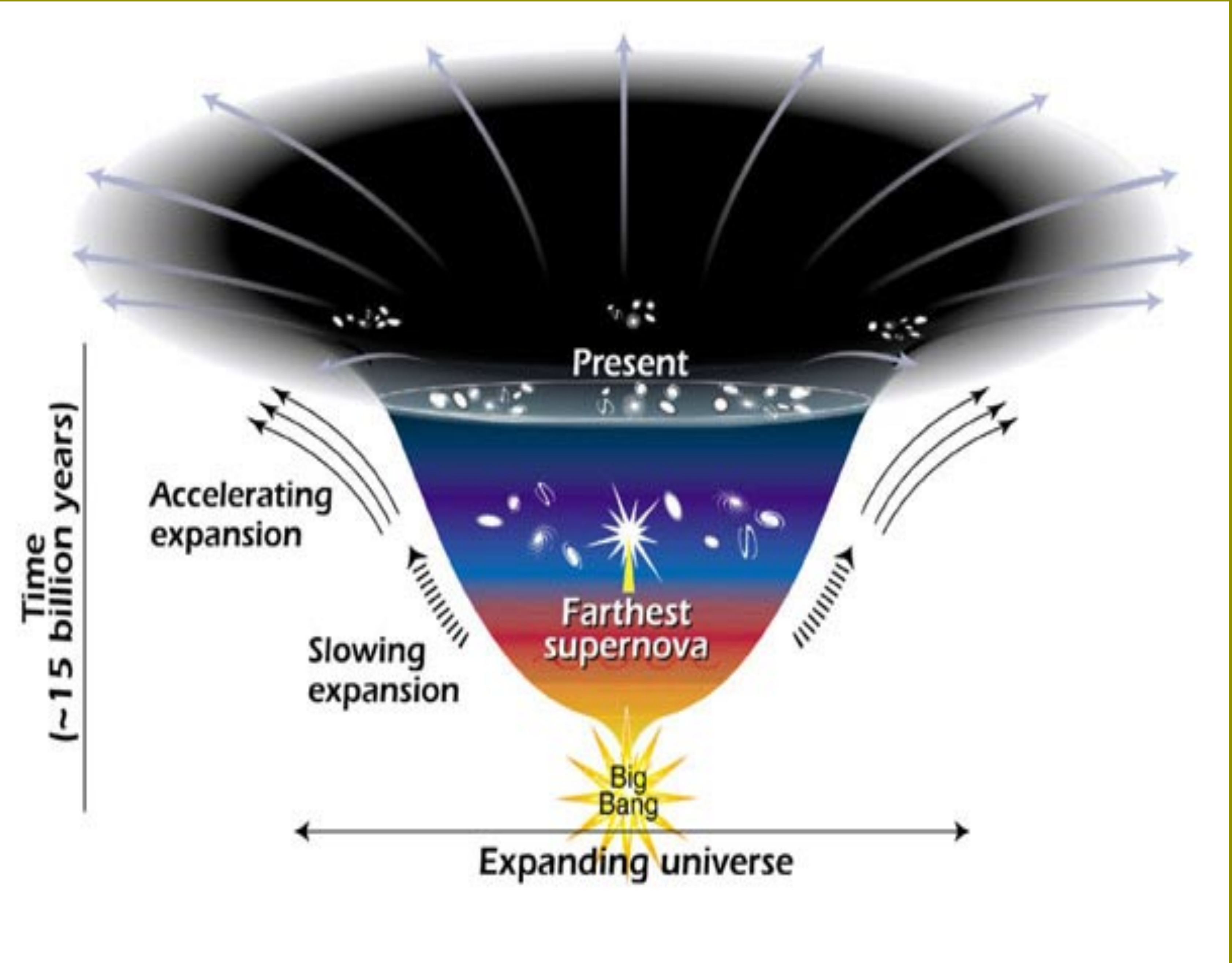
Flat universe: $\Omega_M = 0.25$ [± 0.06 statistical] [± 0.3 systematic]

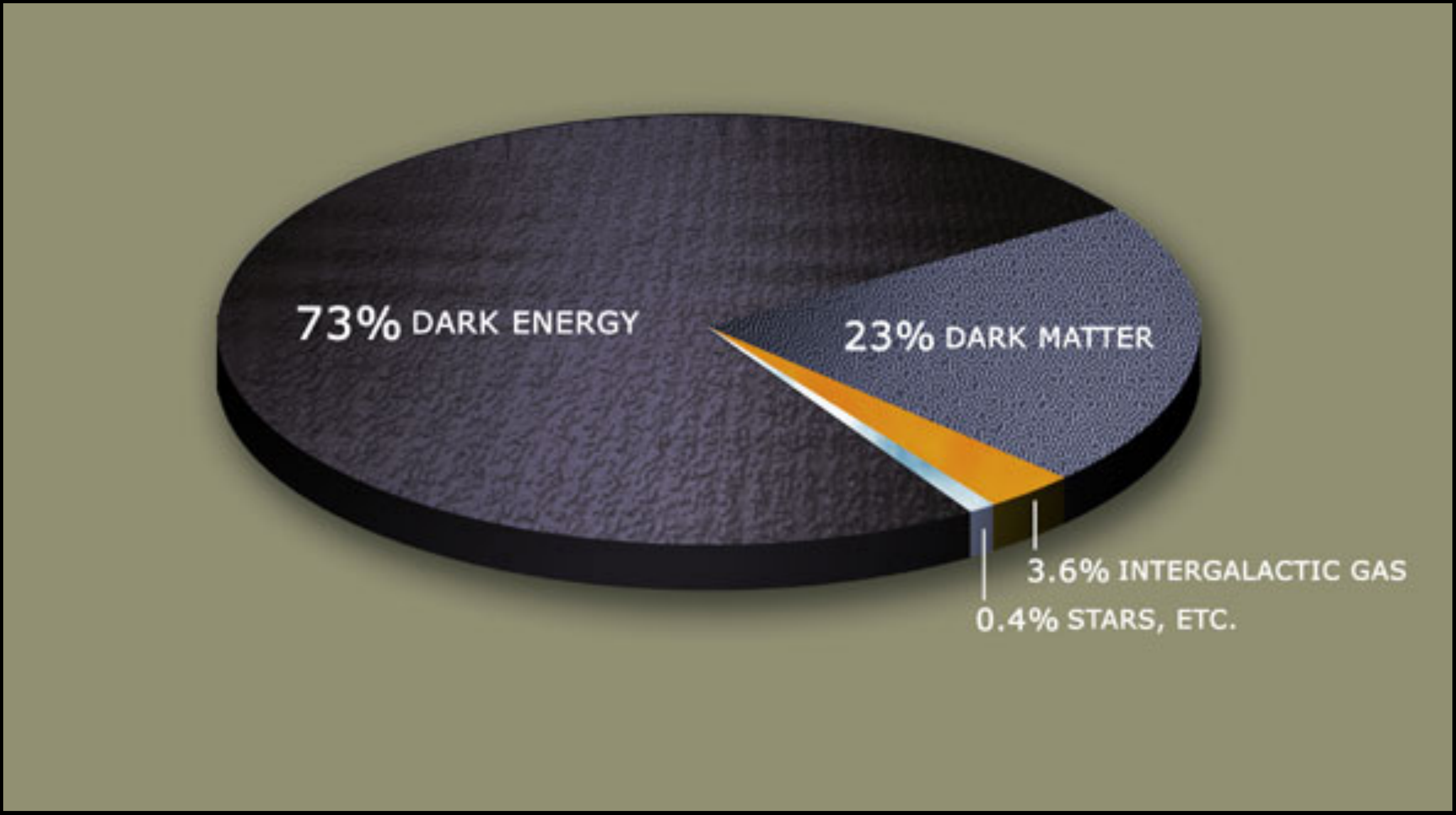
$\Lambda = 0$ universe: $\Omega_M = -0.4$ [± 0.1 statistical] [± 0.5 systematic]

The green dashed curve shows the distribution of residuals from this flat-universe fit expected, given the statistical uncertainties on the supernova apparent magnitudes (primarily due to sky-background photon noise). The systematic uncertainty quoted corresponds to a 0.2 magnitude uncertainty.

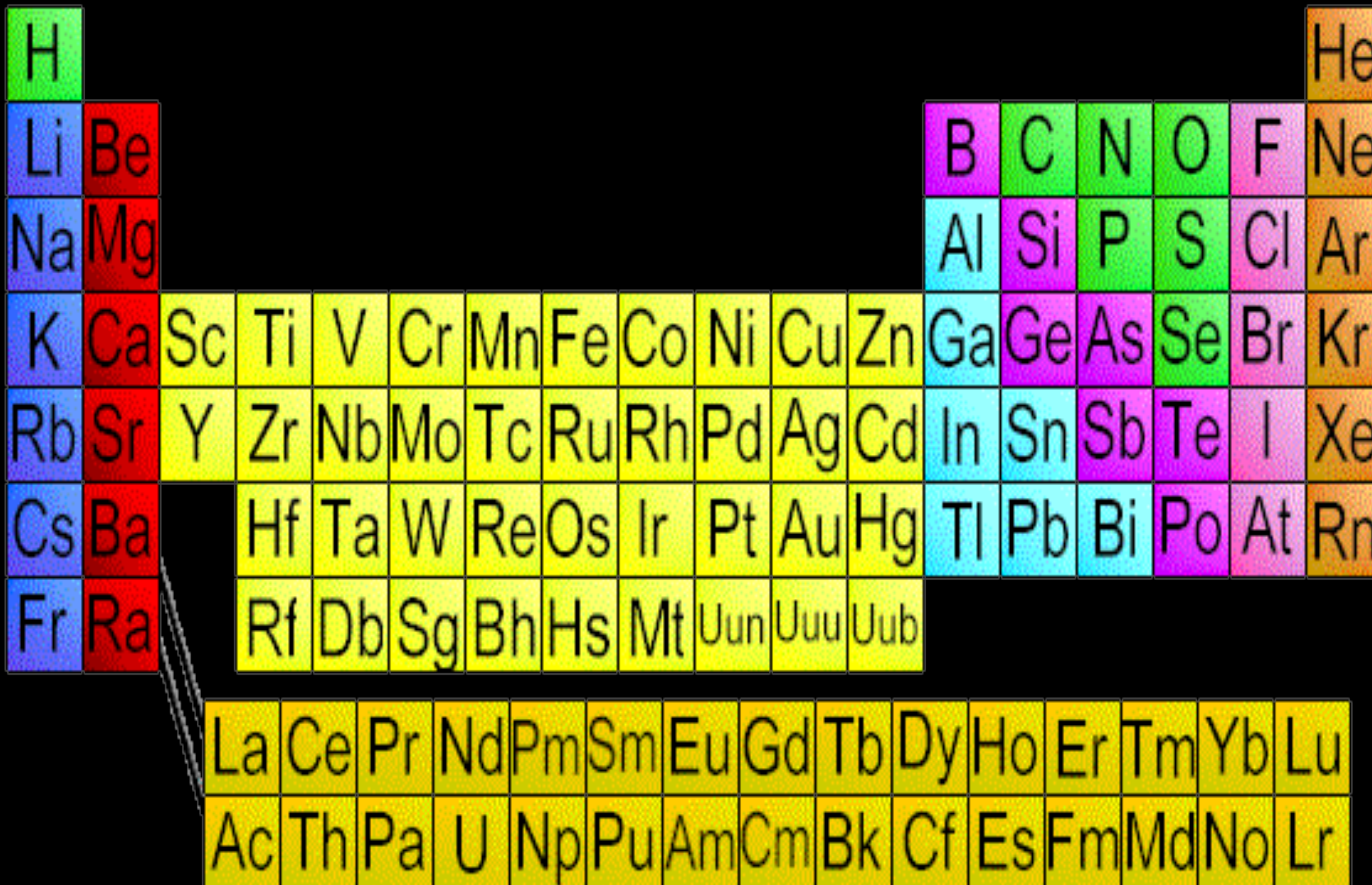


BRIGHTNESS
0.0001
0.001
0.01
0.1
1
1.5
1.0
0.5
0.0
SCALE OF THE UNIVERSE RELATIVE TO TODAY
expands forever
collapses
0
0.5
1
1.5
2
3
REDSHIFT
After inflation, the expansion either...
first decelerated, then accelerated
...or always decelerated
past
today
future
–20
–10
0
10
BILLIONS OF YEARS BEFORE AND AFTER TODAY

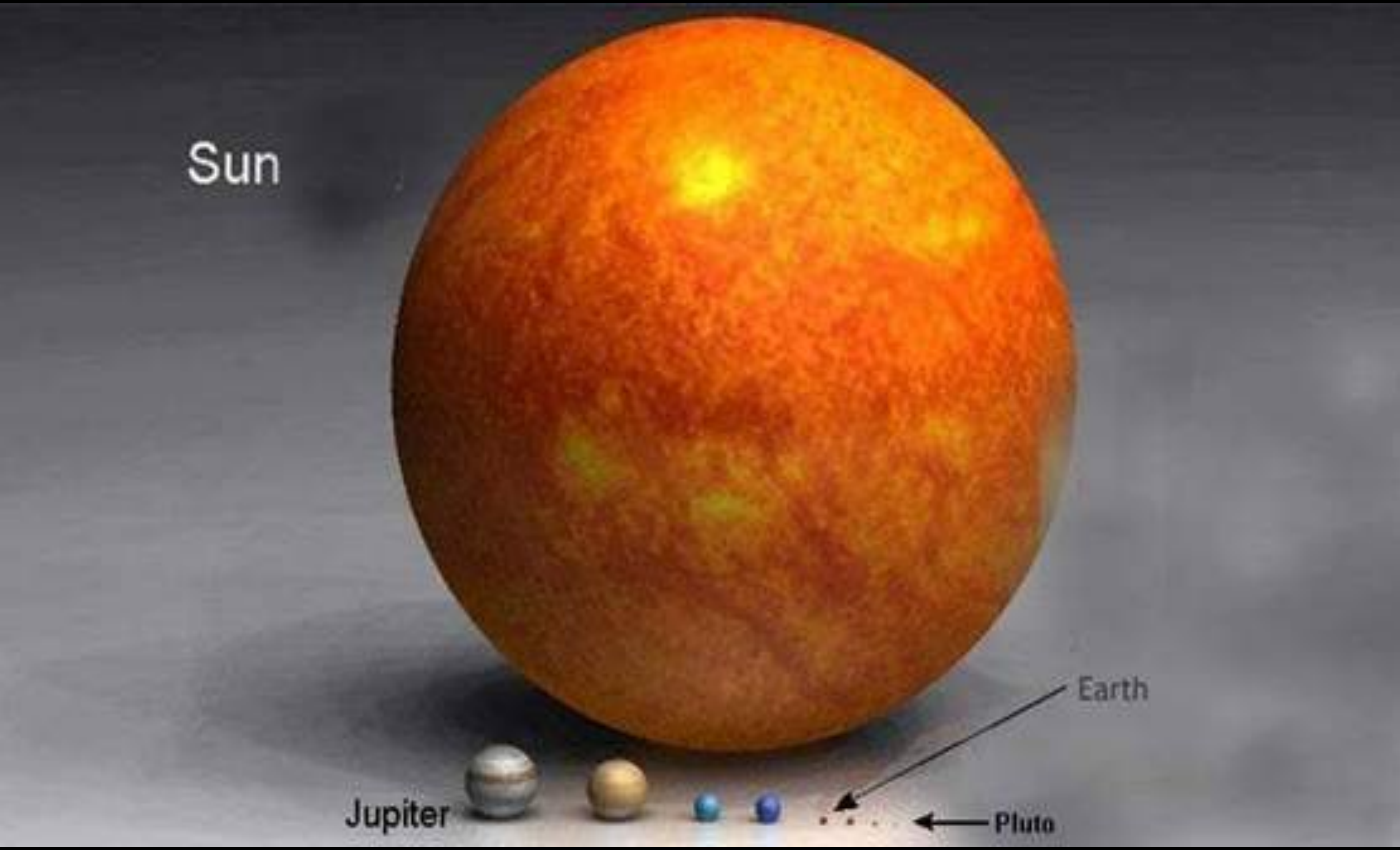

Present
Time
(~15 billion years)
Accelerating
expansion
Slowing
expansion
Farthest
supernova
Big
Bang
Expanding universe

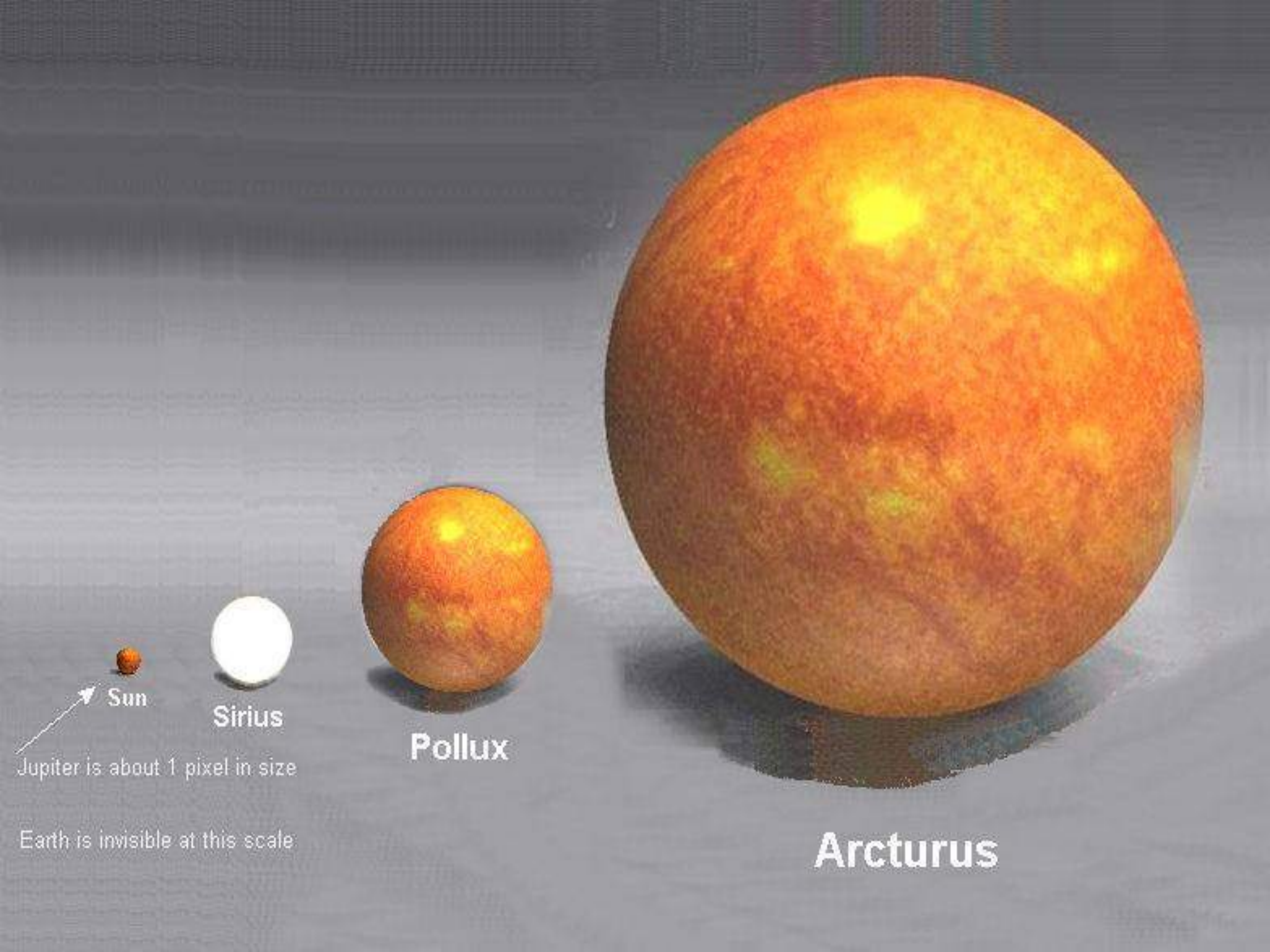


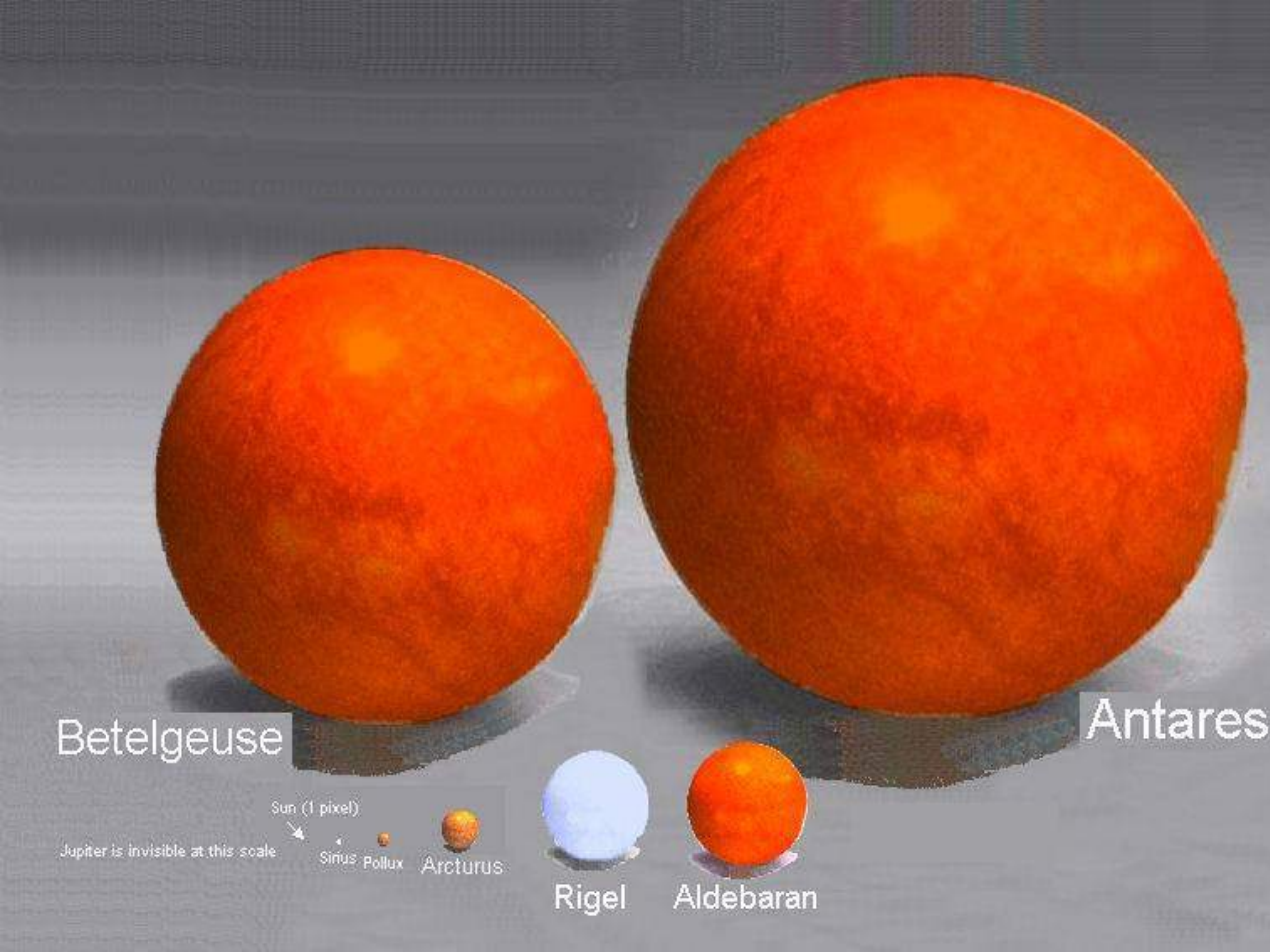
73% DARK ENERGY
23% DARK MATTER
3.6% INTERGALACTIC GAS
0.4% STARS, ETC.

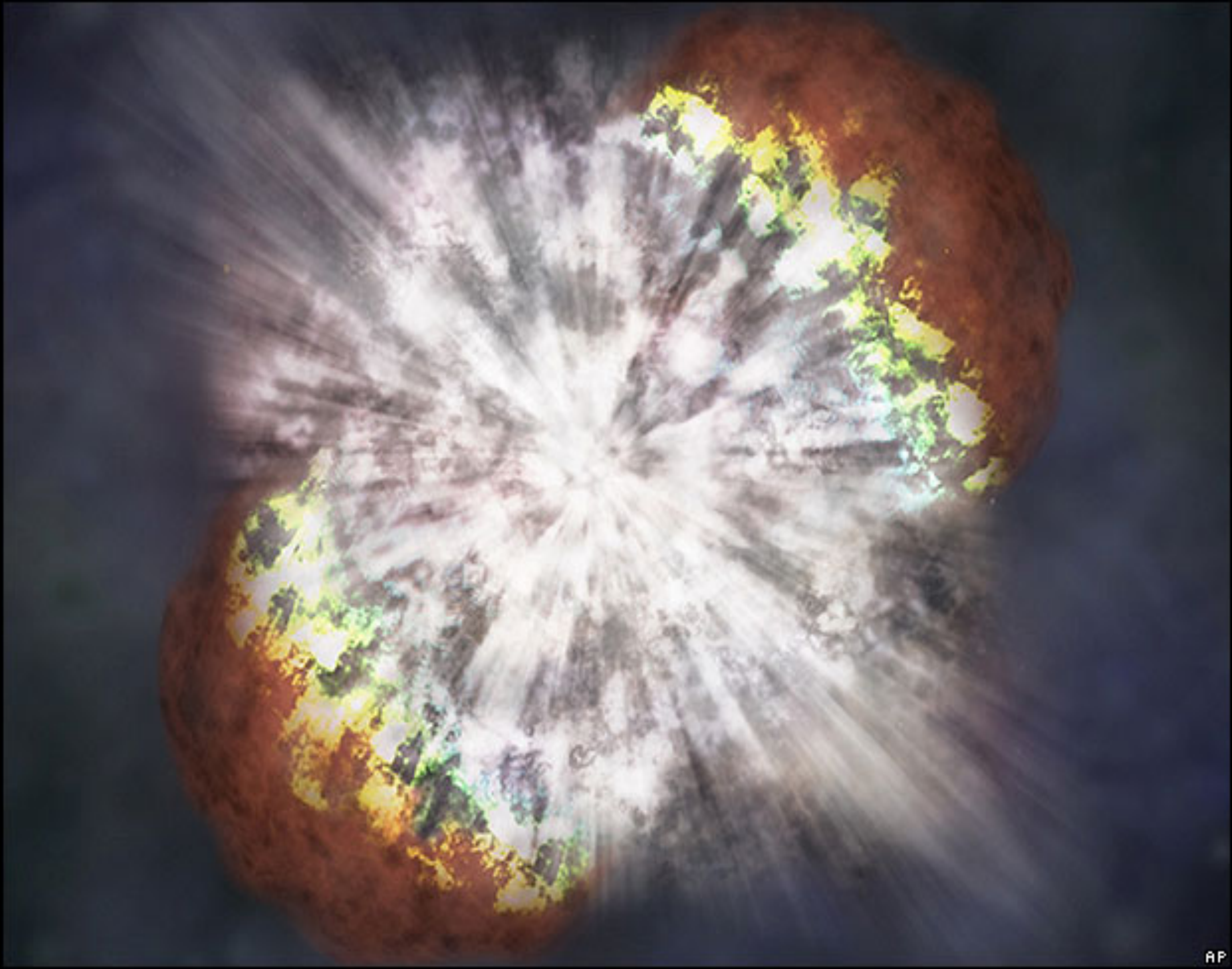

H He
Li Be B C N O F Ne
Na Mg Al Si P S Cl Ar
K Ca Sc Ti V Cr Mn Fe Co Ni Cu Zn Ga Ge As Se Br Kr
Rb Sr Y Zr Nb Mo Tc Ru Rh Pd Ag Cd In Sn Sb Te I Xe
Cs Ba Hf Ta W Re Os Ir Pt Au Hg Tl Pb Bi Po At Rn
Fr Ra Rf Db Sg Bh Hs Mt Uun Uuu Uub
La Ce Pr Nd Pm Sm Eu Gd Tb Dy Ho Er Tm Yb Lu
Ac Th Pa U Np Pu Am Cm Bk Cf Es Fm Md No Lr

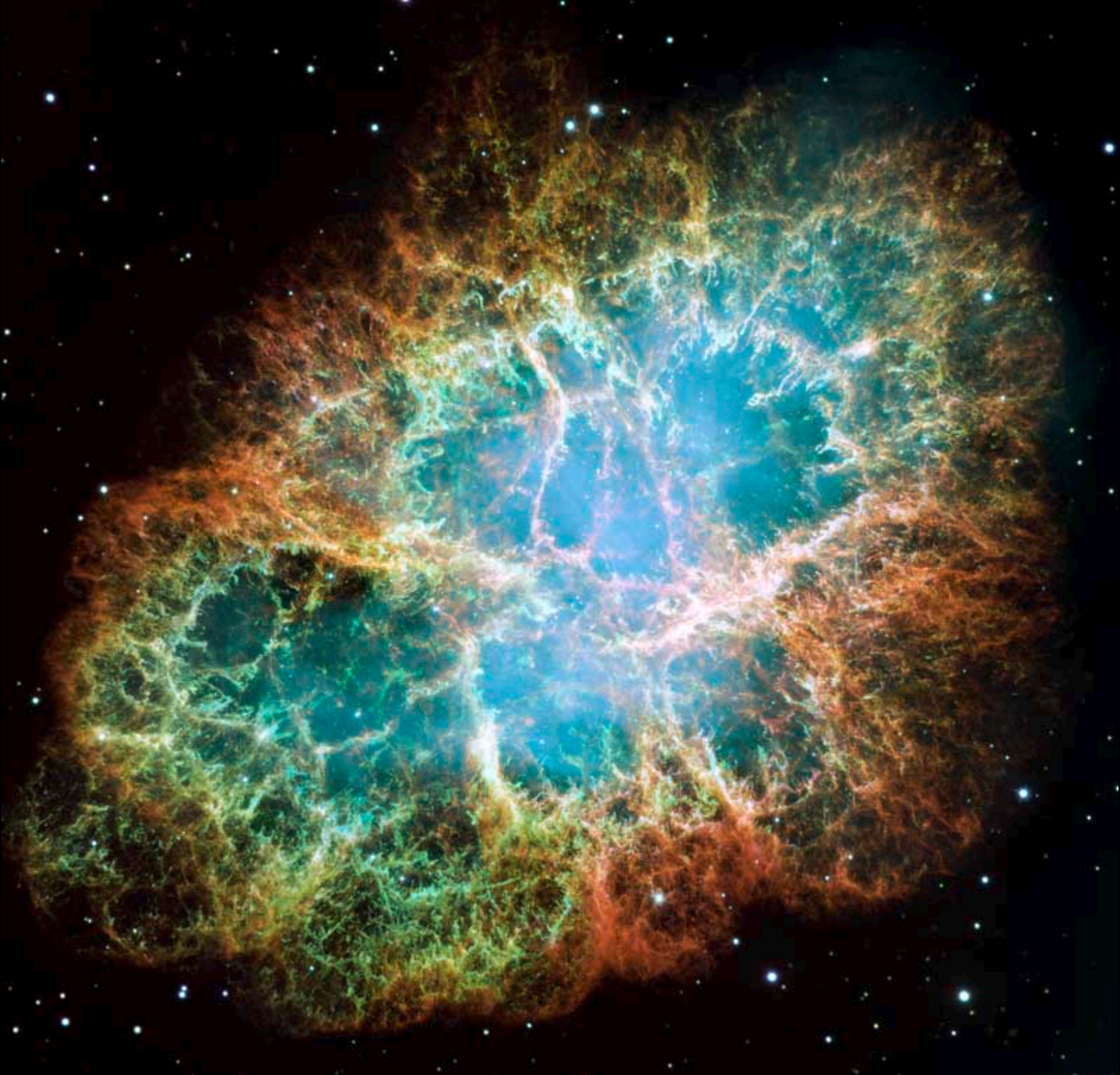
Arthur Eddington

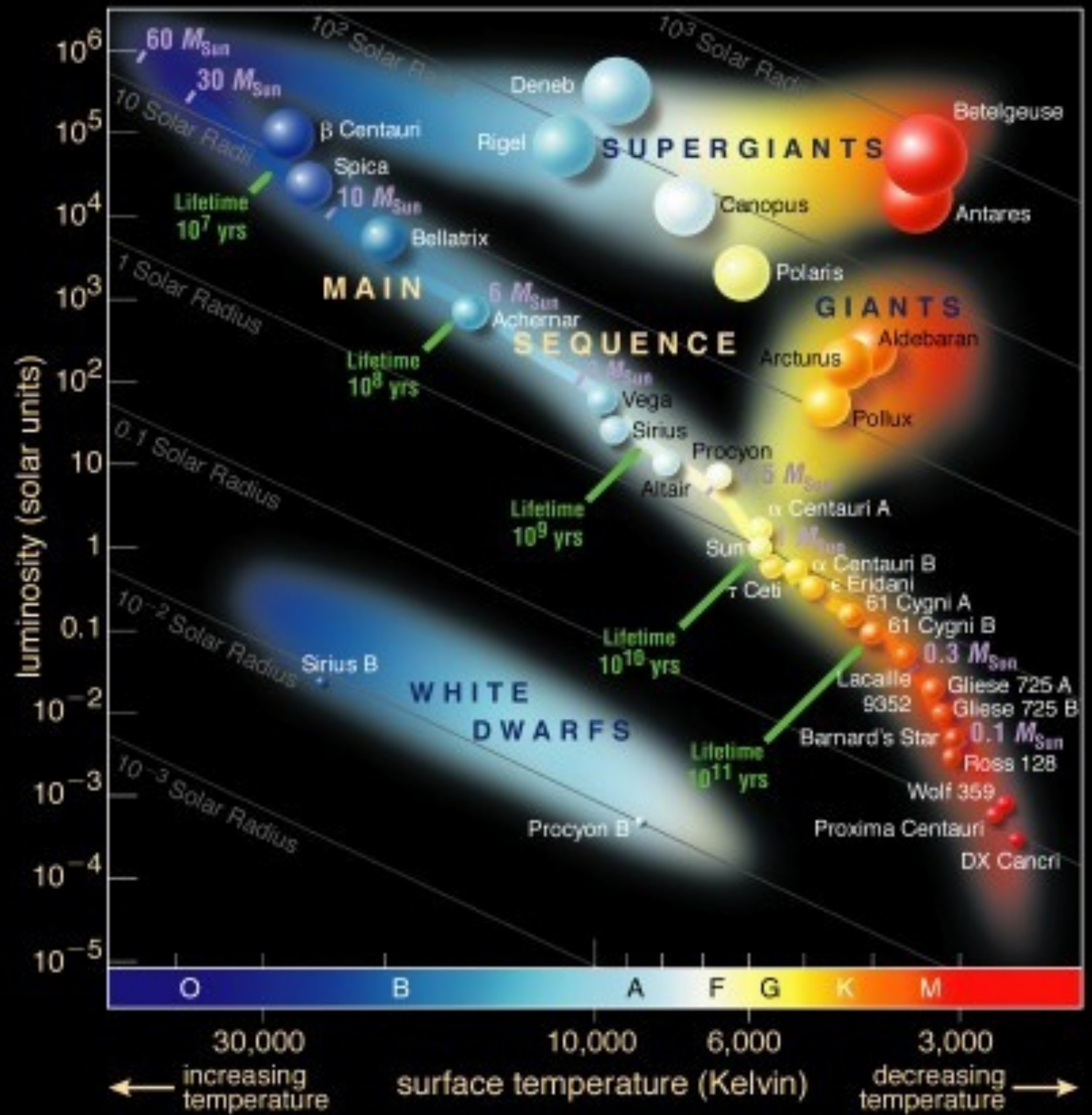

Sun
Earth
Jupiter
Pluto


Sun
Sirius
Pollux
Jupiter is about 1 pixel in size
Earth is invisible at this scale
Arcturus


Betelgeuse
Antares
Sun (1 pixel)
Jupiter is invisible at this scale
Sirius
Pollux
Arcturus
Rigel
Aldebaran


AP

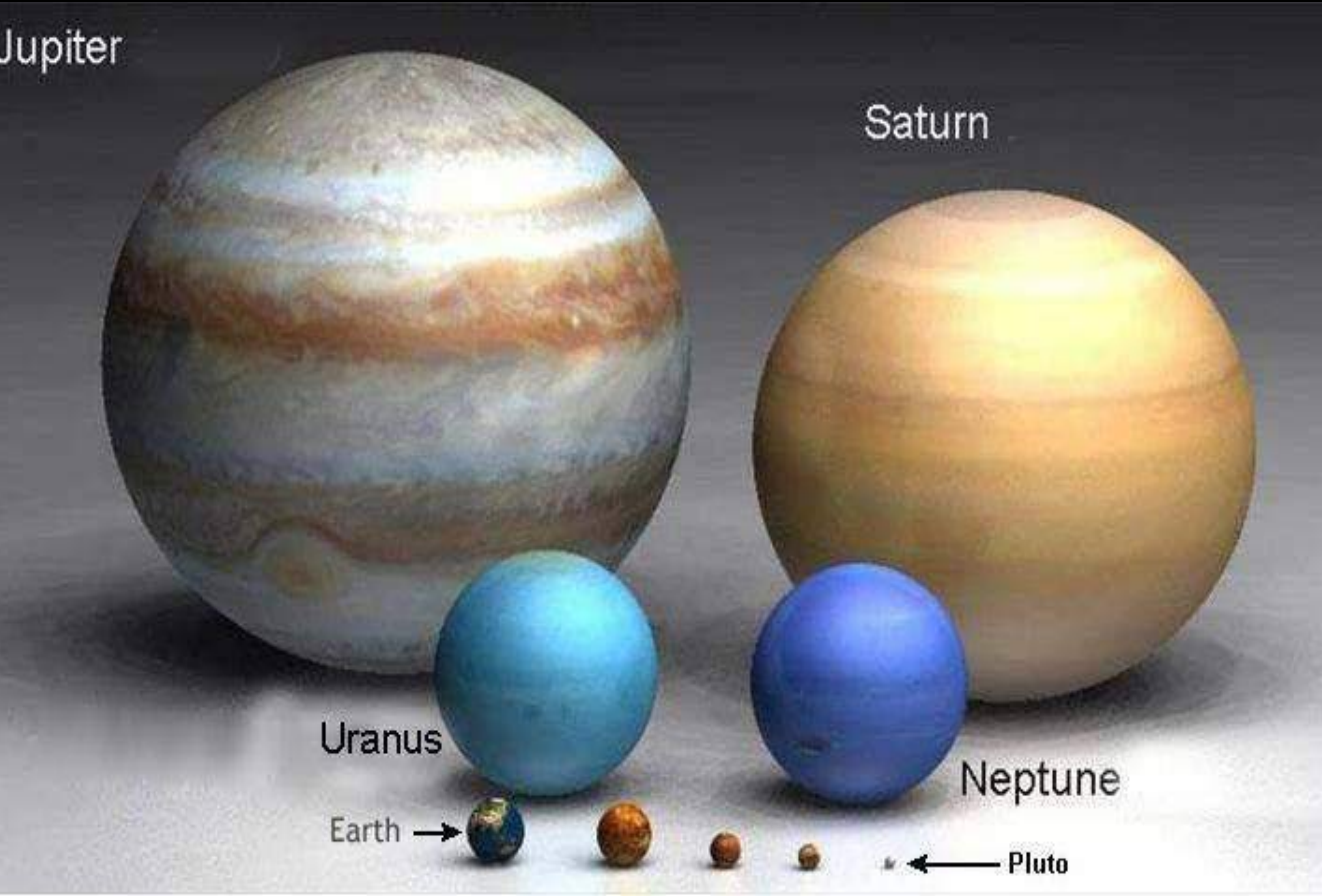



60 M_{Sun}
30 M_{Sun}
10 M_{Sun}
6 M_{Sun}
0.3 M_{Sun}
0.1 M_{Sun}
10^2 Solar Radii
10^3 Solar Radii
10 Solar Radii
1 Solar Radius
0.1 Solar Radius
10^{-2} Solar Radius
10^{-3} Solar Radius
SUPERGIANTS
GIANTS
MAIN
SEQUENCE
WHITE
DWARFS
Deneb
Rigel
Betelgeuse
Antares
Canopus
Polaris
β Centauri
Spica
Bellatrix
Achernar
Aldebaran
Arcturus
Pollux
Vega
Sirius
Procyon
Altair
α Centauri A
Sun
α Centauri B
ε Eridani
τ Ceti
61 Cygni A
61 Cygni B
Lacaille 9352
Gliese 725 A
Gliese 725 B
Barnard's Star
Ross 128
Wolf 359
Proxima Centauri
DX Cancri
Sirius B
Procyon B
Lifetime 10^7 yrs
Lifetime 10^8 yrs
Lifetime 10^9 yrs
Lifetime 10^{10} yrs
Lifetime 10^{11} yrs
luminosity (solar units)
10^6
10^5
10^4
10^3
10^2
10
1
0.1
10^{-2}
10^{-3}
10^{-4}
10^{-5}
O
B
A
F
G
K
M
30,000
10,000
6,000
3,000
increasing temperature
surface temperature (Kelvin)
decreasing temperature

Protoplanetary Disks
Orion Nebula

HST • WFPC2

PRC95-45b • ST ScI OPO • November 20, 1995
M. J. McCaughrean (MPIA), C. R. O'Dell (Rice University), NASA


Jupiter
Saturn
Uranus
Neptune
Earth
Pluto

Valore delle costanti fondamentali – il principio antropico

Boltzman's constant	$k = 1.38 \times 10^{-23}$ j/°K
Planck's constant	$h = 6.63 \times 10^{-34}$ J/s
Speed of light	$c = 3.00 \times 10^{8}$ m/s
Gravitational constant	$G = 6.67 \times 10^{-11} \dfrac{N - m^2}{kg^2}$