Past, Present and Future of the Expanding Universe

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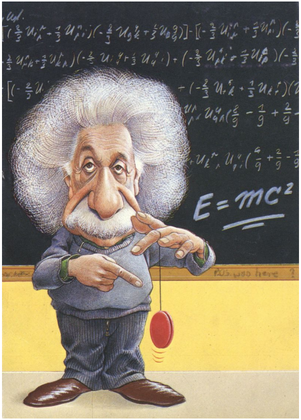
Talk presented at TEDA College on the occasion of its Tenth Anniversary

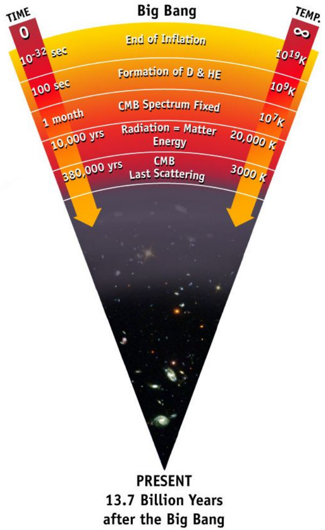
October 17, 2010

Motto



Make things as simple as possible, but not simpler!

Introduction



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- planets, stars, galaxies and clusters of galaxies

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- Many more nuclear fusion reactions

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- The mass of a white dwarf cannot exceed 1.44 $M_{\odot}$ (Nobel prize Chandrasekhar 1930).

Distances

earth – sun	8 Lmin
next fixed star	4 Ly
to center of galaxy	25 kLy
M31 (Andromeda galaxy)	2.2 MLy
Ia-Supernova 1994D	50 MLy
AM 0644-741 (ring galaxy)	300 MLy
Hubble Deep Field Survey	several GLy
Abell 1835	$\approx$ 13 GLy

M83

M83, diameter 60 thousand light years

Andromeda nebula

2.2 million light years

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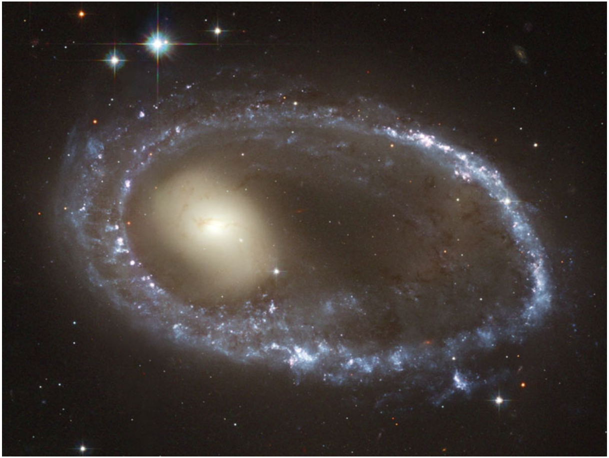
- When surpassing 1.44 $M_{\odot}$ there will be a Ia supernova with allways the same time profile and absolute brightness (standard candle).
- If absolute and apparent brightness are known, the distance of the Ia supernova can be worked out.

IaSN 1994D

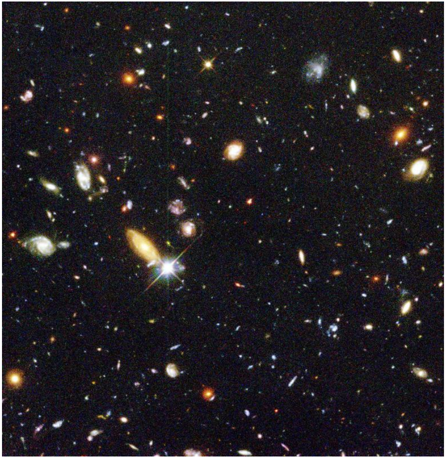
60 million light years away

Ring galaxy



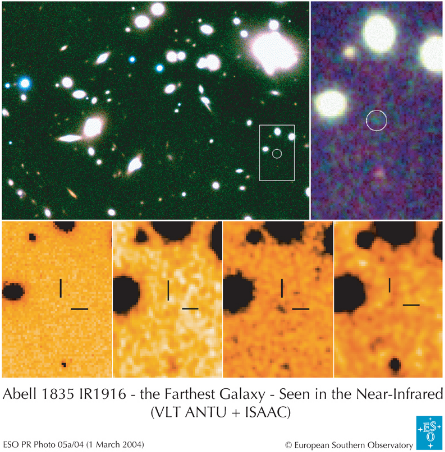
300 million light years away

Hubble Deep Field Survey



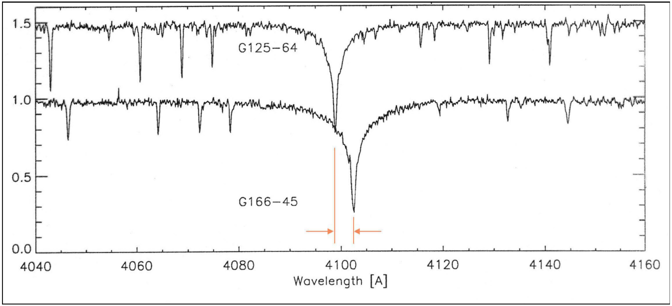
10 days light collection, more than one billion light years deep.

Abell 1835



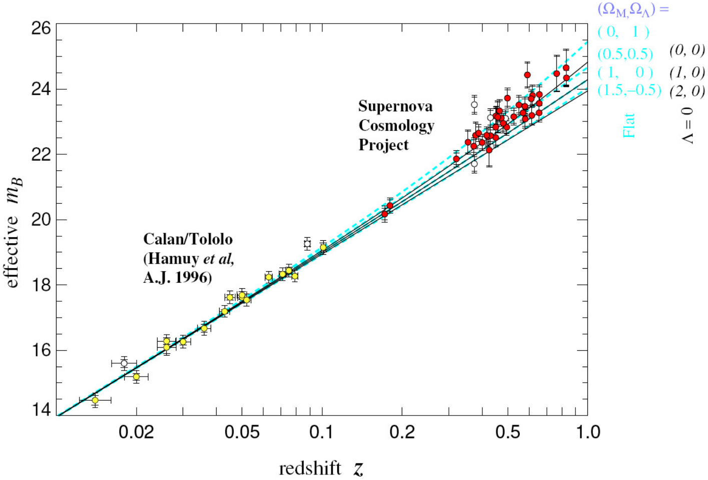
approximately 13 billion light years

Spectral lines



redshift $z = \dfrac{\lambda' - \lambda}{\lambda}$

Red shift


$(\Omega_M, \Omega_\Lambda) =$
(0, 1)
(0.5,0.5)
(1, 0)
(1.5,–0.5)
(0, 0)
(1, 0)
(2, 0)
Flat
Λ = 0
Supernova Cosmology Project
Calan/Tololo (Hamuy et al, A.J. 1996)
effective m_B
redshift z
26
24
22
20
18
16
14
0.02
0.05
0.1
0.2
0.5
1.0

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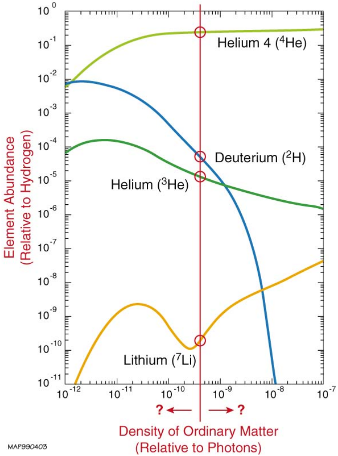
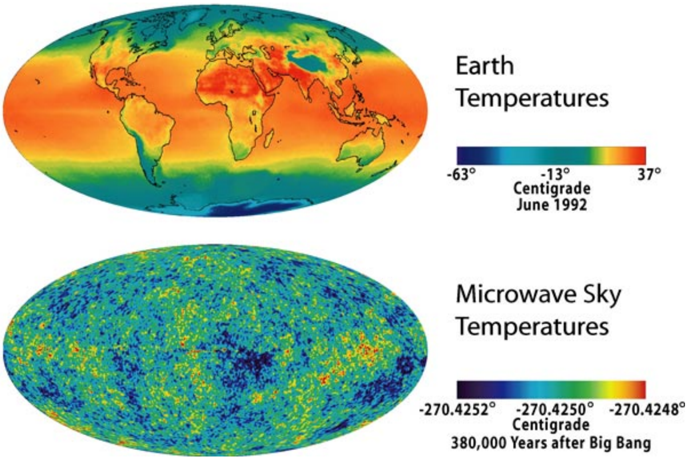
- Unavoidable conclusion: *Big Bang*

Synthesis in an early stage of the universe



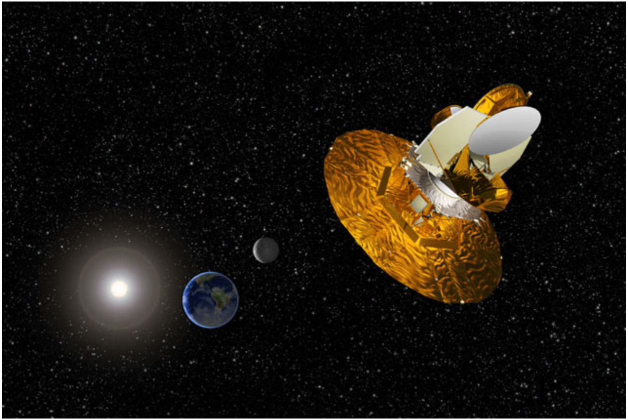
Synthesis in the early universe

Microwave background radiation



Wilkinson Microwave Asymmetry Probe (WMAP), NASA, 2003

WMAP sattelite



Orbits the sun in sync with earth, four times moon distance

Four important facts

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Four important facts

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- Also the cosmic background radiation (afterglow) is isotropic.
- Abundance of elements indicates extreme temperature of the early universe.

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- Cosmological principle: all locations and all directions are equivalent.

Space, time and matter

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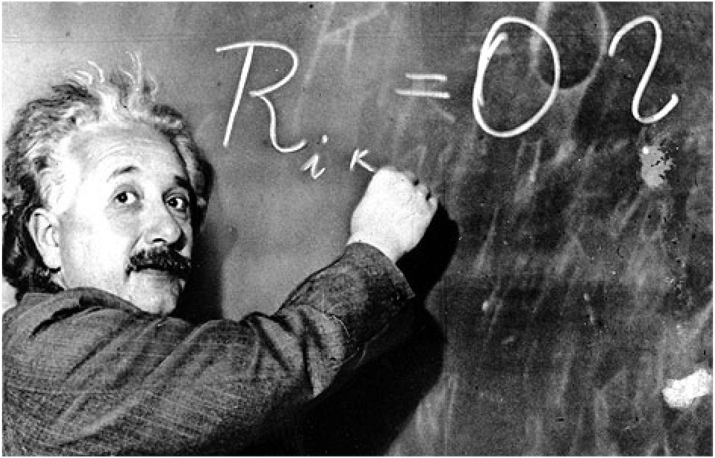
- which are defined by the metric (see above)

Can you still follow me?



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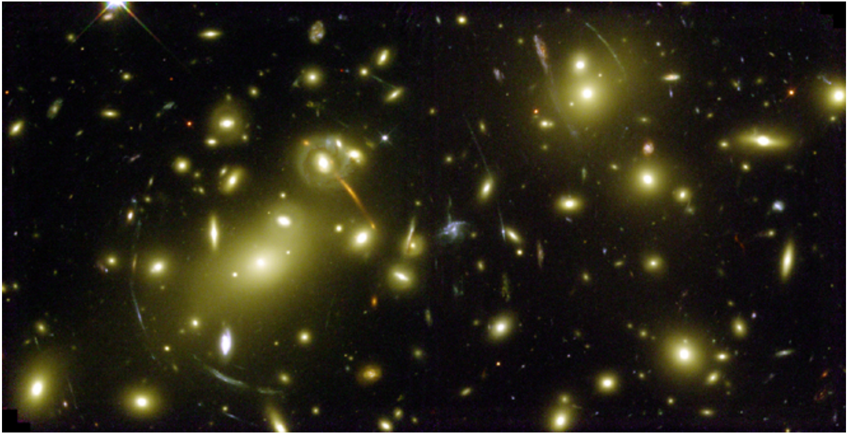
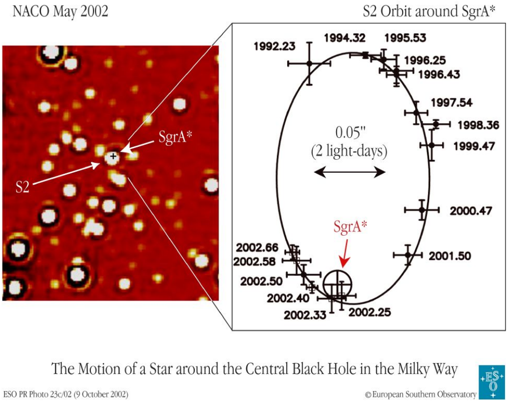


Black hole in the center of our Galaxy



Orbit in 15 years, closest distance 17 light hours, more than four million sun masses

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- mass density ρ and pressure p (equation of state) must be known

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- Radiation decoupled from matter after 380 thousand years.

History

Big Bang	13.7 GY
solar system	4.6 GY
first protozoae	3.5 GY
vertebrates	500 MY
flowering plants	100 MY
mammals	50 MY
Homo habilis	2 MY
Homo sapiens	200 kY
early civilizations	5 kY

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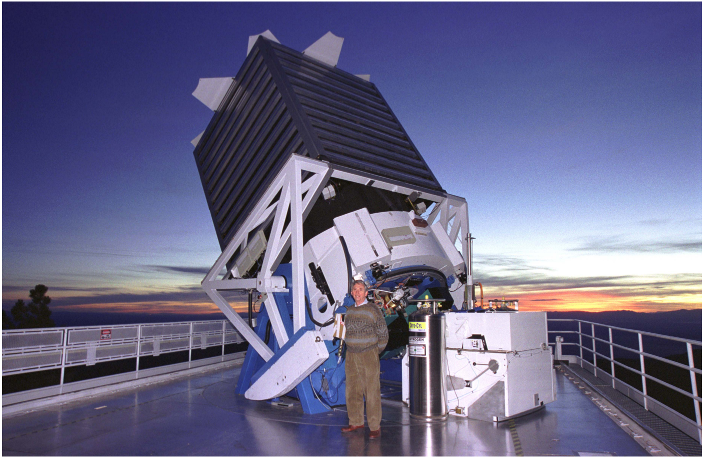

Planck

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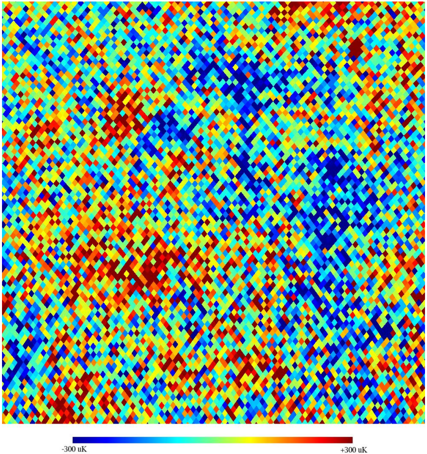
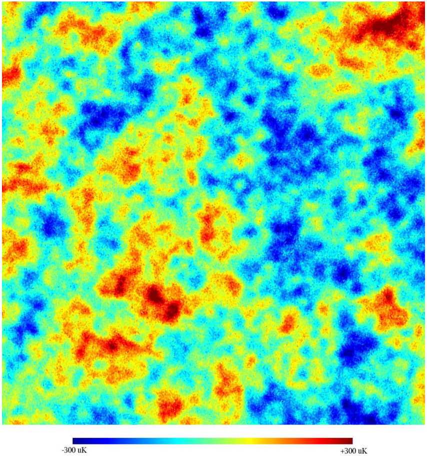
- however: enormous amount of data

WMAP detail



Temperature fluctuations - detail of the WMAP map

Planck detail



Temperature fluctuations - as Planck will see it

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- causes 73% of the expansion of the universe!
- Virtual particle/antiparticle pairs? Vacuum zero point energy?

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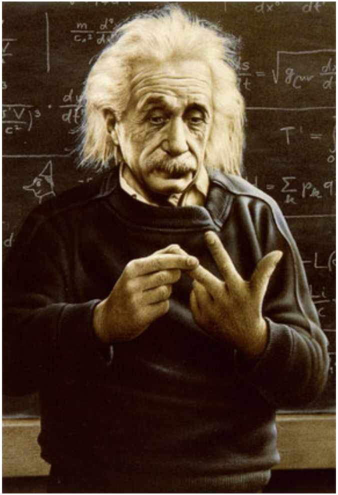
- . . . or even more exotic quantum effects?



The most incomprehensible thing about the world is that it is at all comprehensible.