Chapter 1

Introduction

Some history

Ptolemäus (85 – 165 b.c.)	**antropocentric view; earth = centre of the universe**
Kopernicus (1473 – 1543)	**earth and planets orbit the sun**
Kepler (1571 – 1630)	**elliptical orbits**
Newton (1643 – 1727)	**laws of gravity**
Kant (1724 – 1630)	**Milky Way = island of stars**
Herschel (1738 – 1822)	**Milky Way is disk-like**
Einstein (1917)	**GRT; gravitation ↔ curved space-time, i.e. matter distorts space-time; first triumph: light deflection by sun (1919)**
Friedmann (1922) **Lemaître (1927)**	**static & expanding solutions of Einstein's field equations**

Some history

Hubble (1929)	**discovery of cosmic expansion**
Oort (1932) **Zwicky (1933)**	**Dark Matter in Coma Cluster of galaxies**
Gamow (1948)	**formation of light elements in the universe; prediction of CMB as relict of BB**
Penzias & Wilson (1965)	**discovery of 3K CMB**
COBE (1992)	**CMB spectrum is perfectly Planckian; anisotropy of CMB is $\Delta T/T \leq 10^{-5} \Rightarrow$ DM on cosmic scales**
WMAP (2003)	**power spectrum of CM; "precision cosmology"; detection of CMB polarization**

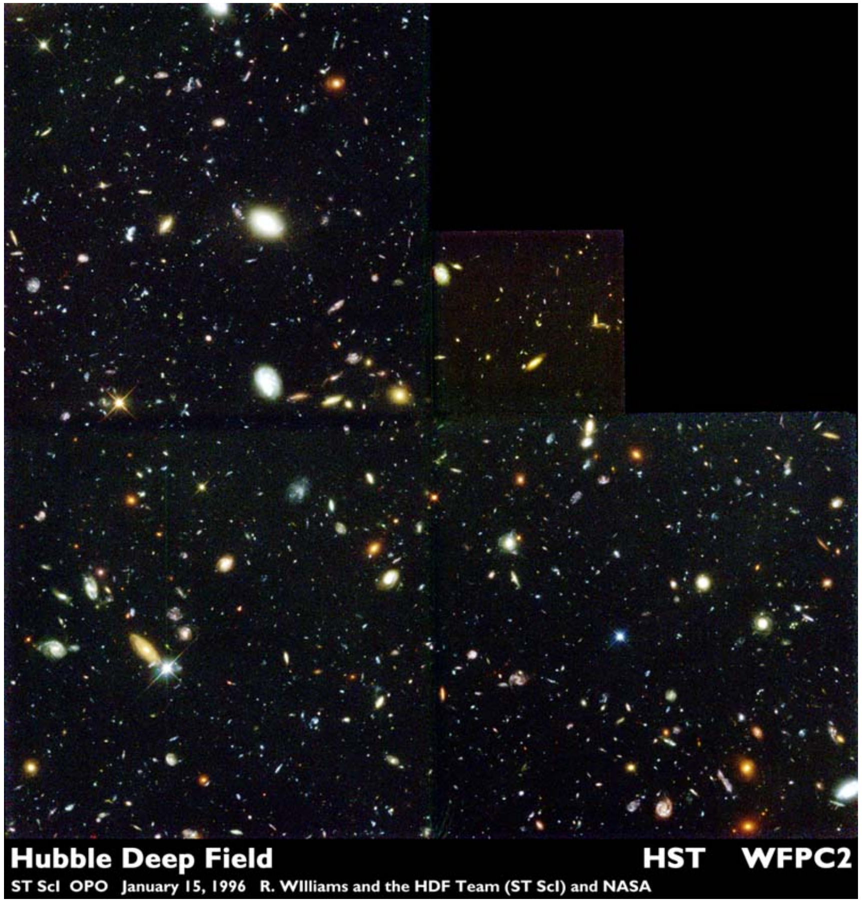
Galaxies

10^{11} stars
10^{5} light years diameter

a few thousand galaxies
a few Mpc diameter

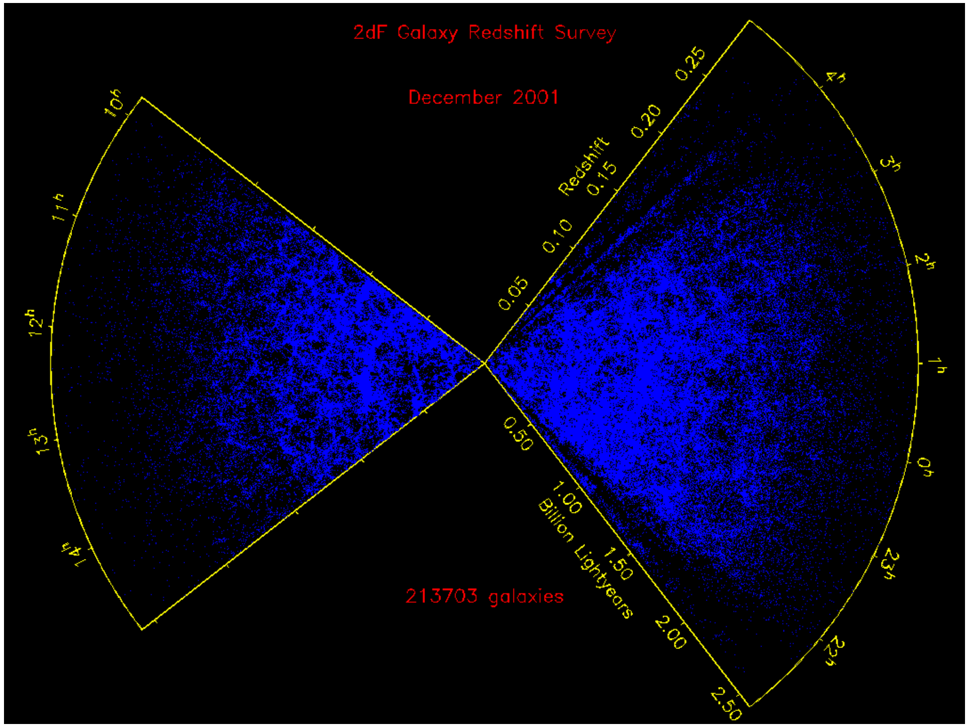
The Hubble Deep Field

the Hubble Space Telescope

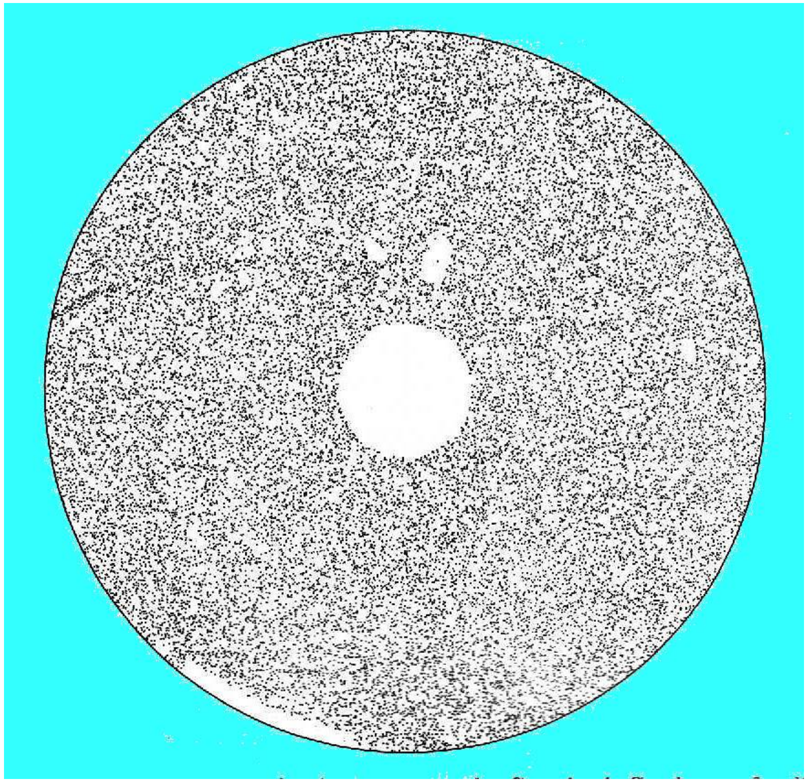


140" $\rightarrow$ 3.6 $\cdot 10^{-8}$ of total sky
~ 3500 galaxies!

Isotropy

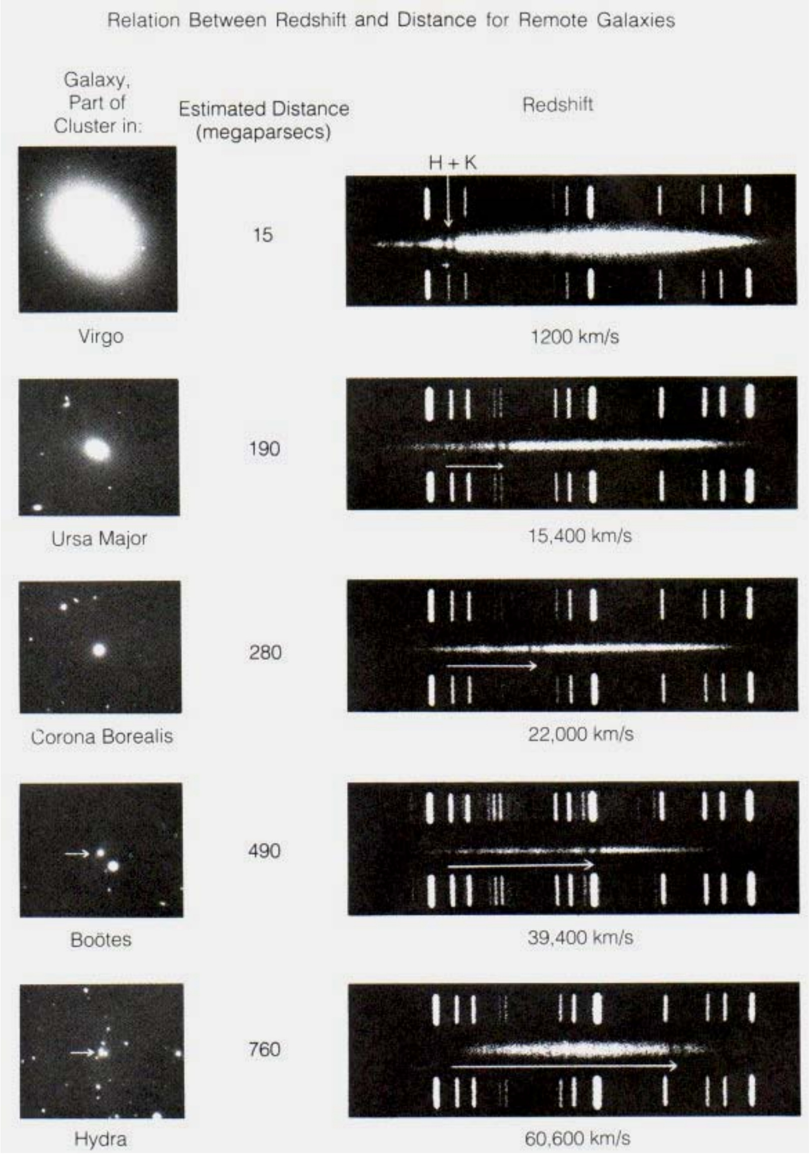


2dF redshift survey
~ 200000 galaxies



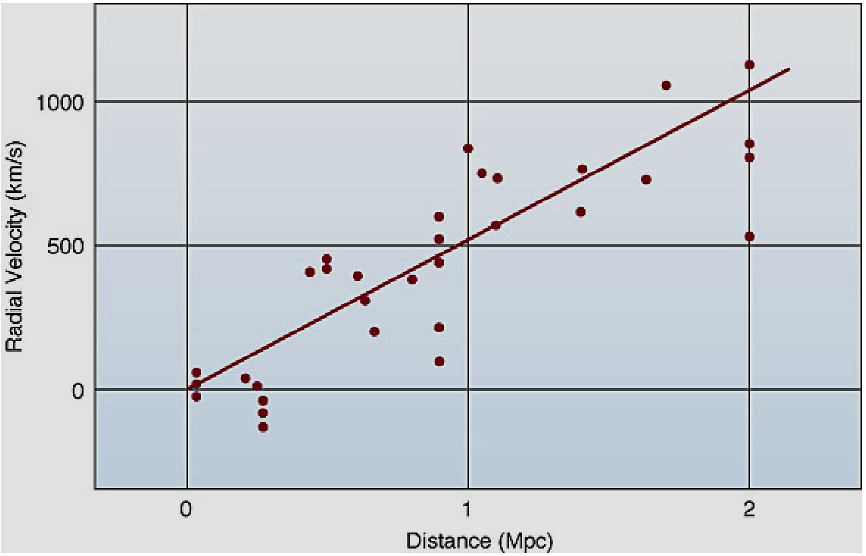
NRAO 5 GHz radio survey
~ 31000 radio sources

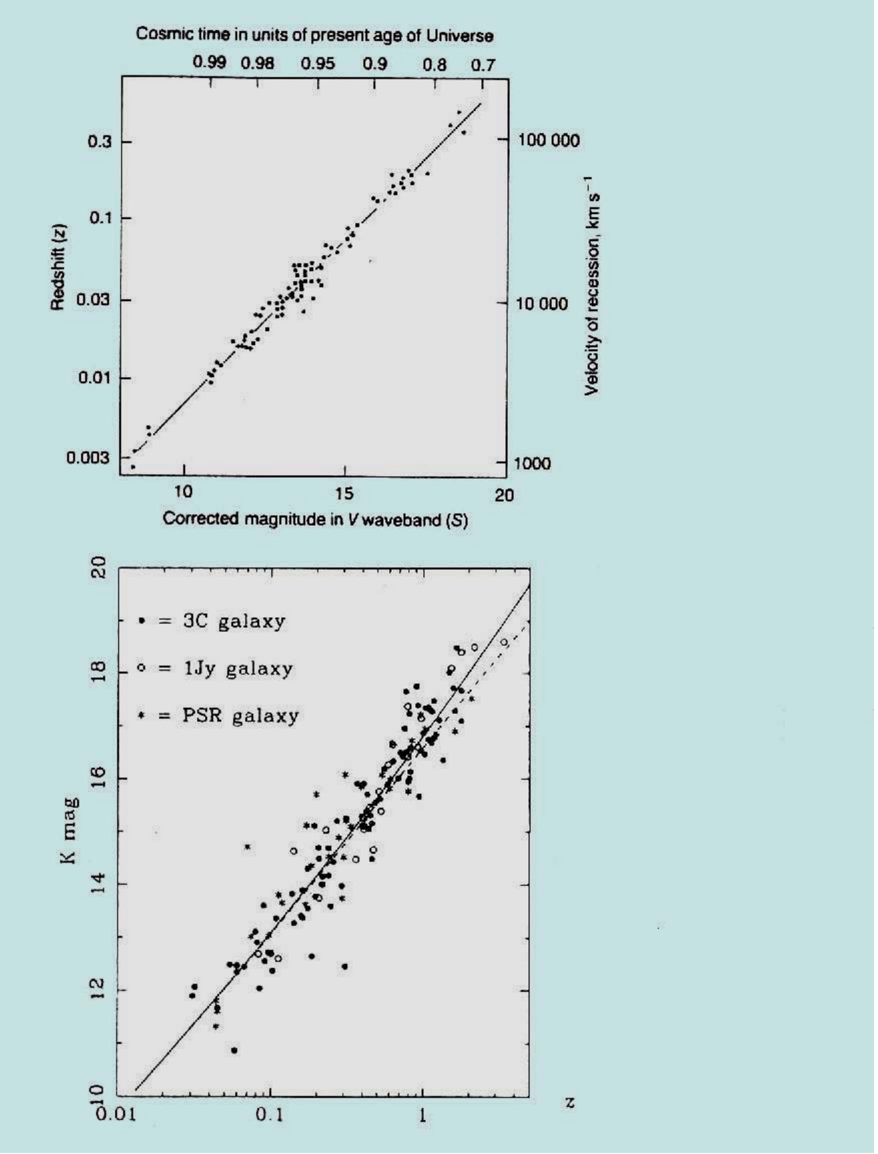
Redshift



emission-line spectra of galaxies; white arrow indicates location of H + K lines of calcium

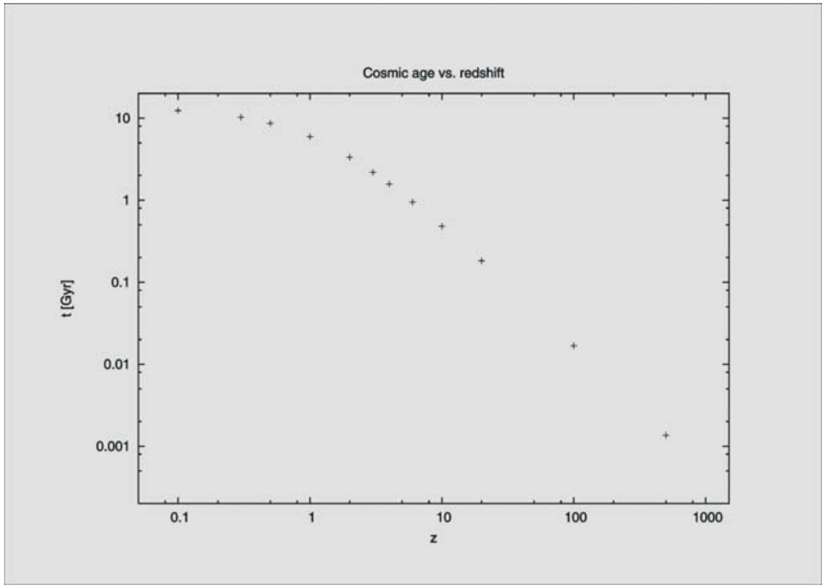
Hubble diagramme



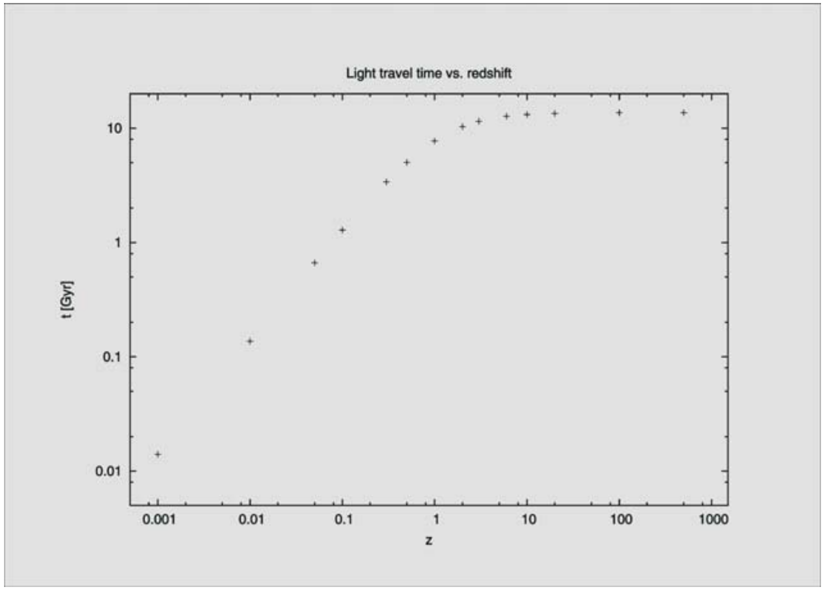


Old (top) and new (right) version of the Hubble diagram

Age and size of universe

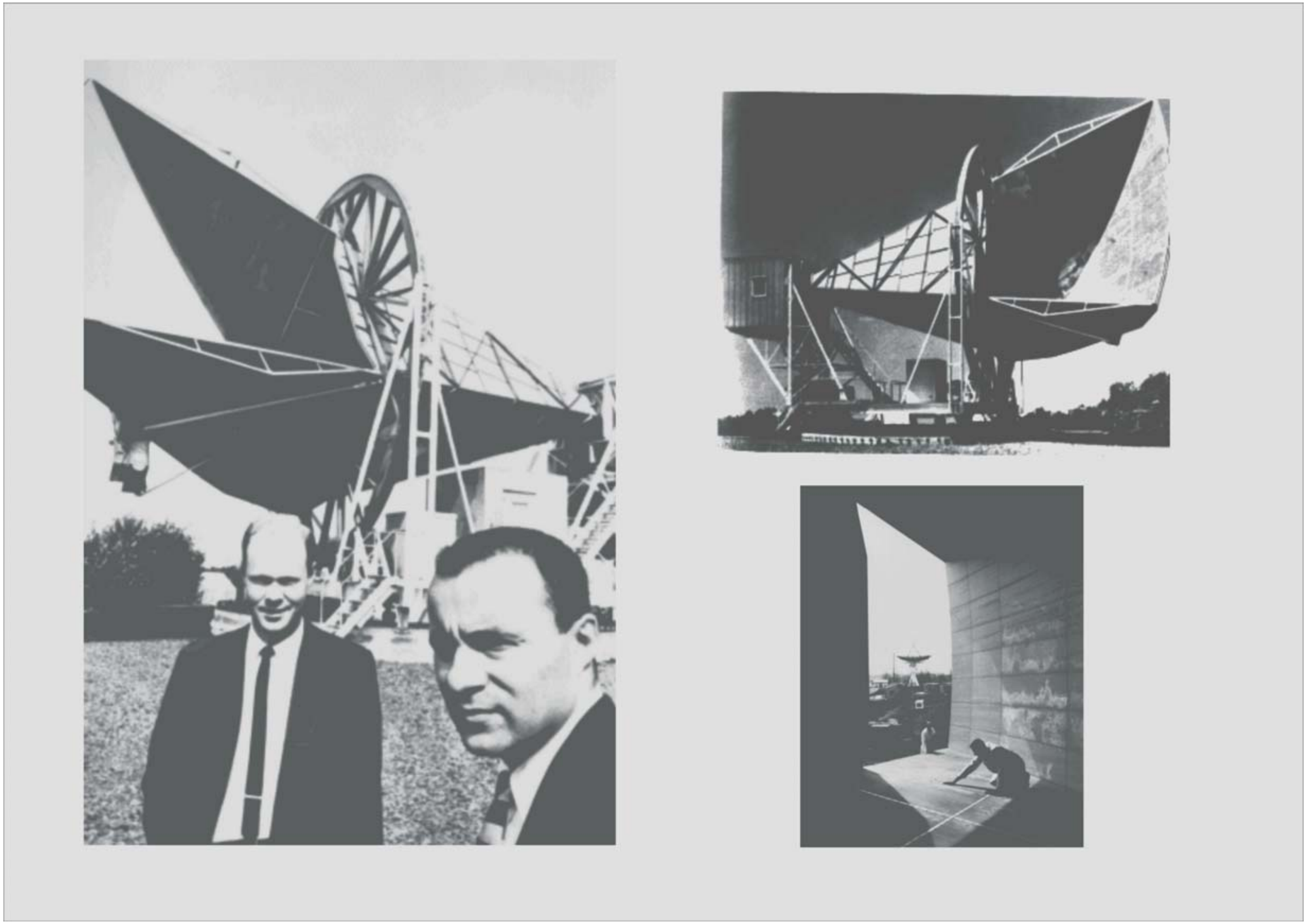


cosmic age versus redshift



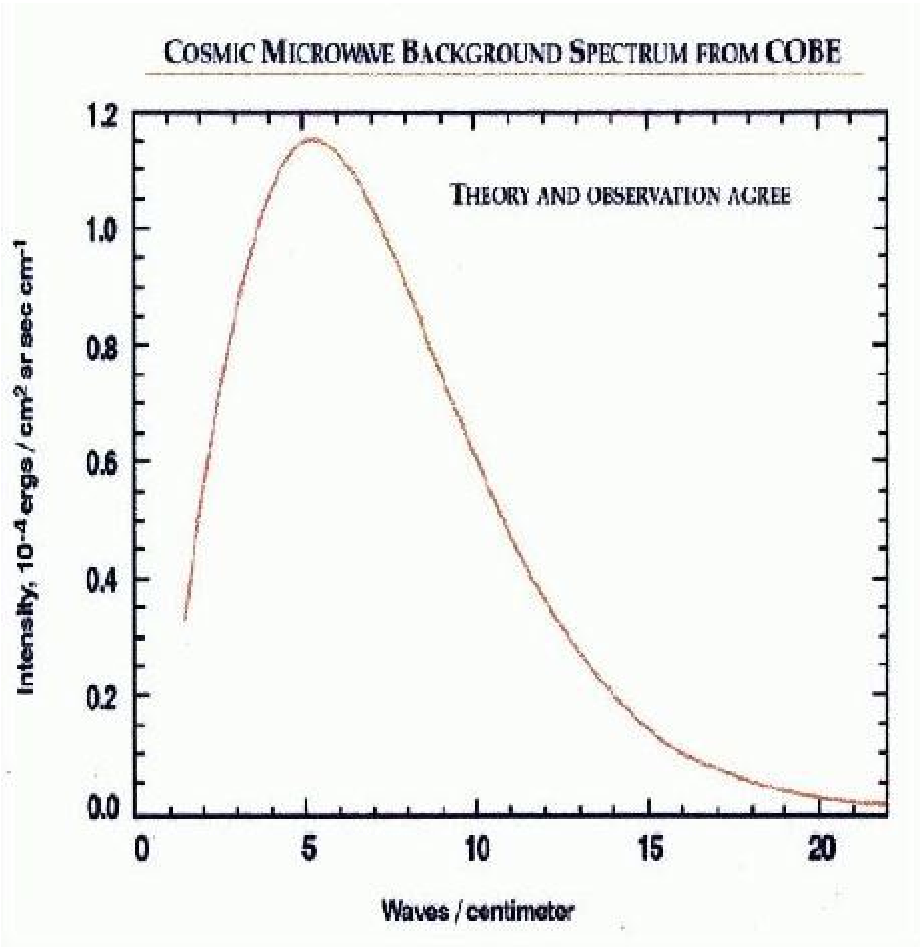
light travel time versus redshift

CMB

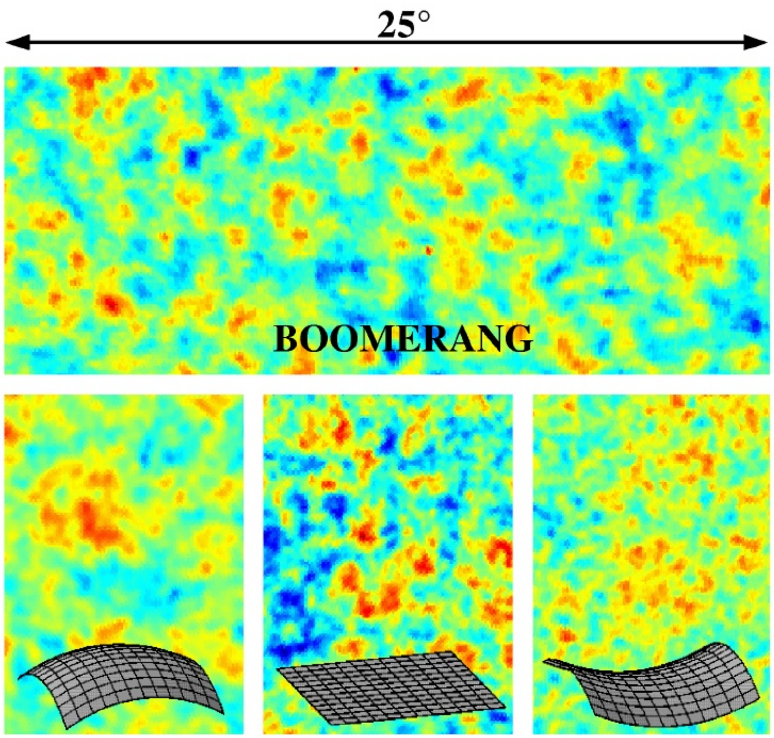


Penzias & Wilson with horn antenna

CMB



CMB spectrum

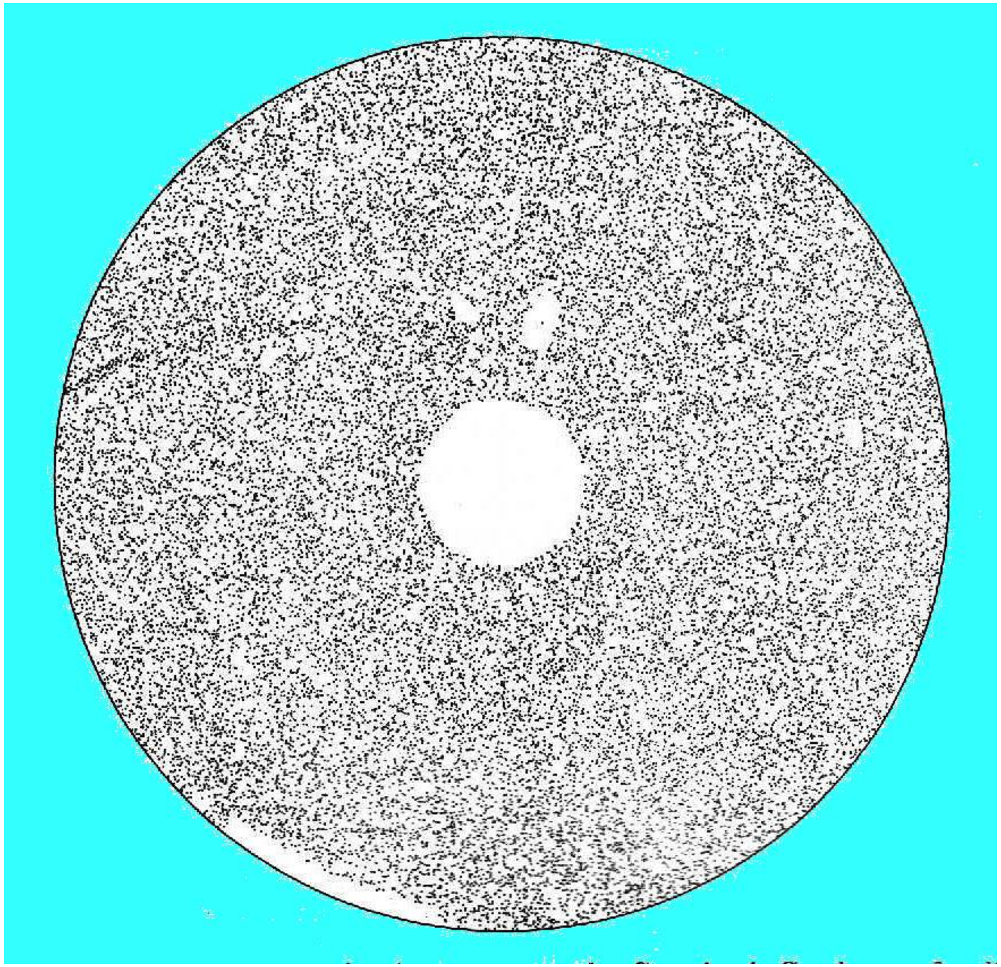


CMB anisotropies

top: measured by ***Boomerang***

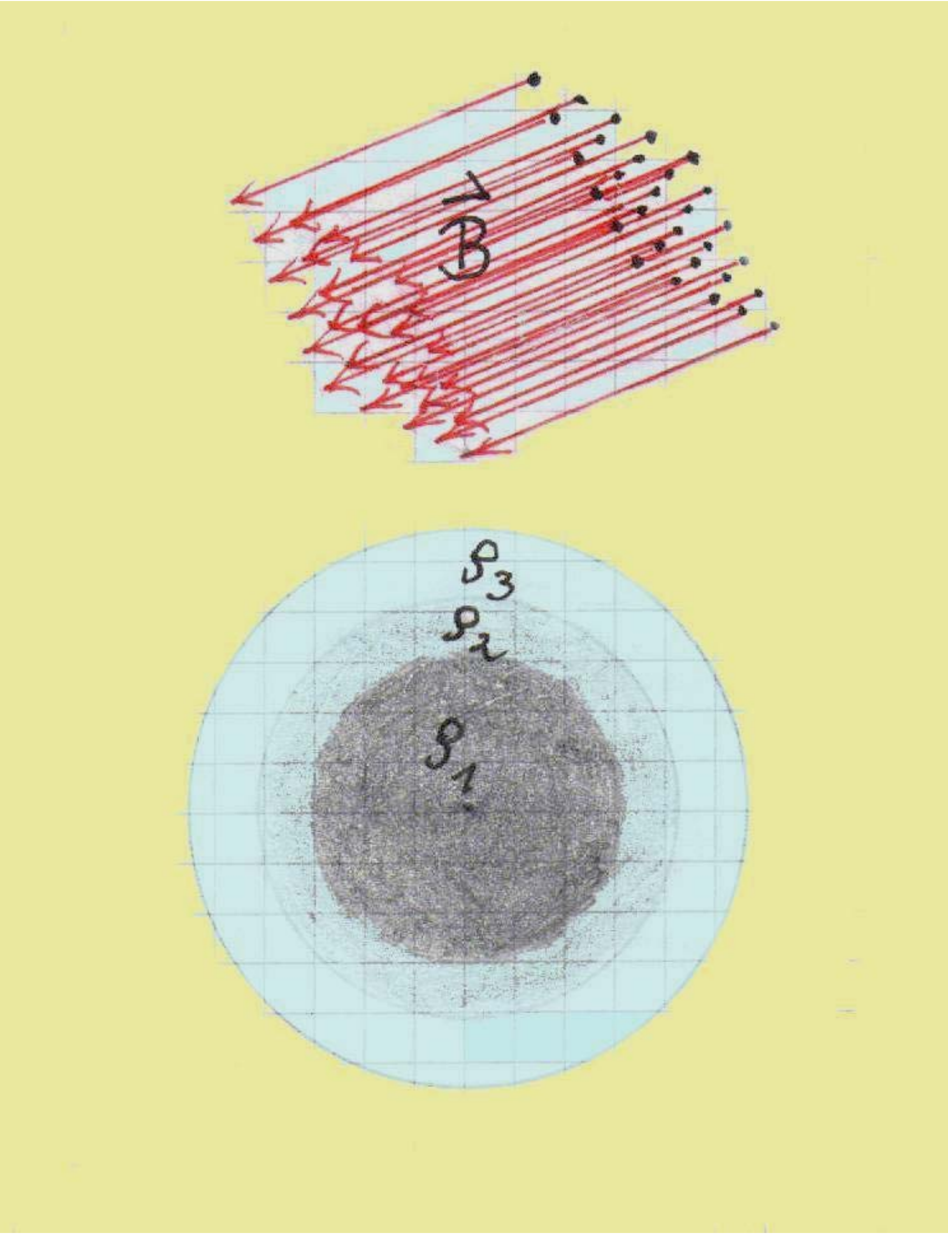
bottom: expected for closed (left)
flat (middle)
open (right) universe

Isotropy



radio sources probe large scales

Homogeneity & Isotropy



a homogeneous, but anisotropic universe ...

an isotropic, but inhomogeneous universe ...

Relevant constants, quantities, and units

Quantity	Symbol	Value
speed of light	c	$2.99792458 \cdot 10^{10}$ cm s^{-1}
light year	ly	$9.46 \cdot 10^{17}$ cm
parsec	pc	$3.09 \cdot 10^{18}$ cm
solar luminosity	$L_\odot$	$3.83 \cdot 10^{33}$ erg s^{-1}
solar mass	$M_\odot$	$1.99 \cdot 10^{33}$ g
Hubble parameter	H_0	$100 \cdot h$ km s^{-1} Mpc^{-1}
normalized	h	0.71 ± 0.07
Planck constant	h	$6.6261 \cdot 10^{-27}$ erg s
gravitational constant	G	$6.67259 \cdot 10^{-8}$ cm^3 g^{-1} s^{-2}
Boltzmann constant	k	$1.38066 \cdot 10^{-16}$ erg K^{-1}
Stefan-Boltzmann const.	σ	$5.66962 \cdot 10^{-5}$ erg cm^{-2} s^{-1} K^{-4}
proton mass	m_p	$1.6726 \cdot 10^{-24}$ g
electron mass	m_e	$9.1094 \cdot 10^{-28}$ g
critical density	ρ_c	$1.879 \cdot 10^{-29} \cdot h^2$ g cm^{-3}
		i.e. $11 \cdot h^2$ protons m^{-3}
Planck mass	m_{pl}	$2.177 \cdot 10^{-5}$ g
Planck time	t_{pl}	$5.391 \cdot 10^{-44}$ s
Planck length	l_{pl}	$1.616 \cdot 10^{-33}$ cm

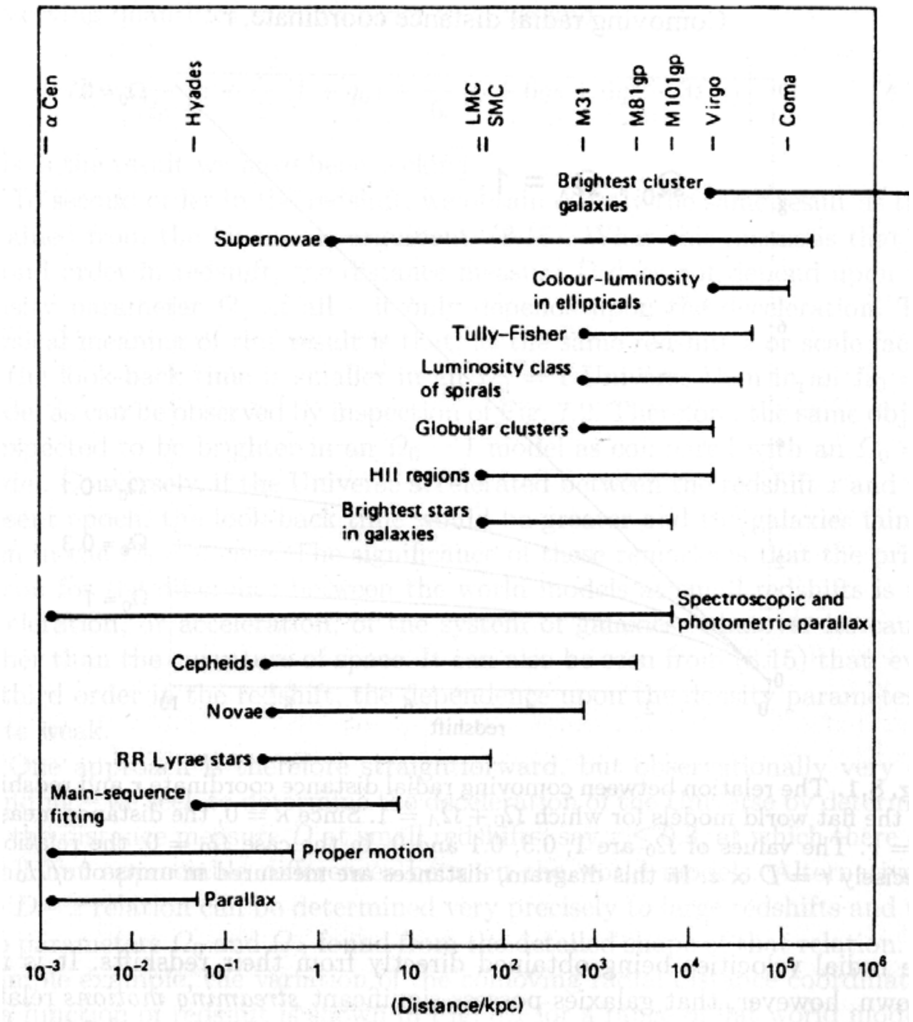
$$\rho_c = \frac{3 \cdot H_0^2}{8\pi \cdot G}$$

$$m_{pl} = \left(\frac{h}{2\pi \cdot c \cdot G} \right)^{\frac{1}{2}}$$

$$l_{pl} = \left(\frac{h}{2\pi \cdot c^3 \cdot G} \right)^{\frac{1}{2}}$$

$$t_{pl} = \left(\frac{h}{2\pi \cdot c^5 \cdot G} \right)^{\frac{1}{2}}$$

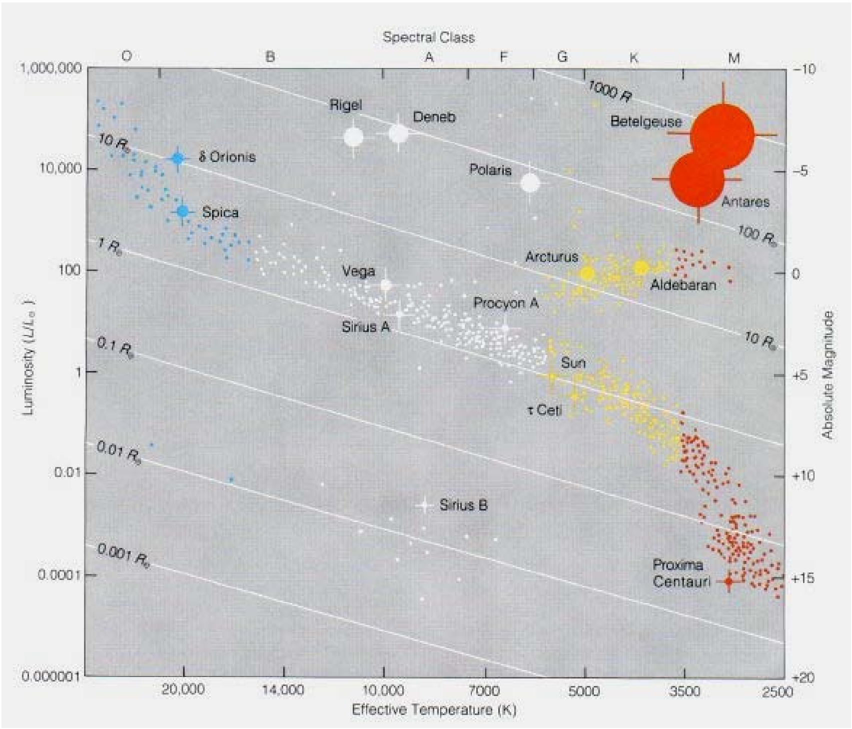
Cosmological distance ladder

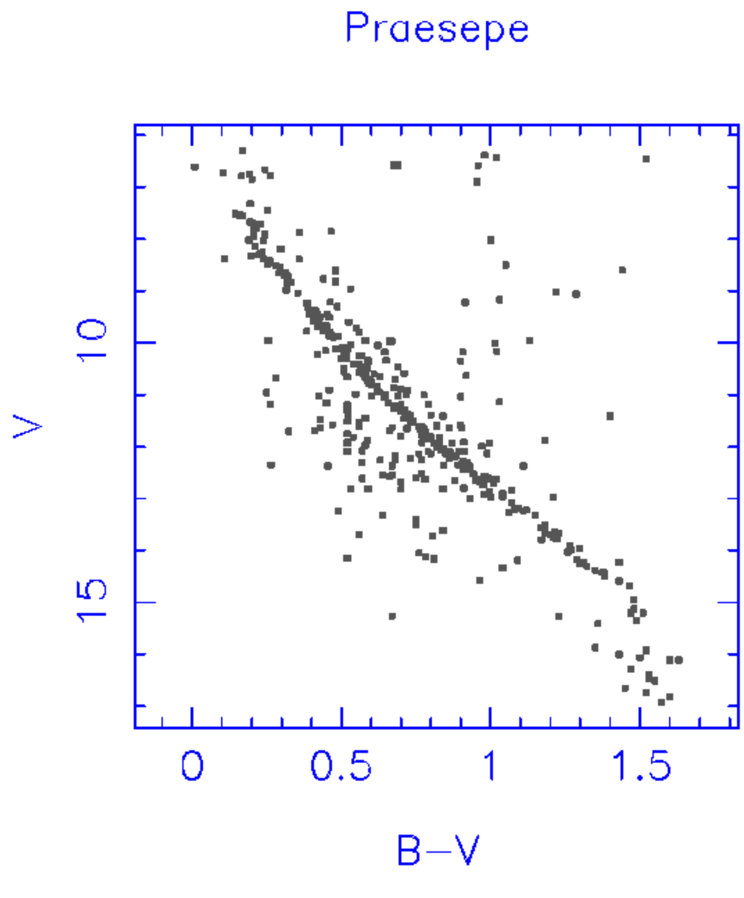


cosmological distance ladder from ~1 pc through >1 Gpc

note: supernovae (Type Ia) now (2004) reach out to z = 1.7!

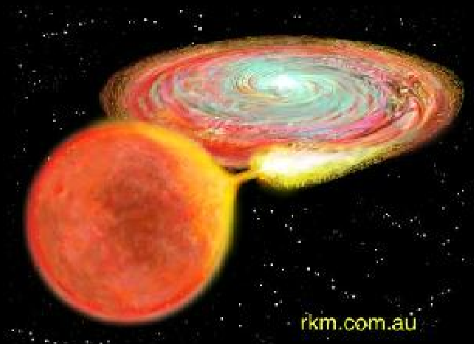
Spectroscopic parallax



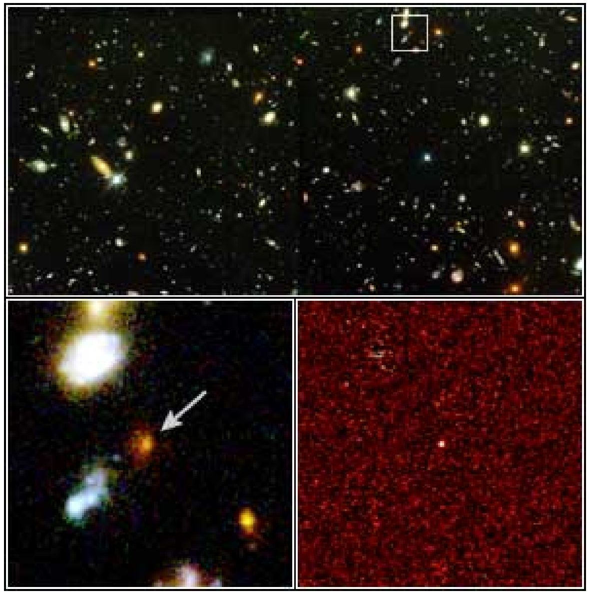


Supernovae Ia

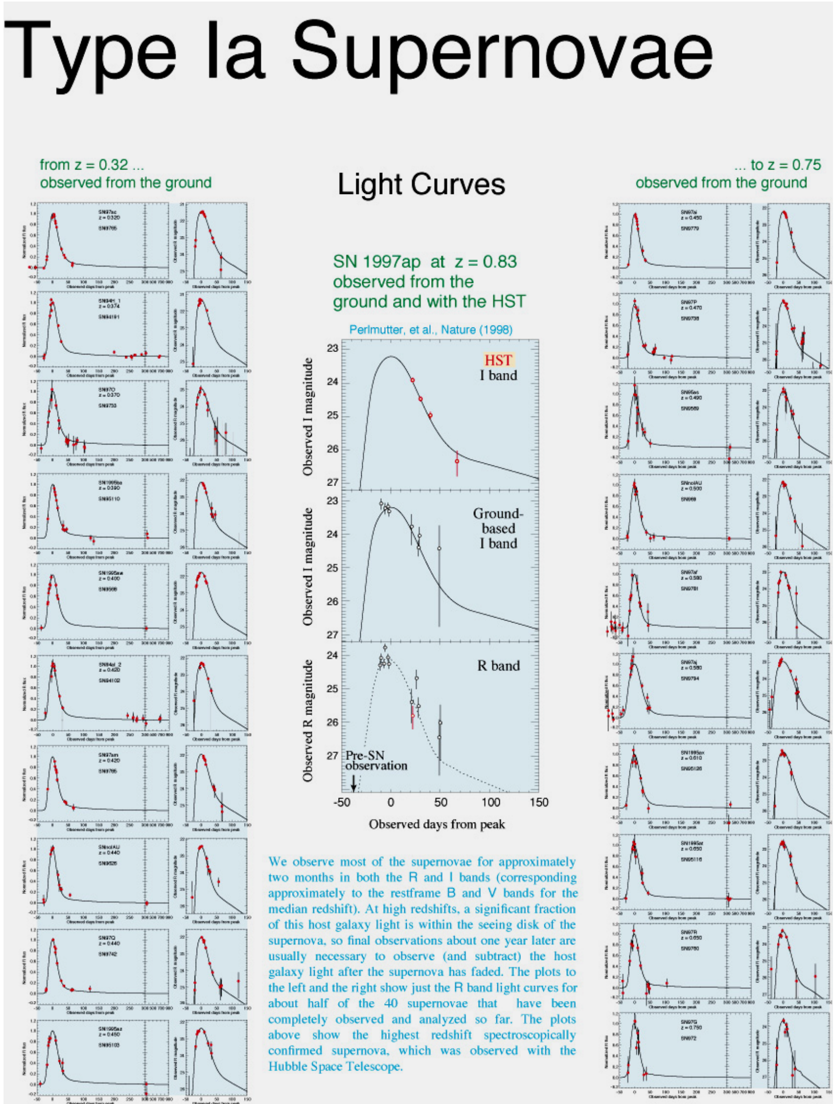
To measure the expansion rate at large distances, we search for events that are very bright, and predictably so: Type Ia Supernovae.

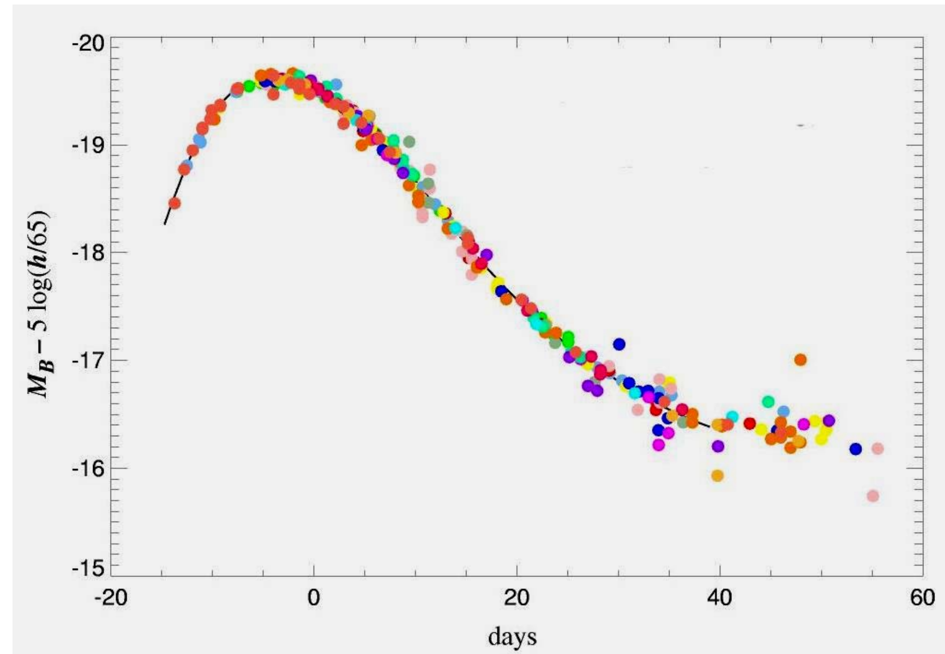


Matter gradually accretes onto a compact white dwarf star, until the gravitational pull becomes too great (at the Chandrasekhar limit) and the star collapses and explodes.



SN Ia as distance indicators

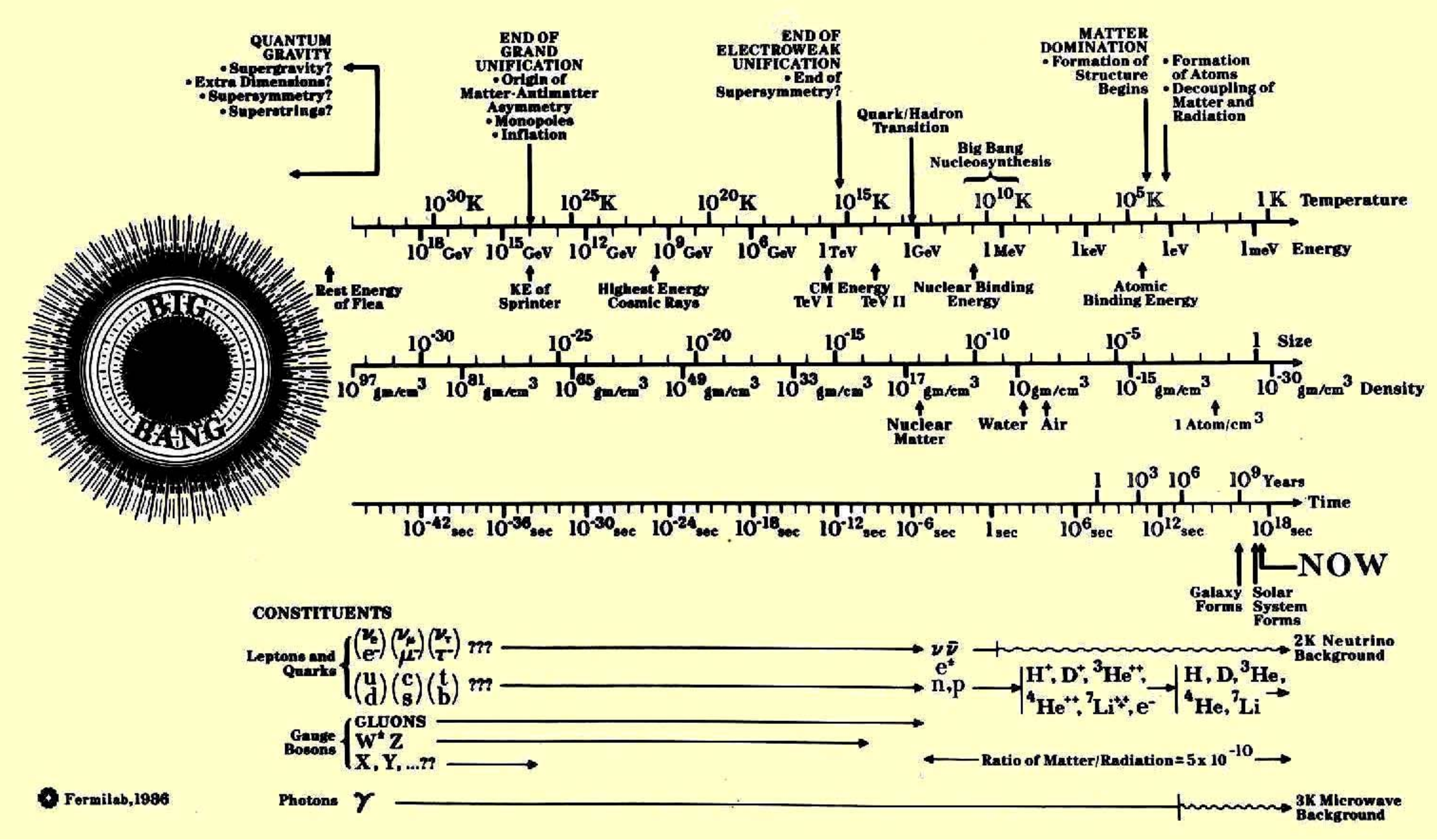




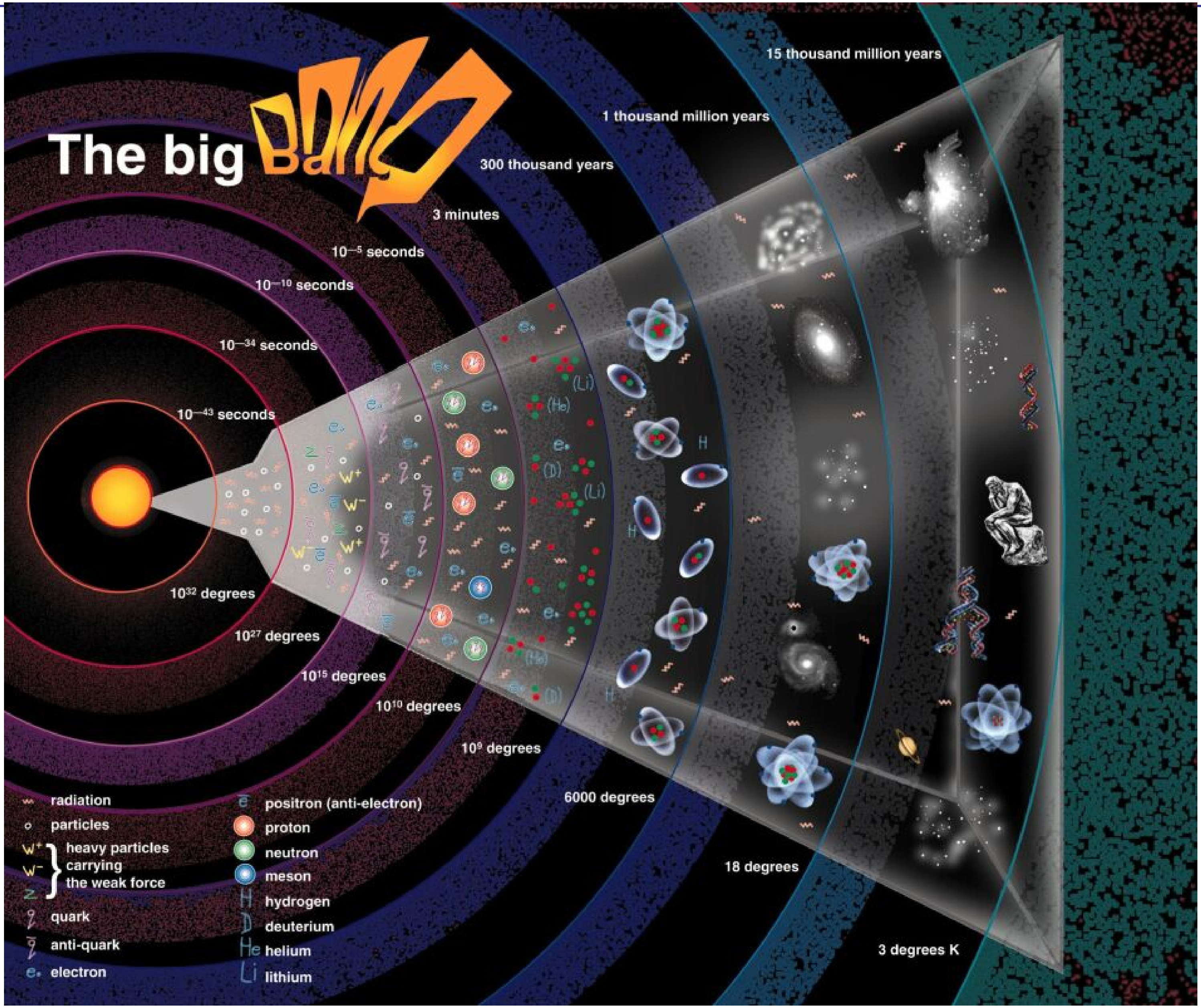
top: SN Ia light curves superimposed to same distance

left: raw light curves

Big Bang History



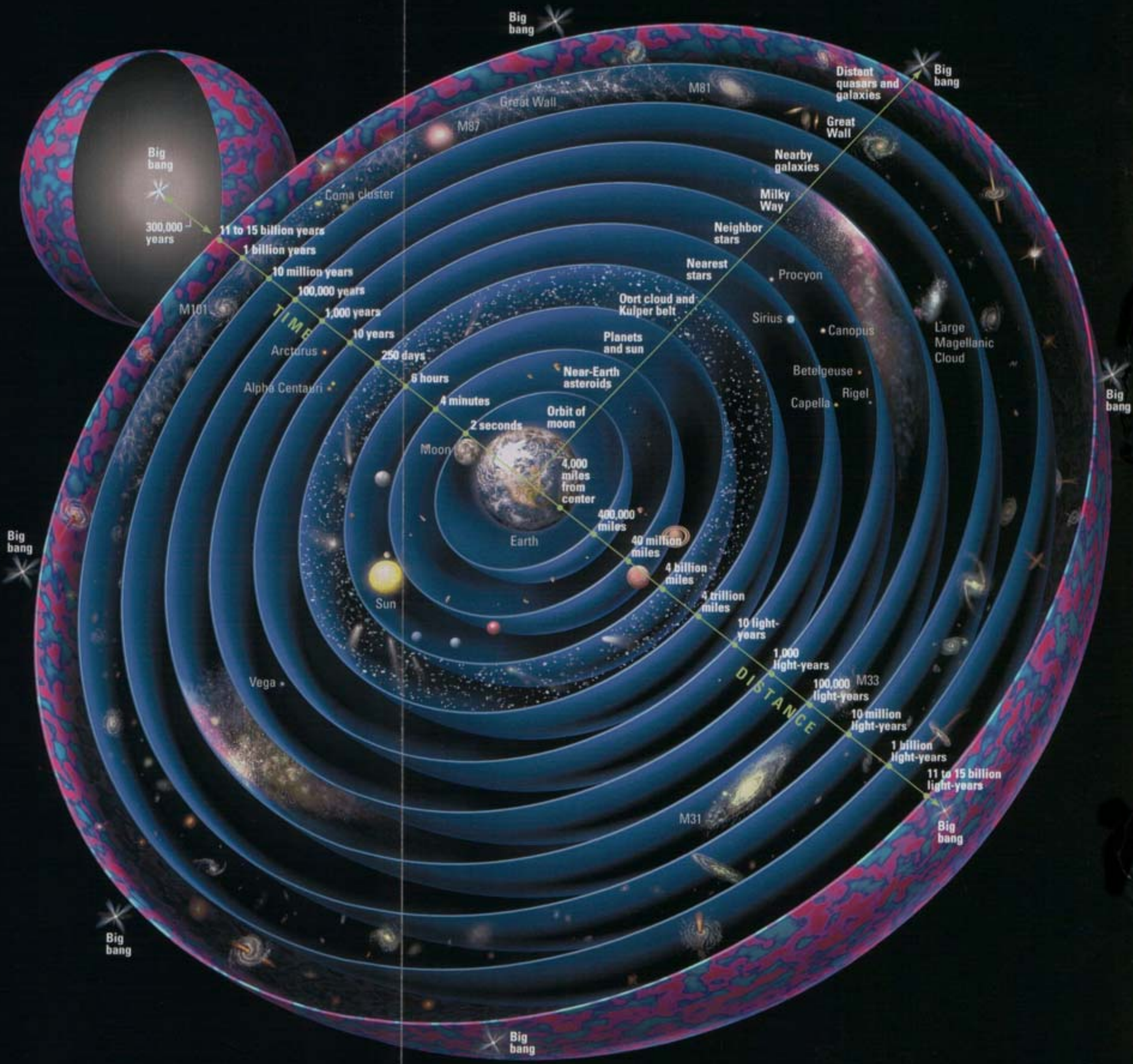
BB 'inside-out'



BB ‘outside-in’

The view from Earth

The ancients had it wrong: The Earth is not the center of the universe. But the Earth *is* at the center of the part of the universe that we can see. A being on a planet orbiting, say, a star in the galaxy M87 would see a different part of the universe, one centered on him. In a universe thought to be 11 to 15 billion years old, we can see out a distance of 11 to 15 billion light-years in all directions. From the Earth’s viewpoint at midnight GMT, January 1, 2000, the elements of the cosmos will appear as they do here (right). Distances are not shown to scale but increase dramatically as they become more remote. The farther out we look, the farther back in time we see. Light takes 50 million years to arrive from M87, so we see it as it appeared 50 million years ago. The limit of our view is the time when the universe emerged from a state of hot plasma and became transparent, some 300,000 years after the big bang. That period is seen as the glow of the microwave background (shown in red and blue). If we could look beyond that veil, we would see—according to the standard models—the big bang itself, no matter in which direction we looked. The portion of the big bang we could then observe would be a point of infinitesimal size and infinite density.



ART BY CHRISTOPHER SLOAN, NGS STAFF, AND DAVID FIERSTEIN. SOURCES: RICHARD GOTT, JEFF HAYES, ROBERT OSSERMAN, JEFF WEEKS (ABOVE); RICHARD GOTT, LI-XIN LI (BOTTOM RIGHT)