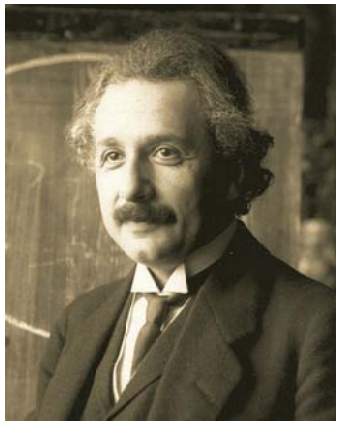
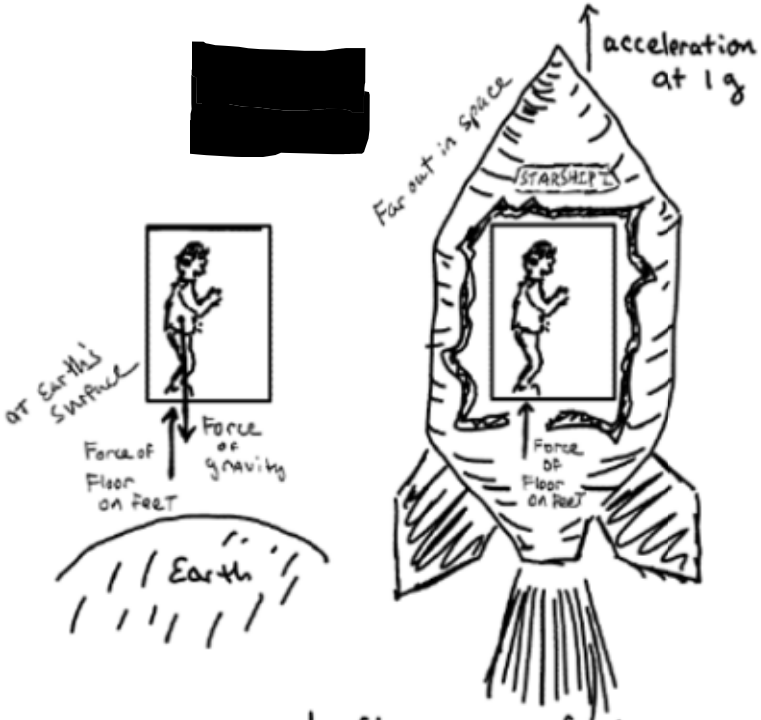
Physics 102 - March 30, 2011

Gravitation - The general theory of relativity

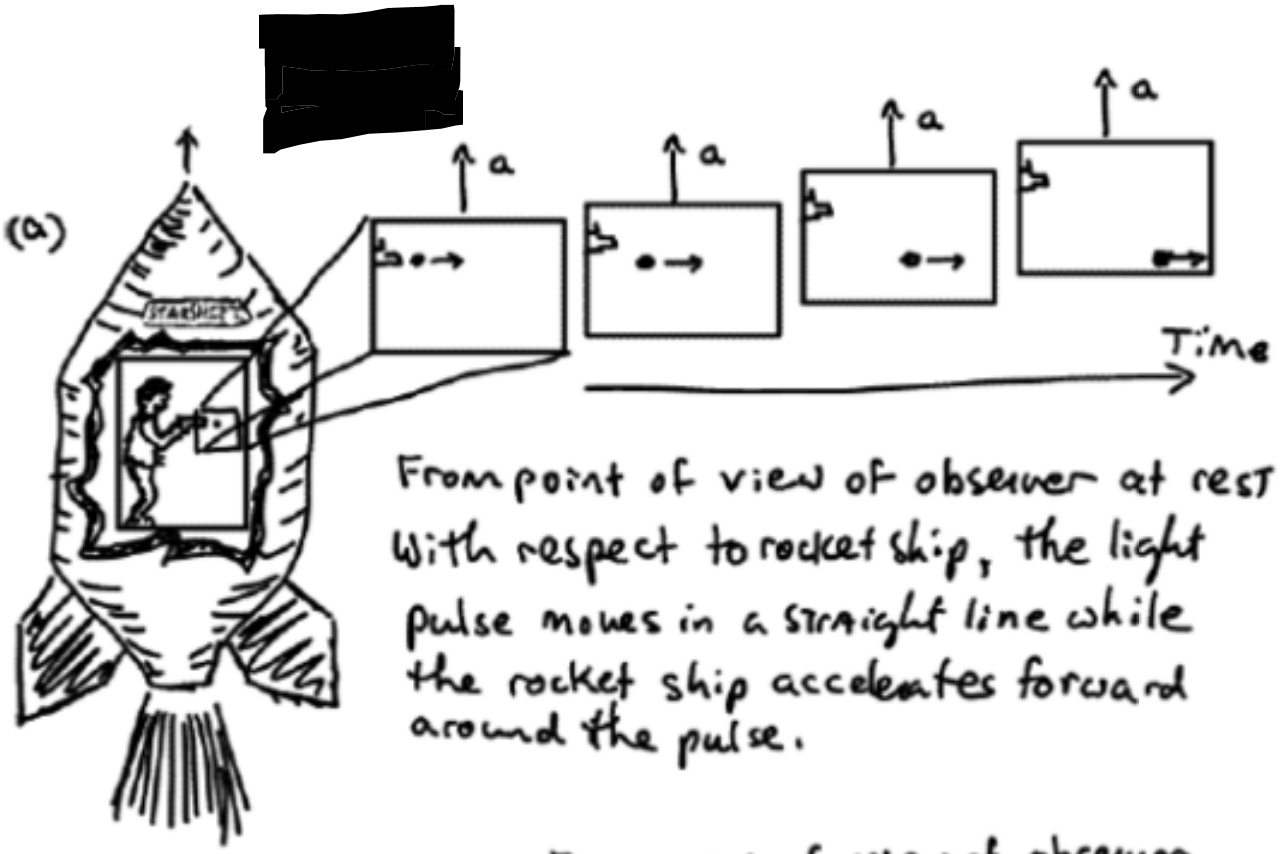


Equivalence principle

Accelerated reference frame
|||
gravitational field



The Force of the floor on your feet is the same in both cases. This is what you perceive as your weight.


(a)
a
a
a
a
Time
From point of view of observer at rest
With respect to rocket ship, the light
pulse moves in a straight line while
the rocket ship accelerates forward
around the pulse.
(b)
From point of view of observer
on the rocket ship, the light
pulse seems to travel in a
path that curves downward.

Apparent position

Actual position

- Bending of light by gravitational field ✓

- Gravitational Redshift of light ✓

- Perihelion advance of Mercury ✓

- Gravitational Waves ?

Amplitude ~ 10^{-16} m

LIGO

The fecund multiverse - cosmological natural selection

Fruitful in offspring

Lee Smolin
"The Life of the Cosmos"
Oxford Univ. Press 1997

What happens inside a Black hole?

Beasts Dwell here
→ Singularity

Classical general relativity:
curvature of spacetime is ∞
Physics as we know it ends

Quantum gravity to the rescue?

Physical Parameters + laws of daughter universe similar to but NOT identical to parent universe?

Parent universe

Collapse inside Black Hole

Bounce due to quantum gravity effects

Time

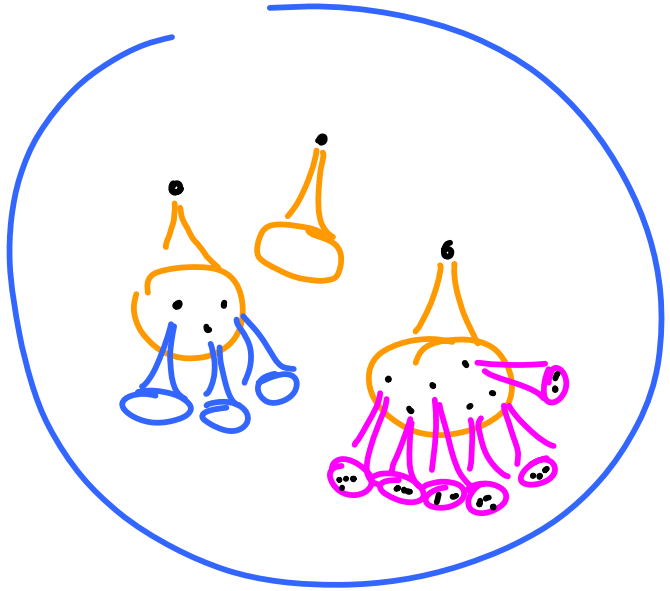
Event horizon of original Black Hole still Present

Big Bang Birth of a universe

Original universe and offspring disconnected

daughter universe

Cosmological Natural selection



Parameters of universes in the greater cosmos will evolve toward optimal production of Black holes

This type of universe will be predominant

Black holes → long life stars → also good for life as we know it

natural reason for Fine-tuning in our universe

Anthropic selection

Falsifiable hypothesis

Light travels at a finite speed

On to the very big ...

Telescopes are time machines

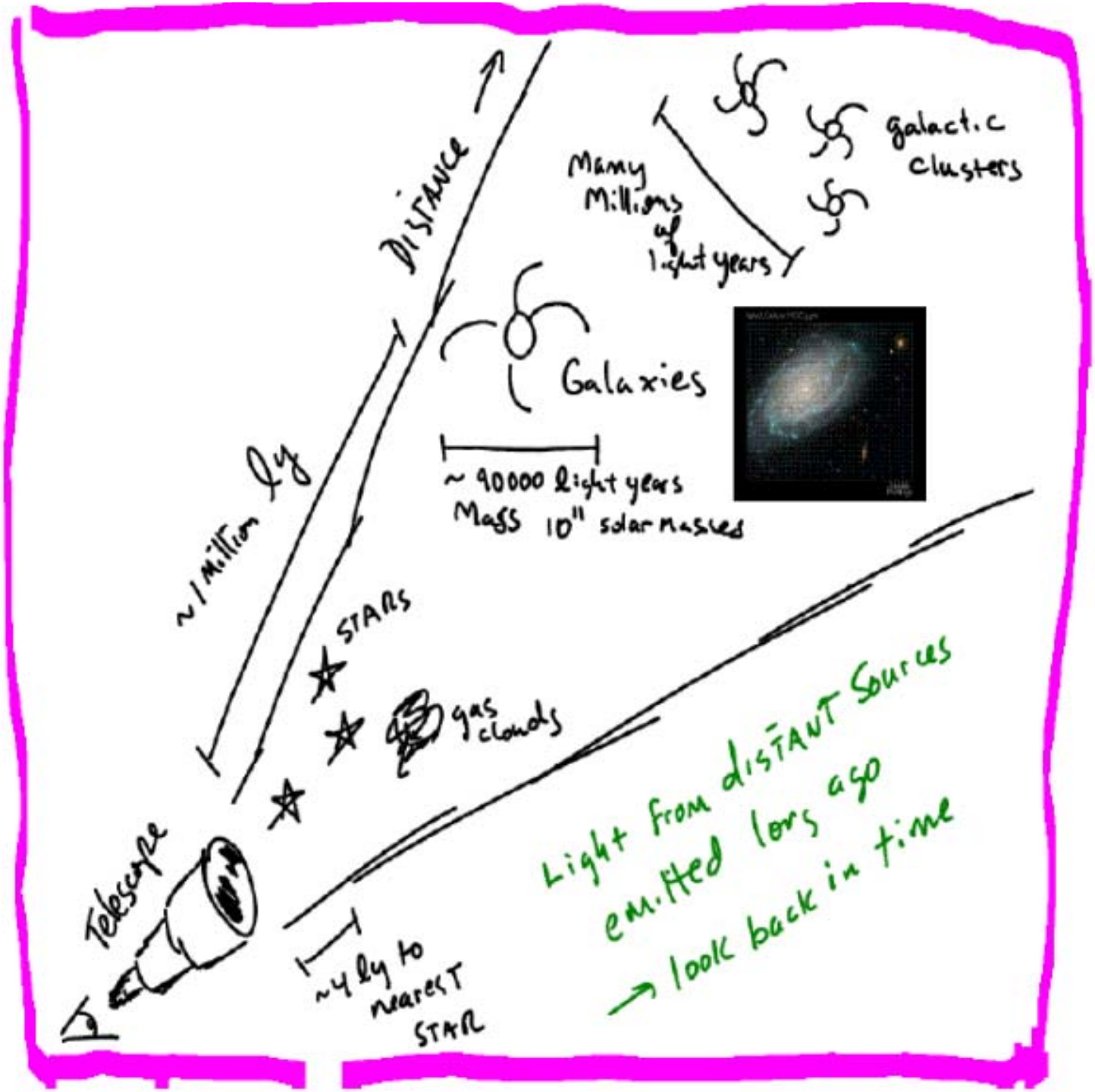
1 Mpc= 1 Megaparsec = 3×10^{22} m

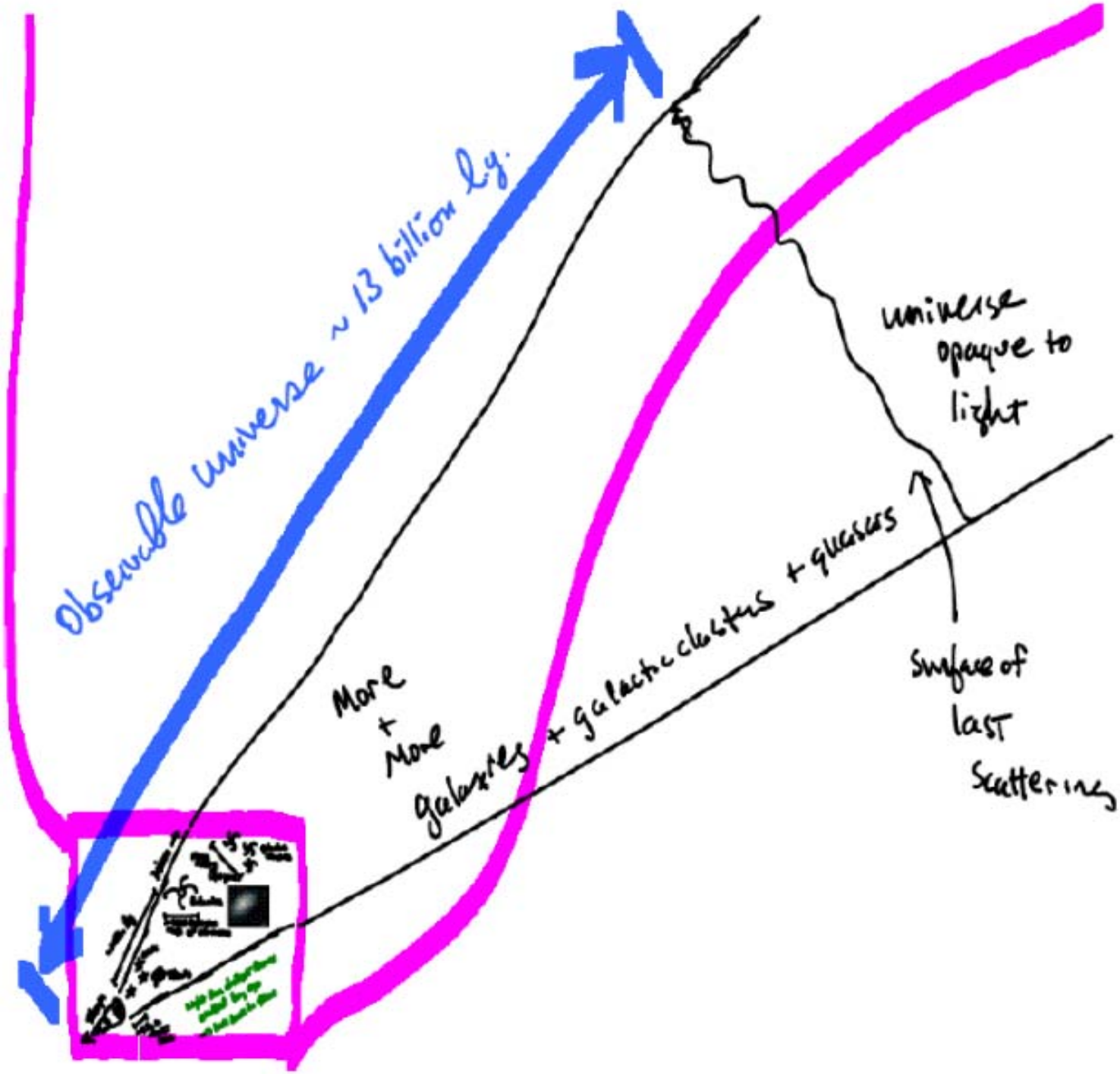
1 light year = 9×10^{15} m

Light travels from NYC to San Francisco in 1/100 second

.... and it travels 1 Mpc in 3 million years

Farther away the object ... longer ago light emitted.


DISTANCE
Many Millions of light years
galactic clusters
Galaxies
~ 90000 light years
Mass 10^11 solar masses
~1 Million ly
STARS
gas clouds
Telescope
~4 ly to nearest STAR
Light from distant sources emitted long ago
→ look back in time

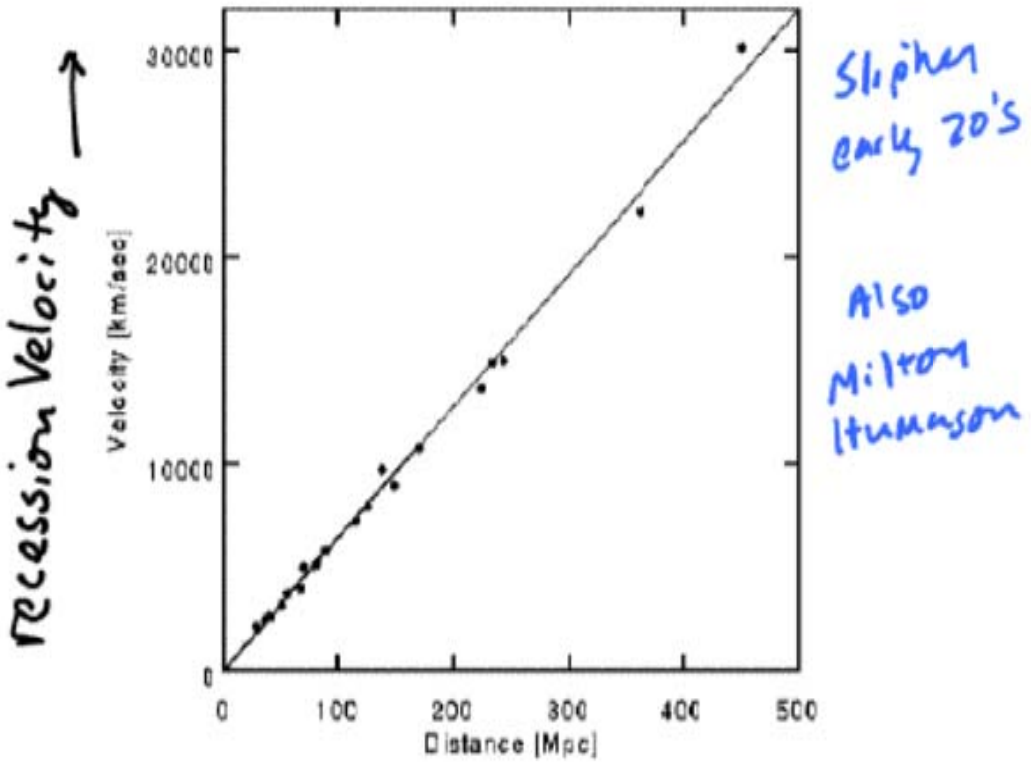

Observable universe ~ 13 billion ly.
universe opaque to light
More + More galaxies + galactic clusters + quasars
Surface of last Scattering

We live in an expanding universe

Edwin Hubble
(1929)

Slipher
early 20's

Also
Milton
Humason



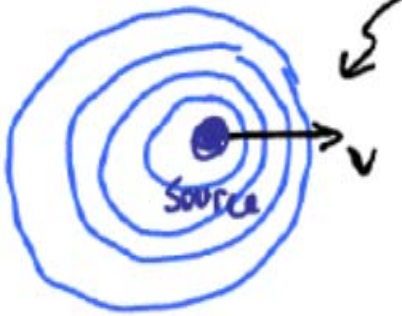
Distance to galaxy

Determined by
redshift of atomic
spectral lines

Determined by brightness
(supernova in distant galaxy)

"Redshifted" light

Frequency Appears lower to objects in direction away from direction of Motion

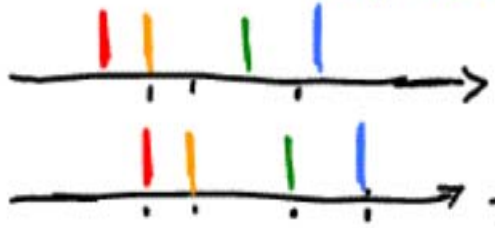


Frequency Appears higher to observers in direction of Motion

observer

"Blueshifted" light

larger v — larger the red and blue shifts.



ATOMIC Spectrum

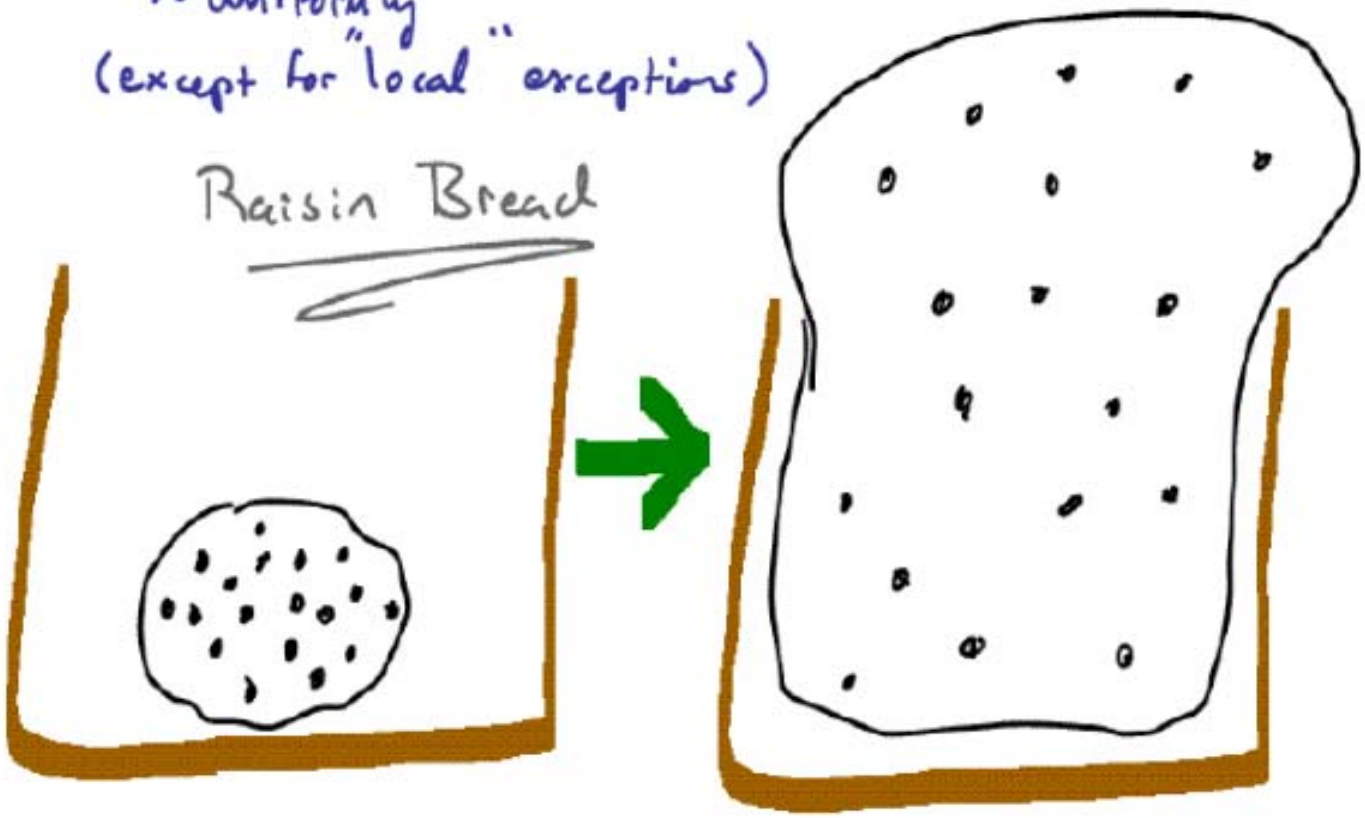
spectrum line position shifted in color/frequency for source moving away from observer

(Color also changes — not shown)

Galaxies Receding in all directions

~ uniformly

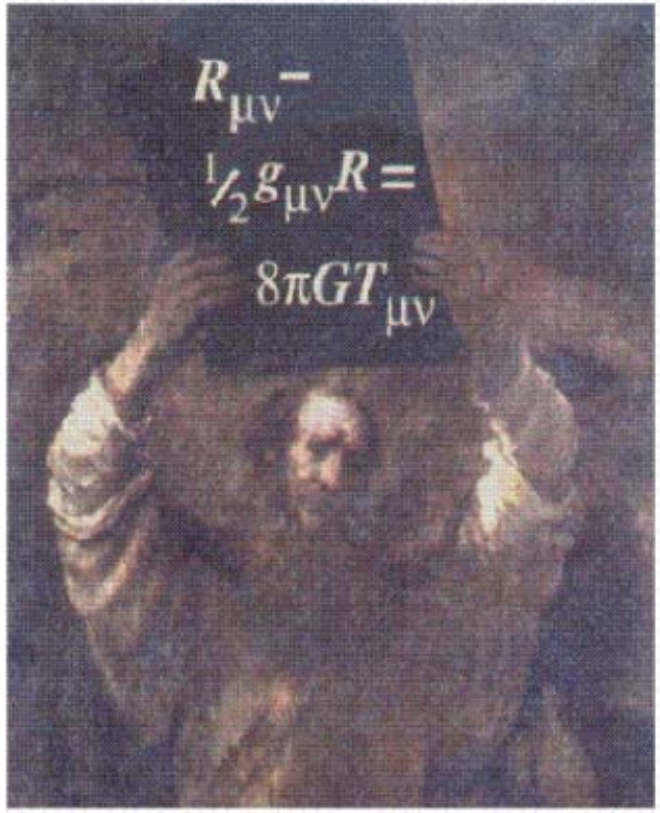
(except for "local" exceptions)



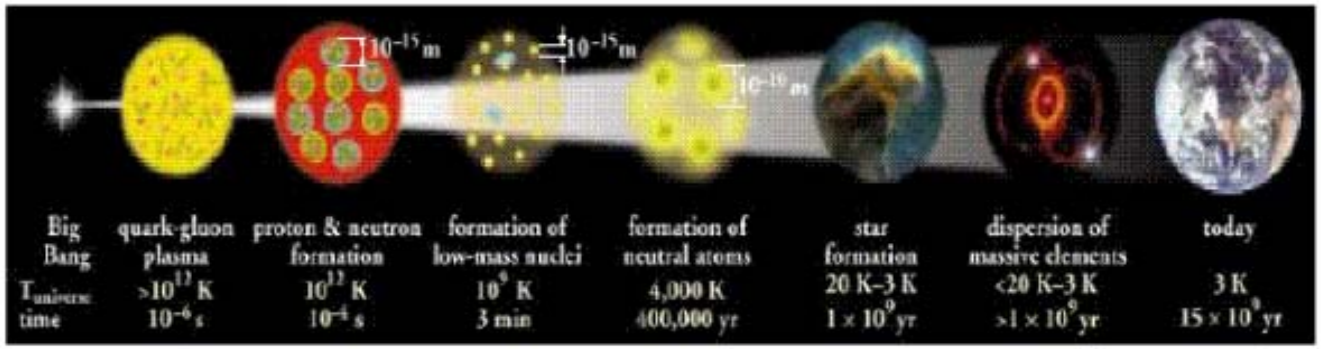
No need to think our galaxy is at center of universe.

Expansion of space makes effect same to all observers throughout universe.

Why Believe ? ...



– R. Kolb



↑

Hot Big Bang predicts this

light should Travel to us from time ~ 400K yr to now ... massively redshifted

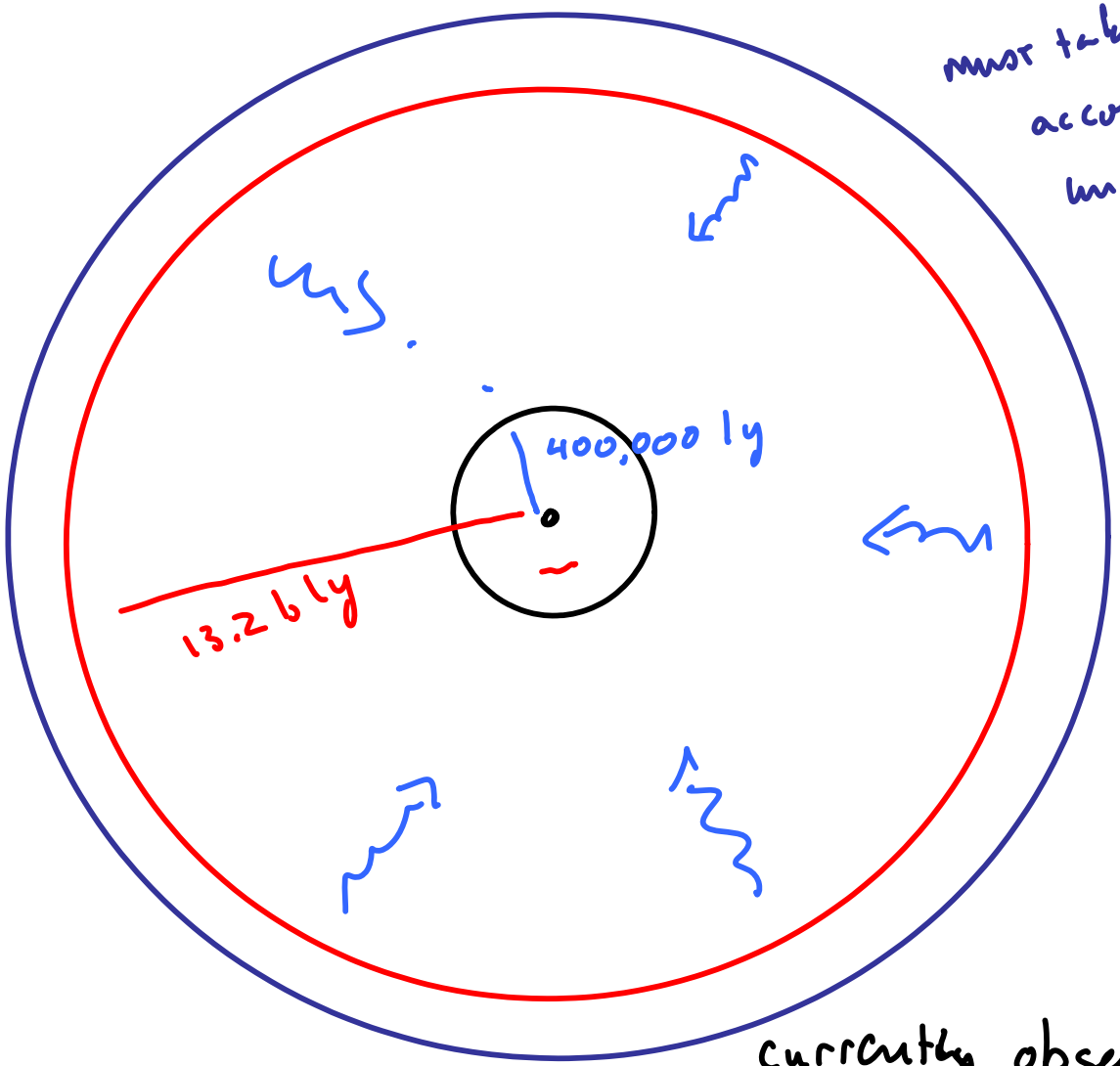
$t = 4000\ K \longrightarrow t = 4\ K$

"Perfect Blackbody"

Should come to us from all directions

Cosmic Microwave Background

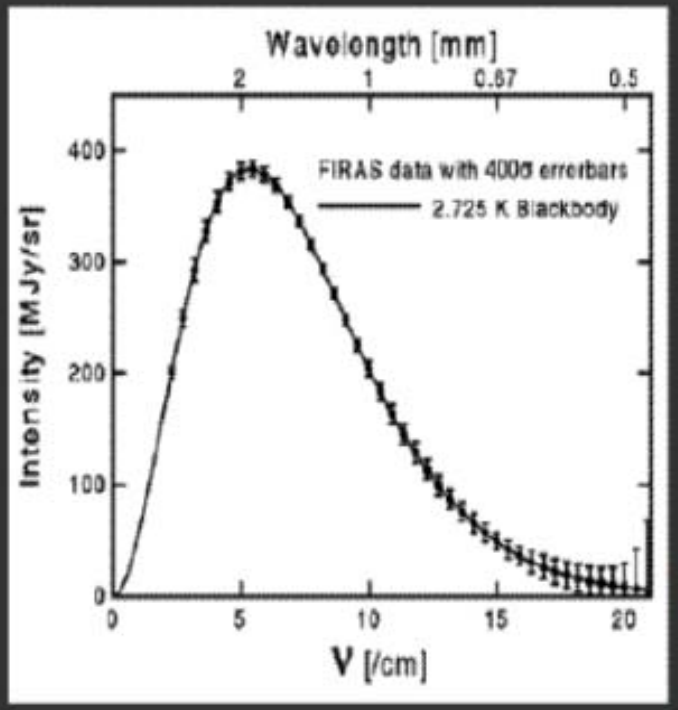
"CMB"

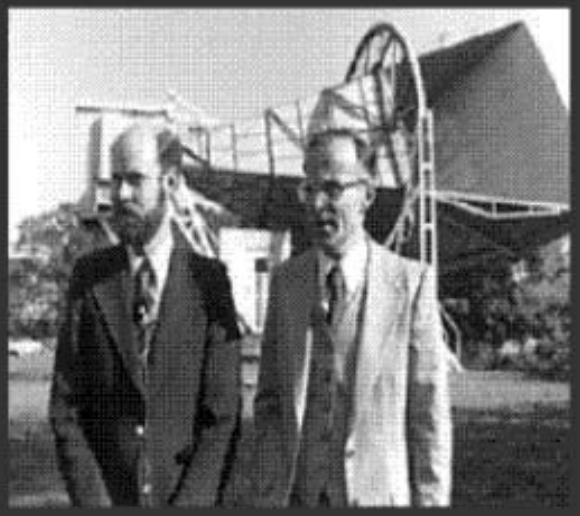

must take into account universe is expanding too
400,000 ly
13.2 bly
currently observable universe

Evidence for Big BANG

Cosmic Microwave Background

Penzias and Wilson - 1964





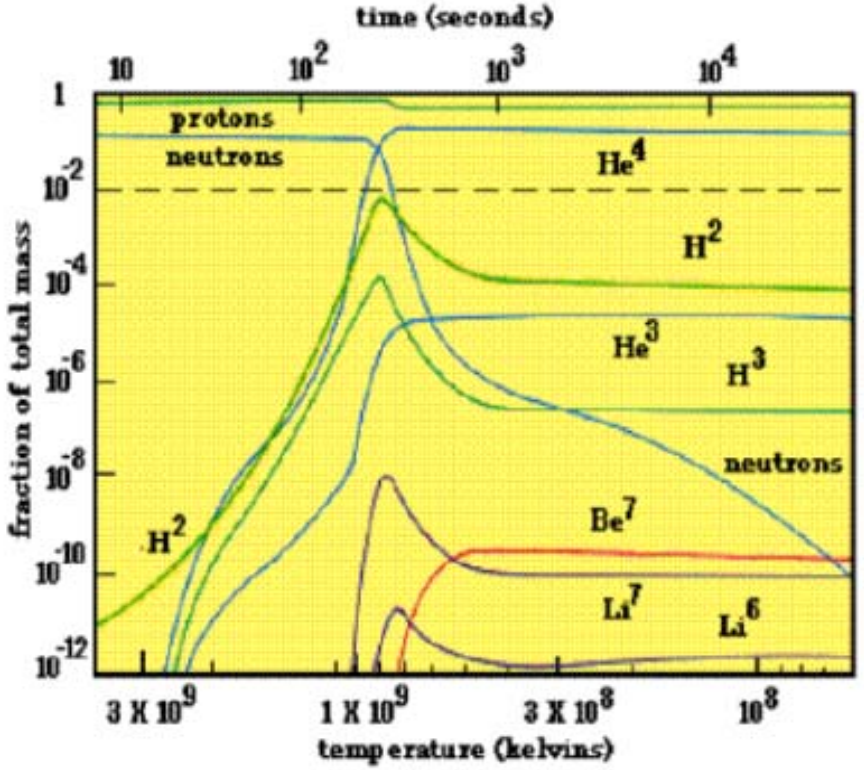
Uniform and isotropic

– in as far as they could measure

1978 Nobel Prize

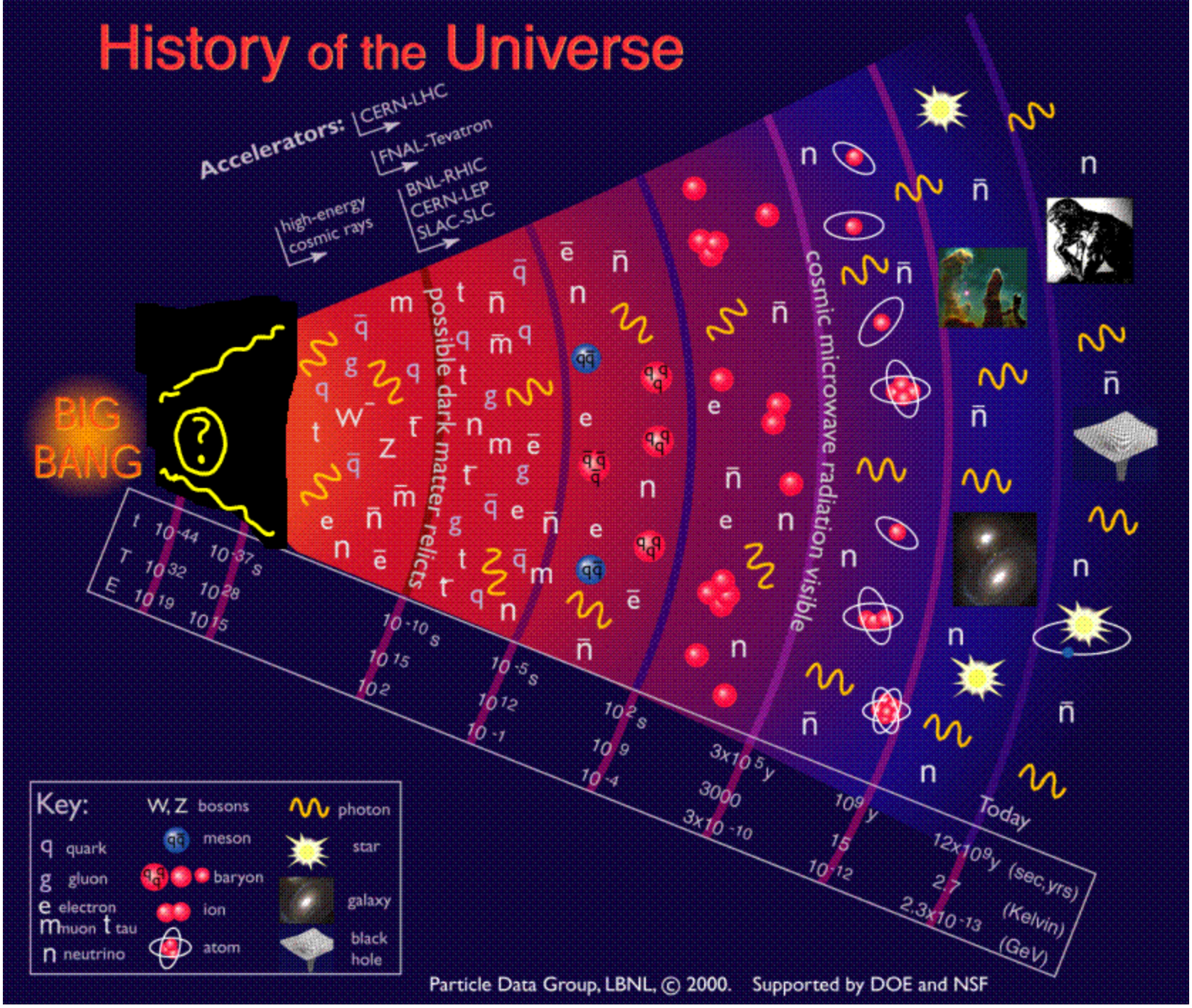
Big Bang Nucleosynthesis

$t \cong 100$ seconds



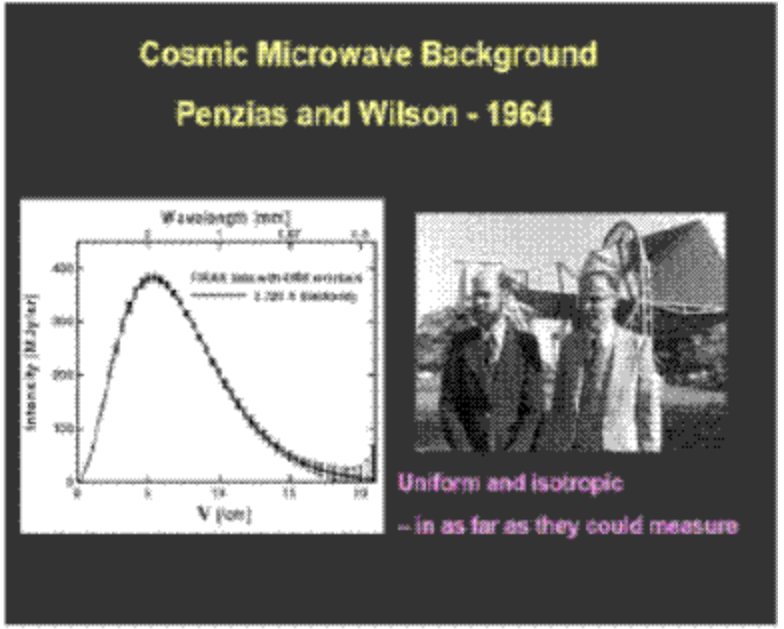
http://www.astro.ucla.edu/~wright/BBNS.html

We see ~expected distribution of light nuclei in universe.

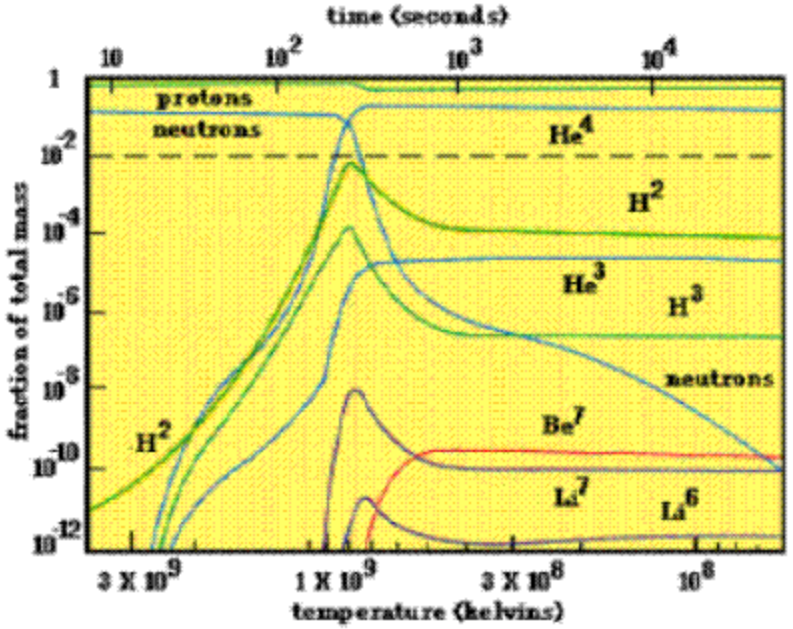

History of the Universe
Accelerators:
CERN-LHC
FNAL-Tevatron
BNL-RHIC
CERN-LEP
SLAC-SLC
high-energy cosmic rays
BIG BANG
possible dark-matter relicts
cosmic microwave radiation visible
t 10-44 10-37 s
T 10 32 10 28
E 10 19 10 15
10 -10 s
10 15
10 2
10 -5 s
10 12
10 -1
10 2 s
10 9
10 -4
3x10 5 y
3000
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

- Observe light from Time universe became TRANSPARENT
  T ~ 400,000 years

- Perfect blackbody all directions in sky



- Amount of light nuclei in interstellar / intergalactic space agrees w/ expectation from Big Bang Nucleosynthesis
  T ~ 3 Minutes



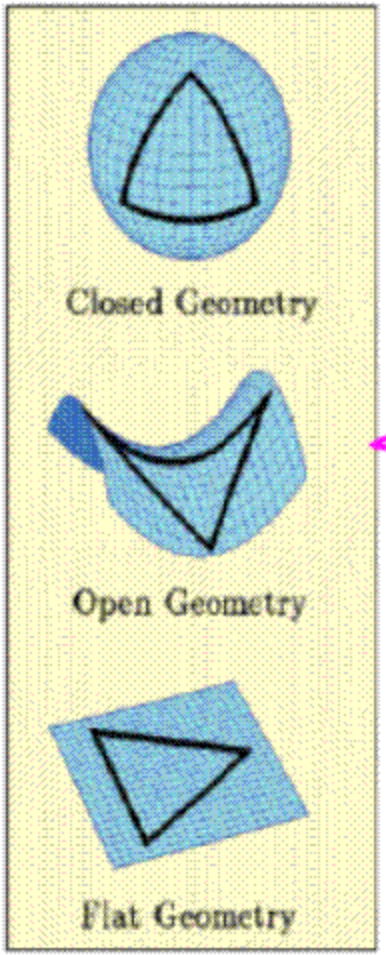
Problems w/ Big Bang

nonstatic universe expected from Relativity

Relativity allows space to have different curved geometries ?

Which is our universe?

Flat space is A very special case!



Sum of angles in triangle

$>180°$ ← universe expands... slows down + collapses

$<180°$ ← universe expands forever

$=180°$ ← universe expands to a stop

Very special case

- Singularity Problem – Yikes!! All of the universe at a Point?

- Horizon Problem – Why is universe so smooth and isotropic on large scales?

  Why CMB so smooth and isotropic

  at T = 400,000 yrs

  only parts of universe as large as 400,000 light years could be causally connected

  yet all at same temperature??

- Flatness problem – universe appears to be very close to "flat" ... very special case.

  Requires fine tuning of basic Model