

# Physics 102 - November 16, 2009

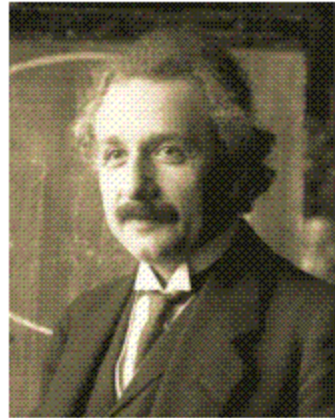
- EXAM 2 - 1 week from Now  
Monday Nov. 23 at 2 in Hoyt
  - Email with Material to be covered went out last Thursday or Friday

Through Particle Physics
- Recitation 9 - Exam prep - old exam probs
  - Nov 17 + 20
  - No recitation 9 on Nov. 23
- PS 9 ... Particle Physics  
realized that link needed  
Activation this morning ... Sorry

Last Time -

Gravitation -

The general theory  
of relativity

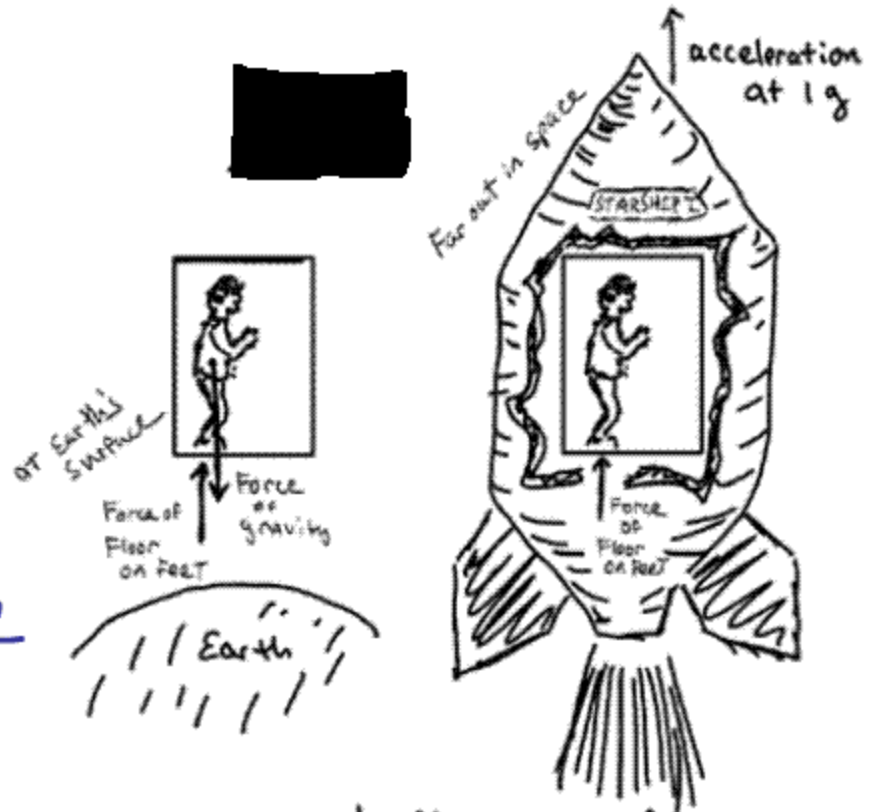


Equivalence Principle

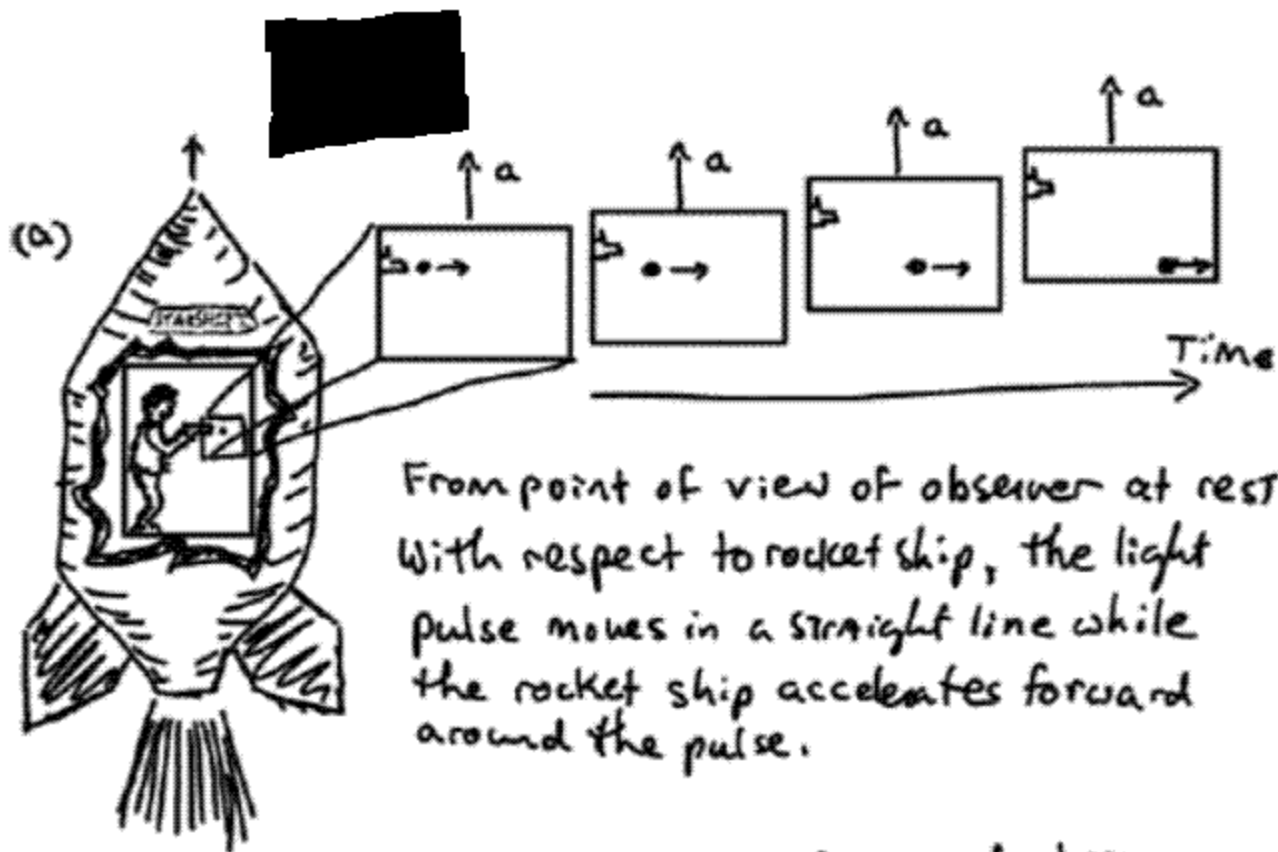
Accelerated reference frame

|||

gravitational field

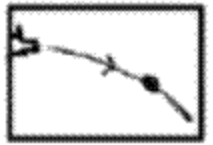


The force of the floor on your feet is the same in both cases. This is what you perceive as your weight.

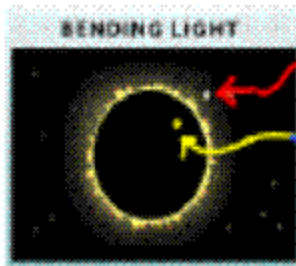


From point of view of observer at rest with respect to rocket ship, the light pulse moves in a straight line while the rocket ship accelerates forward around the pulse.

(b)



From point of view of observer on the rocket ship, the light pulse seems to travel in a path that curves downward.

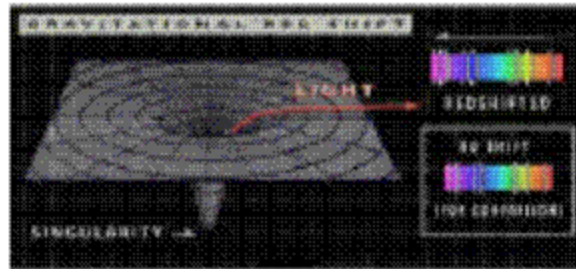


Apparent position

■ Bending of light by gravitational field ✓

Actual position

■ Gravitational redshift of light ✓



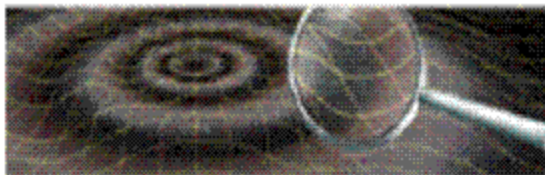
■ Perihelion advance of Mercury ✓



■ Gravitational Waves ?

Amplitude  $\sim 10^{-16}$  m

LIGO

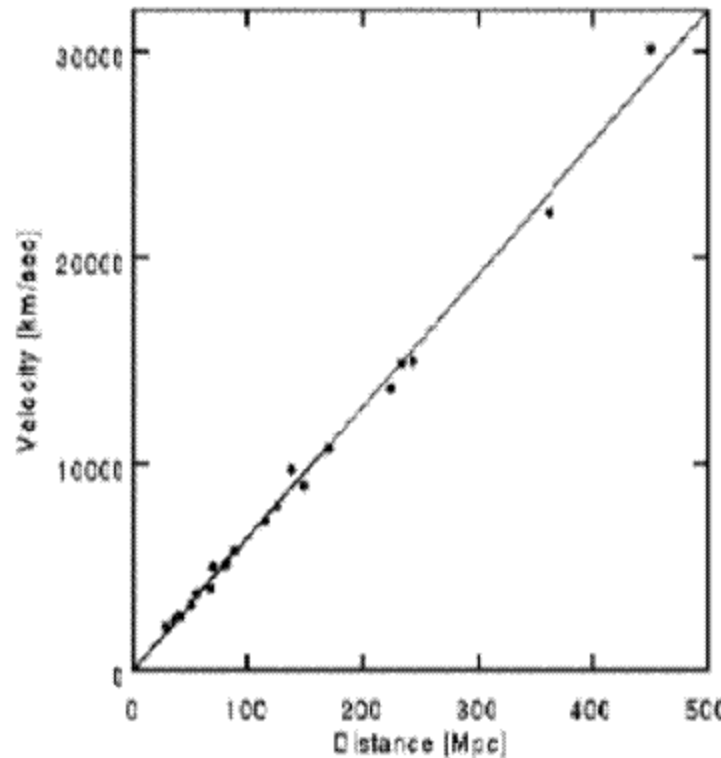


# We live in an expanding universe



Edwin Hubble  
(1929)

Recession Velocity  $\uparrow$



Slipher  
early 20's

Also  
Milton  
Humason

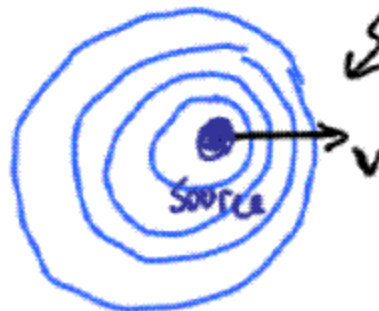
Determined by  
redshift of Atomic  
Spectral lines

Distance to galaxy

Determined by brightness  
(Supernova in distant galaxy)

"Redshifted" light

frequency appears lower to objects in direction away from direction of motion

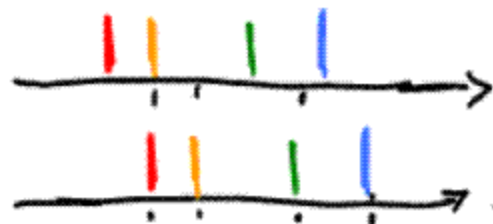


frequency appears higher to observers in direction of motion

"Blueshifted" light

larger  $v$  — larger the red and blue shifts.

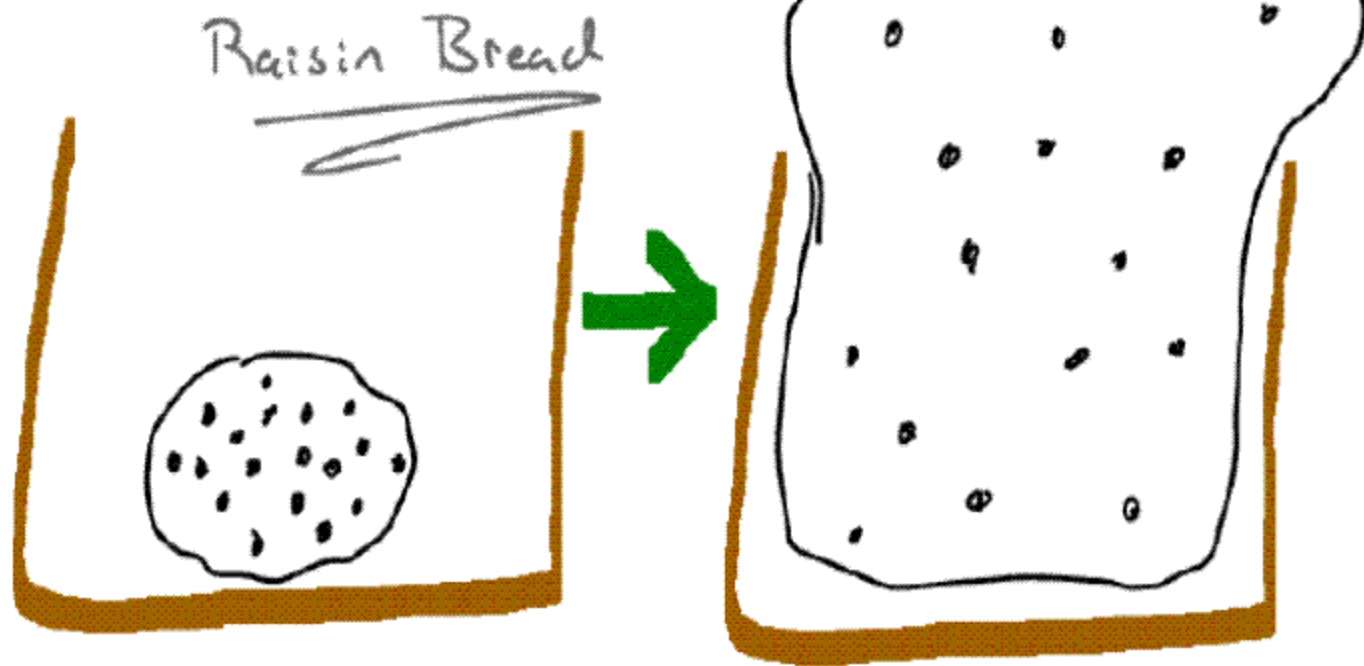
Atomic Spectrum



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

(color also changes - not shown)

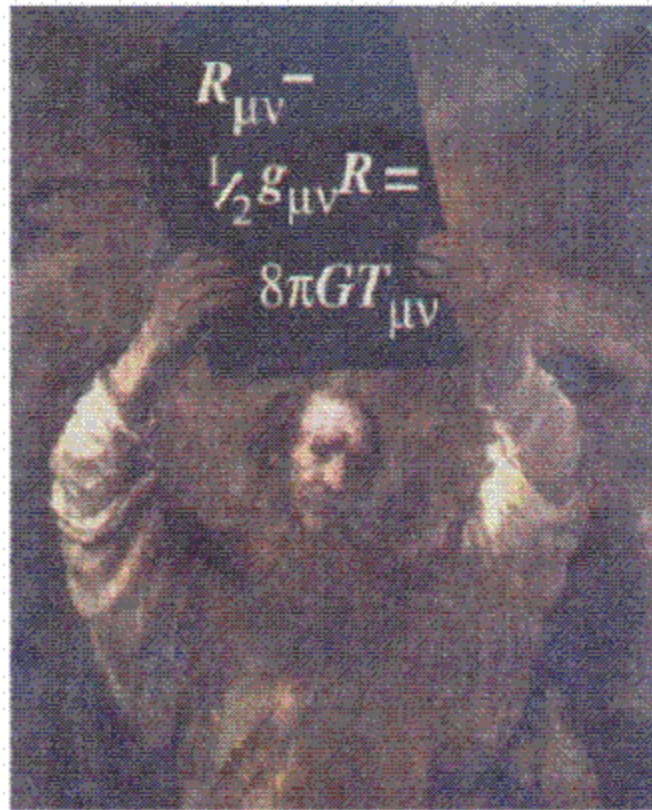
Galaxies Receding in all directions  
~ uniformly  
(except for "local" exceptions)



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

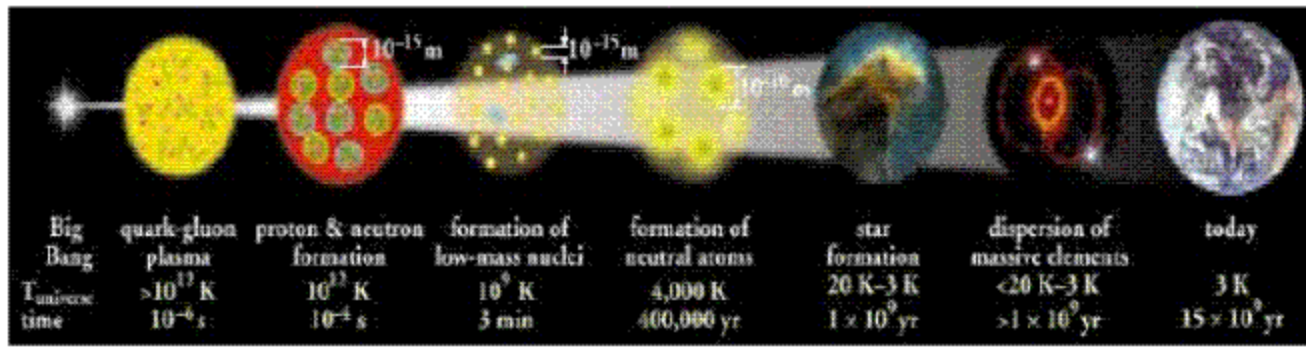
Expansion of space makes effect same to all  
observers throughout universe.

# Why Believe? ...



- R. Kolb





Hot Big Bang predicts this

light should travel to us from time  $\sim 400$  k yr to now ... massively redshifted

$$t = 4000 \text{ K} \longrightarrow t = 4 \text{ K}$$

"perfect Blackbody"

Should come to us from all directions

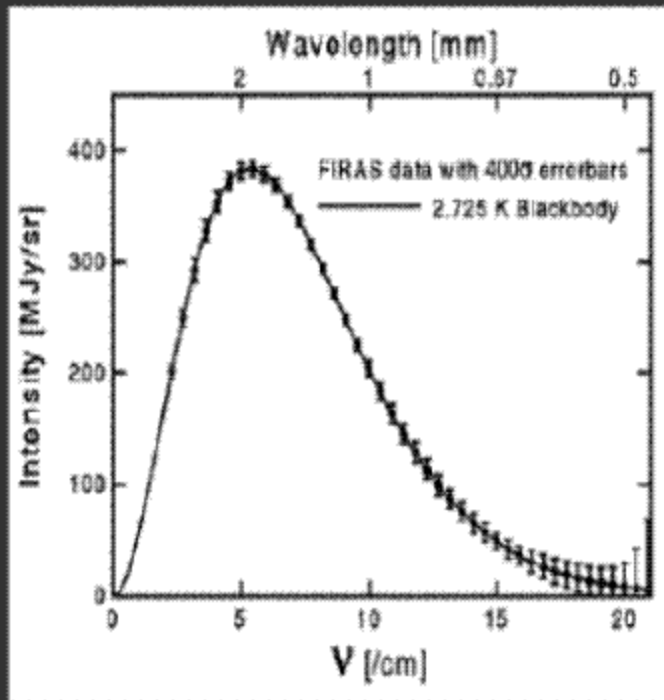
"CMB"

Cosmic Microwave Background

Evidence for Big Bang

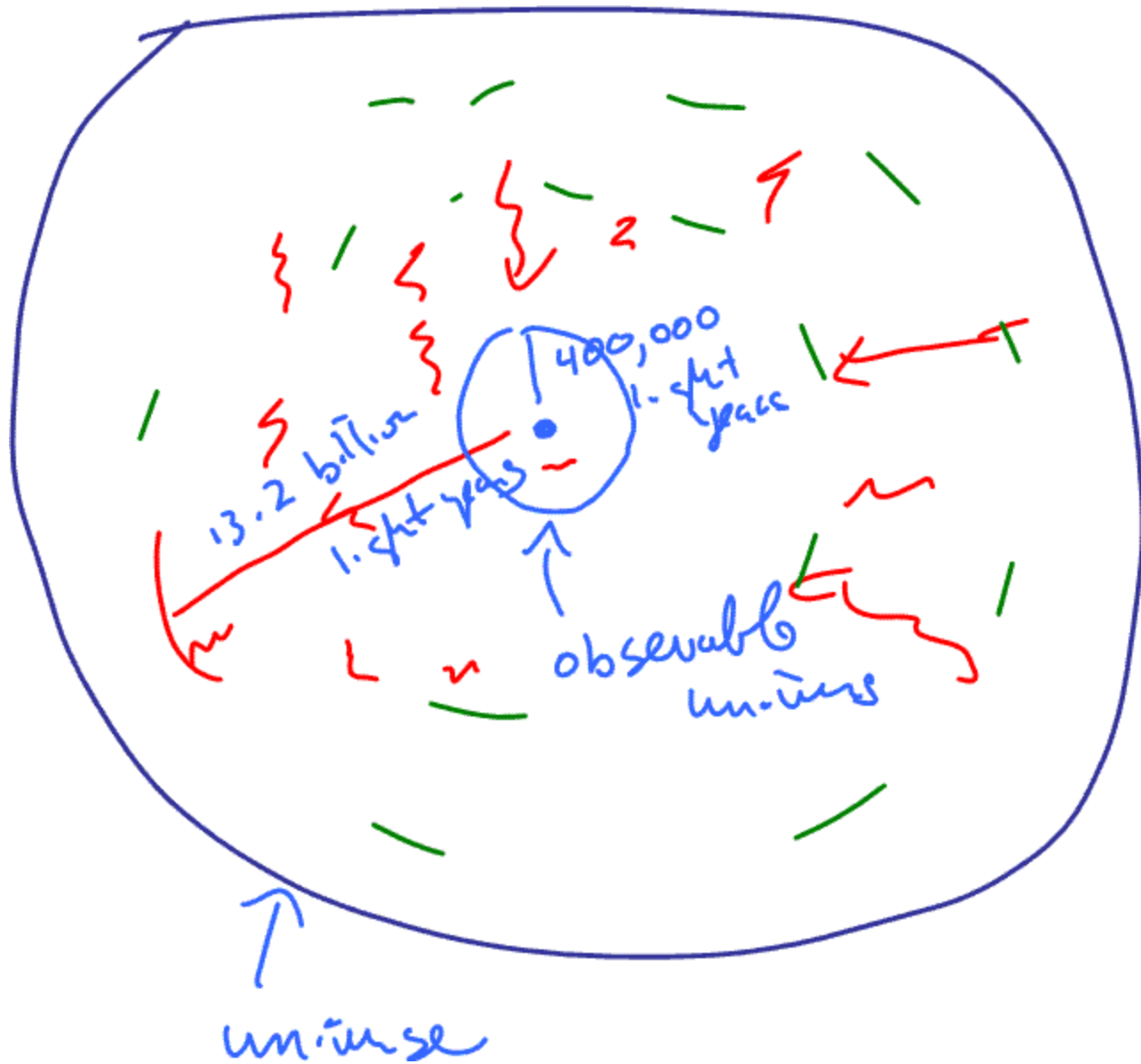
# Cosmic Microwave Background

## Penzias and Wilson - 1964



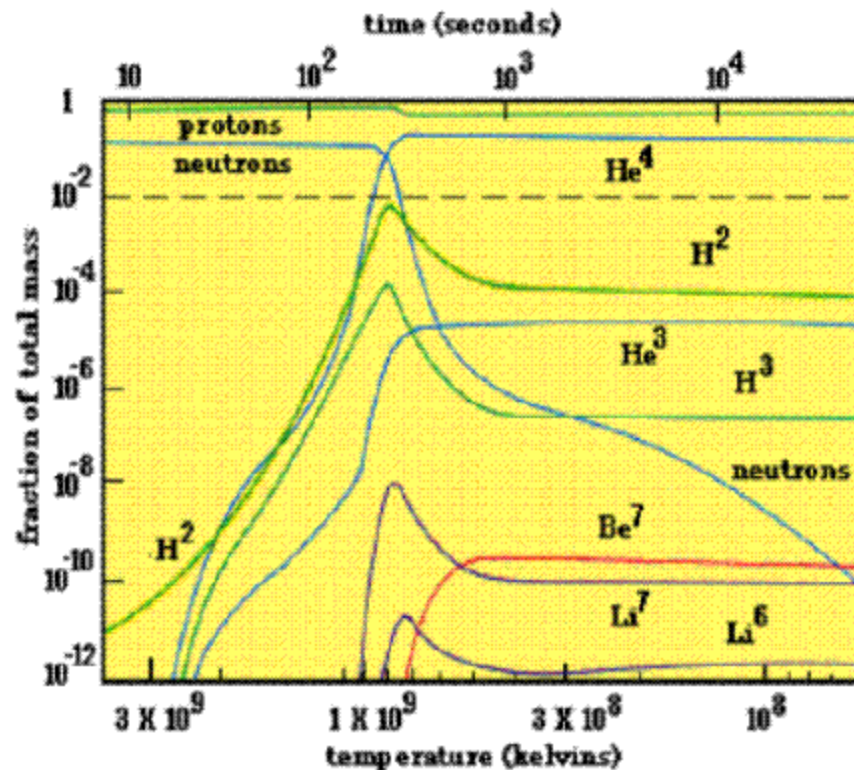
Uniform and isotropic  
– in as far as they could measure

1978 Nobel Prize



# Big Bang Nucleosynthesis

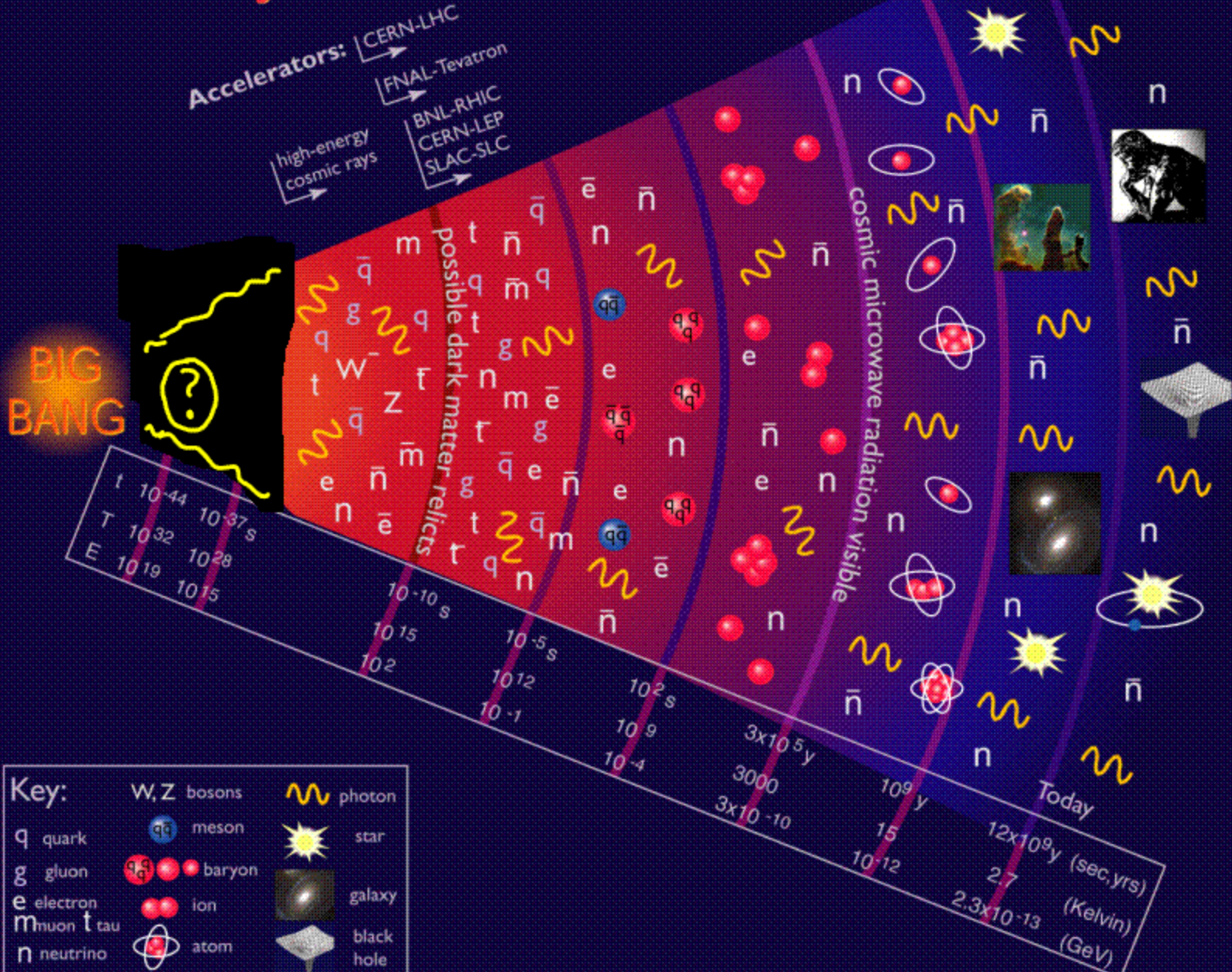
$t \approx 100$  seconds



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

We see ~expected distribution of light nuclei in universe.

# History of the Universe



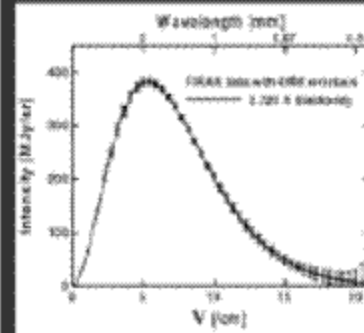
Observe light from  
 Time universe became  
 transparent  
 $T \sim 400,000$  years

Perfect blackbody  
 all directions in sky

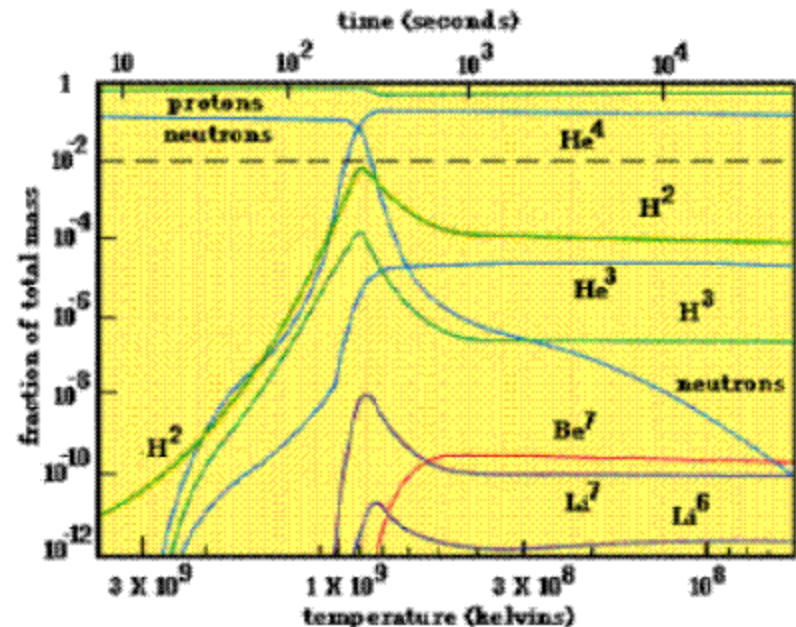
Amount of light  
 nuclei in  
 interstellar / intergalactic  
 space agrees w/  
 expectation from Big  
 Bang nucleosynthesis  
 $T \sim 3$  minutes

## Cosmic Microwave Background

Penzias and Wilson - 1964



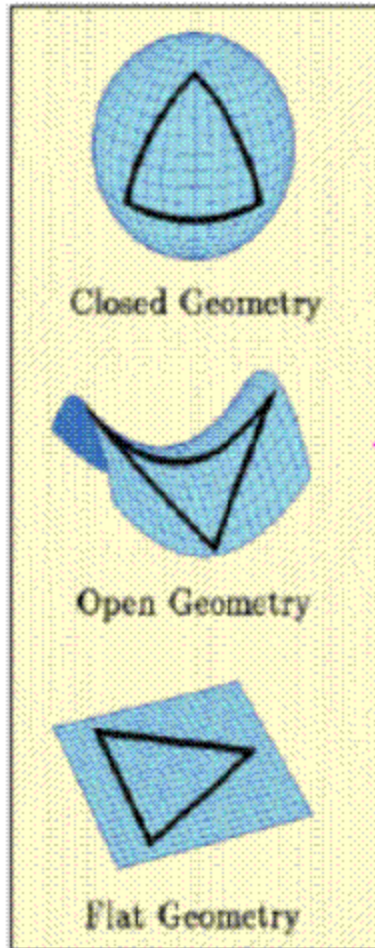
Uniform and isotropic  
 - in as far as they could measure



# Problems w/ Big Bang

NON-STATIC 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

$$> 180^\circ$$

← universe EXPANDS...  
Slows down + collapses

$$< 180^\circ$$

← universe expands forever

$$= 180^\circ$$

← 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

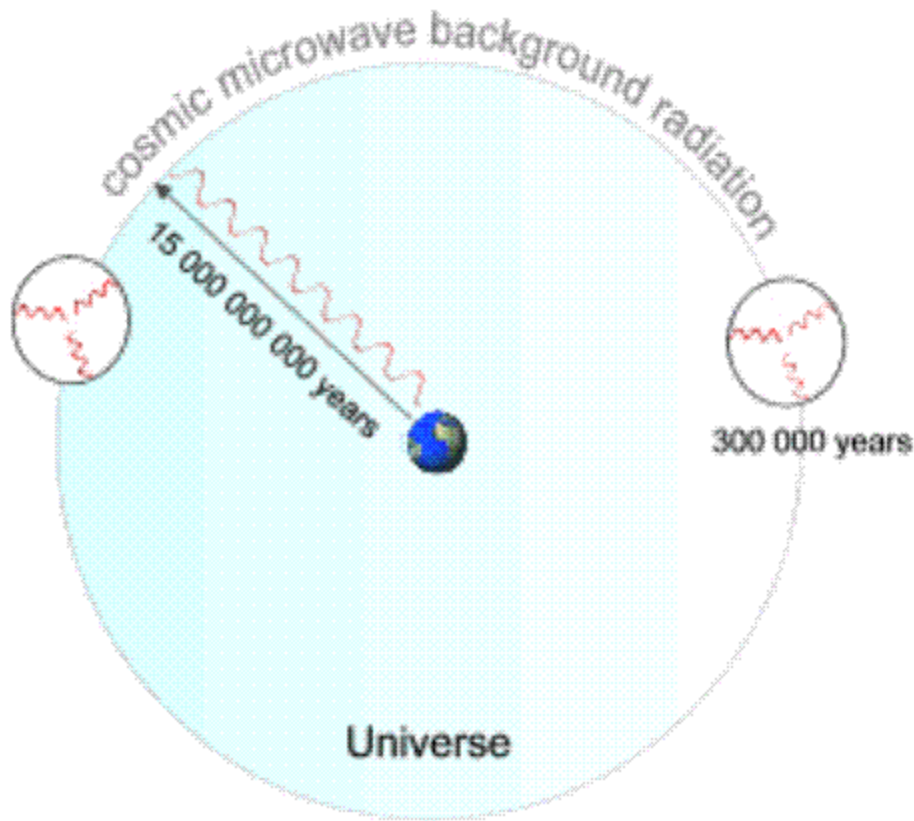
yet all at same temperature ??

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

Requires fine tuning of basic Model



# Horizon Problem



- drawing by  
Theresa Knott  
Taken from Wikipedia

■ large Scale Structure problem - how do galactic structures form in a perfectly homogenous universe?



Hubble Deep Field South  
PRC98-41a • STScI OPO • November 23, 1998  
The HDF-S Team • NASA

HST • WFPC2