final exam

COURSE	SECTION	DATE	TIME	LOCATION
AST121H1S		WED 24 APR	PM 2-5	BN2S

what to bring to exam:

pencil, eraser

non-programmable calculator

what's in the exam:

20 multiple choice (answer with scantron)

6 short answer questions (half quantitative, half conceptual)

1. Is there anti-matter in our universe?
2. What is dark matter and where is it?
3. How do we know there is dark matter?
4. Why do stars form in the inner region of the galaxy, while dark matter remains further out?
5. When the Milky Way and the Andromeda galaxy collide, what will happen to us?
6. What are the main stages in the evolution of the Sun?
7. What is nuclear fusion?
8. What is the influence on Earth as the Sun ages?
9. What is an absorption spectrum? an emission spectrum?
10. What is a blackbody spectrum?
11. Why do Hydrogen atom show emission or absorption lines at quantized wavelengths?
12. Why are images of far-away galaxies distorted by intervening mass (gravitational lensing)?

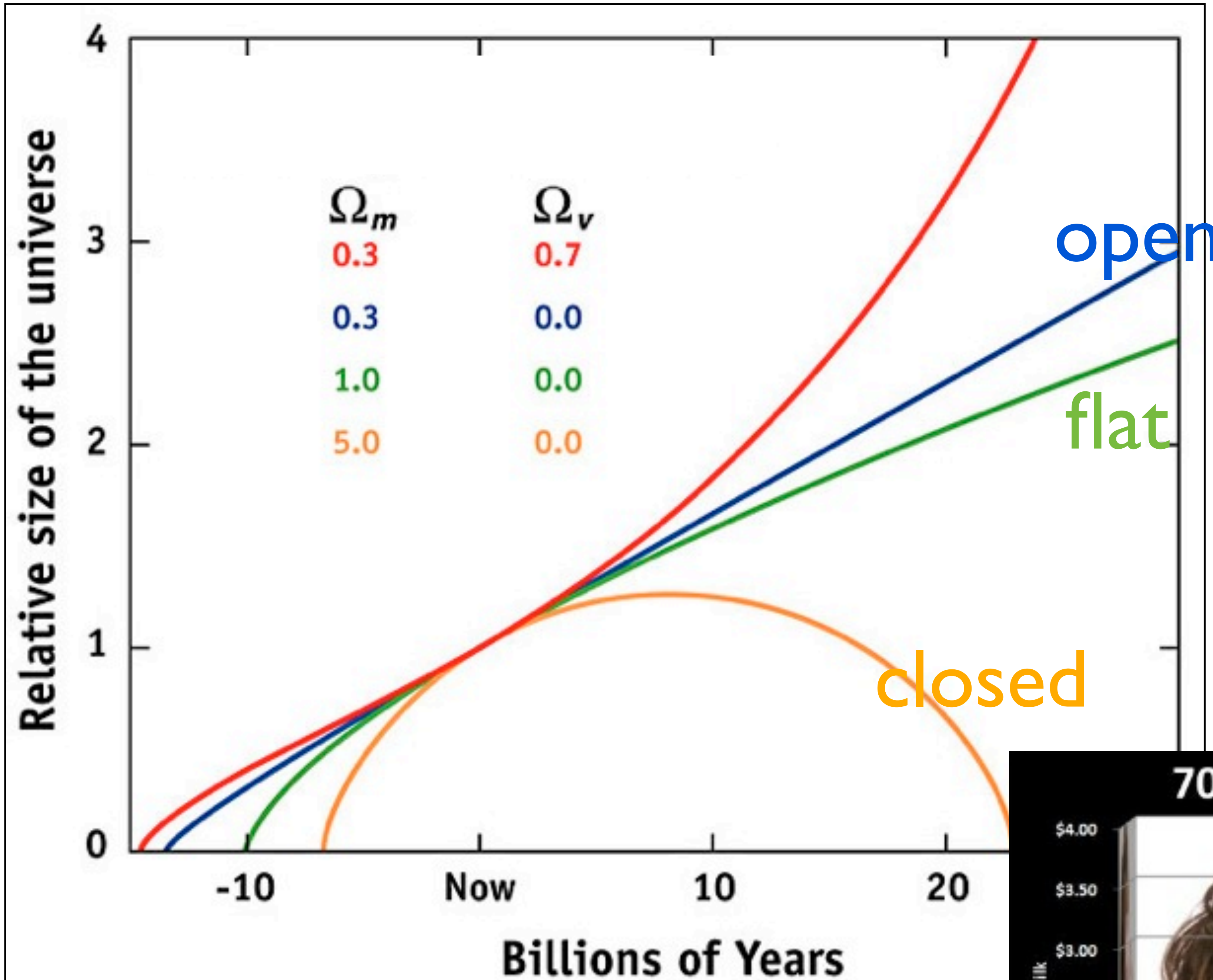
a (incomplete) list of Conceptual Questions

All answers are in lecture notes/textbook.

To prepare for the quantitative questions, work through all problem sets.

1. What is the currently most accepted model for the Universe?
2. What is the evidence for the Big Bang?
3. What happened during the Big Bang?
4. Why do we believe ‘inflation’ has occurred?
5. What is this "anti-gravity"? [The cosmological constant]
6. Why do we think that the expansion of the Universe is accelerating?
7. How old is the Universe?
8. Is the Universe really infinite or just really big?
9. How can the Universe be infinite if it was all concentrated into a point at the Big Bang?
10. Can objects move away from us faster than the speed of light?
11. Are galaxies really moving away from us or is space just expanding?
12. Why doesn't the Solar System expand if the whole Universe is expanding?
13. How do one measure the expansion rate of the universe?
14. what is the Scale Factor of the Universe?
15. What is the connection between redshift and scale factor?
16. What is meant by a flat Universe?
17. How do we know that our universe is largely flat?
18. What is the Universe expanding into? does our universe have an edge?
19. What came before the Big Bang?
20. Why is the sky dark at night?
21. Will the Universe expand forever or recollapse?
22. What are the different stages in the universe as it ages (in terms of dominant energy density)?

Scale Factor of the Universe



Inflation Index

Friedmann's equation describes how the scale factor evolves in time

$$H^2 = \left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G}{3}\rho - \frac{kc^2}{a^2} + \frac{\Lambda c^2}{3}$$

dark energy speeds up expansion

"kinetic energy" a big kick @ big bang

gravity slows down expansion

curvature (once flat, always flat)

3 special cases

$$\rho = \rho_{\rm crit}\ (\Omega_m = 1), \quad k = 0,\ \Lambda = 0$$

matter-dominated flat universe

$$\rho = 0,\ \Lambda = 0, \quad k = -1$$

empty universe, open

$$\rho = 0,\ k = 0, \quad \Lambda = \text{constant}.$$

dark-energy dominated flat universe

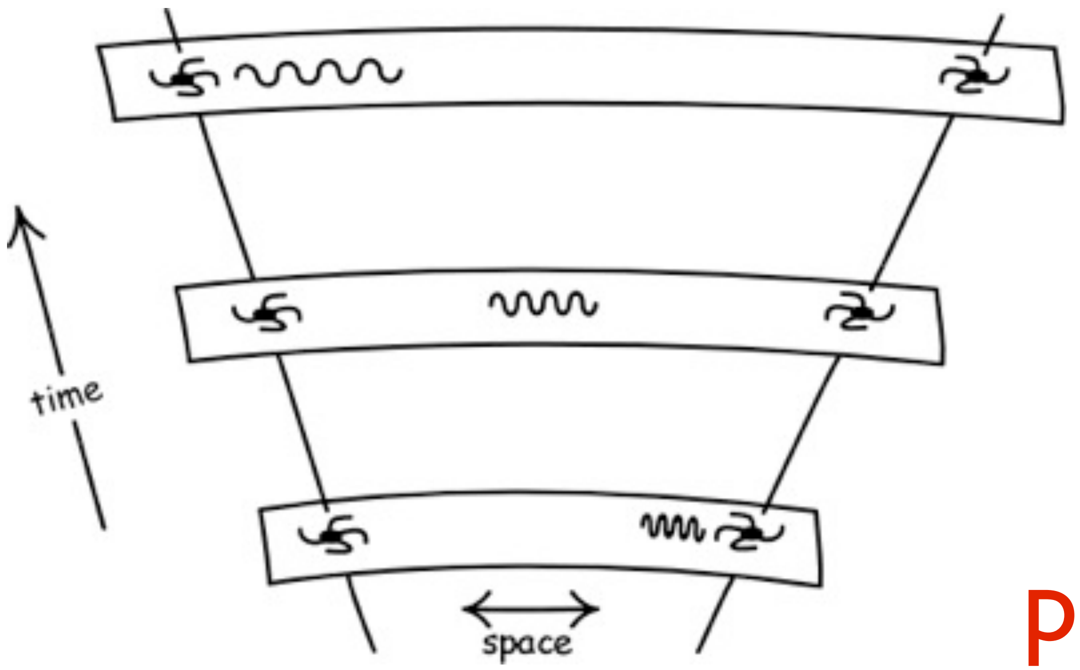
CMB photons, when emitted at that time, was in the optical wavelength, say, 1 micron.

By the time we observe it today, it has red-shifted to 1100 microns.

If the scale factor = 1 at the time of CMB, how big is the scale factor today?

$$\boxed{1 + z = \lambda(t)/\lambda_0 = a(t)/a_0}$$

Cosmological Redshift:
light redshifted, but not Doppler Effect



photon emitted with λ_0
when universe size a_0

photon stretched as it propagates,

a=a(t) is also called
the scale factor of
the universe.

at reception, $\lambda(t)$
universe size $a(t)$

redshift: tells you how
small the universe was
relative to today.

$$\boxed{1 + z = \lambda(t)/\lambda_0 = a(t)/a_0}$$

higher redshift= earlier time = smaller universe

How big is a patch of the universe today if it was 1cm @ CMB (z~1100)?

Would the answer depend on the curvature, mass density, dark energy in the universe?

$$1 + z = \lambda(t)/\lambda_0 = a(t)/a_0$$

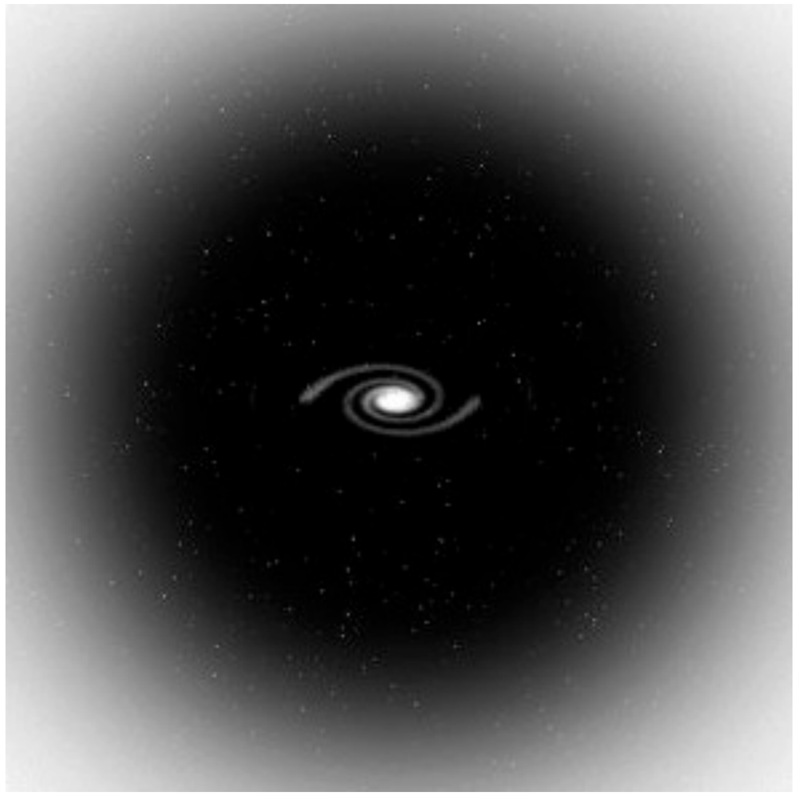
$$H^2 = \left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G}{3}\rho - \frac{kc^2}{a^2} + \frac{\Lambda c^2}{3}$$

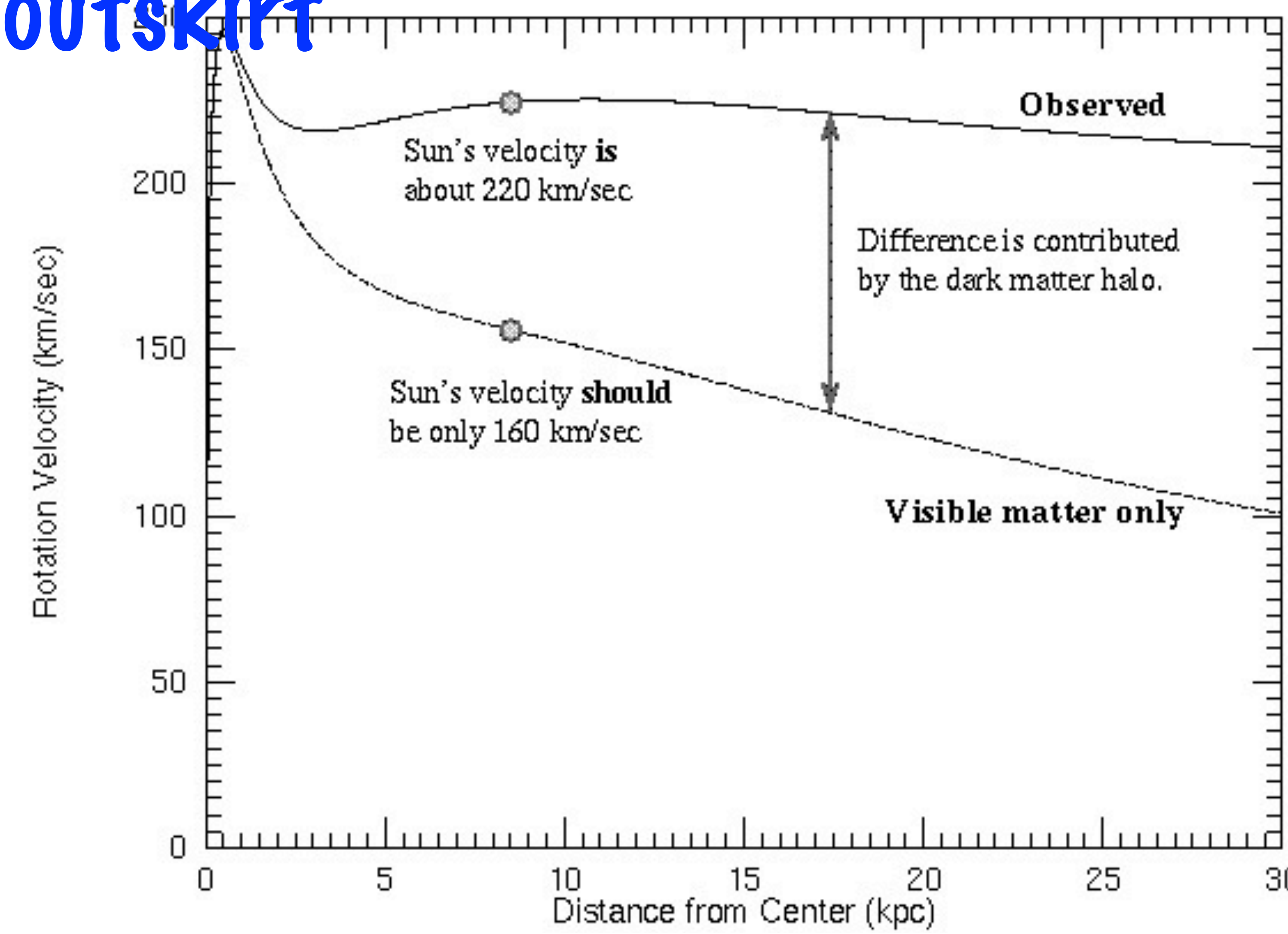
- How to measure ρ?
- How to measure H?
- How to measure k?
- How to measure Λ?

Over the last century, we have pretty much figured out the global properties of the universe.

• How to measure ρ (matter density)?

Galaxy mass largely dominated by dark matter -- in the outskirt





When falling into the potential well of a galaxy,

gas: collides and loses angular momentum, forms disk/bulge in the inner part of the galaxy

dark matter: no collision, can not lose angular momentum, orbit further out with nearly isotropic velocity dispersion (halo)

Back to Kepler's Third law

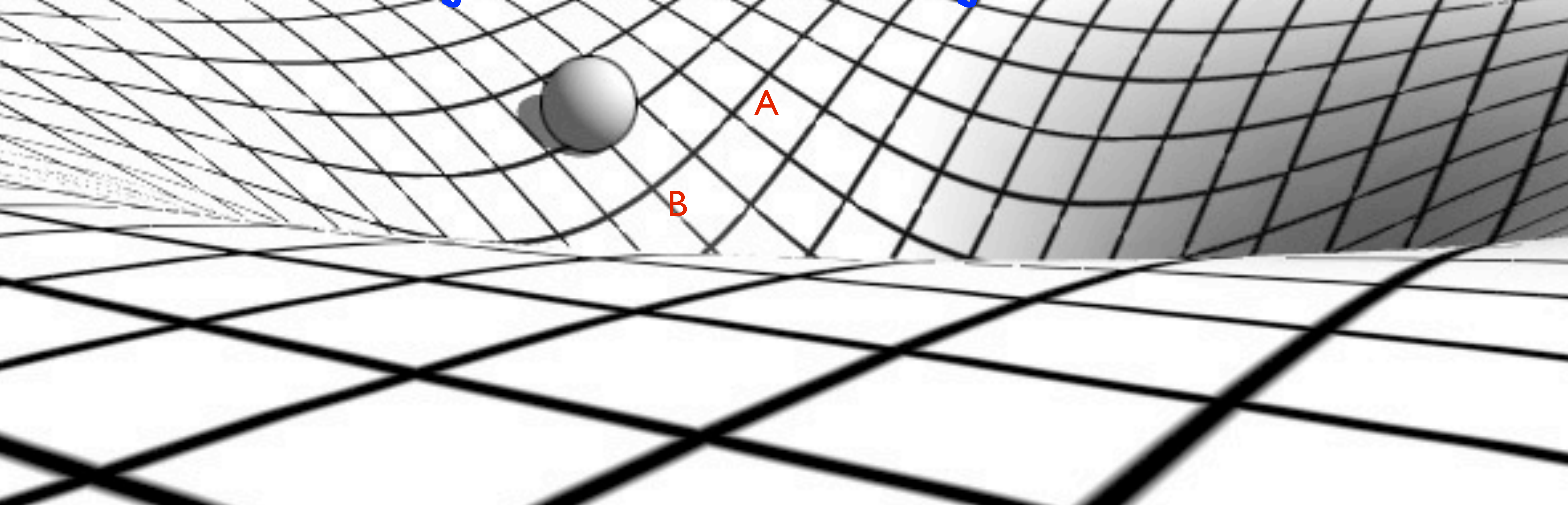
- Centripetal force keeps planet in orbit around the sun: $F_c = mv^2/R$
- Gravitational force between sun and planet: $F_g = GMm/R^2$
- Equate these two forces → $\boxed{v^2 = GM/R}$
- Show in problem set: $P^2 = 4\pi^2R^3/GM$

But that means we can calculate masses of celestial bodies through gravity!

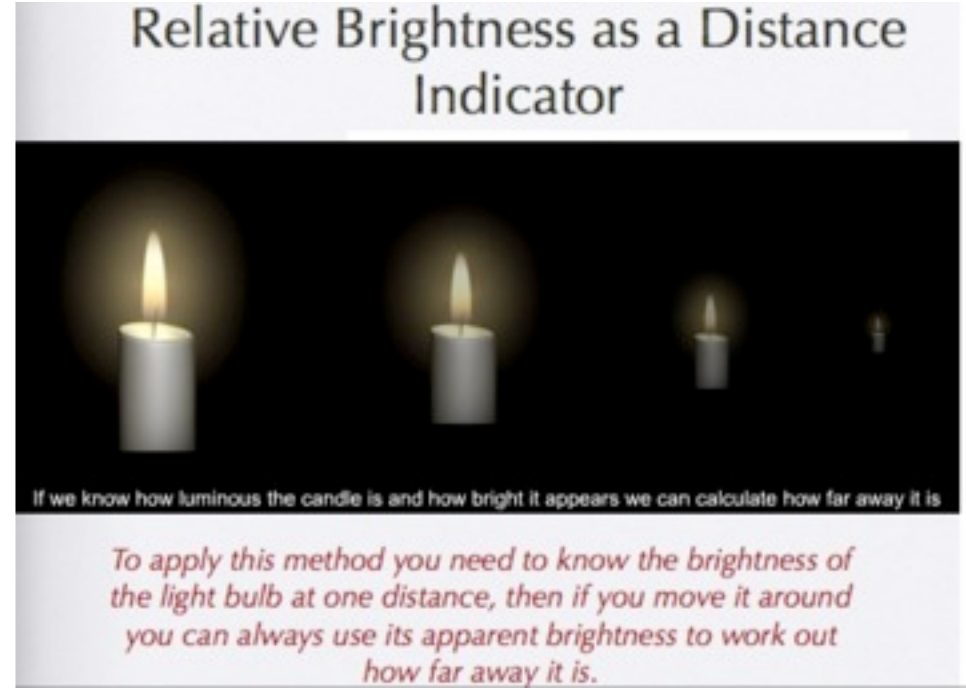
Clusters of galaxies are also bound by their dark matter

$V^2 = GM/R$

We can also measure the dark matter mass using gravitational lensing.

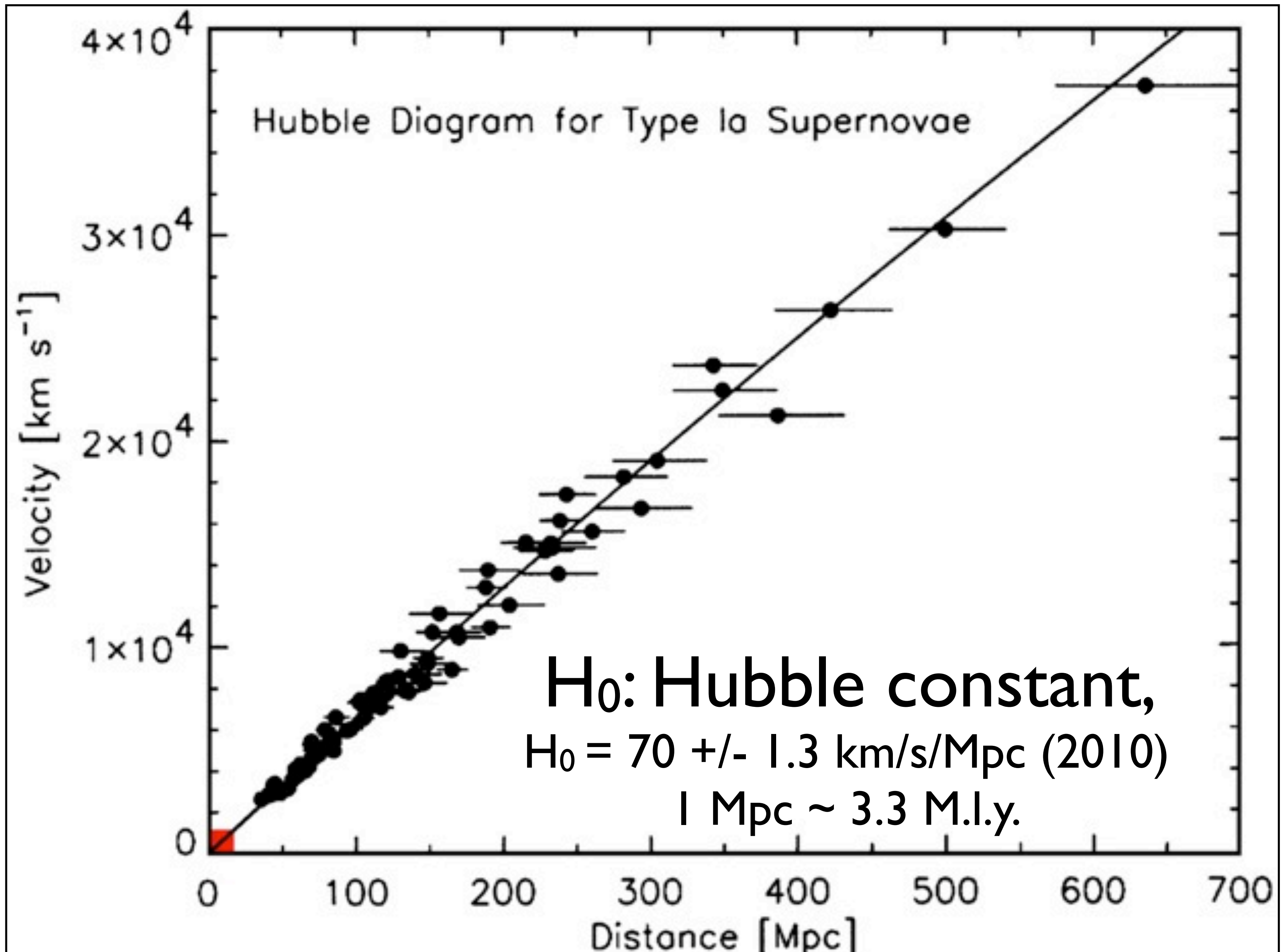


● How to measure H (Hubble's constant)?



Hubble's Law
v ~ H * d

H = 1/a * da/dt



Hubble expansion (~ 1920s) first measured using Cepheid stars.

H_0: Hubble constant,
H_0 = 70 +/- 1.3 km/s/Mpc (2010)
1 Mpc ~ 3.3 M.l.y.

Age of the Universe

a rough way: H_0 = 70 km/s/Mpc

1 Mpc ~ 3 million-light-years ~ 3 x 10^{19} km

$$H_0 = 70\mathrm{km/s}/(3\times 10^{19}\mathrm{km}) \sim 2.3\times 10^{-18}/\mathrm{s}$$

$$\frac{1}{H_0} \approx 14\mathrm{Gyrs}$$

Age of the Universe

....

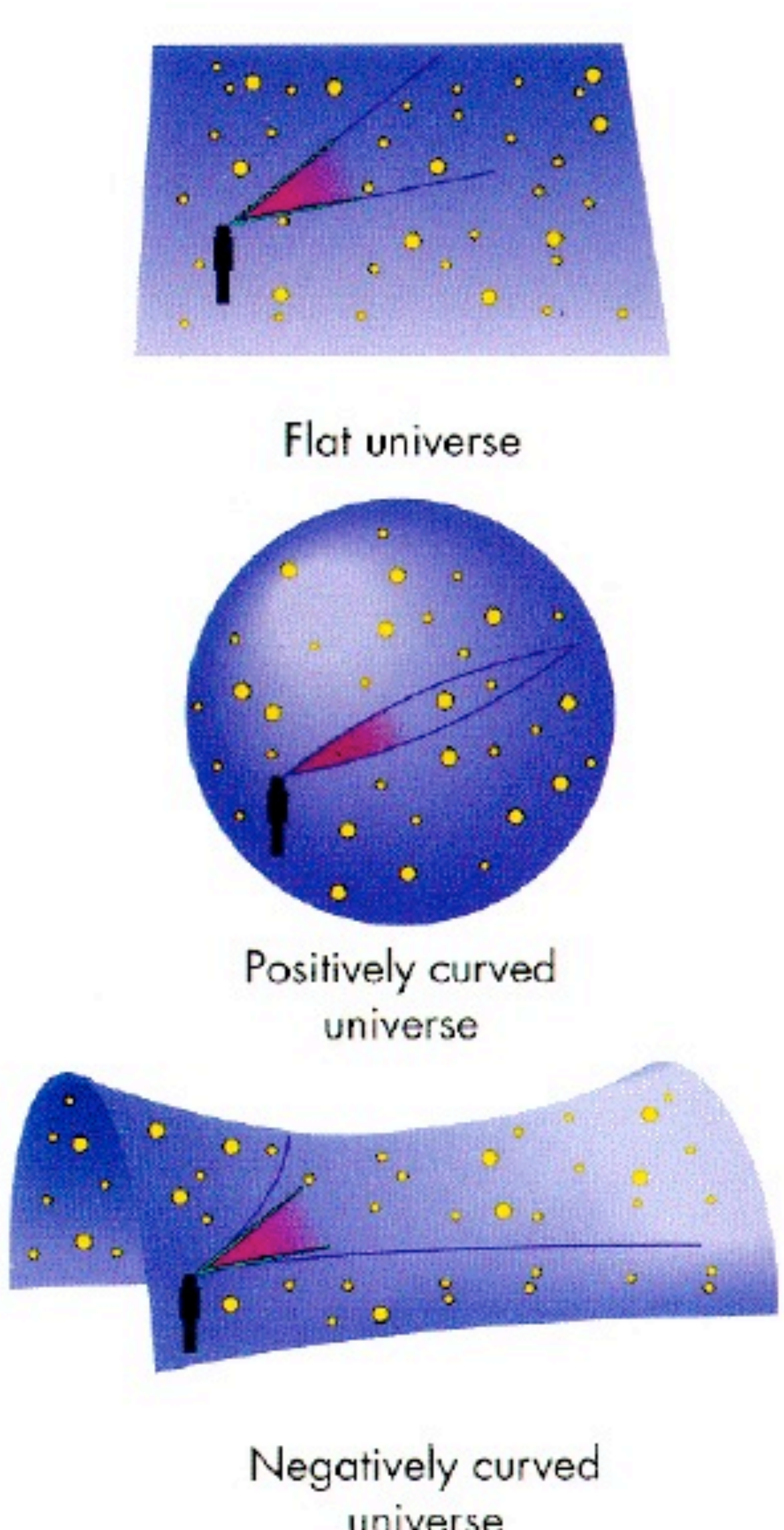
....

....

....

Answer: 10^{-20} yrs

•How to measure k (cosmic curvature)?

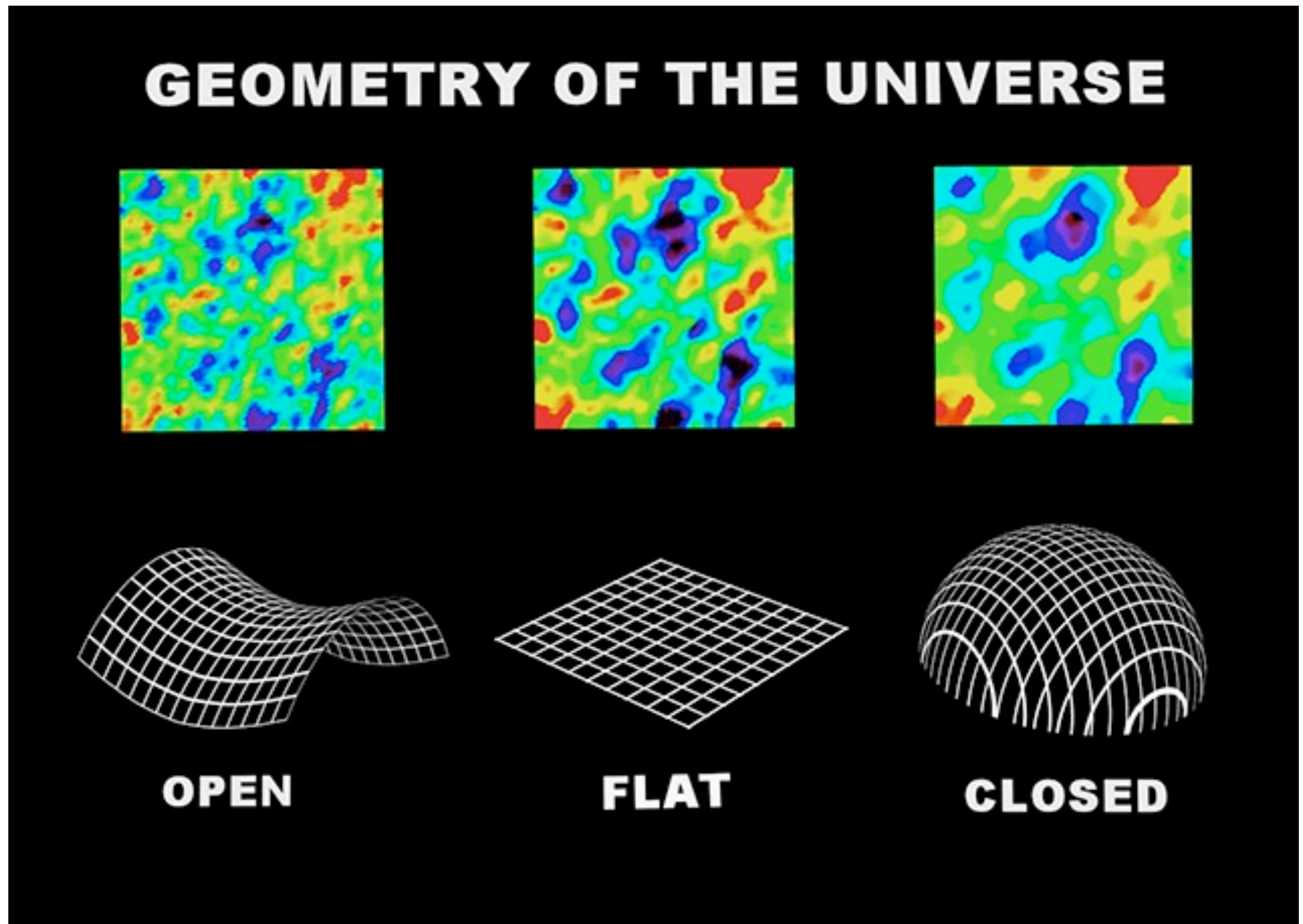


to observers, cmb spot appears smaller than should be

•Spot size on CMB is a "standard ruler"

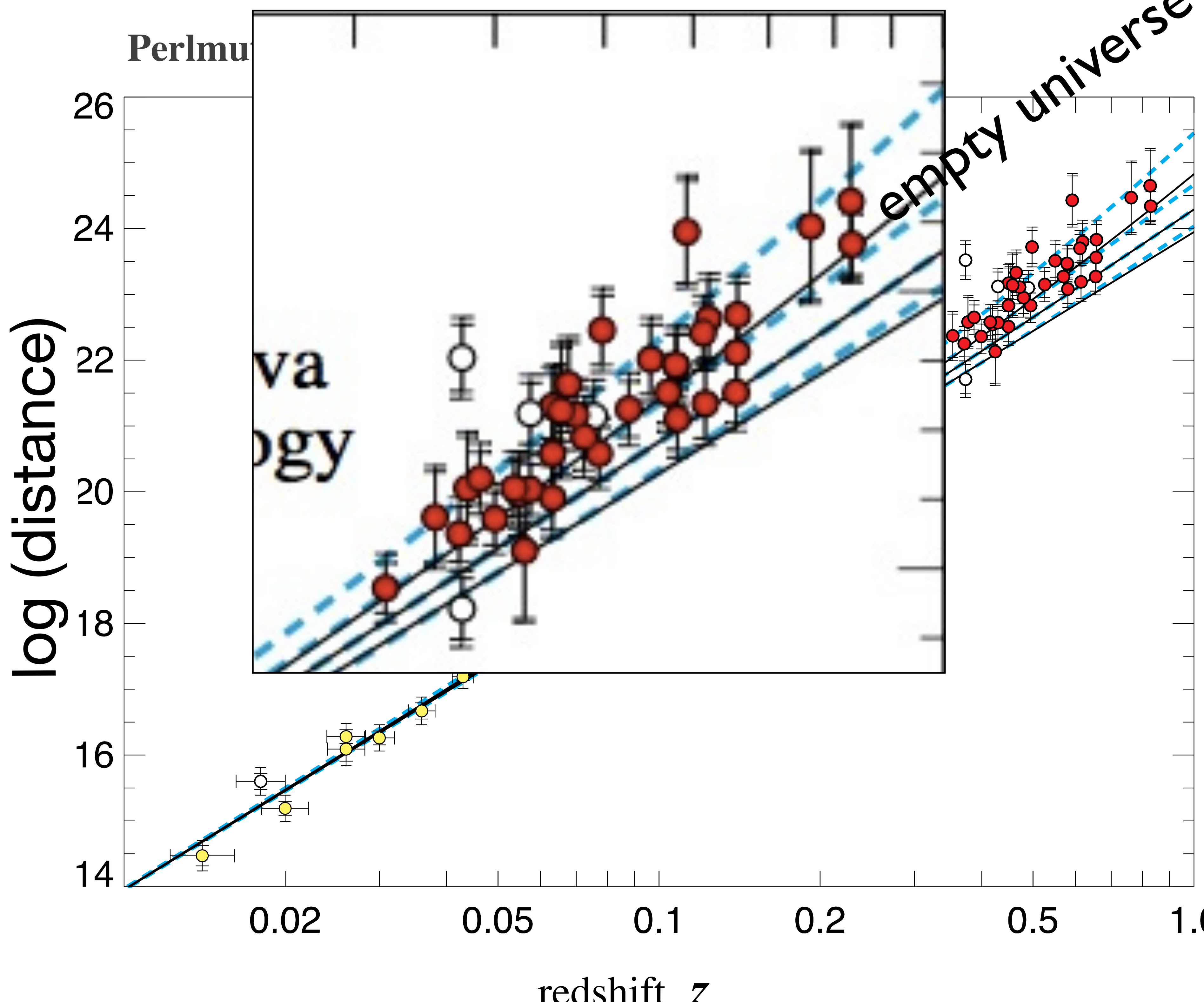
• it is roughly size of horizon at z=1100

•if universe is flat, angular size of spot = spot size/distance



• How to measure Λ (cosmological constant)?

Like Cepheid Stars, Supernova are ‘**standard Candles**’



empty universe ($\Omega_m = 0$): has stretched the most; supernova at a given z should look the dimmest. But real supernova appear even dimmer (1998) --> The universe has stretched even more.

Concordant cosmology: we live in a flat universe, with dark energy and dark matter dominating the energy density

From Cosmic Microwave Background & Other data

Ω_{tot} = 1 +/- 0.01

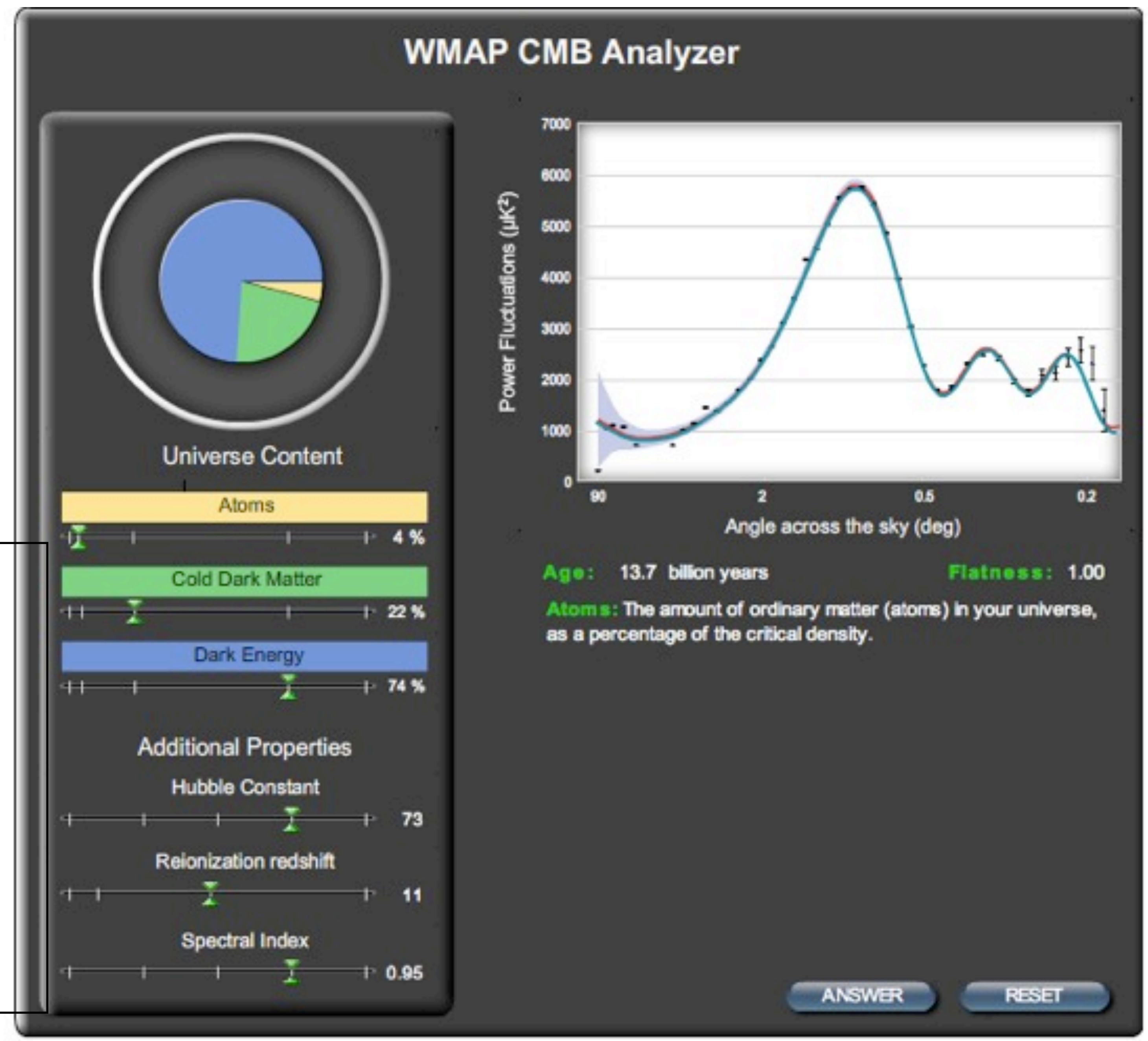
Ω_{m} = 4.6% +/- 0.1%

$\Omega_{\text{dark matter}}$ = 23.3% +/- 1.3%

$\Omega_{\text{dark energy}}$ = 72.1% +/- 1.5%

age = 13.73 +/- 0.12 Gyrs

WMAP 2010



http://map.gsfc.nasa.gov/

Why does the universe have to have a beginning?

Pillars of Big Bang Cosmology

there was a beginning

•No stars older than 13 Gyrs
•Expansion of the universe -- something set it into motion.
•Olbers' paradox *(the oldest argument)*

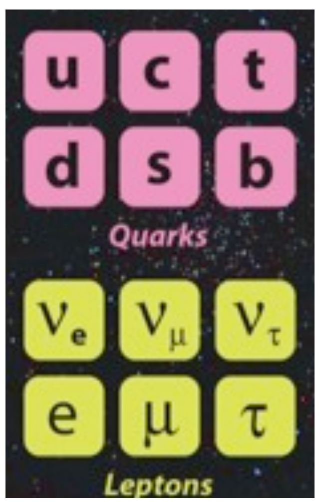
& the beginning was hot

•Cosmic microwave background radiation (cmb)
•Observed helium and deuterium abundances.
•the fluctuations of matter density after a big bang explains the 'large scale structure' (galaxy cluster etc.)

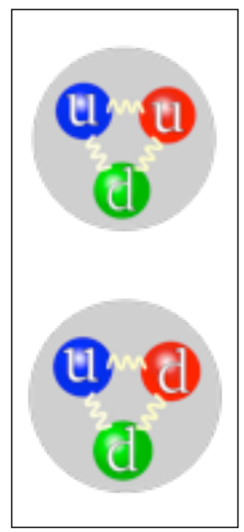
universe ‘freeze’ into shape

In the beginning, there is light.

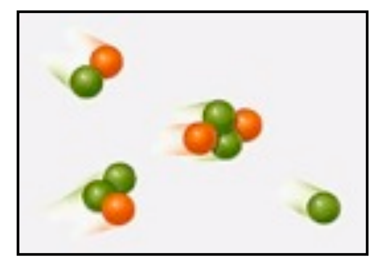
particles
~10^{-10} sec



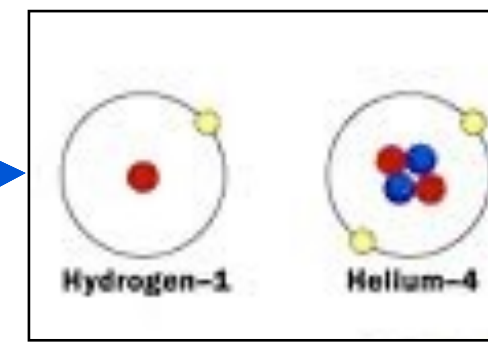
proton & neutron
0.001 sec



nuclei
3 min.



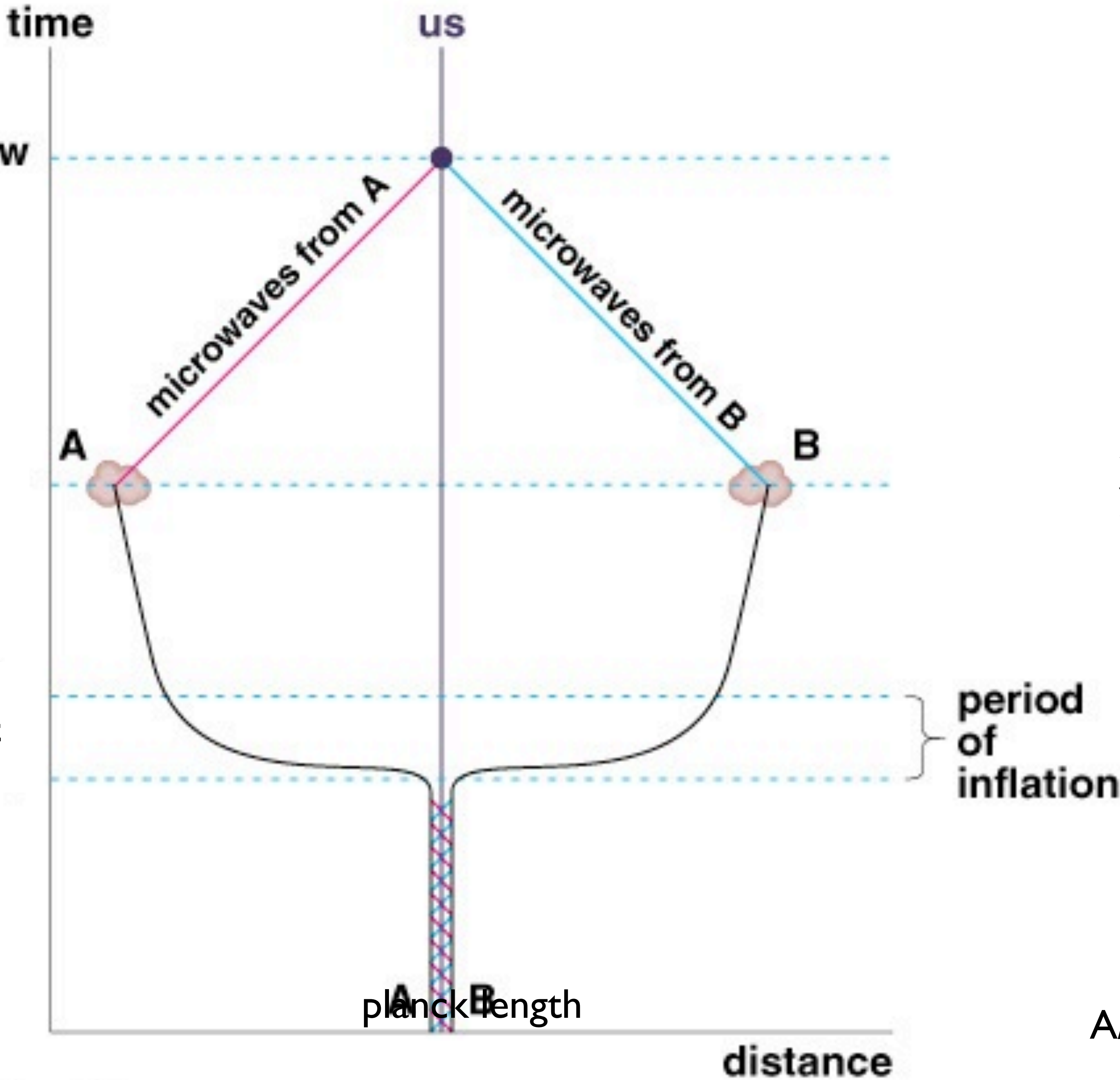
atom
300,000 yrs



~1 Gev ~1 Mev ~1 ev

accelerators

Why do we invoke an early period of 'inflation'?



CMB

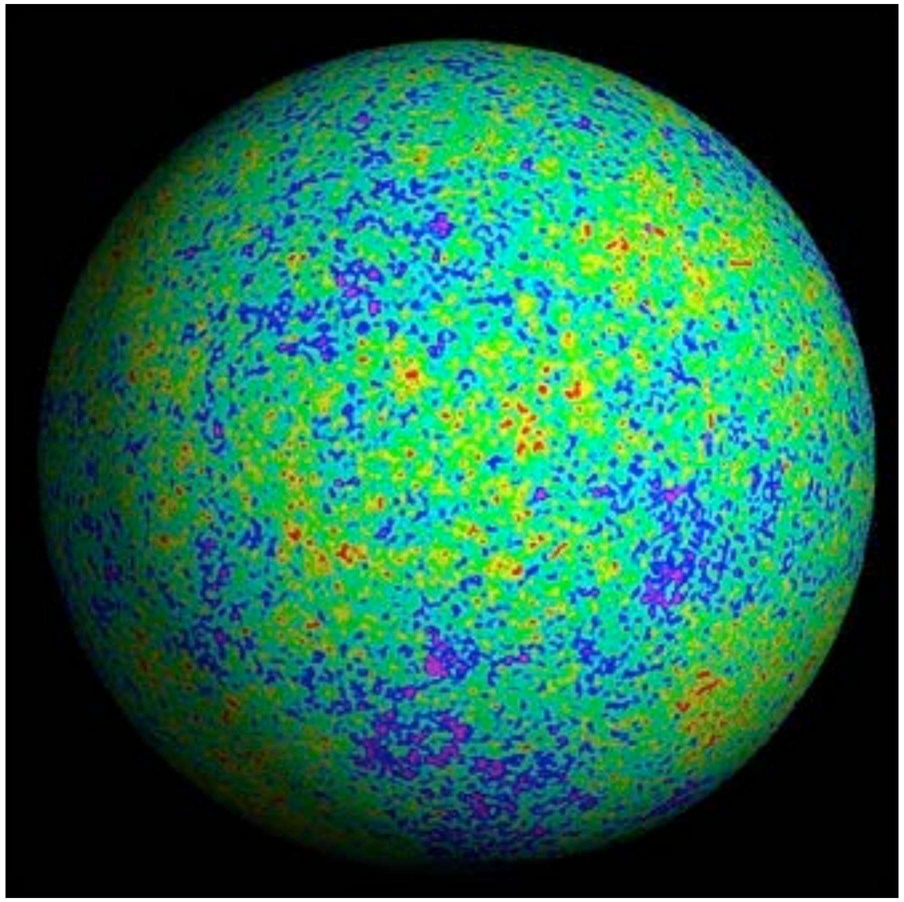
10^{-34} sec

planck length

A/B not in causal contact yet seems to be aware of each other

A/B initially in causal contact

Initial conditions for the universe (post CMB)

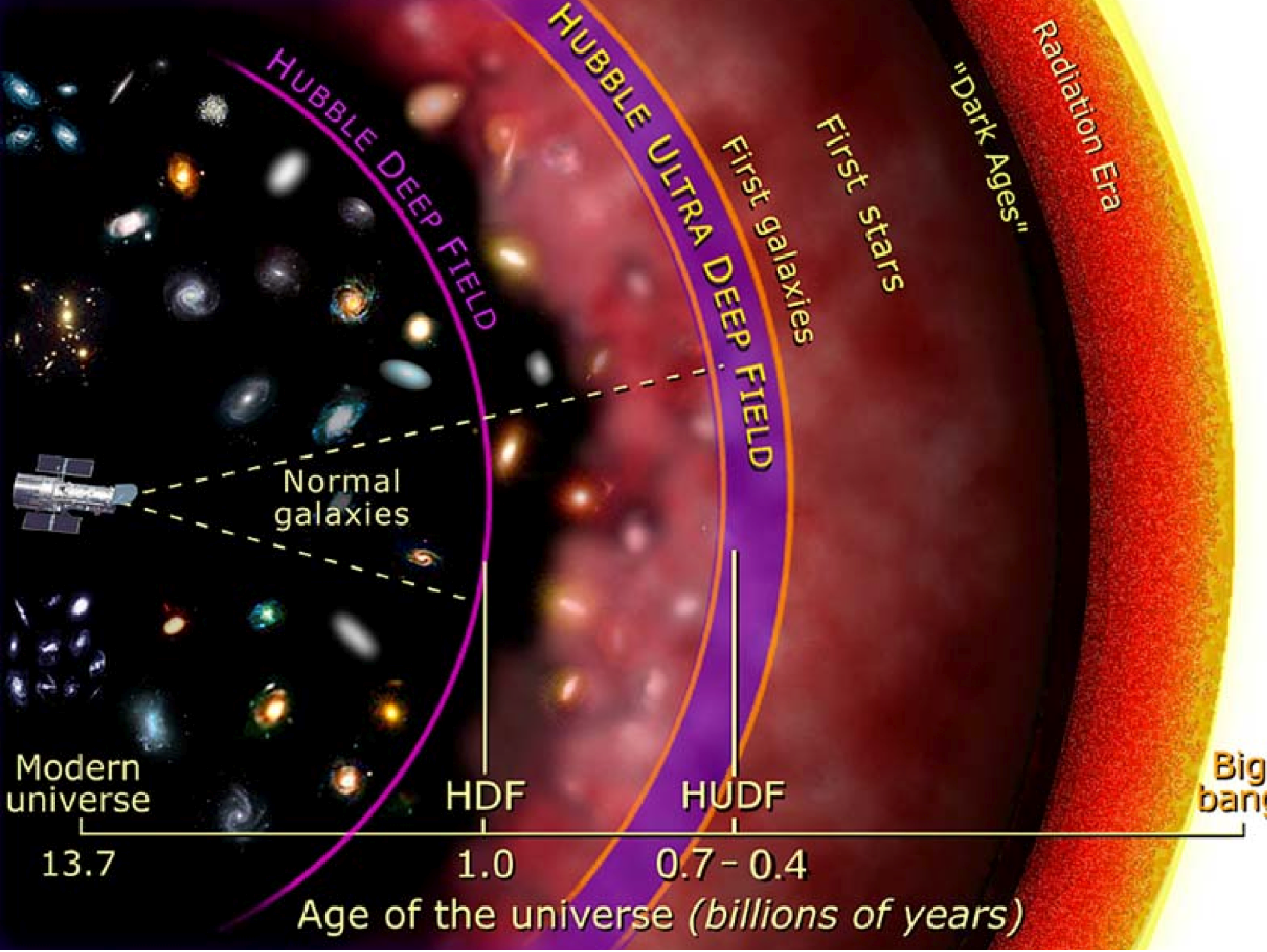


flat, no detectable curvature
T ~ 3000K
75% H + 25% Helium
tiny fluctuations

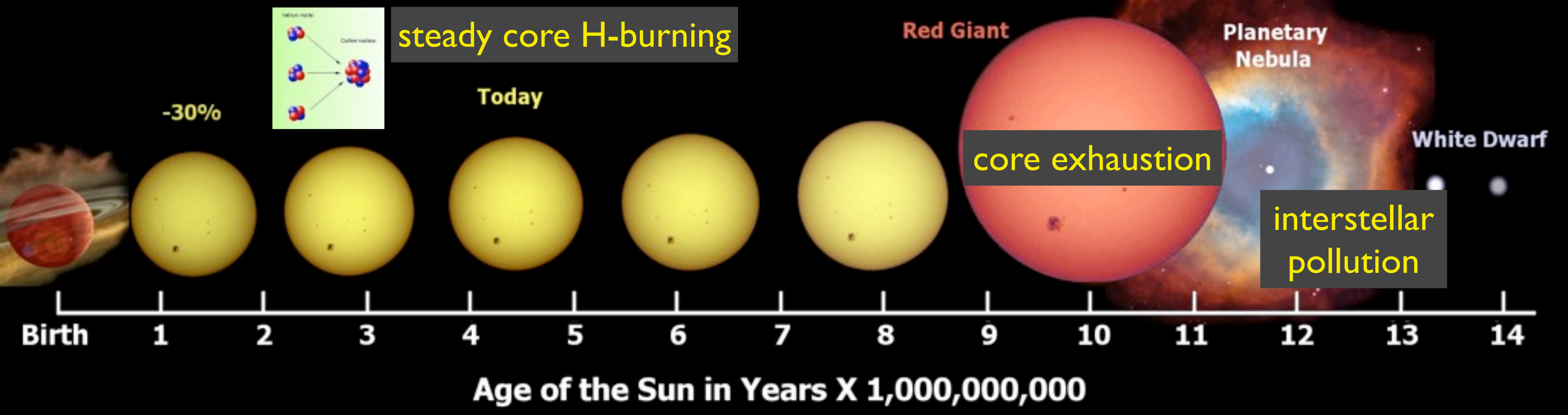
Hot spots: ~10^{-5} higher compared to 2.7K

denser (and therefore hotter) places; gravity is relatively stronger, can slow expansion of the universe, eventually collapse.; forming galaxies, galaxy clusters...

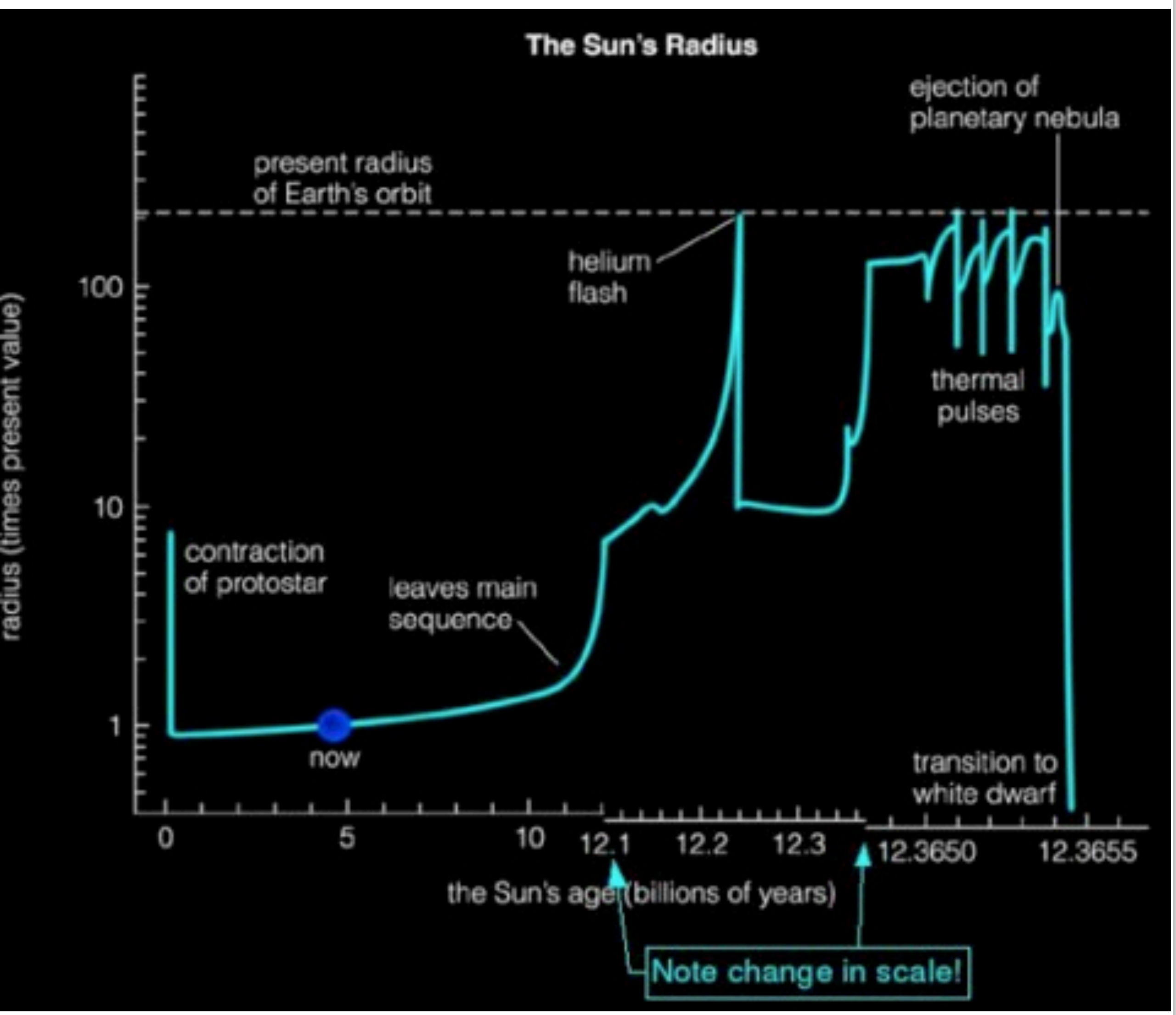
cold spots: void today



HUBBLE DEEP FIELD
HUBBLE ULTRA DEEP FIELD
First galaxies
First stars
"Dark Ages"
Radiation Era
Normal galaxies
Modern universe
HDF
HUDF
Big bang
13.7
1.0
0.7 – 0.4
Age of the universe (billions of years)



red giant



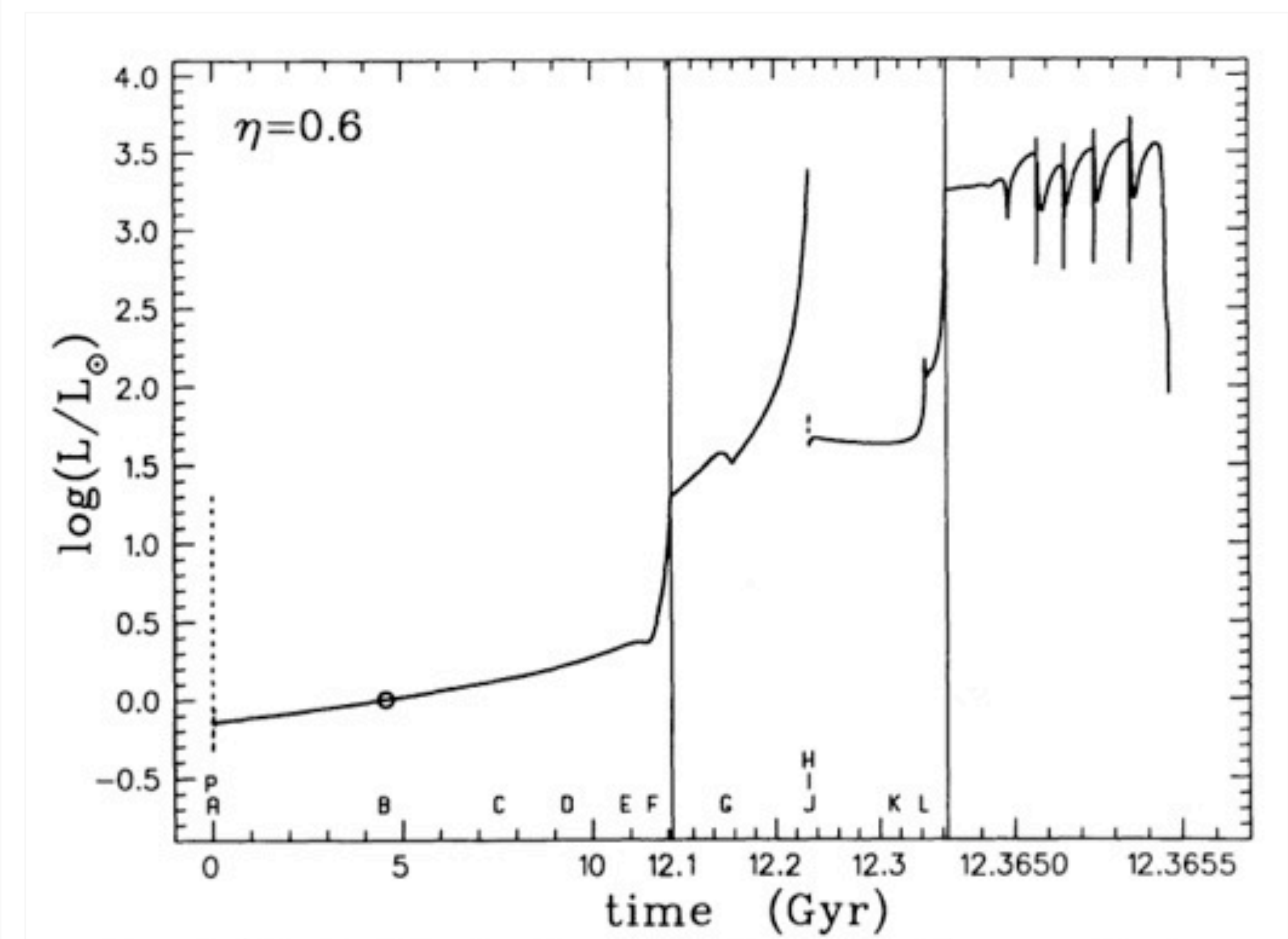


FIG. 4.—The Sun's luminosity as a function of time, for our preferred case. Note the three different time scales, as the evolution speeds up. Symbols have the same meaning as in Fig. 2.

The "Age of Stars"

. early universe, hot background, no metals, proto-galaxies
. 'first stars' likely form at redshift ~ 10-30, ending the 'cosmic dark ages'

. stars live and die, polluting the interstellar medium with metals
. succeeding generations of stars made of gas enriched in metals

. these stars may form accompanied by planetary systems

. gas is continuously recycled into and out of stars, until all gas is locked up in low mass stars that live for a very long time

. eventually even these low-mass stars die, no more light in universe

An anthropic view of the universe:

The role of the universe:
dark matter-assisted collapse into galaxies

The role of galaxies:
provide the dense gas that allow stars to form

The role of stars:
to turn primordial gas into a myriad of elements, so that planets and life can form; to give light and warmth

How did the universe start?

What was before t=0?

What is outside the universe?

What causes inflation?

What is dark energy? dark matter?

Who decides on physical constants (G, m_p, m_e...)?