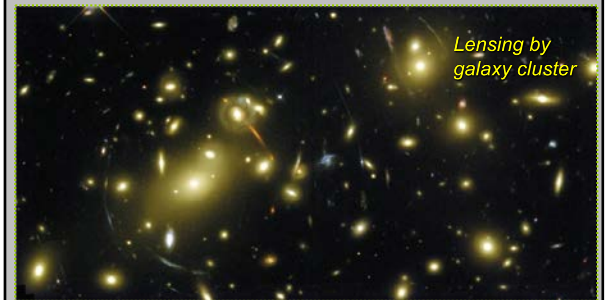
ASTR 1040: Stars & Galaxies



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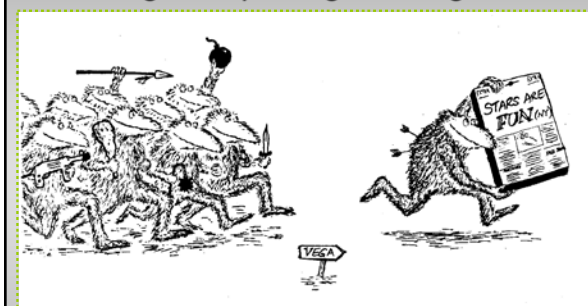
Lecture 27   Tues 4 Dec 2018
zeus.colorado.edu/astr1040-toomre

Our Schedule

- *Third Mid-Term Exam returned today*
- *Homework #12 likewise*
- *Course evaluations (FCQ) online this week+, separately for lecture and recitations*
- *Observatory #11 tonight (last one)*

- Focus on *22.2 Evidence for Big Bang*
- Complete overview read *Chap 23: Dark Matter, Dark Energy, Fate of Universe*

Challenges of putting it all together …



RESULTS FROM THIRD MID-TERM EXAM

THIRD MID-TERM EXAM

- *Grade boundaries, based on 126 points (graded on a "curve"):*

- *If 108/126 (86%) or over, A's [39%]*
- *92/126 (73%) or over, B's [41%]*
- *76/126 (60%) or over, C's [20%]*

Also +, plain, and – within these ranges

Go through answer sheet – and talk to us if do not understand our choices. Keep exam + answers for future review (comp final)

Today's Topics

- Cosmology: *models of the universe*
- Concept of *look-back time*

- Discovery of *cosmic microwave background* implies a big-bang beginning
- How dark matter can influence *"open"* vs *"closed" universe*

Cosmology: Big scales of our Universe

DISTANCE ESTIMATE 5

Use Hubble's Law itself to estimate vast distances D

- *Measure velocity, then:* $D = v / H_o$

REMINDER

- *Example: using* H_o *= 70 km/sec/Mpc, and finding that v = 700 km/sec*

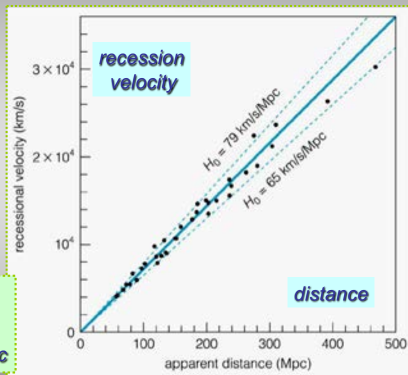
D = 700 km/sec / 70 km/sec/Mpc = 10 Mpc
= 32 million light years

REVIEW

VELOCITY = H_o x DISTANCE

"HUBBLE CONSTANT"

H_o = 71 +/- 4 km / sec / Mpc



REVIEW

Cosmological (Big) Redshifts

(from expansion of universe)

Alternative definition of redshift :

Z = redshift
= change in wavelength/ "normal" wavelength

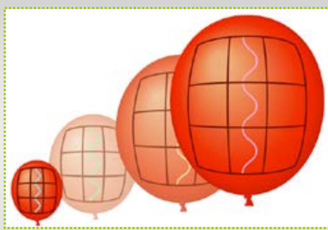
1 + Z =
observed wavelength / "normal" wavelength

redshifts always have Z > 0
(redder light has larger wavelengths)

Redshift is "expansion factor"

1 + Z also measures how much universe has expanded

and wavelength of light is effectively stretched



1 + Z = distance between galaxies now / distance between galaxies then

REVIEW

Relativistic redshifts

If Z is big (~1+), use relativistic formula to get velocity v

RELATIVISTIC DOPPLER REDSHIFTS

WHEN THE RELATIVE SPEED OF RECESSION (REDSHIFT) OR APPROACH (BLUESHIFT) IS A SIGNIFICANT FRACTION OF SPEED OF LIGHT, DOPPLER EFFECT MUST BE MODIFIED,

FROM

$$Z = \frac{\Delta\lambda}{\lambda_0} = \frac{v}{c} \quad \text{(NON RELATIVISTIC)}$$

($\Delta\lambda$: WAVELENGTH SHIFT; λ_0: REST WAVELENGTH; v: RADIAL VELOCITY; c: SPEED OF LIGHT)

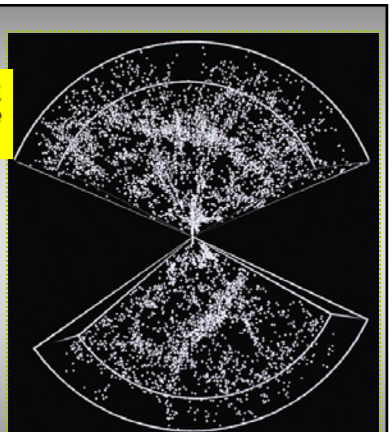
TO

$$Z = \frac{\Delta\lambda}{\lambda} = \sqrt{\frac{1 + (v/c)}{1 - (v/c)}} - 1 \quad \text{(RELATIVISTIC)}$$

EXAMPLE:
IF DOPPLER SHIFT MOVES A SPECTRAL LINE FORMED AT 3000 Å TO 9000 Å, THEN
NONRELATIVISTIC FORMULA ⇒ $\frac{v}{c} = 2$! (FASTER THAN LIGHT!)
RELATIVISTIC FORMULA ⇒ $\frac{v}{c} = 0.8$ (CORRECT)
"Z = 2"

Knowing distances reveals large-scale galaxy clustering

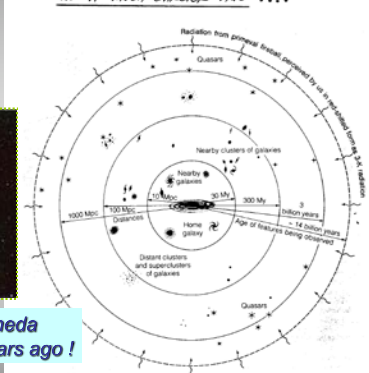
Find clusters + super-clusters : sheets and voids like `bubble bath'



Telescopes are "lookback" time machines

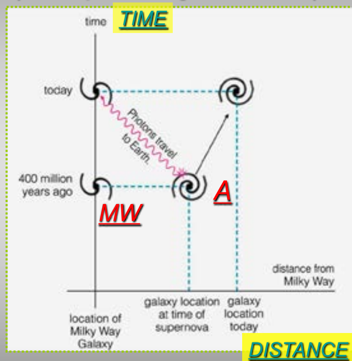
Today, we see Andromeda as she was 2.54 M years ago !

AS WE LOOK OUTWARD, WE LOOK AT OBJECTS AT A MUCH EARLIER AGE ....



Lookback time (in expanding universe)

- Say it takes 400 million years for light to get from galaxy A to us in Milky Way
- Yet during travel in spacetime, both A and MW have changed positions by expansion
- Thus "distance" is a fuzzy concept – LOOKBACK TIME is better



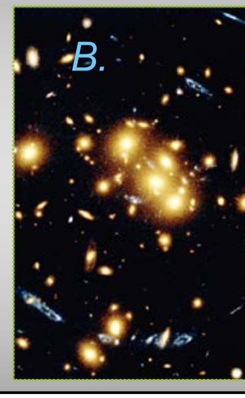
Reading clicker: gravitational lens

- If you measure the redshifts of the yellowish and blue objects, you'll find:

A. The yellow galaxies have similar redshifts, all higher than the blue galaxies

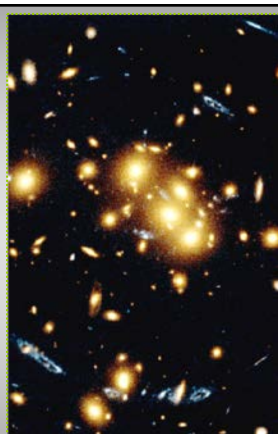
B. The blue galaxies have the same redshift, which is higher than the yellow galaxies

C. Yellow and blue galaxies have similar redshifts



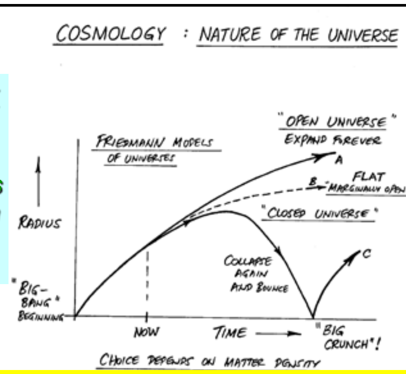
Lensing

- B. The blue images are a single BACKGROUND galaxy being lensed by the foreground cluster (yellow galaxies)
- The blue galaxy (spiral) is farther from us and thus will have a higher redshift



Models of our universe

Dark matter has big influence on "open" vs "closed"



If enough mass, gravity eventually wins!

EARLY DEVELOPMENTS

Predictions of General Relativity Theory (GRT)

- Einstein in 1917 realized GRT (1915) predicted universes in motion, but preferred `steady state' – added `cosmological constant' (CC) as repulsive force in space-time to counteract attractive force of gravity
- Willem de Sitter (A, Dutch, 1917) solves GRT equations with no CC and low density of matter : showed universe must expand
- Alexander Friedmann (M, Russian, 1920) solves GRT with no CC but any density of matter : universes can expand forever, or collapse again, depending on mean matter density

More on … Predictions of GRT

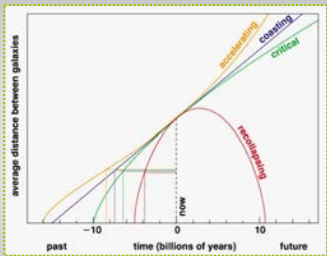
- Georges Lemaitre (P, Belgian, 1927) rediscovers Friedmann solutions, told Hubble (observing redshifts since 1924) that cosmic expansion suggests more distant galaxies should have greater redshifts (Hubble publishes $V = H_o d$ in 1929)
- Einstein visited Hubble in 1932, said CC "biggest blunder"

Very important diagram

"Average distance between galaxies"
= 1 / expansion factor
= 1 / (1 + Z)

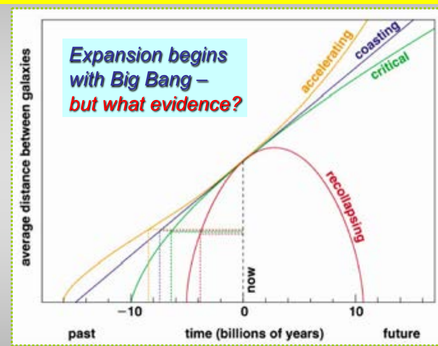
NOW is fixed in time (Z=0)

Hubble constant NOW sets slope of line = how fast universe is expanding NOW



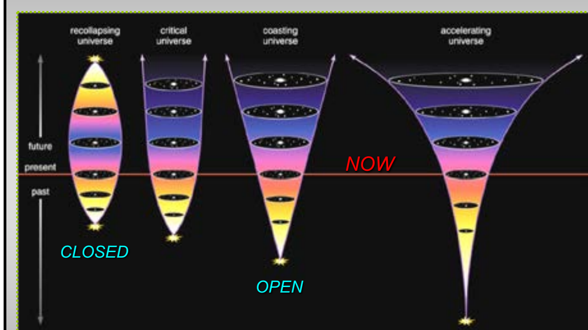
Big Bang = when distance zero
Z = infinity

Dark Matter and Fate of the Universe



Several different models for Past and Future

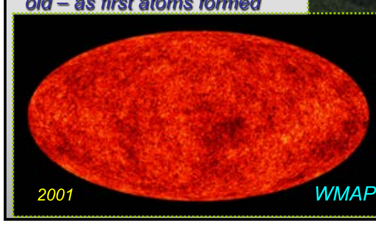
Four models for fates of universe



Big shift in thinking .. Big Bang evidence

Penzias & Wilson in 1965 discovered Cosmic Microwave Background (CMB) radiation --> 2.73 K "black body"

Photons created when hot universe was only 380,000 yrs old – as first atoms formed

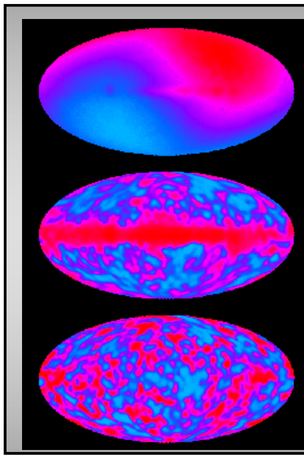


Very uniform radiation from everywhere – (few parts in 100,000) severely redshifted by expansion of universe

CMB (Accidental) Detection Story

- George Gamow, Robert Dicke and Jim Peebles are some players in predicting (1946-1960s) that a remnant radiation signal (microwave background temperature) should survive from "Big Bang" beginning of universe
- Spectrum "temperature" estimates ranged from 50K to 20K or less
- *Robert Dicke* at Princeton in 1964 was building a horn with his earlier WWII design (Dicke radiometer) to look for background microwave radiation
- *Arno Penzias and Robert Wilson* at nearly same time used big horn antenna at Bell Labs (with cooled Dicke radiometer) to start radio mapping of Milky Way
- Their *"background noise" at 4000 MHz (7.35 cm)* was inexplicable – *Bernie Burke* told them to talk to Dicke!

COBE (satellite) Mapping Steps



Remove big "Dipole asymmetry": solar system moving at 600 km/s (few parts in 1000)

Glow from dust in plane of Milky Way (few parts in 100,000)

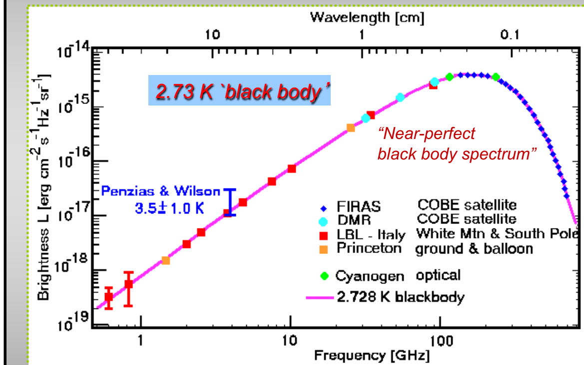
Cleaned up: glow from "cosmic photosphere" when universe ~380,000 yrs old (few parts in 100,000)

Cosmic Background Explorer 1989-1993

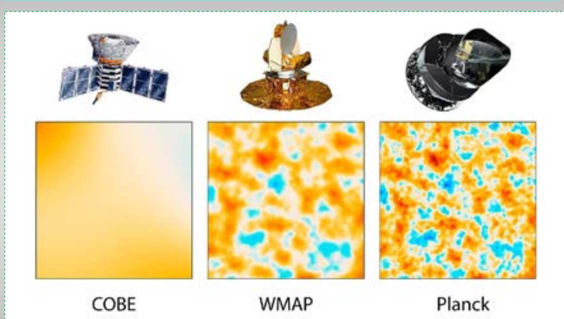
Light from beginning of time

- This faint light looks light a solid glowing wall
- Thermal spectrum at 3000 K, if redshifted by factor ~1000 → microwaves !

Spectrum of Cosmic Microwave Background (CMB)

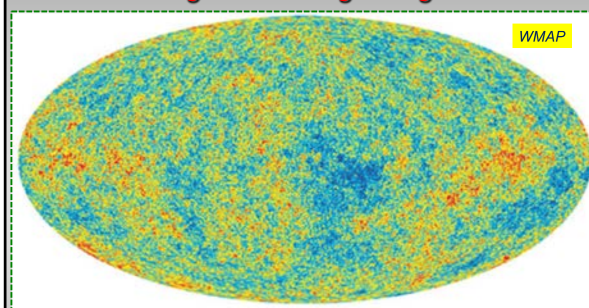


Major improvements in CMB spatial resolution and sensitivity



1989+ 2001+ 2009+

CMB: Light from beginning of time



- This faint light looks like a solid glowing wall
- Thermal spectrum at 3000 K (visible), if redshifted by factor ~1000 → 3 K ! (microwaves)