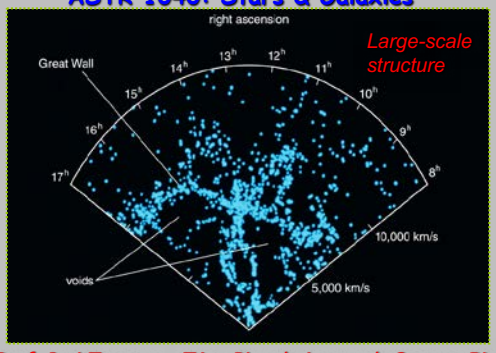
## ASTR 1040: Stars & Galaxies



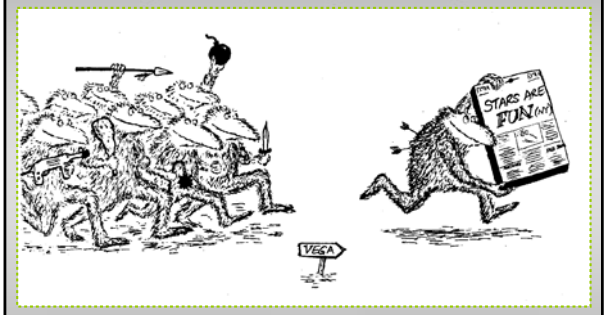

*Prof. Juri Toomre TAs: Piyush Agrawal, Connor Bice*
*Lecture 27 Tues 25 Apr 2017*
*zeus.colorado.edu/astr1040-toomre*

## Our Schedule

- *Third Mid-Term Exam returned today*
- *Homework #12 likewise*
- *Course evaluation (FCQ) in next class*
- *Last Observatory tonight (but dubious)*

- 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 124 points (graded on a "curve"):*

- *If 111/124 (90%) or over, A's [37%]*
- *95/124 (77%) or over, B's [44%]*
- *78/124 (63%) or over, C's [19%]*

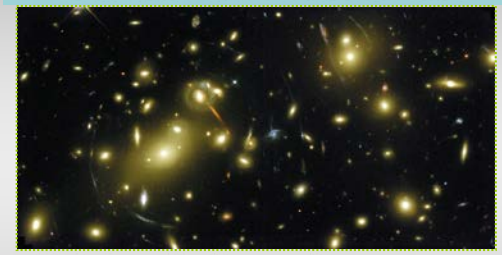
*Also +, plain, and – within these ranges*

*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

- Just what might be *dark matter ?*
- 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

## How much dark matter overall?



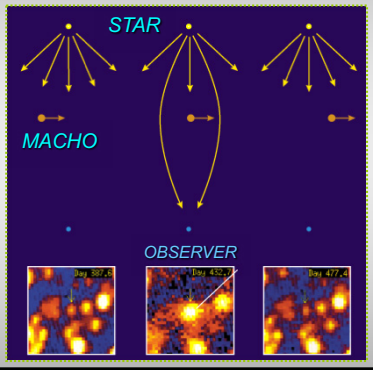
- *All cluster methods generally agree*
- *About 5 times as much dark matter as "normal" matter overall in the universe*
- *Is DM measurable in our solar system?*

## Big Puzzle: What is Dark Matter?

- Two possible flavors for Dark Matter:
- Possibility 1. MACHOs
- Massive Compact Halo Objects
- Very faint, actual things; baryonic matter
- Brown dwarfs, black holes, black dwarfs … etc.
- May be floating through the galaxy halo unnoticed

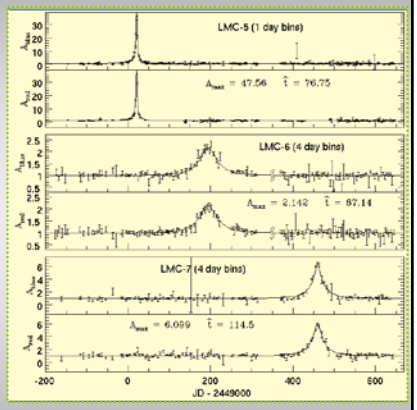
## MACHO Searches

- Use gravitational lensing
- When a MACHO floats in front of a star, the star suddenly brightens
- Focusing effect of compact massive object




## MACHO hunt results

- MACHOs are detected by brightenings
- But not enough to explain all dark matter




## Possibility 2. WIMPs

- Weakly Interacting Massive Particles
- Non-baryonic → subatomic particle (possibly made in Big Bang?)
- Neutrinos? probably not…. they move too fast and cannot be collected into stable galaxy halos
- Slower (unknown) particles: "Cold Dark Matter"
  ……. BIG SEARCHES underway

## 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

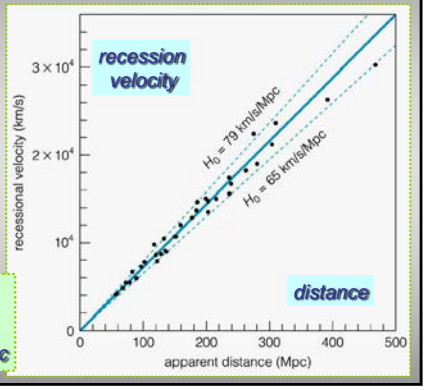
$D$ = 700 km/sec / 70 km/sec/Mpc = 10 Mpc
= 32 million light years

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

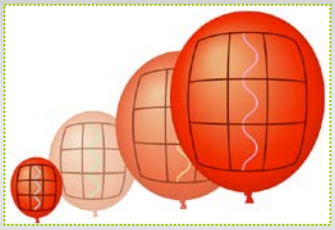
$1 + Z$ =
observed wavelength / "normal" wavelength

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 $Z = \frac{\Delta\lambda}{\lambda_0} = \frac{v}{c}$ (NONRELATIVISTIC)

(WAVELENGTH SHIFT; RADIAL VELOCITY; REST WAVELENGTH; SPEED OF LIGHT)

TO

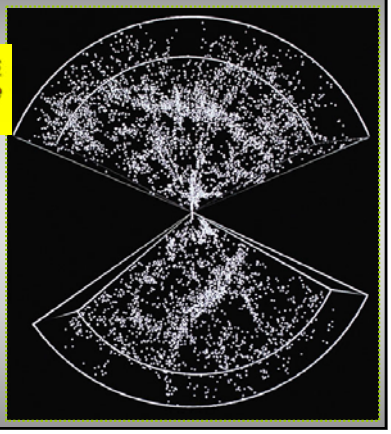
$$Z = \frac{\Delta\lambda}{\lambda} = \sqrt{\frac{1 + (v/c)}{1 - (v/c)}} - 1$$

(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

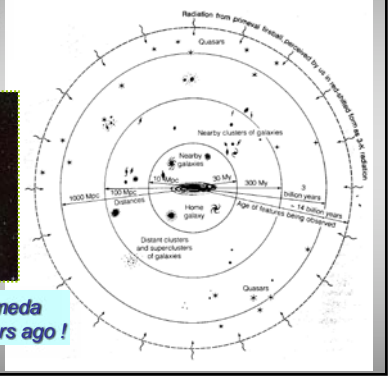
Find clusters + super-clusters : sheets and voids like `bubble bath'



## Telescopes are "lookback" time machines

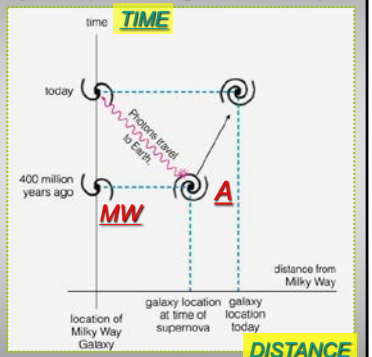
Today, we see Andromeda as she was 2.5 M years ago !

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

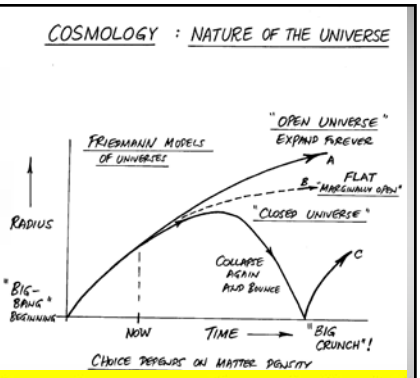
**C.** Yellow and blue galaxies have similar redshifts


## Lensing

- **B.** The blue images are a single BACKGROUND galaxy being lensed by the foreground cluster (yellow galaxies)
- The blue galaxy 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 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

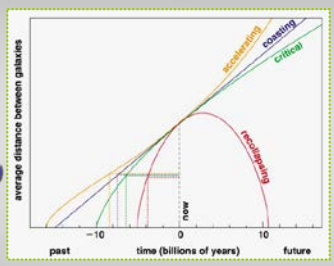
- Georges Lemaitre (P, Belgian, 1927) rediscovers Friedmann solutions, told Hubble (observing redshifts since 1924) that cosmic expansion suggests more distant galaxies should have greater redshifts (Hubble publishes $V = H_o d$ in 1929)
- Einstein visited Hubble in 1932, said CC "biggest blunder"

## Very important diagram

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

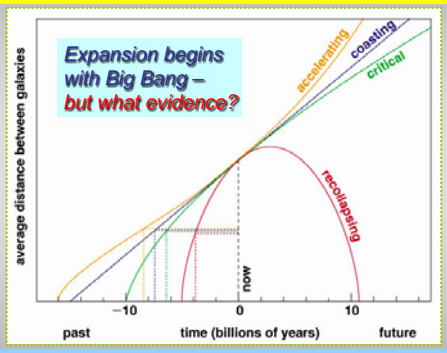
NOW is fixed in time ( Z=0 )

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




Big Bang = when distance zero
Z = infinity

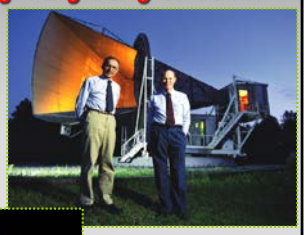
## Dark Matter and Fate of the Universe



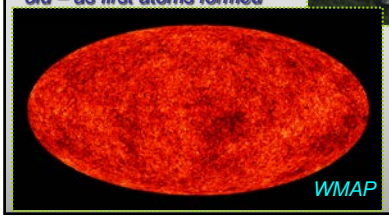

Several different models for Past and Future

## Big shift in thinking .. Big Bang evidence

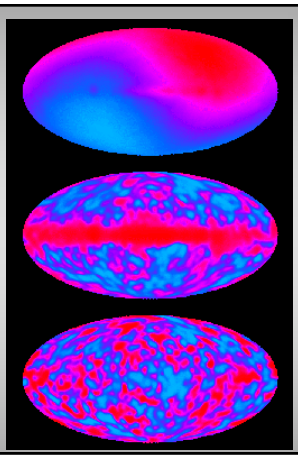
Penzias & Wilson in 1965 discovered Cosmic Microwave Background (CMB) radiation --> 2.73 K "black body"



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



## COBE 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)