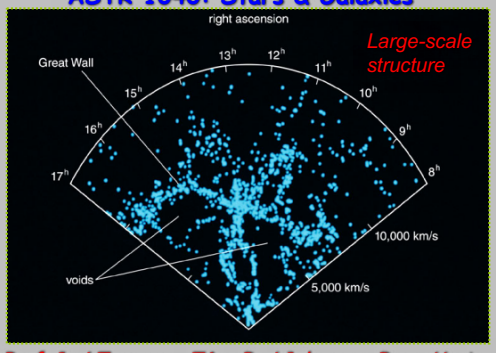
ASTR 1040: Stars & Galaxies



Prof. Juri Toomre TAs: Peri Johnson, Ryan Horton

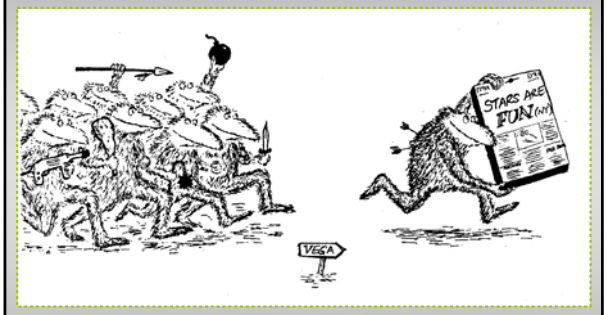
Lecture 27 Tues 24 Apr 2018

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 #7 tonight (but dubious), extra nights Mon Apr 30 + Wed May 2*
- 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 [38%]*
- *95/126 (76%) or over, B's [42%]*
- *80/126 (64%) or over, C's [15%]*

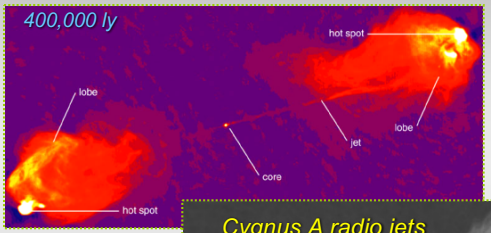
Also +, plain, and – within these ranges

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

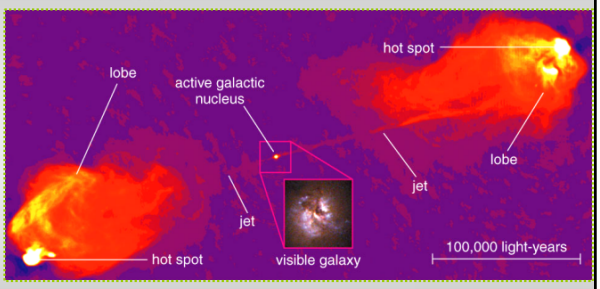
- Revisit *"active galactic nuclei" (AGNs)*
- Just what might be *dark matter ?*
- Cosmology: *models of the universe*
- Concept of *look-back time*
- Discovery of *cosmic microwave background* implies a big-bang beginning
- How dark matter can influence *"open"* vs *"closed" universe*

REVISIT ACTIVE GALACTIC NUCLEI



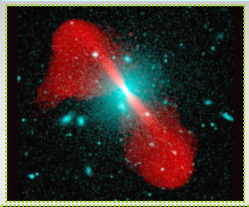
Jet as fine thread, big lobes at end, central hot spot

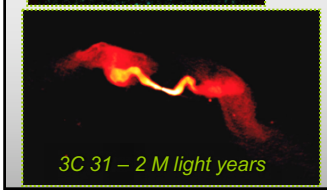
Cygnus A in more detail



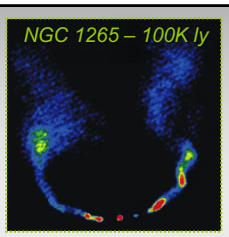
VLA imaging

Radio tails: many shapes



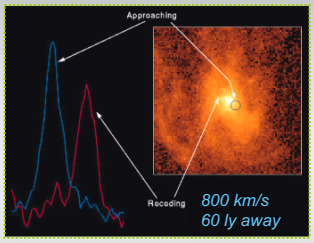


3C 31 – 2 M light years



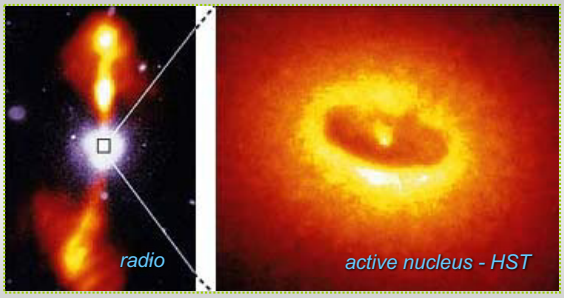
NGC 1265 – 100K ly

M87 – elliptical with jet



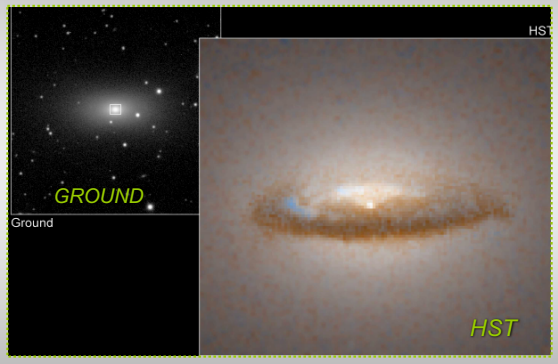
- Active galactic nucleus beams out very narrow jet
- Accretion disk shows gas orbiting a 2.7 billion solar mass black hole – first real proof !

Another example of "central beaming engine"



- 400 light year wide disk of material in core of elliptical galaxy with radio jets – looks like supermassive BH at work!

Disk around 'black hole' in NGC 7052



Jet in Chandra view of very distant quasar

(10 Bly, 1 Mly jet)

Typical properties of "active galaxies"

synchrotron emission !

source very small in size

Most quasars present when universe was young

PROPERTIES OF "ACTIVE GALAXIES"

RADIO GALAXIES, SEYFERT GALAXIES, BL LACERTAE OBJECTS, QUASARS *"SOME HAVE MORE THAN OTHERS!"

1. HIGH LUMINOSITY
   - MUCH MORE LUMINOUS THAN NORMAL GALAXIES
2. NON-THERMAL EMISSION
   - EXCESS RADIATION IN UV, IR, RADIO, X-RAY
   - IMPLYING SYNCHROTRON EMISSION FROM RELATIVISTIC ELECTRONS SPIRALLING IN MAGNETIC FIELDS
3. SMALL, COMPACT SIZE OF INTENSE EMISSION
   - NUCLEUS VERY BRIGHT COMPARED TO REST OF GALAXY
4. RAPIDLY VARYING EMISSION
   - SOURCE MAY BE A FEW LIGHT HOURS OR DAYS IN SIZE
5. EXPLOSIVE FEATURES
   - JET-LIKE EXTENSIONS, FILAMENTS
6. GRAVITATIONAL DISTURBANCES
   - VERY HIGH INTERNAL VELOCITIES DEDUCED FROM BROAD SPECTRAL EMISSION LINES
   - PECULIAR OPTICAL APPEARANCE
7. LARGE REDSHIFTS
   - IMPLYING HIGH RECESSIONAL VELOCITIES, VERY LARGE DISTANCES

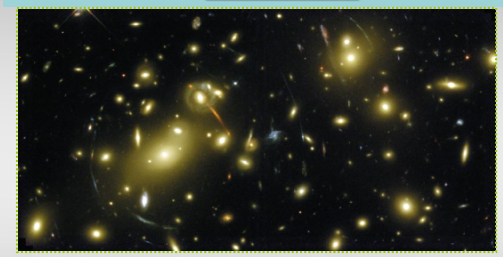
Reading clicker – the boss galaxy

- Which of the following is NOT a feature of a central dominant (cD) galaxy in clusters?

A.

- **A.** They are often spiral galaxies
- **B.** They are found in clusters of galaxies
- **C.** They often have multiple galactic nuclei near their centers
- **D.** They are thought to form by the merger of several smaller galaxies

How much dark matter overall?



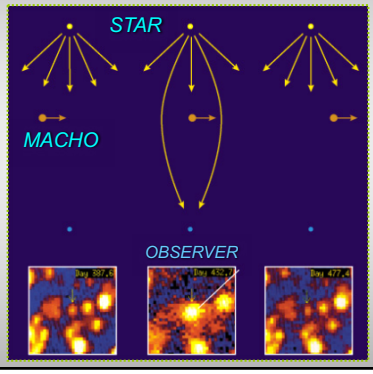
- All cluster methods generally agree
- About 5 times as much dark matter as "normal" matter overall in the universe
- Is DM measurable in our solar system?

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

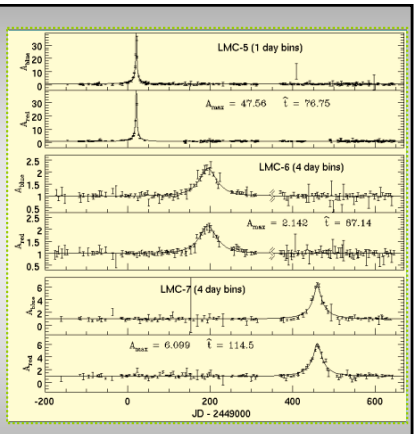
MACHO Searches

- 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

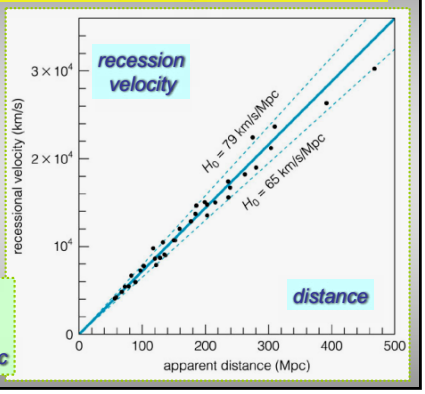
D = 700 km/sec / 70 km/sec/Mpc = 10 Mpc
= 32 million light years

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

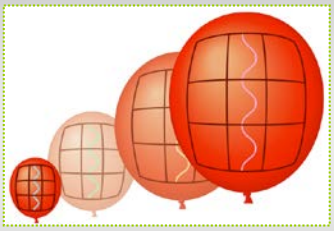
$1 + Z$ =
observed wavelength / "normal" wavelength

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

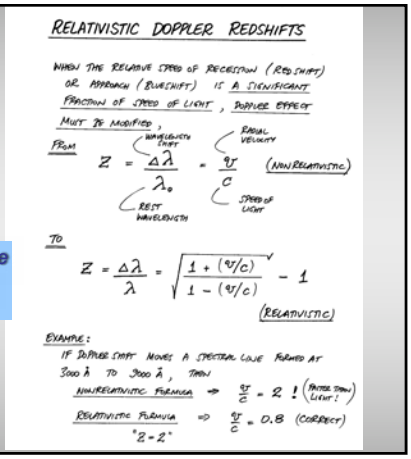


$1 + Z$ =
distance between galaxies now
distance between galaxies then

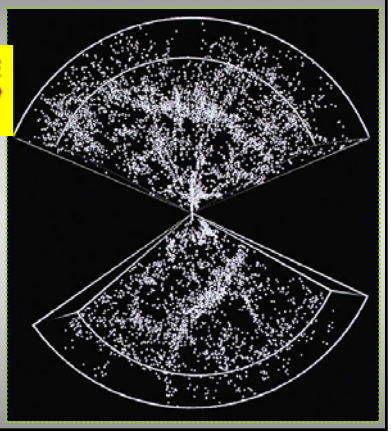
REVIEW

Relativistic redshifts

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

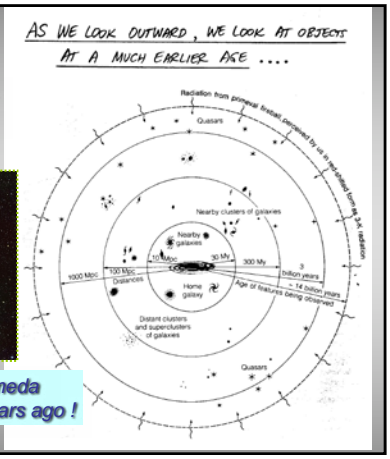


Knowing distances reveals large-scale galaxy clustering



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

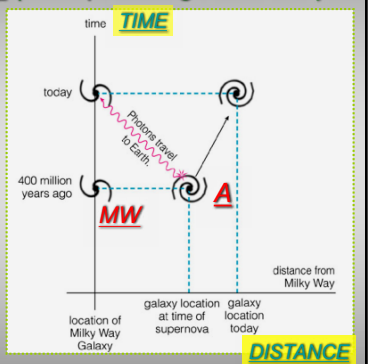
Telescopes are "lookback" time machines



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

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

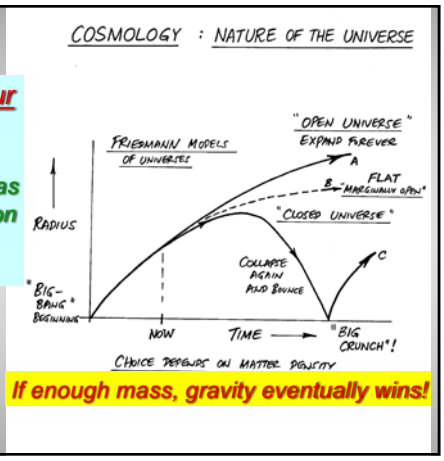
C. Yellow and blue galaxies have similar redshifts

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

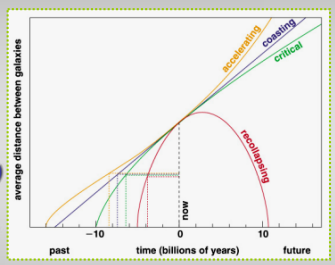
- Georges Lemaitre (P, Belgian, 1927) rediscovers Friedmann solutions, told Hubble (observing redshifts since 1924) that cosmic expansion suggests more distant galaxies should have greater redshifts (Hubble publishes $V = H_o d$ in 1929)
- Einstein visited Hubble in 1932, said CC "biggest blunder"

Very important diagram

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

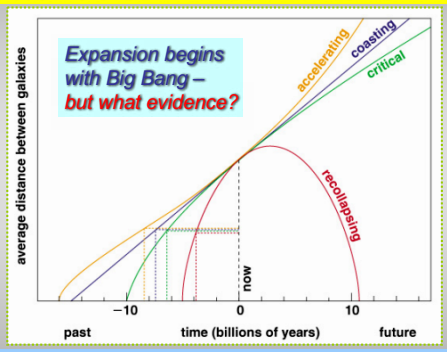
NOW is fixed in time (Z=0)

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