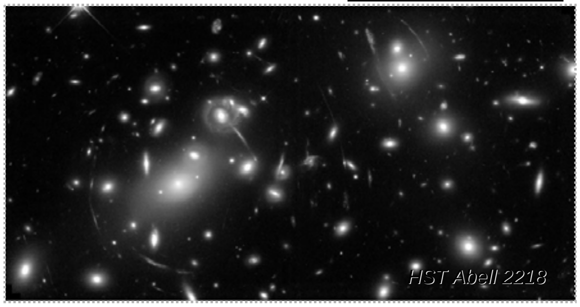
ASTR 1040 Accel Astro: Stars & Galaxies



Prof. Juri Toomre TA: Kyle Augustson, Ben Brown

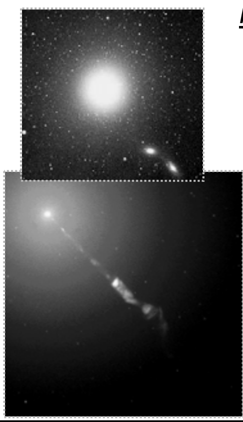
Lecture 27 Tues 22 Apr 08

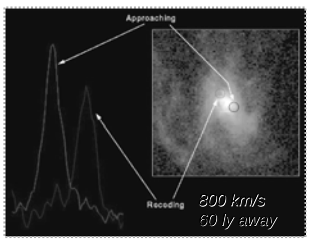
zeus.colorado.edu/astr1040-toomre

Dark Matter Mysteries

- How do we see *really far back in time*? *Quasars and gravitational lensing* both help
- Begin looking at evidence for *dark matter* in galaxies, and within galaxy clusters
- *Gravitational lensing* helps us get information from very distant galaxies – thus look *very far back in time*
- Implications for *models for our universe*
- Complete detailed reading *Chap 22: Dark Matter and Fate of Universe*
- New (and final) *Homework Set #12* today
- Last *Observatory Night # 6* tomorrow, 8:30pm+
- Course evaluation during next class

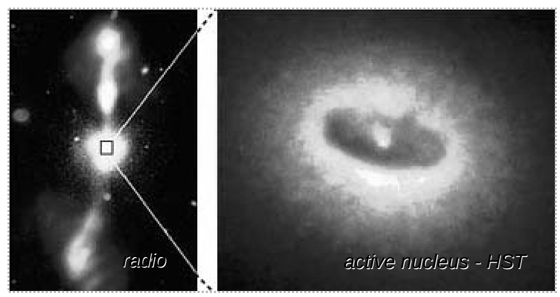
M87 – elliptical with jet





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

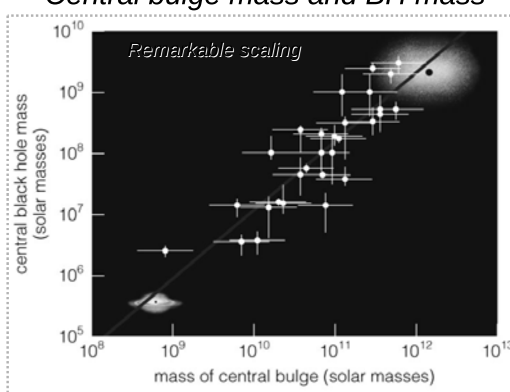
Another example of "central beaming engine"



- *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

Central bulge mass and BH mass



Do ALL galaxies have supermassive black holes?

- As of early 2008: probably YES !
- Part of normal galaxy formation ?
- More quasars seen in the distant (early) universe than now
- Black holes gradually grow, but can run out of available fuel and become relatively invisible (like in our Milky Way)

Thinking clicker – looking back in time

- If we can detect light from a quasar and decide that its emission line spectrum is at redshift Z = 4, how much bigger has the universe grown since that light left?

C.

- *A.* 2 times bigger
- *B.* 3 times bigger
- *C.* 5 times bigger
- *D.* 16 times bigger

Cosmological Redshifts
(from expansion of universe)

Definition of redshift :

REMINDER

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

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

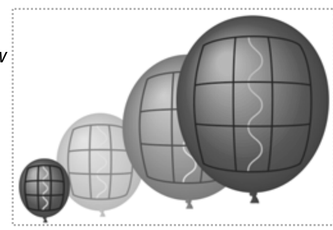
redshifts always have Z > 0
(redder light has larger wavelengths)

Redshift is "expansion factor"

REMINDER

1 + Z also measures how much universe has expanded

wavelength of light is also stretched



1 + Z =

$$\frac{\text{distance between galaxies now}}{\text{distance between galaxies then}}$$

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

NON RELATIVISTIC FORMULA ⇒ $\frac{v}{c} = 2$! (FASTER THAN LIGHT!)

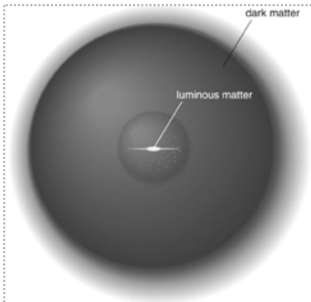
RELATIVISTIC FORMULA ⇒ $\frac{v}{c} = 0.8$ (CORRECT)
"Z = 2"

Now to Case for Dark Matter

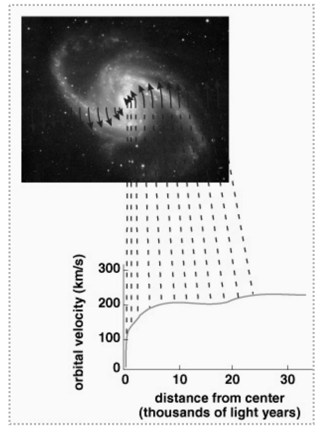
- > 90% of mass of universe is dark matter (invisible, missing matter)
- Detectable ONLY via its gravitational forces on "light" matter (gas and stars)
- Note -- this dark matter is NOT the same as black holes, brown/black dwarfs, or dust

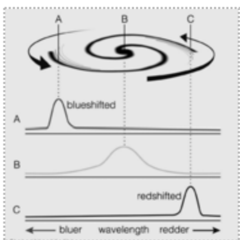
Individual galaxies show it

- *Rotation curves: motions of stars in the galaxy*
- *Reveal that dark matter extends beyond visible part of the galaxy, mass is 10x stars and gas*



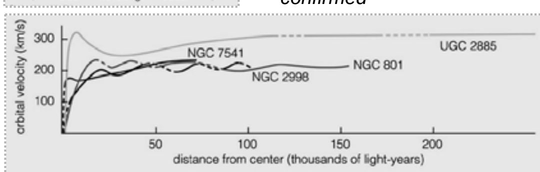
- *Flat rotation curve of galaxy*
- *High speeds far from luminous center: means there is dark matter in the outer regions*



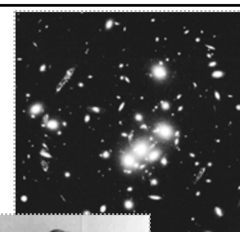


Spiral galaxy ROTATION CURVES

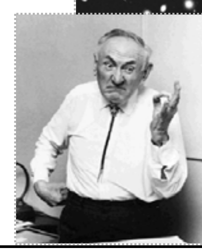
- *Discovered by Vera Rubin in the 1970's*
- *Highly controversial until many rotation curves confirmed*



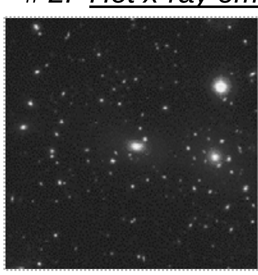
Galaxy Clusters: reveal dark matter in three ways

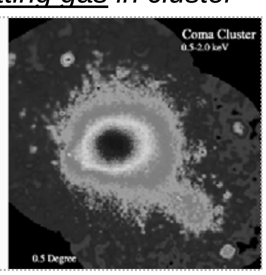


- *# 1: Galaxy velocities too large to be explained by gravity of visible galaxies*
- *Expected ~100 km/sec for a typical cluster, found 1000 km/sec!*
- *Discovered in 1930's by Fritz Zwicky (they didn't believe him, either)*



2: Hot x-ray emitting gas in cluster

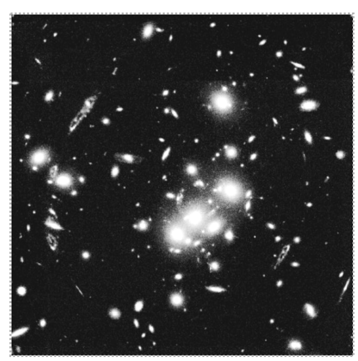




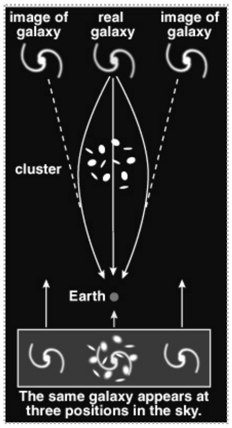
- *Gas between galaxies is also moving because of gravity of dark matter: gets very hot*
- *1000 km/sec → 100 million K: emits x-rays!*

3 Gravitational Lenses

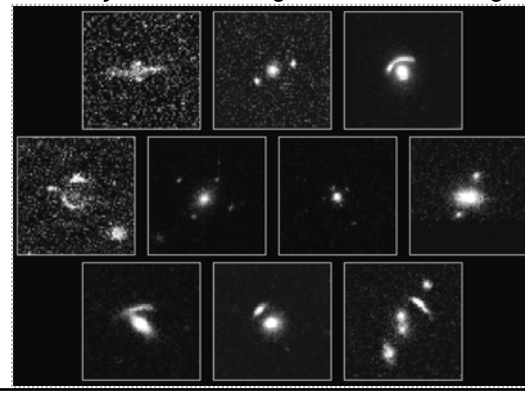
- *Dark (& visible) matter warps space → acts like a lens and distorts and magnifies the view of more distant galaxies*
- *Can form circular arc segments*

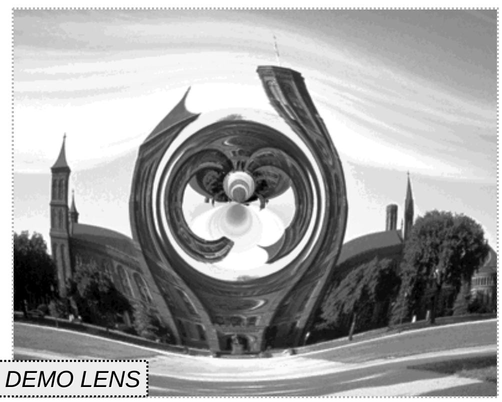


Gravitational lensing:
how it works



Medley of best HST gravitational lensing

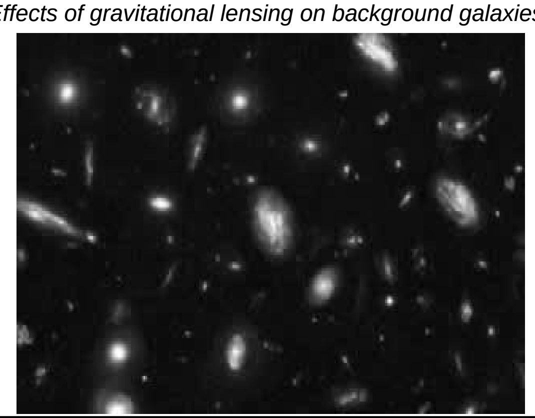




DEMO LENS

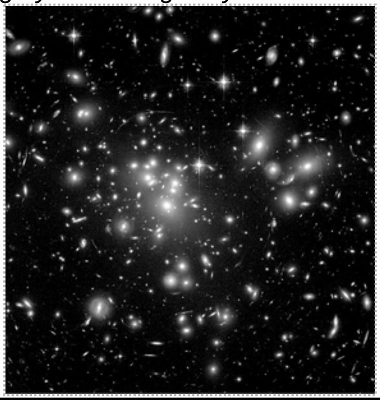
Gravitational lens drifts across your harbor view (Boston)

Effects of gravitational lensing on background galaxies



Bending of light by cluster Abell 2218

Lensing by massive galaxy cluster Abell 1689

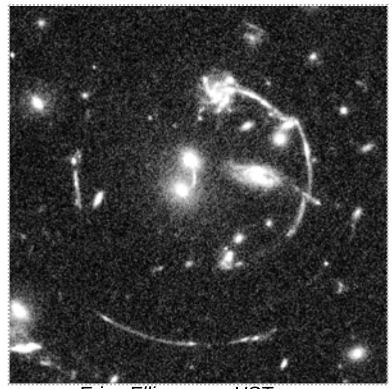


"The Beast"

4 or 5 different galaxies!

Red arc at the bottom: Z = 4.8

Have not gotten the other Z's yet

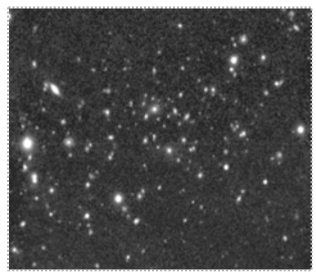


Erica Ellingson -- HST

Clicker on galaxy clusters *C.*

- *Two galaxy clusters are studied. Cluster A has typical velocities for its galaxies of 300 km/sec, Cluster B has 1000 km/sec. Which is most likely?*
- *A.* Cluster A has more galaxies than cluster B
- *B.* Cluster A is more massive than cluster B
- *C.* Gas between galaxies in cluster A will have lower temperature than gas in cluster B
- *D.* Cluster B galaxies are more likely to be spirals

- *C. Lower velocities in "A" mean that there is less mass overall in that cluster. This probably means fewer galaxies. Less mass also means a cooler intracluster gas temperature*



How much dark matter overall?

- *All cluster methods generally agree*
- *About 10 times as much dark matter as "normal" matter overall in the universe*
- *Note: Our solar system has much more light matter than dark matter here! (DM probably not measurable – why so?)*

What is Dark Matter?

- *Two flavors for Dark Matter:*
- *Possibility 1. MACHOs*
- *Massive Compact Halo Objects*
- *Stuff we've studied already: very faint, actual things; baryonic matter*
- *Brown dwarfs, black holes, black dwarfs … etc.*
- *May be floating through the galaxy halo unnoticed*

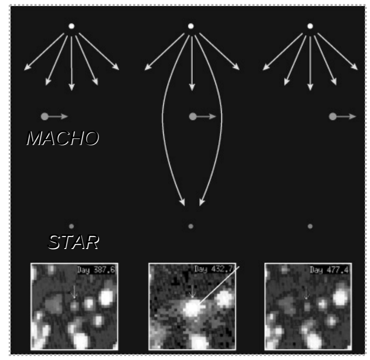
Possibility 2. WIMPs

- Weakly Interacting Massive Particles
- Non-baryonic → subatomic particle
- Neutrinos? probably not…. they move too fast and cannot be collected into stable galaxy halos

Other unknown particles ???
Slower particles: "Cold Dark Matter"

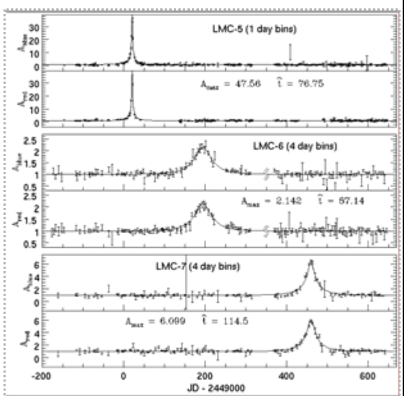
MACHO Searches

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



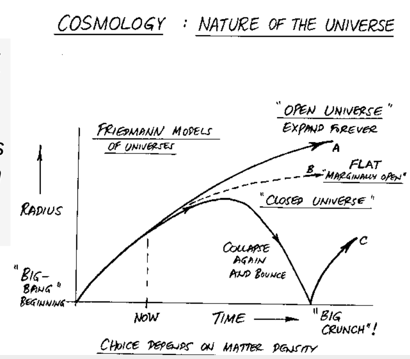
MACHO hunt results

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



Models of our universe

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



If enough mass, gravity eventually wins!