ASTR 1120: Stars & Galaxies

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Lecture 37 Wed 13 Apr 05

zeus.colorado.edu/astr1120-toomre

Today's Events

- Today look at actual *evidence* of *accretion disks and supermassive black holes* at centers of active galaxies
- 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 – overview read *Chap 22: Dark Matter and Fate of Universe*

- *Third Mid-Term Exam* this Friday 15 Apr – Ben Brown runs review session tonight 7pm - 9pm
- *Homework Set 9* (Planet Finder) closes today

Typical properties of "active galaxies"

PROPERTIES OF "ACTIVE GALAXIES"

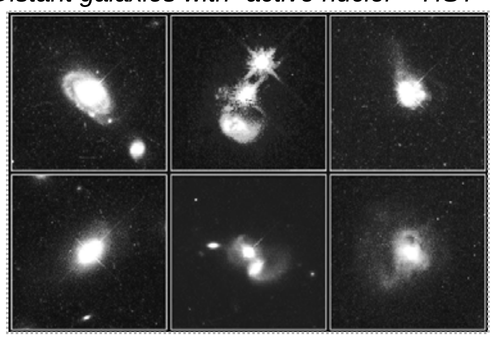
RADIO GALAXIES, SEYFERT GALAXIES, BL LACERTAE OBJECTS, QUASARS "SOME HAVE MORE THAN OTHERS!"

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
   - JETLIKE 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

synchrotron emission !

source very small in size

Distant galaxies with "active nuclei" - HST



- *Galaxies with odd stuff going on in their cores*
- *Nuclei as bright as rest of galaxy*

Epochs for "active galaxies"

SEQUENCE OF EPOCHS (AGES) FOR ACTIVE GALAXIES

BASED ON LARGE REDSHIFTS z

SEYFERT GALAXIES	$0.0 \leq z \leq 0.2$
BL LAC OBJECTS	$0.1 \leq z \leq 0.5$
RADIO GALAXIES	$0.0 \leq z \leq 0.8$
QUASARS	$0.1 \leq z < 4.4$

WITH HIGHER z, "LOOKING BACK FURTHER IN TIME"

QUASARS SEEN NOW EMITTED LIGHT WHEN UNIVERSE WAS MUCH YOUNGER

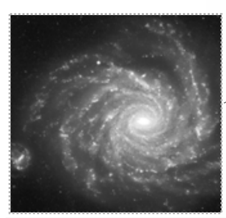
$z = 4.4$ ⇒ 12 BILLION YEAR LIGHT TRAVEL TIME (FLAT UNIVERSE, $H=50$)

Most quasars present when universe was young

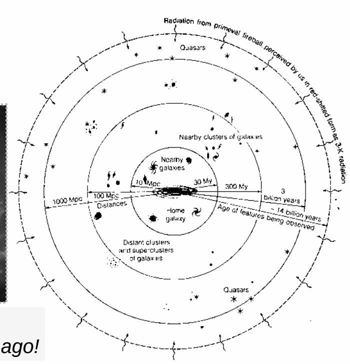
REMINDER

Telescopes are "lookback" time machines

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



We see `NGC 1232' as she was ~300 M years ago!



REMINDER

Cosmological Redshifts
(from expansion of universe)

Definition of redshift :

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

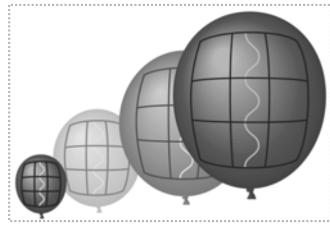
1 + Z =
observed wavelength / "normal" wavelength

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

Redshift is "expansion factor"

1 + Z also measures how much universe has expanded

As universe expands, wavelength of light is also lengthened



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

Relativistic redshifts

If Z is big (~2+), 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

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

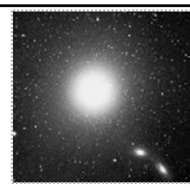
($\Delta\lambda$: WAVELENGTH SHIFT; λ_0: REST WAVELENGTH; v: RADIAL VELOCITY; c: SPEED OF LIGHT)

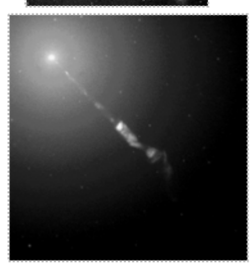
TO

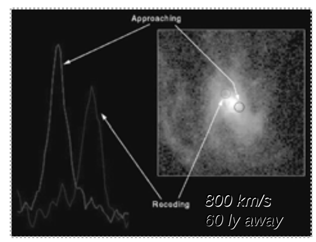
$$Z = \frac{\Delta\lambda}{\lambda} = \sqrt{\frac{1 + (v/c)}{1 - (v/c)}} - 1 \quad \text{(RELATIVISTIC)}$$

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"

M87 – elliptical with jet

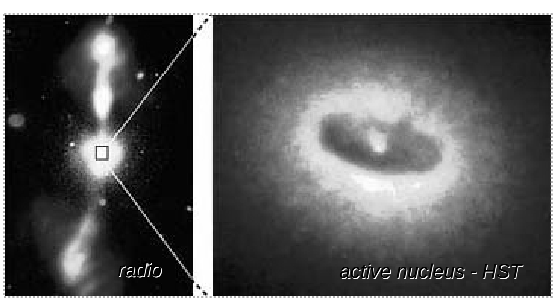






- Active galactic nucleus beams out very narrow jet
- Accretion disk shows gas orbiting a 2.7 billion solar mass black hole – first real proof !

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!

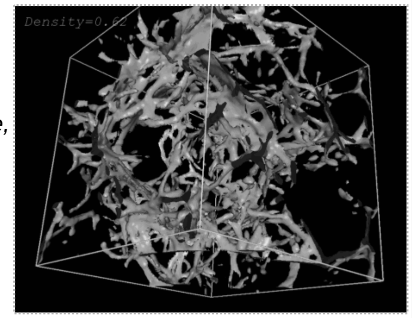
Disk around 'black hole' in NGC 7052

Do ALL galaxies have supermassive black holes?

- *As of early 2005: <u>probably YES</u> !*
- *Part of normal galaxy formation ?*
- *More quasars seen in the distant (early) universe than now*
- *Black holes gradually grow, but <u>can run out of available fuel</u> and become relatively invisible (like in our Milky Way)*

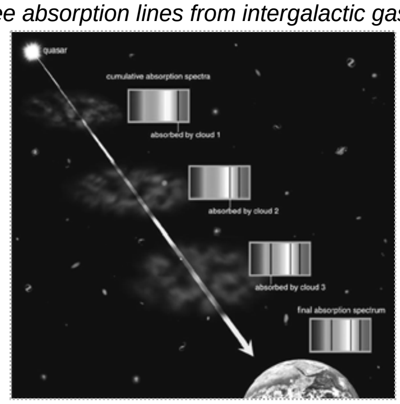
Quasars reveal: <u>Protogalactic Clouds</u>

- *Looking for gas <u>between the galaxies</u>*
- *Cold, invisible, too dim even at 21 cm*
- *But <u>quasars</u> provide the way to detect them!*



Simulation of universe

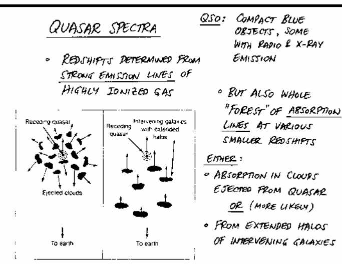
Use quasars as bright beacons –
see absorption lines from intergalactic gas

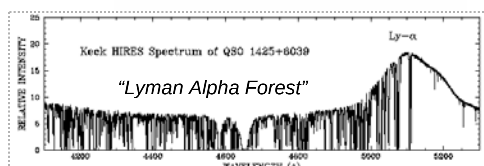


REVISIT

Quasar spectra

Redshifts from emission lines
+
<u>Many absorption lines (forest)</u>



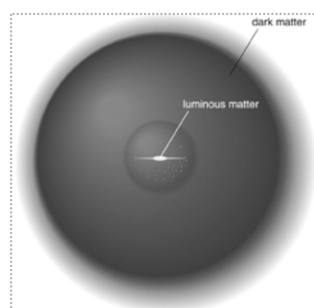


Now to <u>Case for Dark Matter</u>

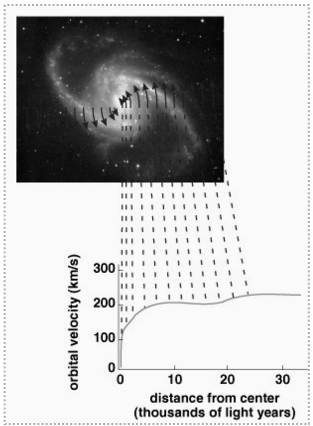
- *> 90% of <u>mass of universe</u> is dark matter (invisible, missing matter)*
- *Detectable ONLY via its gravitational forces on "light" matter (gas and stars)*
- *Note -- this dark matter is NOT the same as black holes, brown/black dwarfs, or dust*

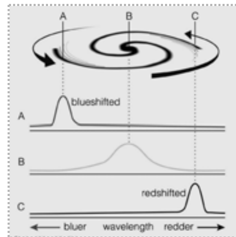
Individual galaxies show it

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



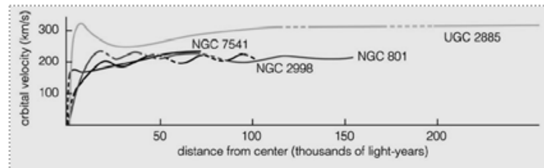
- *Flat rotation curve* of galaxy
- *High speeds far from luminous center*: means there is dark matter in the outer regions



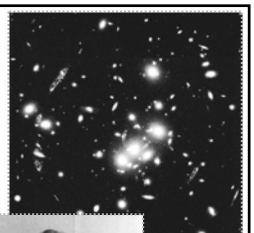


Spiral galaxy ROTATION CURVES

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

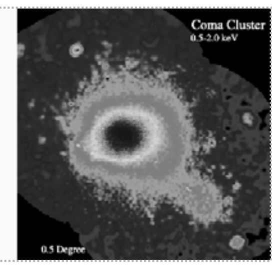


Galaxy Clusters: reveal dark matter in three ways



- *# 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

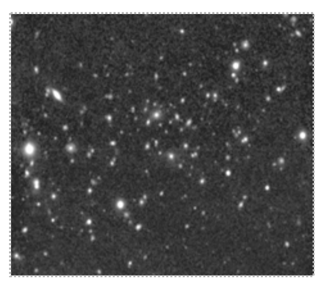


- *Gas between galaxies is also moving because of gravity of dark matter: gets very hot*
- *1000 km/sec → 100 million K: emits x-rays!*

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*



3 *Gravitational Lenses*

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

Gravitational lensing: how it works