ASTR 1040: Stars & Galaxies

Prof. Juri Toomre TAs: Piyush Agrawal, Connor Bice
Lecture 25 Tues 18 Apr 2017
zeus.colorado.edu/astr1040-toomre

Our Schedule

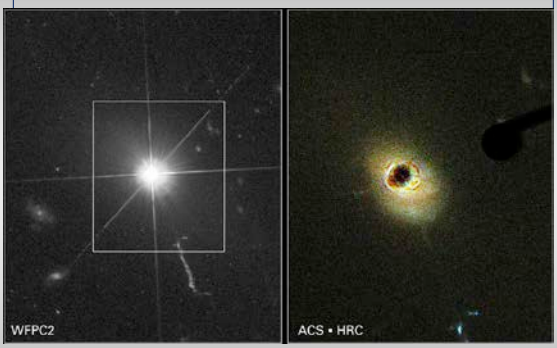
- *Observatory Night #8 + #9* (proj A + spectro), both Wed and Thurs nights, by signup -- starting at 8:30pm
- Review session tomorrow, here 5:00-7:00pm
- *Third Mid-Term Exam* in class on Thursday

- Finish reading *Chap 22 Birth of Universe*
- Start overview read *Chap 23: Dark Matter, Dark Energy, Fate of Universe*
- Focus on *23.2 Evidence for Dark Matter*

Dark Matter in the Universe

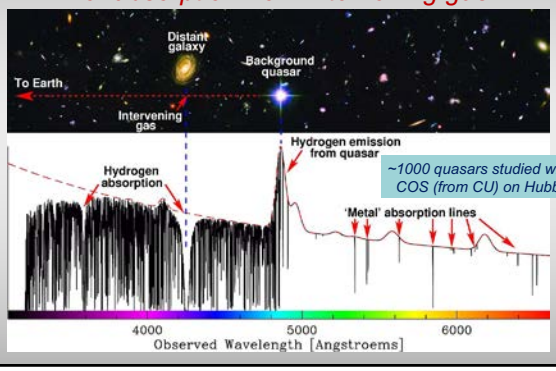
- Briefly revisit *collisions between galaxies: "interacting galaxies" with bridges and tails*
- Also revisit *"radio galaxies" and quasars*
- Evidence for *dark matter* in galaxies
- *Gravitational lensing:* mainly by dark matter
- Measuring *really big distances* in universe, and concept of *"lookback time"*

Revisit Quasar 3C273



With advanced HST instruments, can see extended surrounding galaxy

Viewing distant quasar: "Lyman alpha forest" of absorption from intervening gas



~1000 quasars studied with COS (from CU) on Hubble

REVISIT

Rich galaxy cluster

Galaxies have many neighbors "interactions" most likely!

interesting "arcs of light"

Stefan's Quintet in HST detail

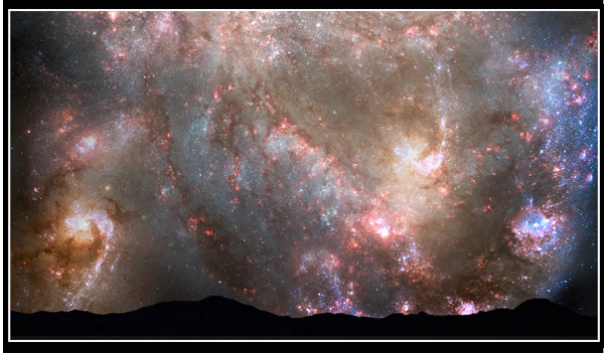
Present Day – distant Andromeda

Future: 2 billion years -- predicted

Future: 3.75 billion years

Future: 3.85 billion years (getting close)

Future: 3.9 billion years (very close)

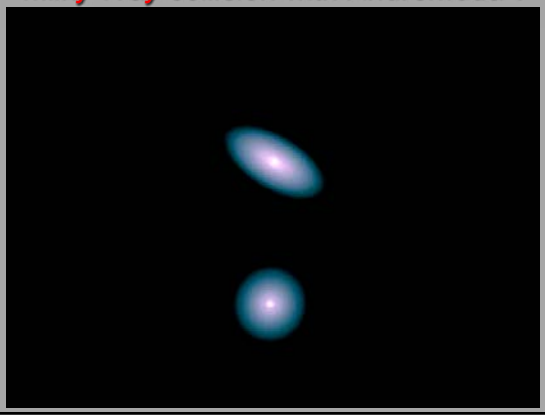


Future: 4 billion years (heading out)

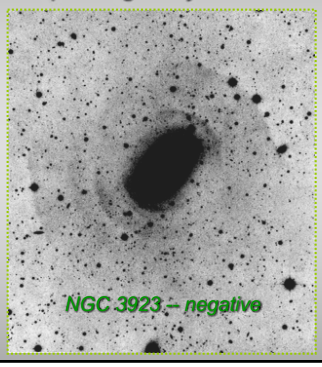
Future: 5.1 billion years (coming back in)

Future: 7 billion years

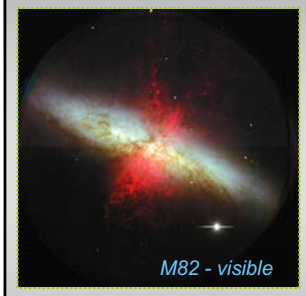
Milky Way collision with Andromeda ?



Signs of having collided:
elliptical galaxy with shells



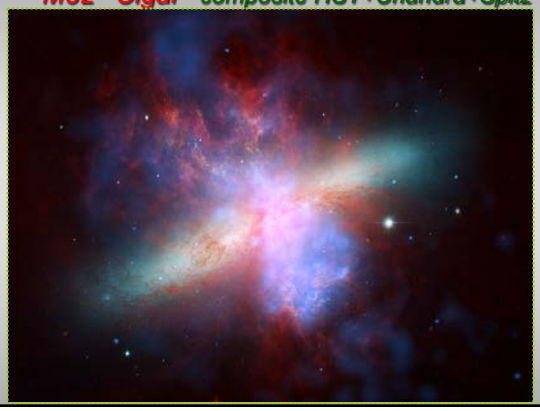
Starburst Galaxies


M82 - visible


Chandra – X-ray

- Milky Way forms about 1 new star per year
- Starburst galaxies form 100's of stars per year

M82 "Cigar" composite HST+Chandra+Spitz

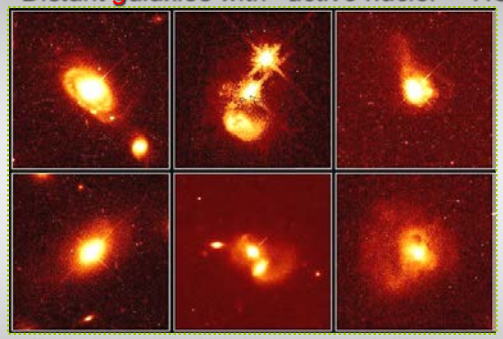


Starburst galaxy in fine detail

NGC 3310 - HST

Big open two-sided spiral structure
--> tidal interaction

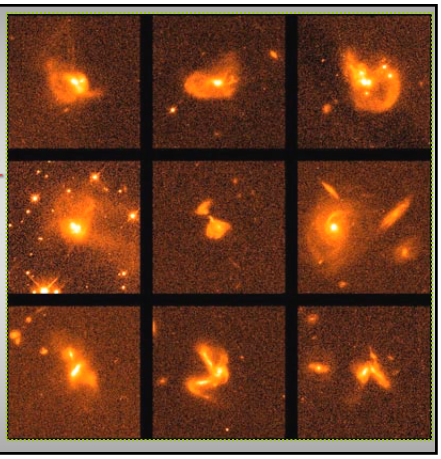
Distant galaxies with "active nuclei" - HST



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

Many interacting galaxy systems

Very distant (big lookback time) with HST



Messages from galaxy interactions

1. In dense clusters, galaxy collisions (grazing or even head-on) must have been common
2. With successive passages, spiral galaxies can tumble together to form a big elliptical
3. Vastly increased star birth from shocking the gas and dust (star burst galaxies)
4. Start rapid feeding of supermassive black hole lurking at center of most galaxies (quasars)

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

REVISIT

Prototypical "radio galaxy"

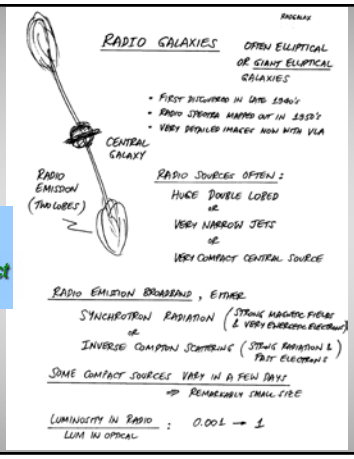
Giant elliptical galaxy NGC 5128 with dust lane (from spiral galaxy?)
+
Centaurus A (Cen A) radio source (color lobes)

REVISIT

Radio galaxies

Central elliptical galaxy, huge lobes of emission, compact central source

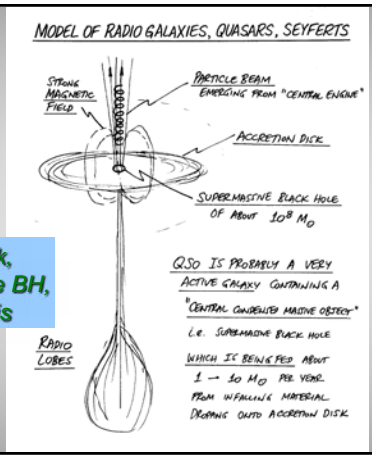
Synchrotron radiation



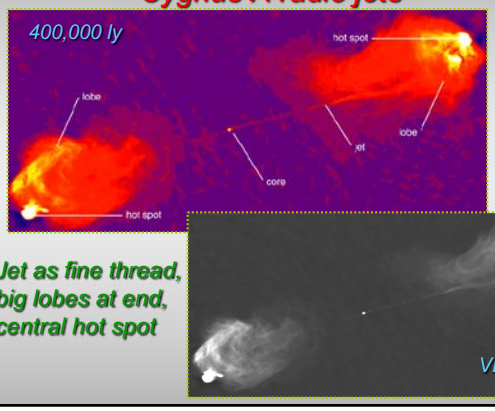
REVISIT

Model for "active galaxies"

Accretion disk, supermassive BH, beams on axis

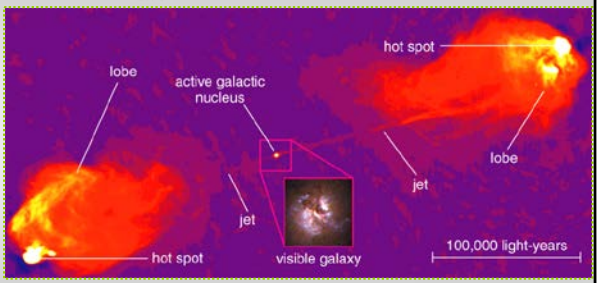


Cygnus A radio jets



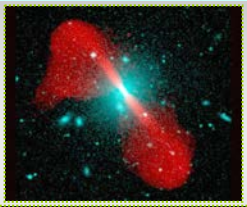
Jet as fine thread, big lobes at end, central hot spot

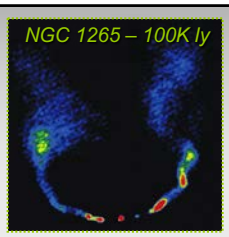
Cygnus A in more detail



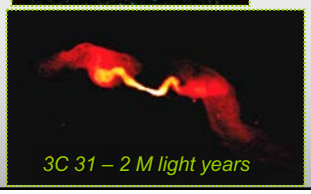
VLA imaging

Radio tails: many shapes



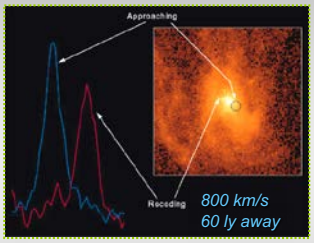


NGC 1265 – 100K ly



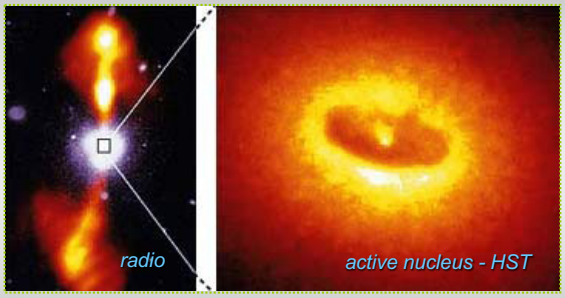
3C 31 – 2 M light years

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 SPIRALING 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

Clicker: galaxy collisions

- Why are collisions between galaxies more likely than between stars within a galaxy?

C.

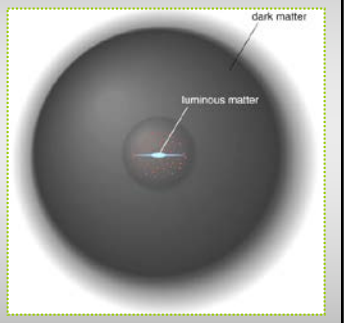
- A. Galaxies are much larger than stars
- B. Galaxies travel through space much faster than stars
- C. Relative to their sizes, galaxies are closer together than stars
- D. Galaxies have higher redshifts than stars

Now to Case for Dark Matter

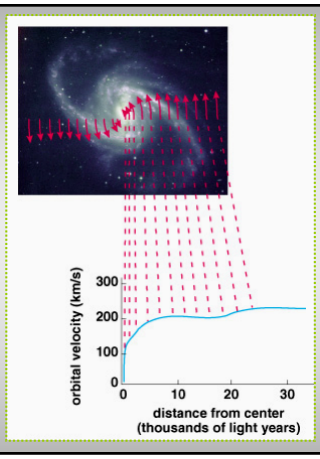
- ~ 80+% of mass of universe is dark matter (invisible, missing matter)
- Detectable ONLY via its gravitational forces on "light" matter (gas and stars)
- Note -- this dark matter is NOT the same as black holes, brown/black dwarfs, or dust

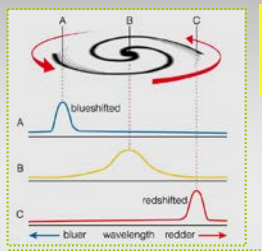
Individual galaxies show it

- 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



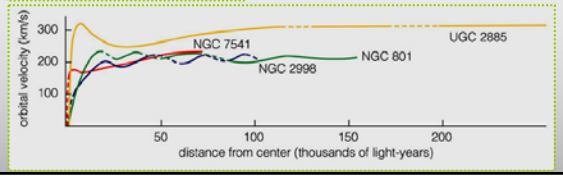
- Flat rotation curve of galaxy
- High speeds far from luminous center: means there is dark matter in the outer regions



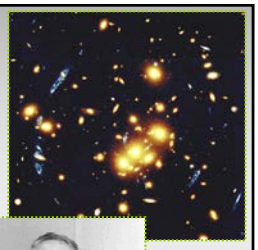


Spiral galaxy ROTATION CURVES

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

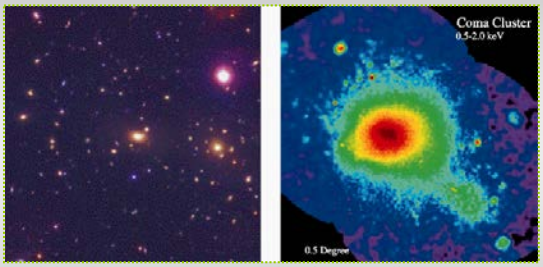


Galaxy Clusters: reveal dark matter in three ways



- # 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)

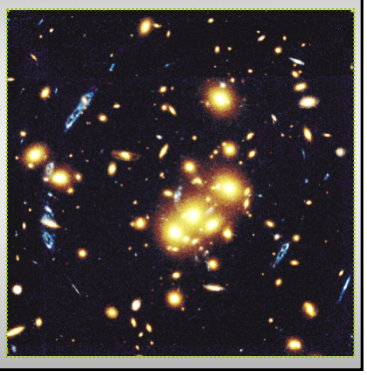
2: Hot x-ray emitting gas in cluster



- 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

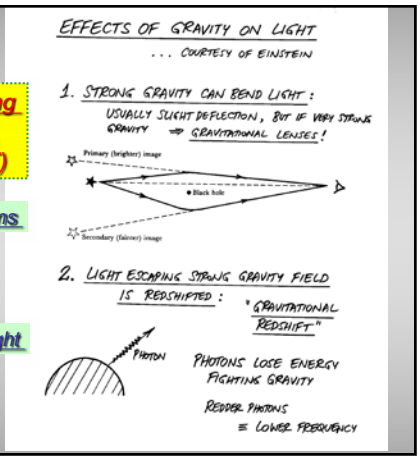


REMINDER

Effects of strong gravity on light (Einstein GRT)

can act like lens

can redshift light



Gravitational lensing: how it works