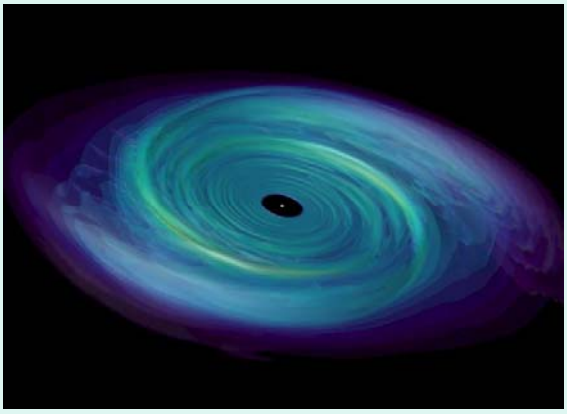
Stars, Galaxies & the Universe Announcements

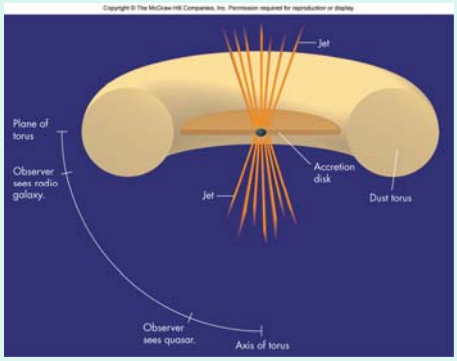
- **Reading Quiz #12**– in class today
- **No HW due this week!**
- **Azimuth of Sunset (M-Th) if clear – be on roof 4:15-4:30 for sunset (sunset occurs just around 4:30 pm)**
- **Exam #3 on Wednesday**
  - study materials available on line!
  - tutorial hours: see http://www.physics.uiowa.edu/academics/astron_tutorial_sched.html
- **Final Exam will be cumulative; Thursday 16 Dec @7:30 am in VAN LR 1; 150 points – 50 questions @3 pts each! We will have a review session sometime during Finals Week.**

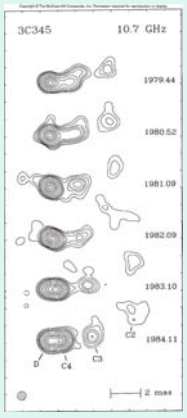
Stars, Galaxies & the Universe Lecture Outline

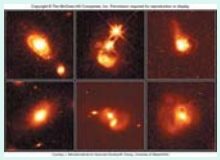
Structure of the Universe (Ch. 25)

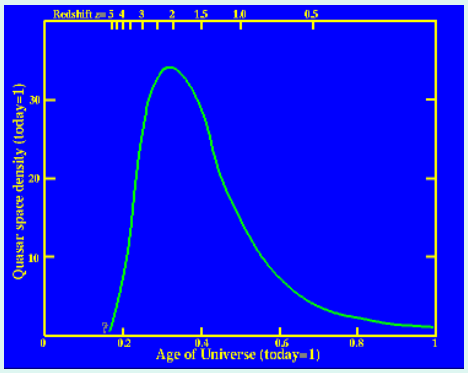
(1) A few last comments on quasars: are there Quasars/active galaxies in the local universe?
(2) The Local Group
(3) Galaxy Clusters
(4) Superclustering & overall structure
(4) Gravitational Lenses and Dark Matter

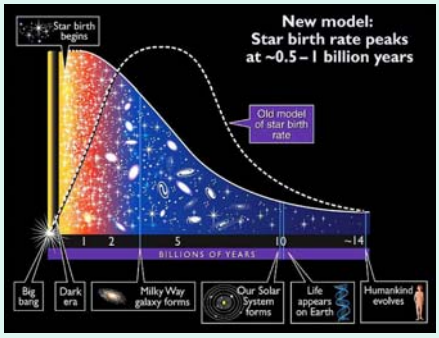


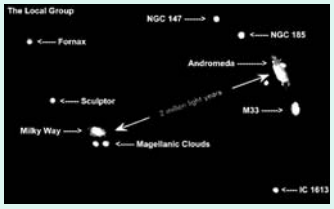

Jet
Plane of torus
Observer sees radio galaxy.
Accretion disk
Jet
Dust torus
Observer sees quasar.
Axis of torus


3C345
10.7 GHz
1979.44
1980.52
1981.09
1982.09
1983.10
1984.11
C4
C3
2 mas




Redshift z= 5
4
3
2
1.5
1.0
0.5
Quasar space density (today=1)
30
20
10
0
0.2
0.4
0.6
0.8
1
Age of Universe (today=1)





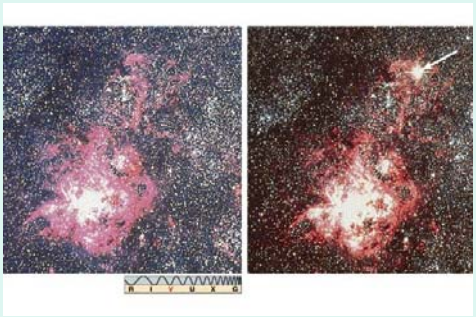
"The Local Group"

- Milky Way is one of ~40 galaxies in the Local Group
- Local group is not a rich cluster, "poor"
- All three galaxy types are represented
  - spiral (biggest: Andromeda, MW)
  - elliptical (many small, dim ones)
  - irregular (LMC and SMC)
- orbital speeds faster than they should be given the mass in visible galaxies! – "dark matter"

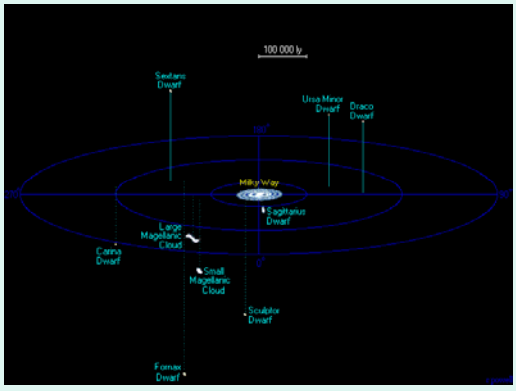
The Large & Small Magellanic Clouds

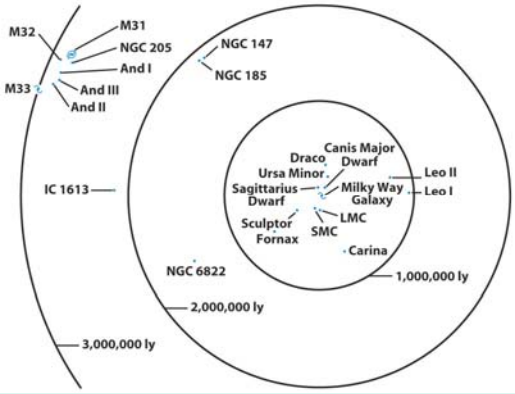
- closest galaxies – LMC: 180,000 ly; SMC: 210,000 ly
- do not have the spiral pattern that Andromeda does
- "irregular, dwarf" galaxies

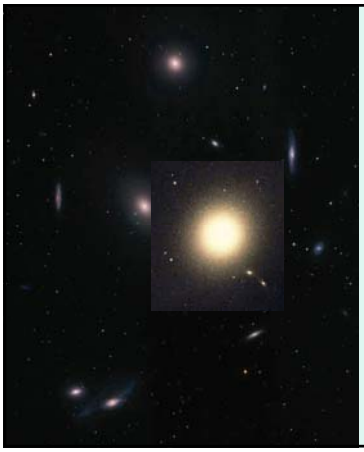
Supernova 1987a – huge increase in optical brightness
- detections of neutrinos slightly earlier



Our “Local Group” of Galaxies







The Virgo Cluster

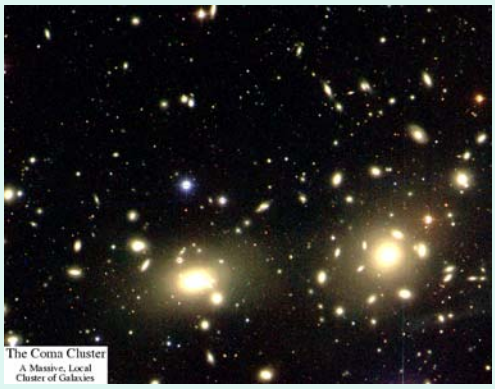
- distance = 20 Mpc
- size = 3 Mpc across - degrees in the sky!
- contains several GIANT ELLIPTICALS
- M87 – prototype elliptical galaxy

Coma cluster ~ 6 Mpc across
~ 4 degrees in the sky!

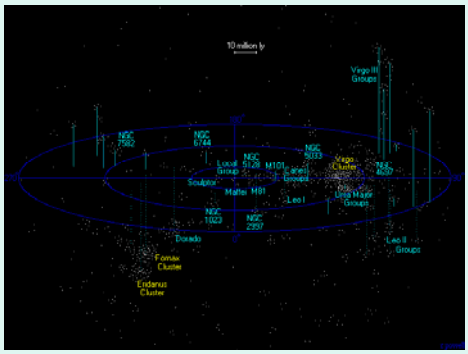
Coma cluster

- distance = 70 Mpc
- very rich cluster
- many bright galaxies
- 10,000 galaxies total

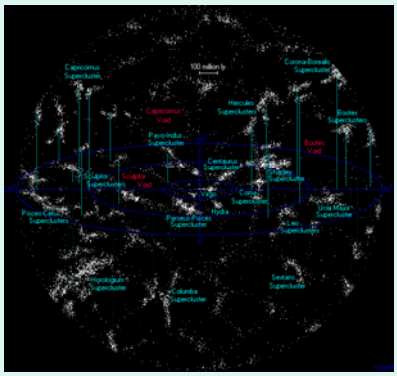
- giant ellipticals in the central regions of cluster ... spirals are on the edges of the cluster



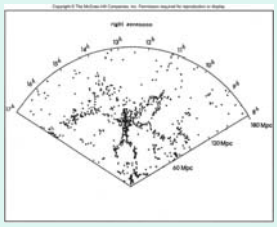
Within 100 million light years of the "Local Group"

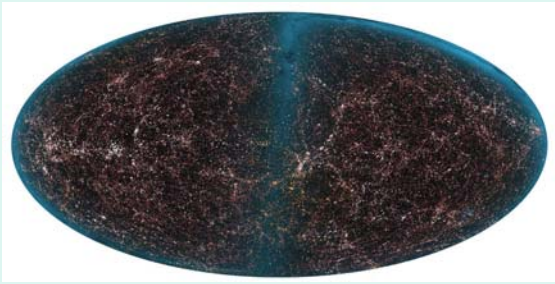


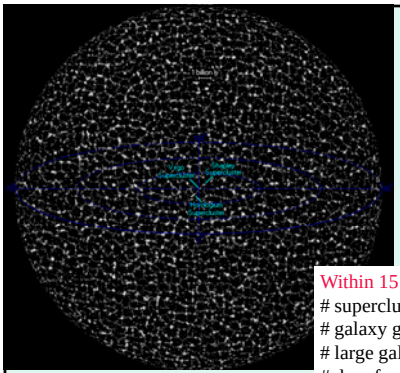
Within 1 billion light years of the Local Group



Clustering of Galaxies – “voids” and “walls”



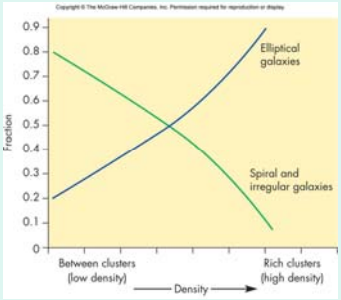




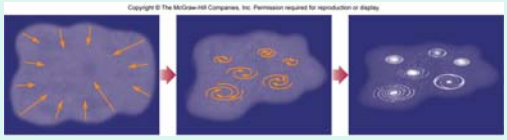
The observable universe

Within 15 billion light years...
superclusters = 270,000
galaxy groups = 500 million
large galaxies = 10 billion
dwarf galaxies = 100 billion
stars = 2000 billion billion

Galaxy clustering – ellipticals vs. spirals



The hierarchical model for galaxy formation – clouds of gas → clusters of stars → galaxies → clusters of galaxies



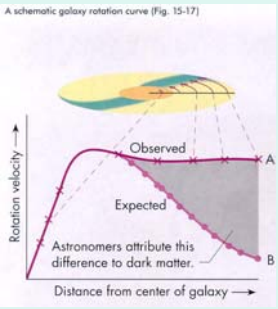
The pancake model of cluster formation – a cloud of gas about the mass of A cluster of galaxies collapses and then forms individual galaxies

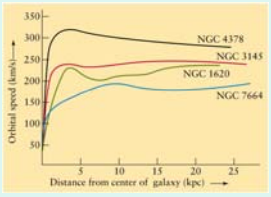
Dark Matter

Evidence?

(1)
(2)
(3)
(4)

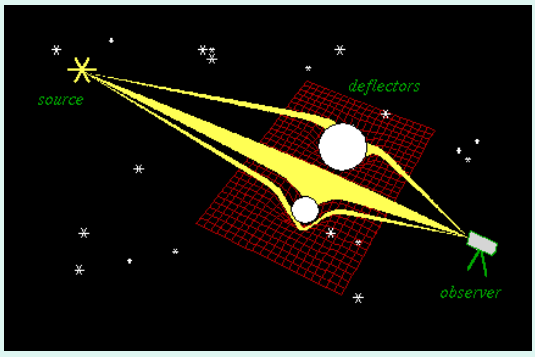
Rotation curves for nearby spiral galaxies:

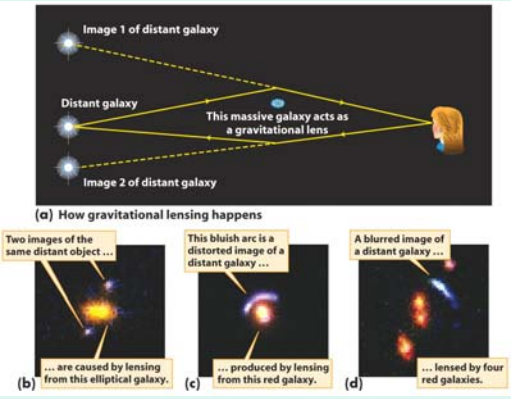




all galaxies have up to 90% "Missing Mass"!!

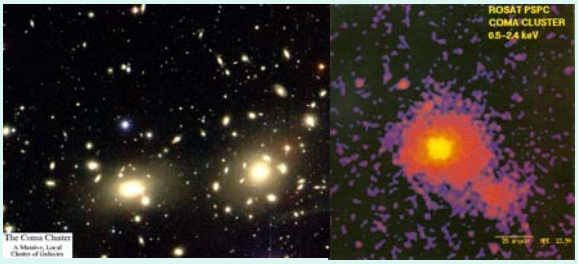
"Gravitational Lenses"



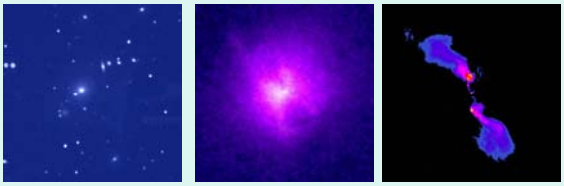


Coma Cluster - VISIBLE

Coma Cluster – X-RAY



Galaxy Cluster 0087



→ some of the missing "visible" mass is due to very hot (10 million K) gas
→ can account for only ~10% of the 90% of the missing mass!

Flat rotation curves, gravitational lenses imply that our Galaxy, other galaxies, galaxy clusters **<u>are full of "dark matter"</u>**

- What do we mean by "dark matter"?

  "missing mass" problem
  can not detect it with any telescope
  does not radiate EM radiation

- How serious is this "missing mass" – 10%, 50% of universe?

  add up all "dark matter" in galaxies
  galaxy clusters
  intergalactic medium

  as much as 90% of universe is INVISIBLE!

What can "dark matter" be? several possibilities...

1. lots of low-mass stars - NO
   even the faintest stars would radiate *something*
   and would be bright if 90% of universe made of them
2. dark, light-absorbing dust - NO
   we would not be able to see as far into galaxies, the universe if the universe were enshrouded by 90% dust
3. black holes - possibly
4. brown dwarfs - possibly
   dim objects "proto-stars", which never collapsed to densities or temperatures enough to fuse hydrogen, M=10 $M_{Jupiter}$
5. white dwarfs – possibly
   very old, dim remnants from solar-type stars
6. unknown elementary particles – possibly
   particles which are not luminous or do not interact with matter in usual ways (new physics required), e.g., WIMPs, MACHOs