

## **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](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.

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## **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

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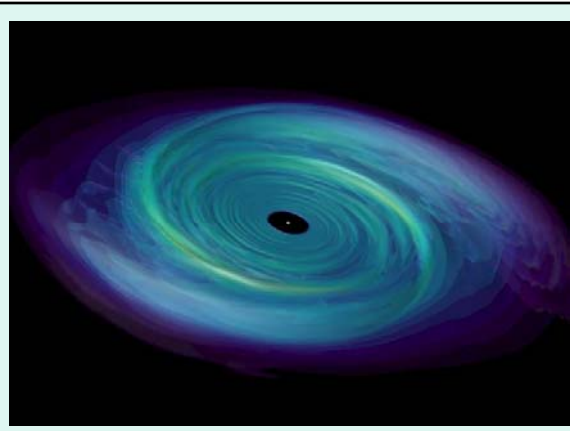
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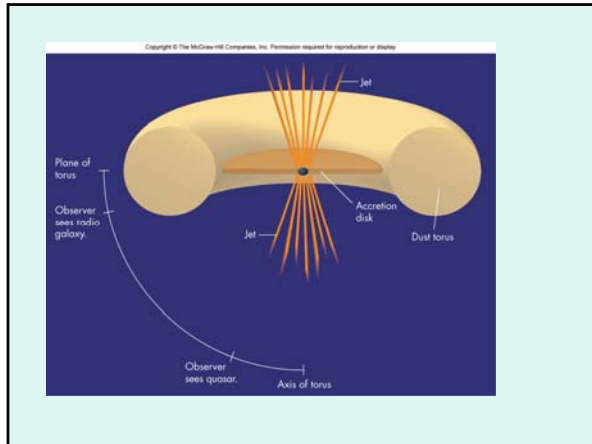
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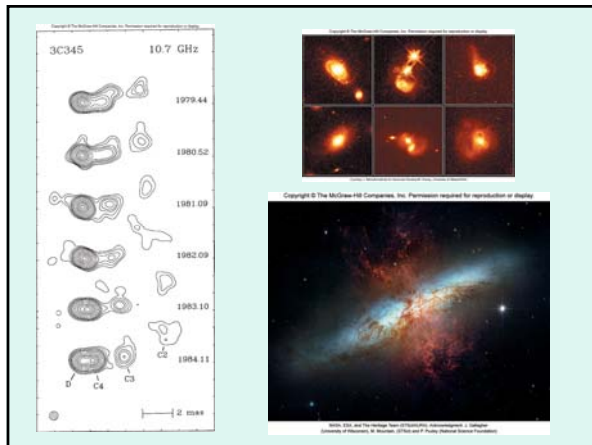
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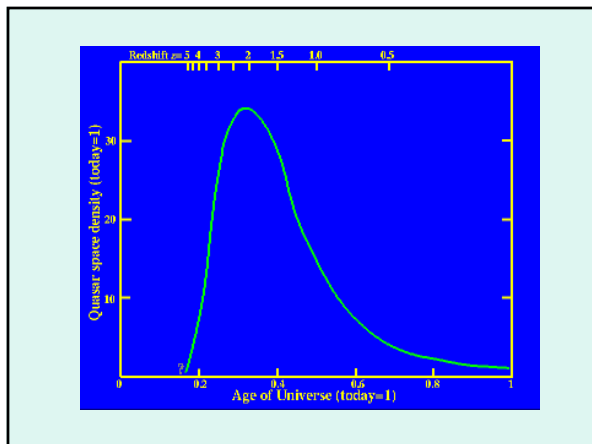
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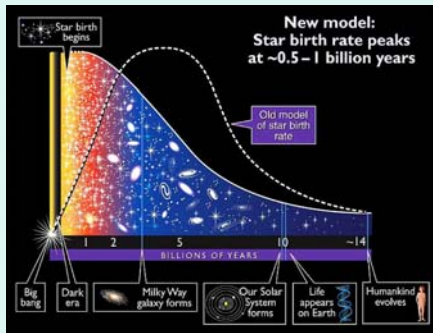
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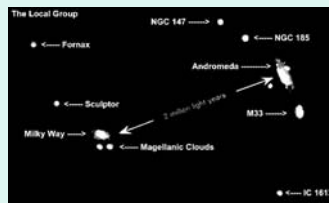
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**“The Local Group”**

- 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”

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#### 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




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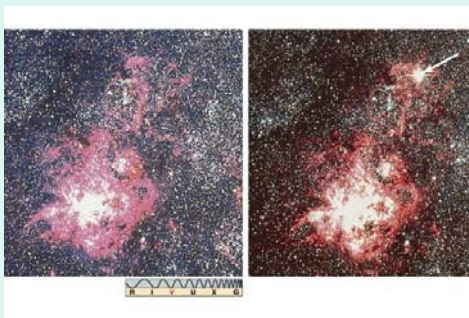
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Supernova 1987a – huge increase in optical brightness  
- detections of neutrinos slightly earlier




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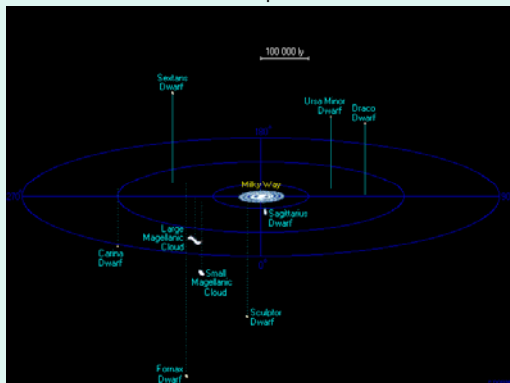
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Our "Local Group" of Galaxies




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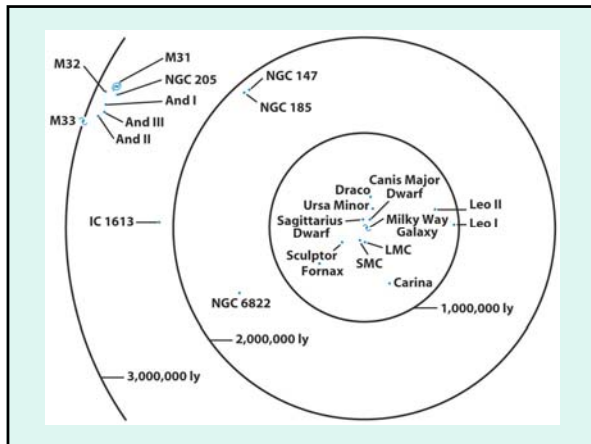
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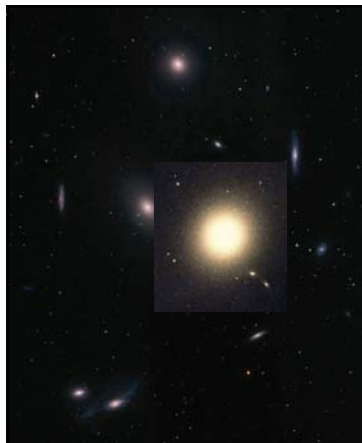
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**The Virgo Cluster**

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

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**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

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

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[illegible]

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Within 1 billion light years of the Local Group

The diagram illustrates the Local Group of galaxies, showing various galaxy clusters and individual galaxies. The clusters are labeled as follows:

- Coma Cluster
- Virgo Cluster
- Centaurus Cluster
- Antennae Cluster
- NGC 4038/4039
- NGC 4076
- NGC 4077
- NGC 4078
- NGC 4079
- NGC 4080
- NGC 4081
- NGC 4082
- NGC 4083
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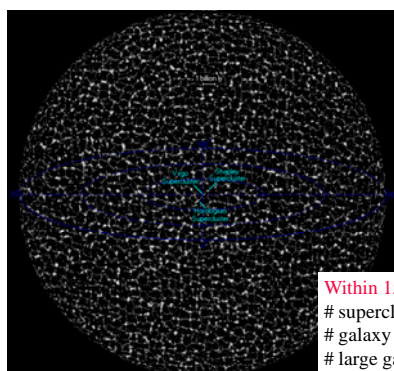
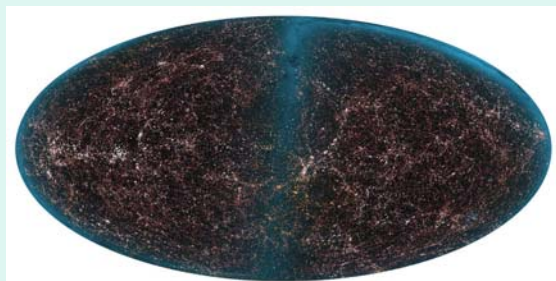
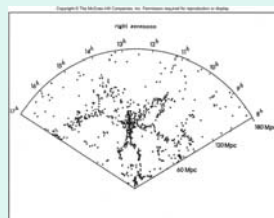
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## Clustering of Galaxies – “voids” and “walls”

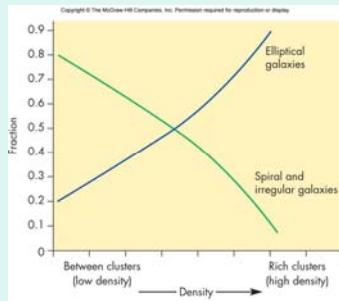


## The observable universe

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




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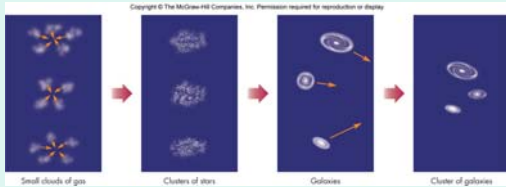
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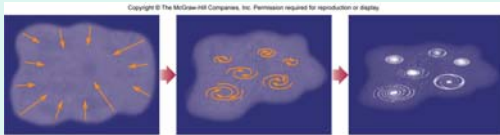
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The hierarchical model for galaxy formation – clouds of gas → clusters of stars → galaxies → clusters of galaxies



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

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## Dark Matter

### Evidence?

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

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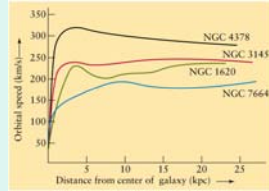
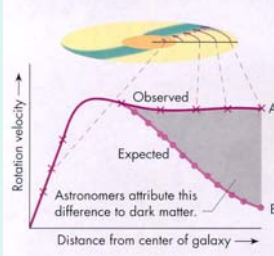
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### Rotation curves for nearby spiral galaxies:

A schematic galaxy rotation curve (Fig. 15-17)



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

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### "Gravitational Lenses"



Galaxy Cluster Abell 2218

HST • WFPC2

NASA, A. Fruchter and the ERO Team (STScI, ST-ECF) • STScI-PRC00-08

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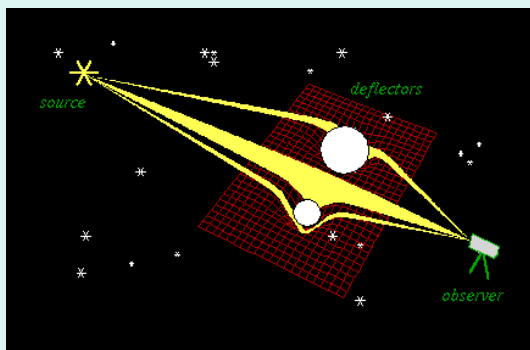
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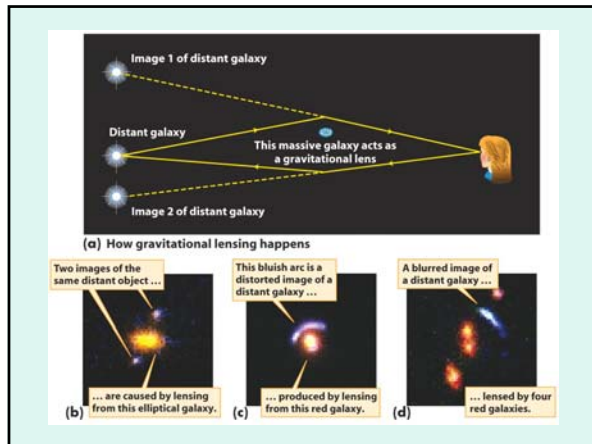
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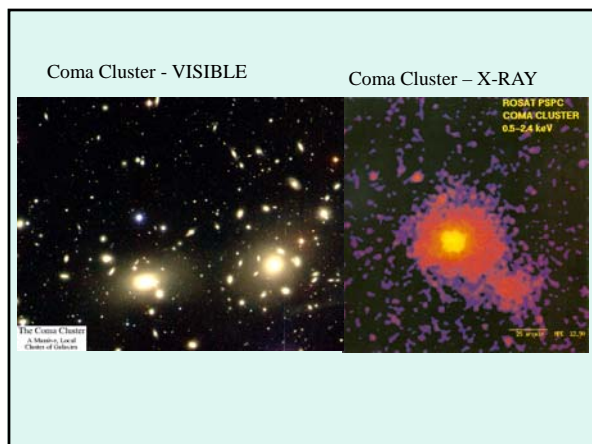
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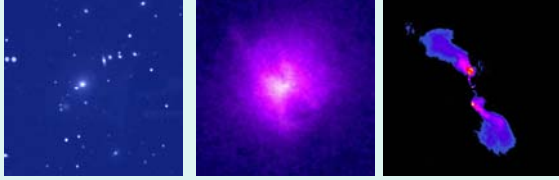
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### Galaxy Cluster 0087



- 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!

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Flat rotation curves, gravitational lenses imply that our Galaxy, other galaxies, galaxy clusters **are full of “dark matter”**

#### • 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!

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### 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,  $M=10 M_{\text{Jupiter}}$
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

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