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.

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
5. Gravitational Lenses and Dark Matter
11/15/2010

“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

- 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”
Clustering of Galaxies – “voids” and “walls”

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”
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 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!

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