Wednesday April 6

Syllabus and class notes are at: www.as.utexas.edu

Reading for this week: Chapters 13 & 14

If you want help on anything covered in the course, come to discussion session Thursday at 6:00 in RLM 15.216B or to our office hours.
Solar Eclipse on Friday

There will be a partial solar eclipse this Friday. It will last from about 4:15 until 6:00, and will be best at about 5:00-5:30.

You can see it through the solar telescope in RLM 13.124. Or make a pinhole camera.
Do not look directly at the Sun!
Topics for this week

How do spiral, elliptical, and irregular galaxies differ?
What does Hubble’s law say?
How is Hubble’s constant measured?
Describe some of the results of galaxy collisions and mergers.
What is meant by the phrase ‘active galaxy’?
What evidence do we have that active galaxies have very massive black holes at their centers?
The Milky Way

These all-sky maps portray the entire Milky Way Galaxy by taking images of the entire celestial sphere, and then unwrapping and stretching them to fit onto a two-dimensional surface. The Galactic Center is at the center of each image, with the plane of the Galaxy stretching from left to right in a manner similar to the equator on Earth.

Each image is dominated by the emission from the disk and central bulge of the Milky Way, where most of the contents of our galaxy are contained.

In the first gamma-ray image (top-left), we see the entire sky at energies above 100 million electron volts. Gamma-rays have more than a million times the energy of visible light! This picture shows us areas where high-energy cosmic rays collide with hydrogen in interstellar clouds. The next gamma-ray image highlights the most intense gamma-ray sources, some of which have been identified as black holes, neutron stars, and supernovae. Most of these phenomena...
Types of Galaxies

Spiral Galaxies
- flat disk with spiral arm pattern with old and young stars
- bulge in center of disk
- halo around disk with old stars and little gas
- may have bars and rings

Elliptical Galaxies
- just a halo with old stars and little gas
- can be small or very large (in mass and size)

Irregular Galaxies
- disorganized – no flat disk or smooth halo
- generally small mass and size
- perhaps relatively recently formed or disrupted
Messier 31 - The Andromeda Galaxy (Type Sb)

- X-Ray: ROSAT
- Ultraviolet: GALEX
- Visible: Jason Ware
- Infrared: IRAS
- Radio: Effelsberg

Messier 77 - Spiral Galaxy (Type Sb)

- X-Ray: ROSAT
- Ultraviolet: ASTRO-1
- Visible: AAO
- Infrared: 2MASS
- Radio: NVSS

Messier 81 - Spiral Galaxy (Type Sb)

- X-Ray: ROSAT
- Ultraviolet: ASTRO-1
- Visible: R. Gendler
- Infrared: Spitzer
- Radio: VLA
Messier 81 - Spiral Galaxy (Type Sb)

- X-Ray: ROSAT
- Ultraviolet: ASTRO-1
- Visible: R. Gendler
- Infrared: Spitzer
- Radio: VLA

Messier 94 - Spiral Galaxy (Type Sb)

- X-Ray: ROSAT
- Ultraviolet: ASTRO-2
- Visible: KPNO
- Infrared: 2MASS
- Radio: NVSS

Messier 106 - Spiral Galaxy (Type Sbp)

- X-Ray: ROSAT
- Ultraviolet: FOCA/CNRS
- Visible: KPNO/NOAO
- Infrared: 2MASS
- Radio: NVSS
M82 is one of the most irregular galaxies in our galactic neighborhood. Due to a recent interaction with M81, this galaxy has tremendous amounts of star formation taking place. The image shows reddened outflows of material that extend hundreds and thousands of light years away from core of the galaxy. Curiously, this galaxy is exceedingly bright in the visible wavelengths of light— but even brighter in emissions at the radio wavelengths!
These NASA Hubble Space Telescope snapshots reveal dramatic activities within the core of the galaxy NGC 3079, where a lumpy bubble of hot gas is rising from a cauldron of glowing matter. The picture at left shows the bubble in the center of the galaxy's disk. The structure is more than 3,000 light-years wide and rises 3,500 light-years above the galaxy's disk. The smaller photo at right is a close-up view of the bubble. Astronomers suspect that the bubble is being blown by "winds" (high-speed streams of particles) released during a burst of star formation. Gaseous filaments at the top of the bubble are whirling around in a vortex and are being expelled into space. Eventually, this gas will rain down upon the galaxy's disk where it may collide with gas clouds, compress them, and form a new generation of stars. The two white dots just above the bubble are probably stars in the galaxy.

**Credits:** NASA, Gerald Cecil (University of North Carolina), Sylvain Veilleux (University of Maryland), Joss Bland-Hawthorn (Anglo- Australian Observatory), and Alex Filipenko (University of California at Berkeley).
Small Magellanic Cloud
The Antennae Galaxies

Distance: 63 million light-years (19.3 Mpc)  Image Size = 3.5 x 3.5 arcmin  Visual Magnitude = 11.2

X-Ray: Chandra  Visible: DSS  Visible: Color © AAO  Visible: Color Brad Whitmore
The galaxy pair NGC 4038 and NGC 4039 are commonly referred to as the Antennae because wide-angle, visible-light photographs from ground-based telescopes are suggestive of antennae on an insect. They are located in the southern constellation of Corvus. These galaxies are in the process of undergoing a titanic collision, which actually started perhaps 100 million years ago, and are producing widespread bursts of star formation as a result.

The visible-light images shown above are zoomed into the heart of the intergalactic collision, with the field of view being only 15 percent of the diameter of a full Moon. The black-and-white DSS image (above left) over-exposes the galaxies. Nonetheless, you can easily see some obscuring dust throughout the photograph, especially near the image center. A more detailed color image (above right) begins to reveal the spectacular nature of this galaxy pair. Both members of the interacting pair are thought to have originally been spiral galaxies. The yellowish light is from older stars, while the bluish light identifies regions where massive and hot young stars have recently formed from the maelstrom. The pink regions denote emission nebula within the turbulent interstellar medium of these colliding galaxies. Dark dust filaments are also seen throughout the photo. The points of light scattered around the periphery are foreground stars within our own Milky Way Galaxy.
Motions of Galaxies

In 1920s Vesto Slipher measured spectra of galaxies. He found that most galaxies are redshifted, that is they are moving away from us. Soon after that Edwin Hubble measured the distances to galaxies. He found that in general more distant galaxies are moving away from us faster than closer galaxies are.

This is Hubble’s law: $v = H \cdot d$ or $v \propto d$

The Hubble diagram is like the H-R diagram, but each dot is a galaxy (instead of a star) and the axes are distance and speed (instead of temperature and luminosity).
How are distance and speed measured?

Speed is from the Doppler shift – the faster a galaxy moves away from us, the more the spectrum is shifted to longer wavelengths.

Distance is more difficult.

No galaxy is close enough for us to measure its parallax. The measurement used to require a difficult chain of measurements, but with the Hubble Space Telescope we can see Cepheid variable stars in many galaxies. From the periods of their variation we know the luminosities of these stars, and then by measuring their apparent brightnesses (fluxes) we can calculate their distances.
Hubble’s Law

Hubble found that a galaxy’s speed away from us is proportional to its distance from us.

\[ v = H d \]

What does this mean?
If galaxies are objects like the Milky Way, why would they all be moving away from the Milky Way?
And are they accelerating, so they move faster as they move away? What would cause this?