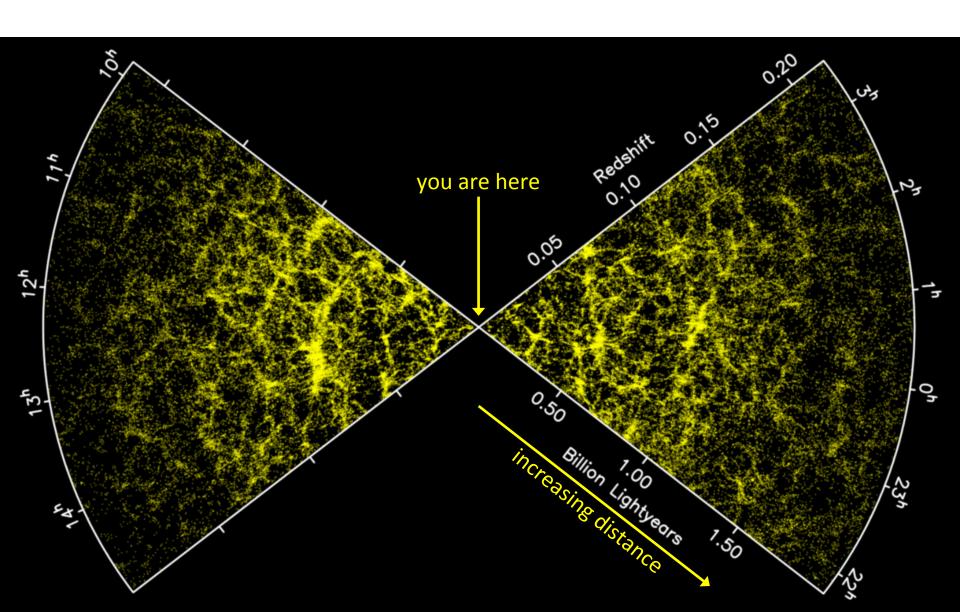
Announcements

- Today: more on Chapter 15, Galaxies
- Midterm 3: Wednesday April 23
 - Neutron stars and black holes (Ch 13)
 - -The solar system (Chs 4, 6, 7, + bits of Ch 5 [Earth] and 8 [moons of Jupiter, Saturn])
 - -The Milky Way Galaxy (Ch 14)
- Review on Monday April 21

Astronomy 103

Galaxies
Please read chapter 15

The Distribution of Galaxies in Space

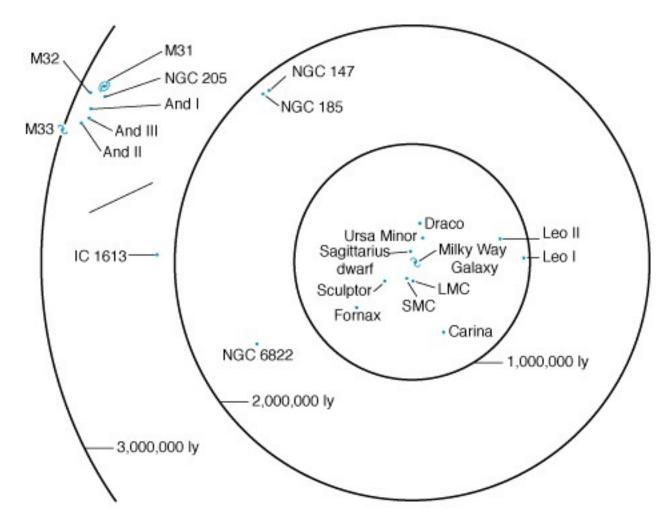


Collections of Galaxies

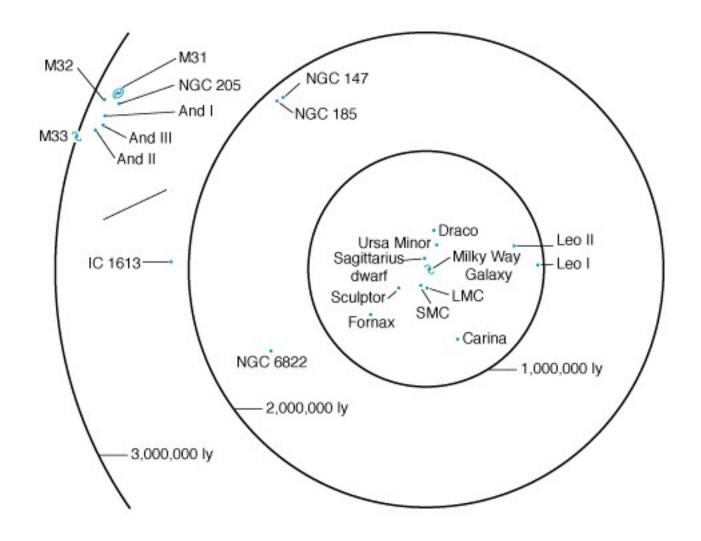
- Galaxies are not distributed randomly throughout the universe – they are usually found in associations of galaxies called groups and clusters
- Groups are smaller associations, with usually less than 50 galaxies
- Clusters are larger and can contain thousands of galaxies – galaxy clusters are the most massive gravitationally bound objects in the universe

Galaxy clusters and groups

- Galaxy clusters and groups consist of a collection of galaxies orbiting one another, bound together by their own gravity
- The Milky Way, Andromeda, and several other smaller galaxies form the Local Group
- The nearest large galaxy cluster to the Local Group is the Virgo Cluster
- Galaxy clusters themselves tend to clump together into superclusters. The Virgo Cluster, the Local Group, and several other nearby clusters form the Local Supercluster

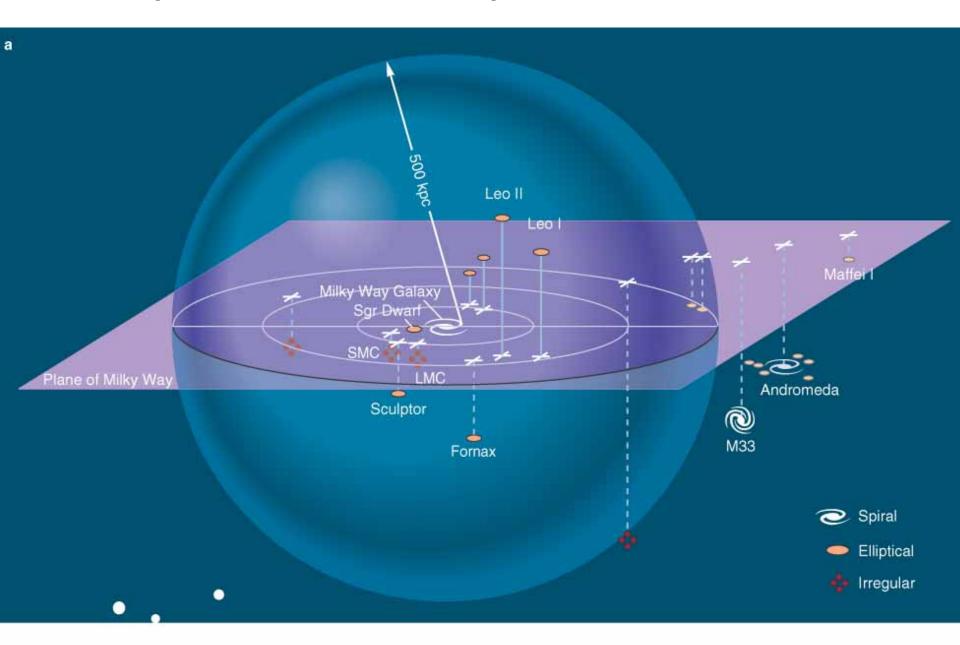


The Milky Way lives in a small group which also contains the Andromeda galaxy and many smaller galaxies. This is called the **Local Group**. The Milky Way and Andromeda make up about 90% of the mass of the Local Group.

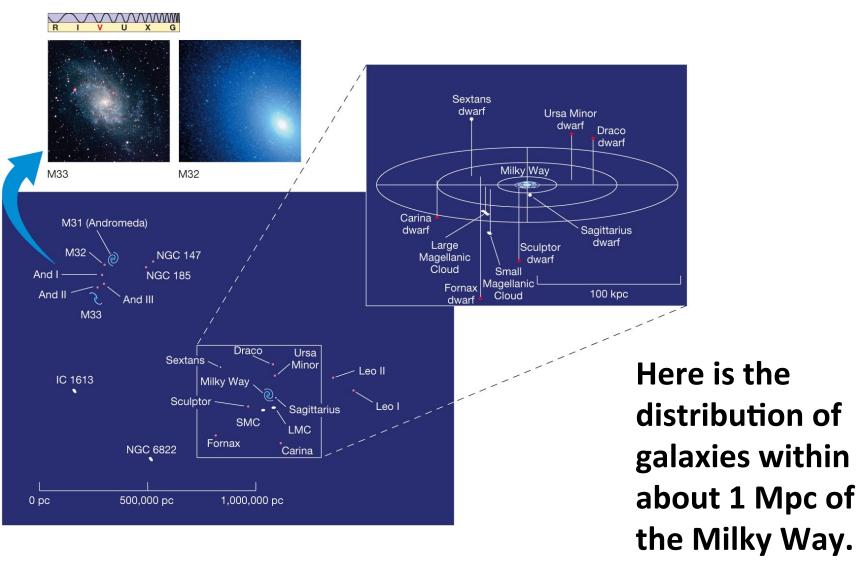


Galaxies in the Local Group are gravitationally bound to each other. The Milky Way and Andromeda are approaching each other, and will collide in billions of years.

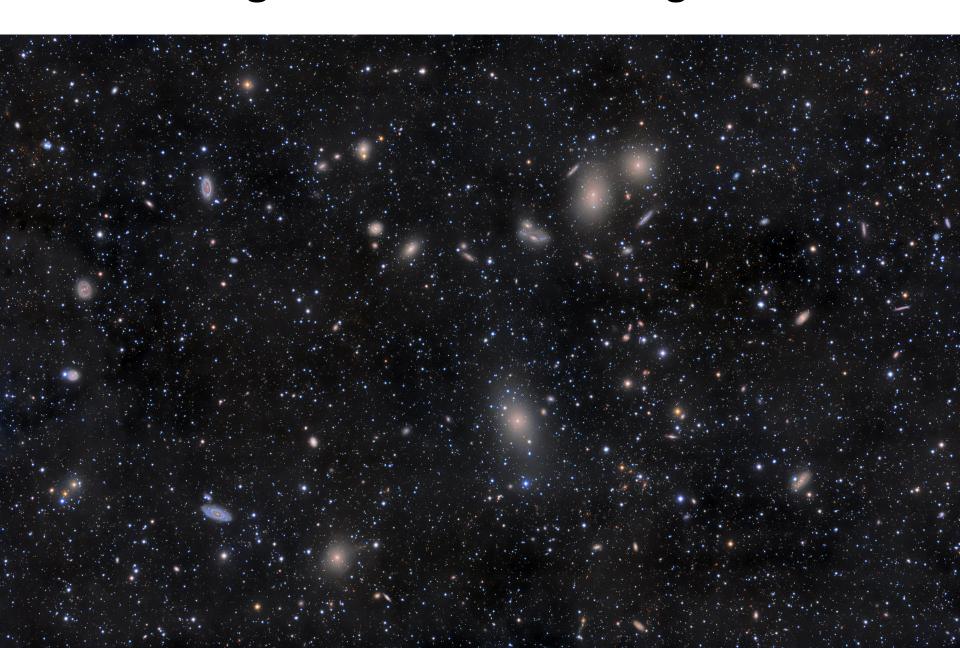
3-D map of the Local Group



The Distribution of Galaxies near the Milky Way



The Virgo Cluster: closest large cluster

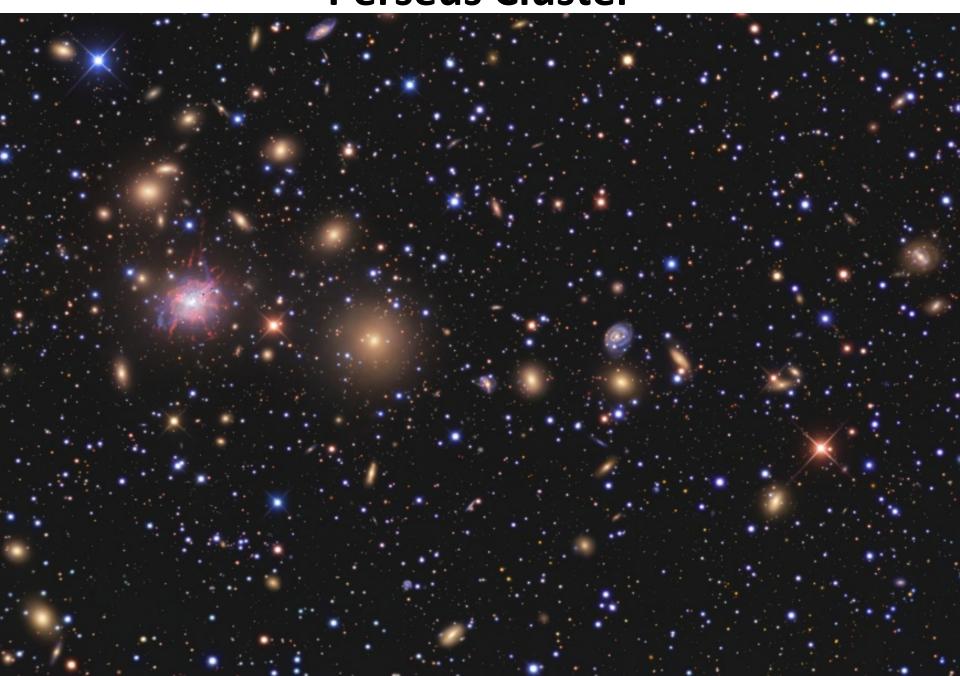


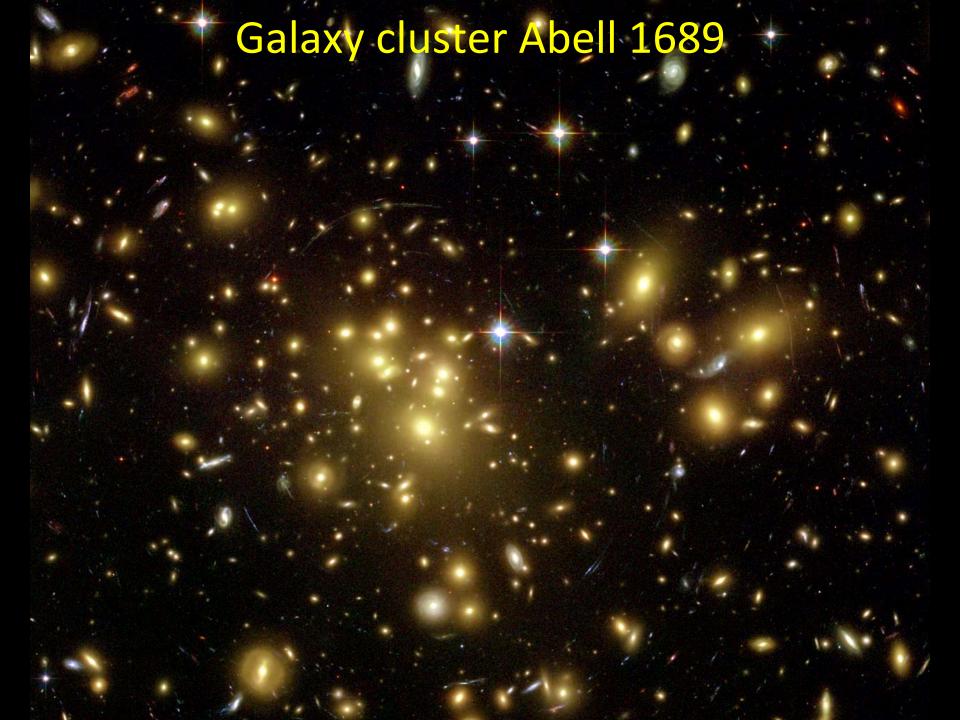
Virgo Cluster



- Covers about 10 x 10 degrees on the sky!
- Contains ~250 large galaxies and >2000 smaller ones
- 4 brightest galaxies are giant ellipticals, mix of spirals and ellipticals otherwise

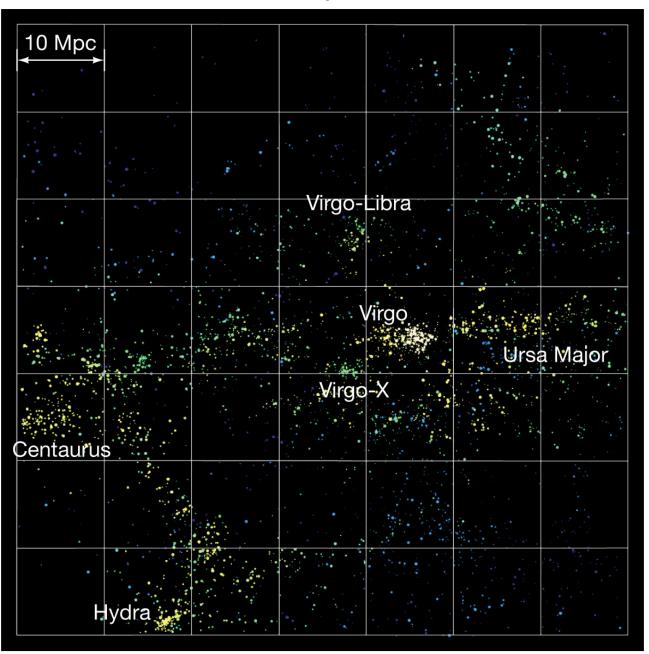
Perseus Cluster



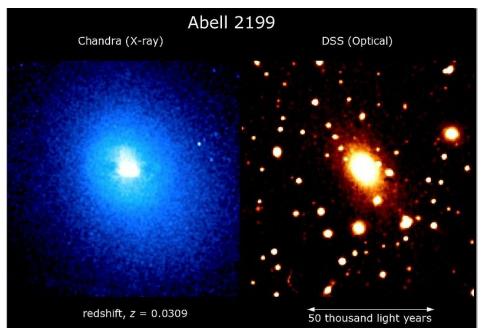




Local Supercluster



Masses of Galaxy Clusters



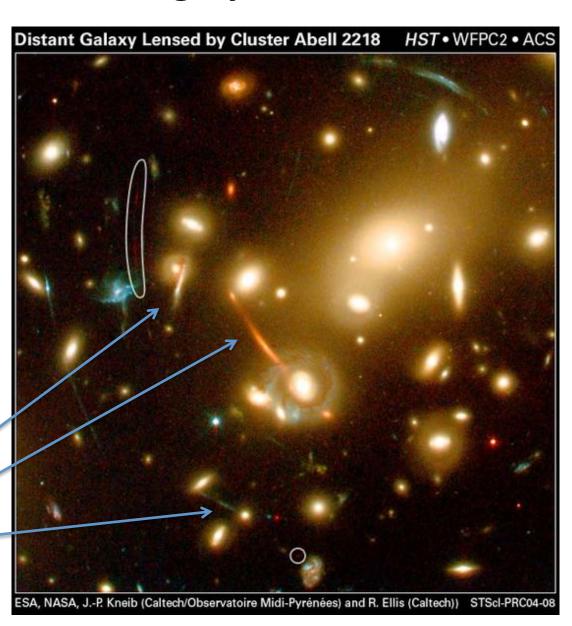
- Most of the mass of a galaxy cluster is not galaxies!
- Lots of very hot gas we see in x-rays: the intracluster medium
- Lots of dark matter
- First evidence for dark matter came from determining mass of Coma Cluster: more on that later!

Gravitational Lensing by Clusters

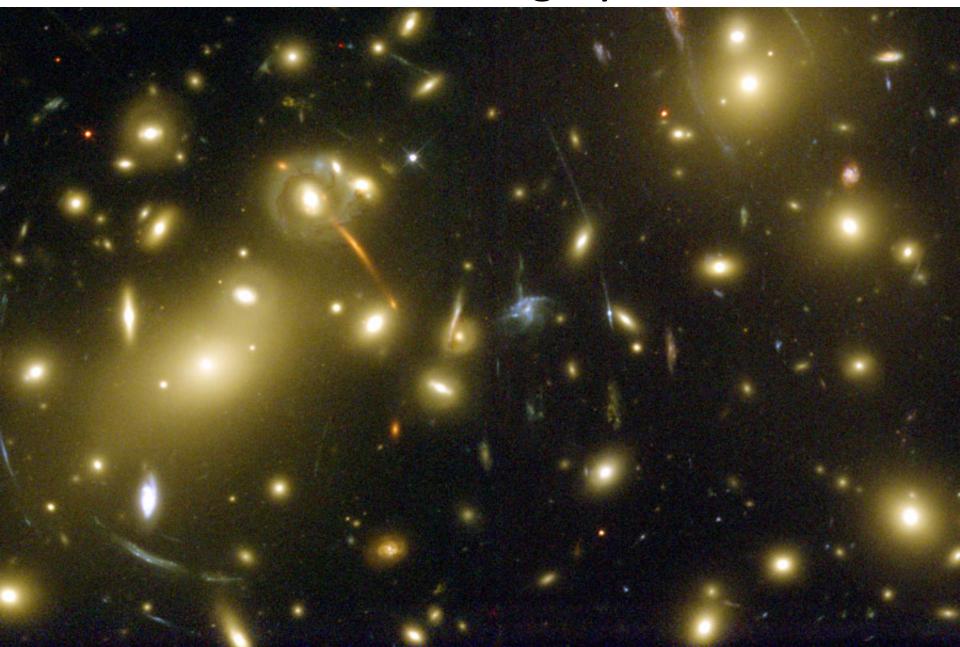
Clusters are so massive that they distort the images of galaxies behind them.

Background galaxies are seen as stretched objects.

Lensed galaxies



Gravitational Lensing by Abell 2218



The Hubble Law

Starting in 1914, Vesto Slipher found that galaxies outside the Local Group are all moving away from us!



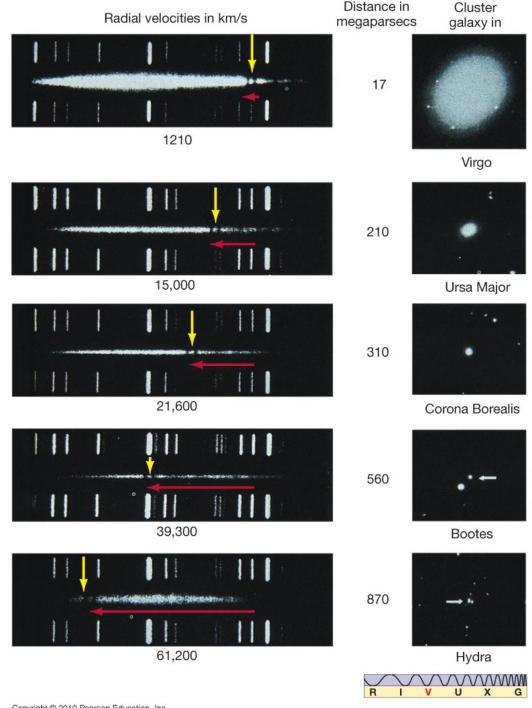
Vesto Slipher

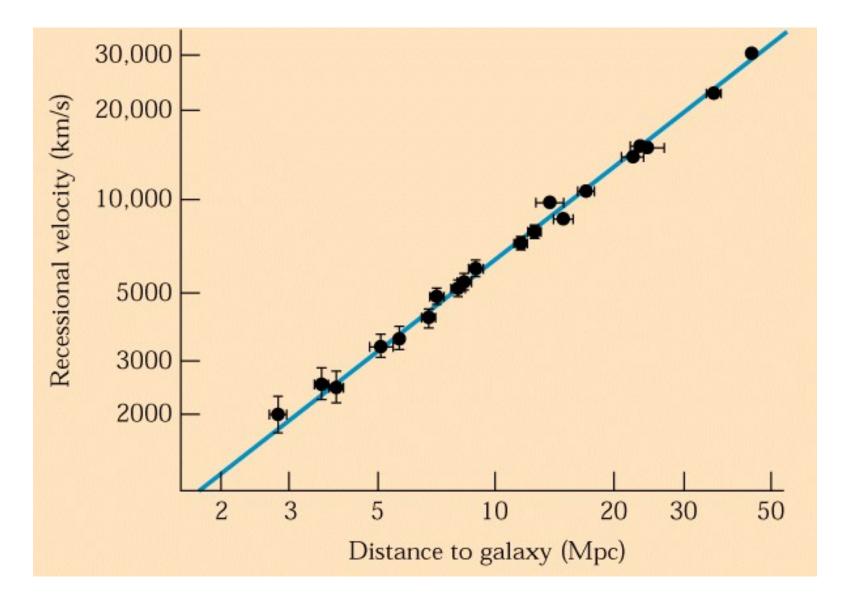
When Hubble started measuring their distances using Cepheids, he found that the speed at which they move away increases as the distance to the galaxy increases



Edwin Hubble

Velocity is measured from the redshift of absorption lines – **the** faster a galaxy is moving away, the larger the redshift





Each dot shows the distance to a galaxy and the speed with which it is moving away from us.

Galaxies outside our local group of galaxies are moving away from us, because the universe is expanding! Their speed increases with their distance from us according to the **Hubble law**:

$$v = H \times d$$

v = velocity in km/s

 $d = distance in megaparsecs (1 Mpc = 3.26 x <math>10^6 light years)$

The Hubble constant: H = 70 km/s/Mpc

(Uncertainty: 65-75 km/s/Mpc)

Hubble's Law

- v = H × d is called the Hubble Law and H is the Hubble constant.
- To determine it, we need to measure the velocity of many many galaxies, and their distances
- Velocities are easy, from the redshift of spectral lines
- Distances are harder: we use the Cepheid variable stars we talked about earlier and other methods

The value of Hubble's constant relies on using Cepheids to obtain the distance to the Virgo Cluster (50 Mly or 18 Mpc) and to other galaxies

within 100 Mly

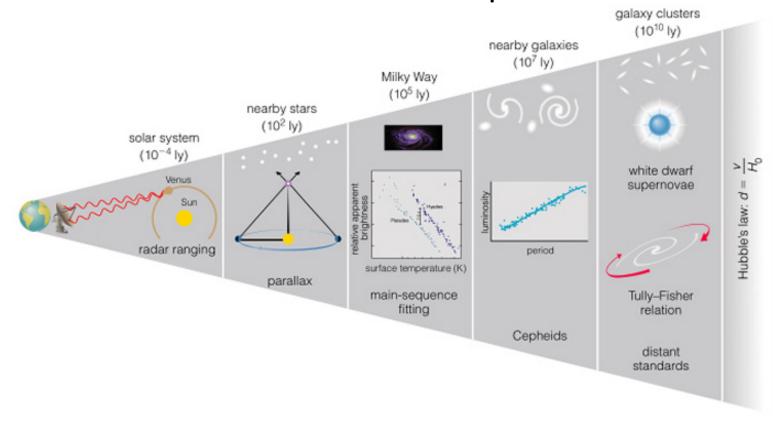
Key Project of Hubble Space Telescope: Measure the Hubble constant using Cepheid variable stars

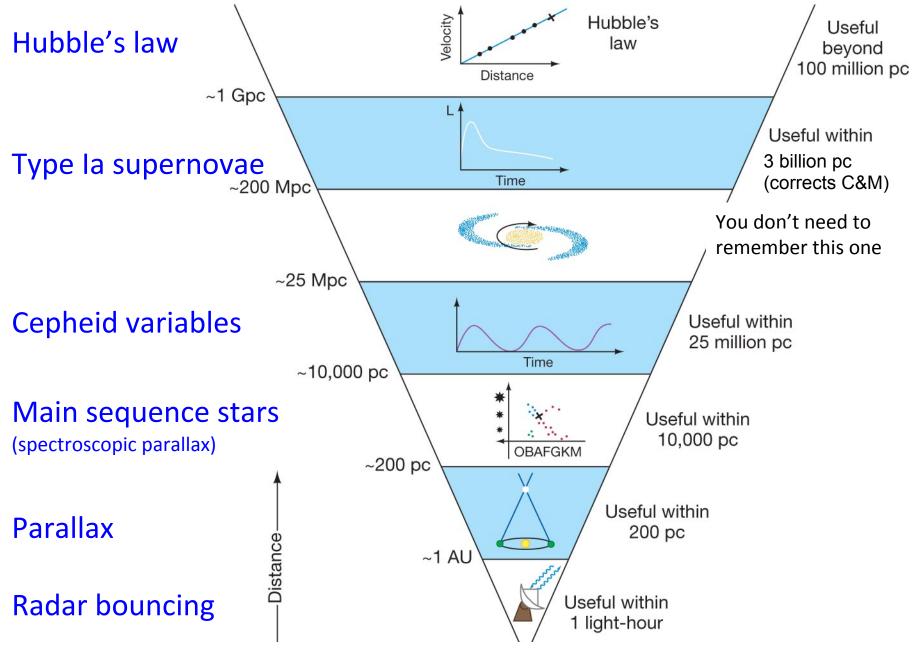
Wendy Freedman et al



Hubble's Law and the Distance Ladder

- Once we figure out the value of Hubble's constant, we can use the velocity of distant galaxies (easy to measure) to get their distance.
- So our distance ladder is complete!

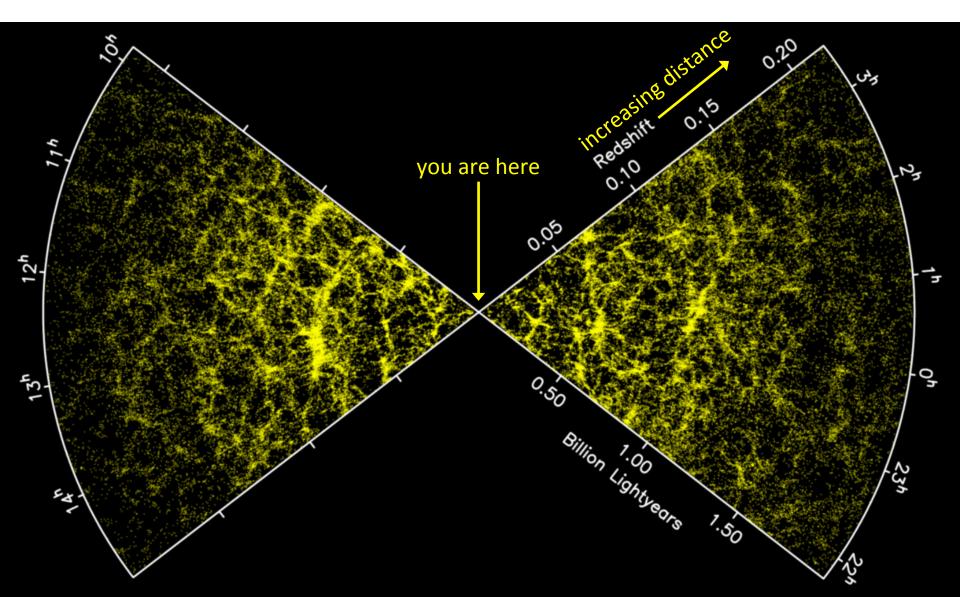




Minor corrections to C&M's diagram: 1. Hubble's law and Type Ia supernovae both rely on distances from Cepheids. You don't need Type Ia supernovae to get Hubble's law.

2. Type Ia supernovae have now been found at distances of 3 billion pc

Redshift Surveys Map the Distribution of Galaxies



Hubble's Law

$$v = H \times d$$
, H = 70 km/s/Mpc

Let's do a few examples.

1. A galaxy is 100 Mpc away. How fast is it moving away from us?

$$v = H \times d = 70 \times 100 = 7000 \text{ km/s}$$

2. A galaxy is 2000 Mpc away. How fast is it moving away from us?

$$v = H \times d = 70 \times 2000 = 140,000 \text{ km/s}$$

Hubble's Law

$$v = H \times d$$
, H = 70 km/s/Mpc

Let's do a few examples.

- 1. A galaxy is moving at 700 km/s away from us. How far away is it? d = v/H = 700/70 = 10 Mpc
- 2. A galaxy is moving at 21,000 km/s away from us. How far away is it?

$$d = v/H = 21,000/70 = 300 \text{ Mpc}$$

Hubble's Law is based on



More distant galaxies showing greater blueshifts



Distant galaxies appearing proportionally dimmer



More distant galaxies showing greater redshifts



Slowly varying Cepheid variables appearing brighter

Hubble's Law is based on



More distant galaxies showing greater blueshifts



Distant galaxies appearing proportionally dimmer



More distant galaxies showing greater redshifts

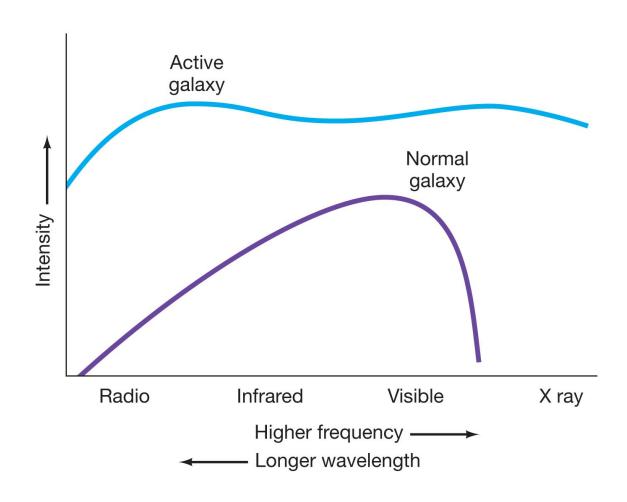


Slowly varying Cepheid variables appearing brighter

Active Galaxies

About 20–25 percent of galaxies don't fit well into the Hubble scheme – they are far too luminous.

Such galaxies are called active galaxies. They differ from normal galaxies in both their luminosity and in the type of radiation they emit.

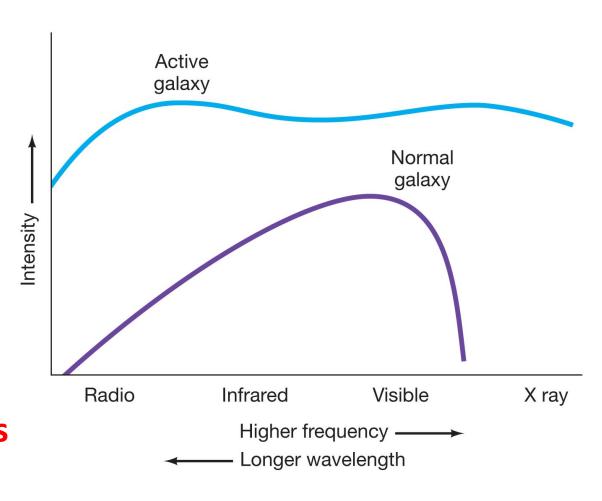


Galactic Spectra

Galaxies are made of large collections of stars, so we might expect their spectra to look like the spectra of a bunch of stars, peaking in visible light

This is true for most galaxies, but not for all of them. Some galaxies show strong nonstellar radiation.

Because they are bright, they are called active galaxies



Active Galaxies

The radiation from these galaxies is called nonstellar radiation, meaning that it is not produced by stars.

Many luminous galaxies are experiencing an outburst of star formation, probably due to interactions with a neighbor. These galaxies are called starburst galaxies, and we will discuss them later.

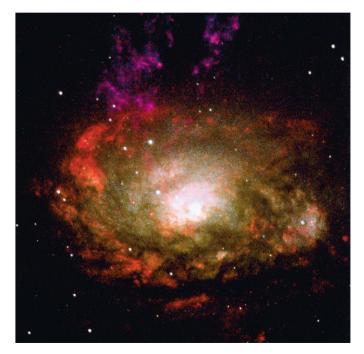
The galaxies we will discuss now are those whose activity is due to events occurring in and around the galactic center. For this reason they are called active galactic nuclei or AGN.

Active Galaxies

Active galaxies are much more luminous than normal galaxies and have nonstellar spectra, emitting most of their energy outside the visible part of the electromagnetic spectrum.

Active galaxies are classified into three types: Seyfert galaxies, radio galaxies, and quasars.

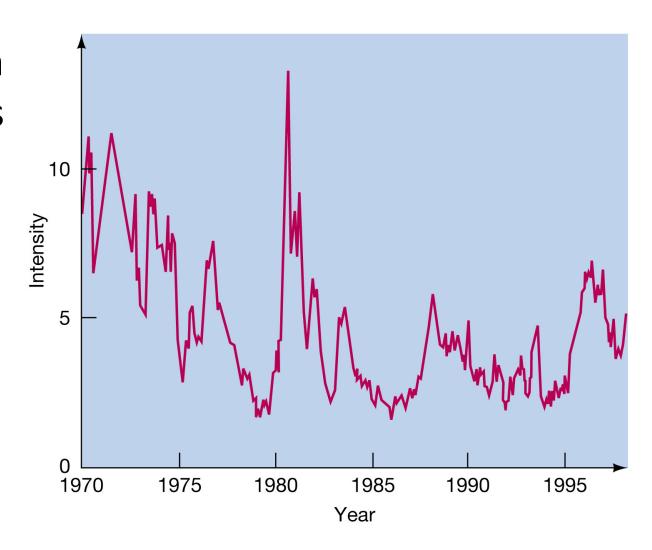
Seyfert galaxies resemble normal spiral galaxies, but their cores are thousands of times more luminous.



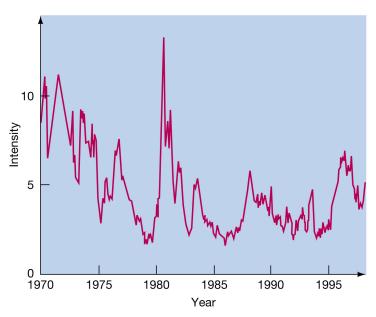
Seyfert Galaxies

Seyferts vary in brightness over a year to few years timescales.

Rapid variability implies that the central source is only a few light years (at most) across.



Seyfert Galaxies

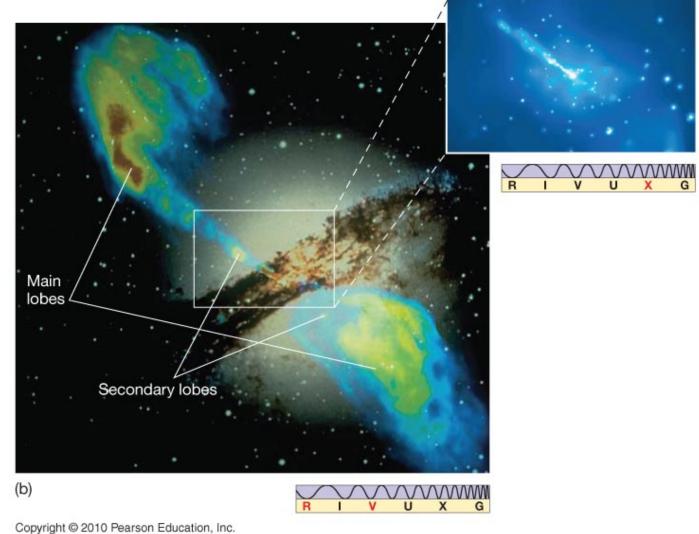


- Why does rapid variability imply small size?
- A source that changes in brightness in time t can't be bigger in size than c x t, since light needs time to travel across the object
- So something that changes in 1 year can't be more than one light year in size!

Other types of galaxies emit very strongly in the radio, but the radio emission doesn't always come from the central source, but instead two giant lobes that extend away from it.

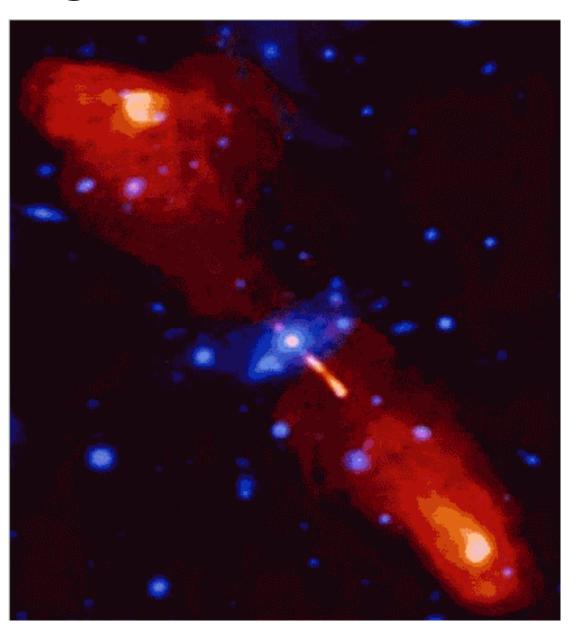
For obvious reasons, these are called radio galaxies.

This picture is a composite of Centaurus A.



Radio galaxies

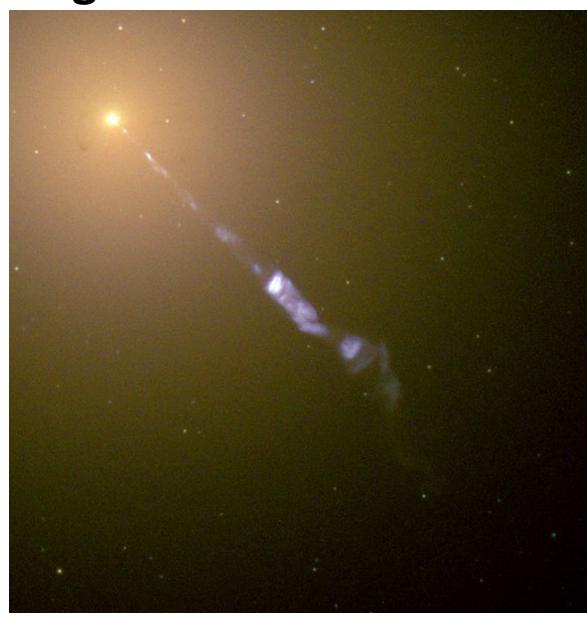
Radio galaxies emit large amounts of energy in the radio part of the spectrum. The corresponding visible galaxy is usually elliptical.



Radio galaxies

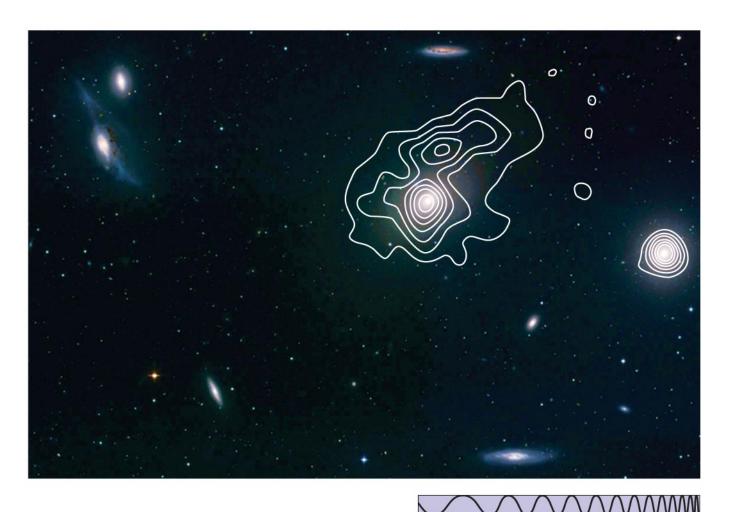
These radio lobes are powered by a powerful jet that is emitted from the center of the galaxy.

When it slams into the intergalactic medium (the gas between galaxies), it blows a bubble that becomes the radio lobe.



Radio Galaxies

Radio galaxies may also be core dominated.



Radio Galaxies

Core-dominated and radio-lobe galaxies are probably the same phenomenon viewed from different angles!

