Chapter 24
Galaxies

Units of Chapter 24

24.1 Hubble's Galaxy Classification

This pair of images shows the Coma cluster of galaxies. Almost every object visible is a galaxy.

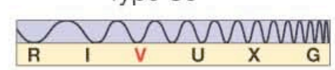
Coma Cluster (a) A collection of many galaxies, each consisting of hundreds of billions of stars. Called the Coma Cluster, this group of galaxies lies more than 100 million pc from Earth. (The blue spiked object at top right is a nearby star; every other object in this image is a galaxy.)

(b) A recent *Hubble Space Telescope* image of part of the cluster.

24.1 Hubble's Galaxy Classification

Spiral galaxies are classified according to the size of their central **bulge**:

(a) M81 Type Sa (b) M51 Type Sb (c) NGC 2997 Type Sc



24.1 Hubble's Galaxy Classification

Type **Sa** has the largest central bulge, Type **Sb** is smaller, and Type **Sc** is the smallest.

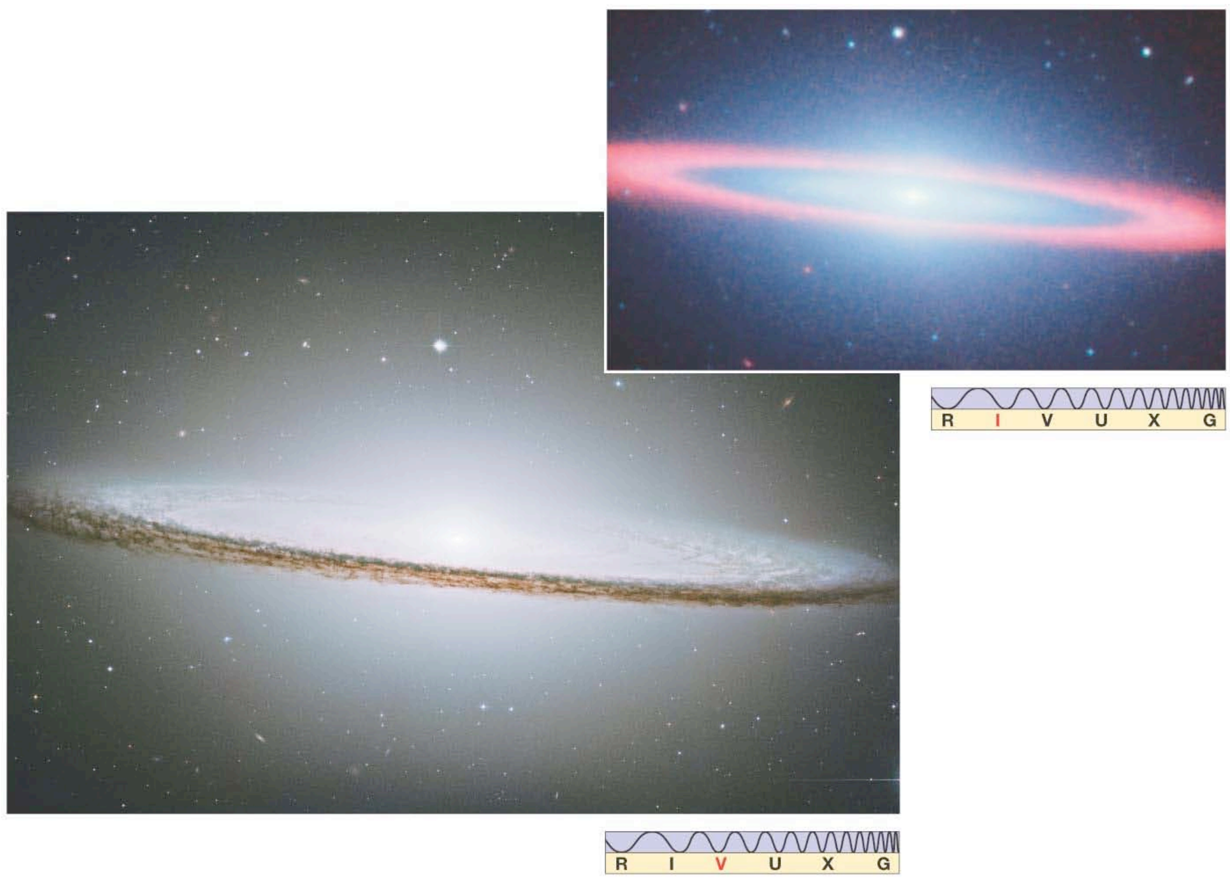
Type Sa tends to have the most tightly bound **spiral arms** with Types Sb and Sc progressively less tight, although the correlation is not perfect.

The components of spiral galaxies are the same as in our own galaxy:

disk, halo, bulge, and spiral arms.

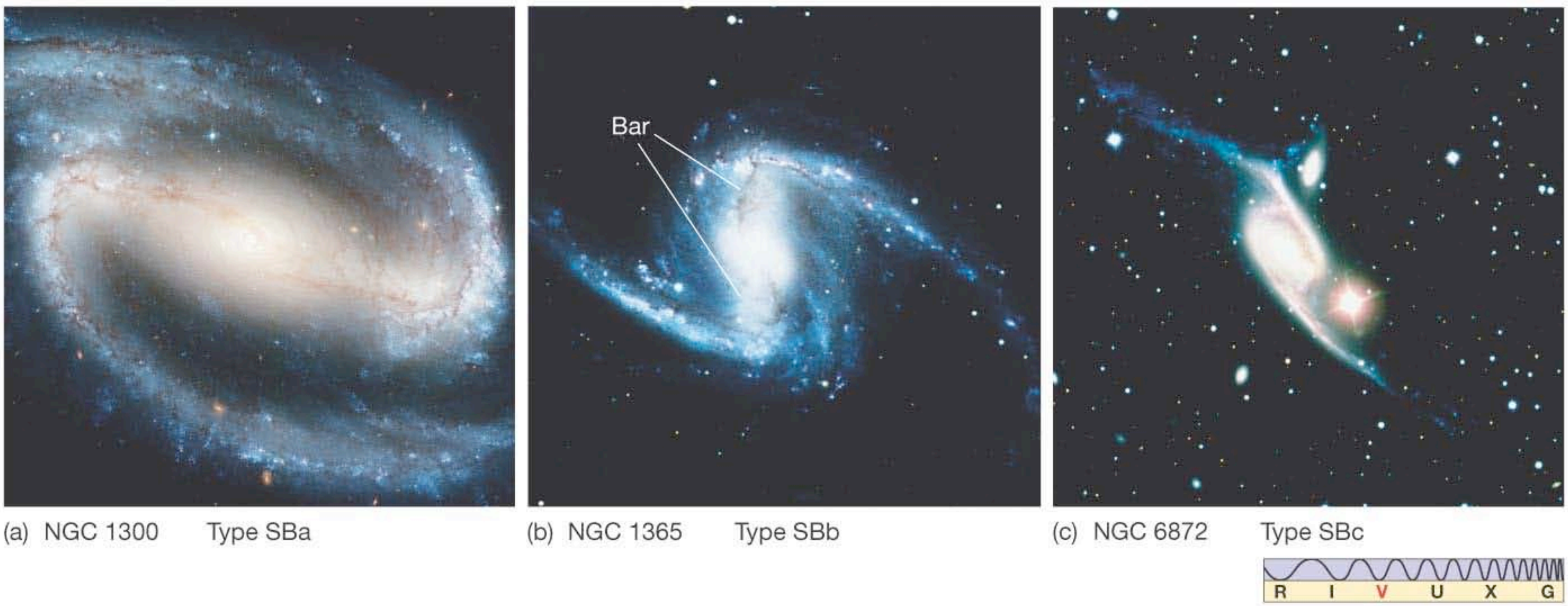
24.1 Hubble's Galaxy Classification

The Sombrero galaxy, with its large central bulge, is a type Sa. We cannot see the spiral arms, as they are edge-on. The dark band is the thin disk of gas and dust. The upper image shows the galaxy in the IR, where the dust-content shows up strongest.



24.1 Hubble's Galaxy Classification

Similar to the spiral galaxies are the **barred spirals**:



(a) NGC 1300 Type SBa (b) NGC 1365 Type SBb (c) NGC 6872 Type SBc

Variation in shape among barred-spiral galaxies. The variation from SBa to SBc is similar to that for the spirals in Figure 24.2, except that now the spiral arms begin at either end of a bar through the galactic center. In frame (c), the bright star is a foreground object in our own Galaxy; the object at top center is another galaxy that is probably interacting with NGC 6872.

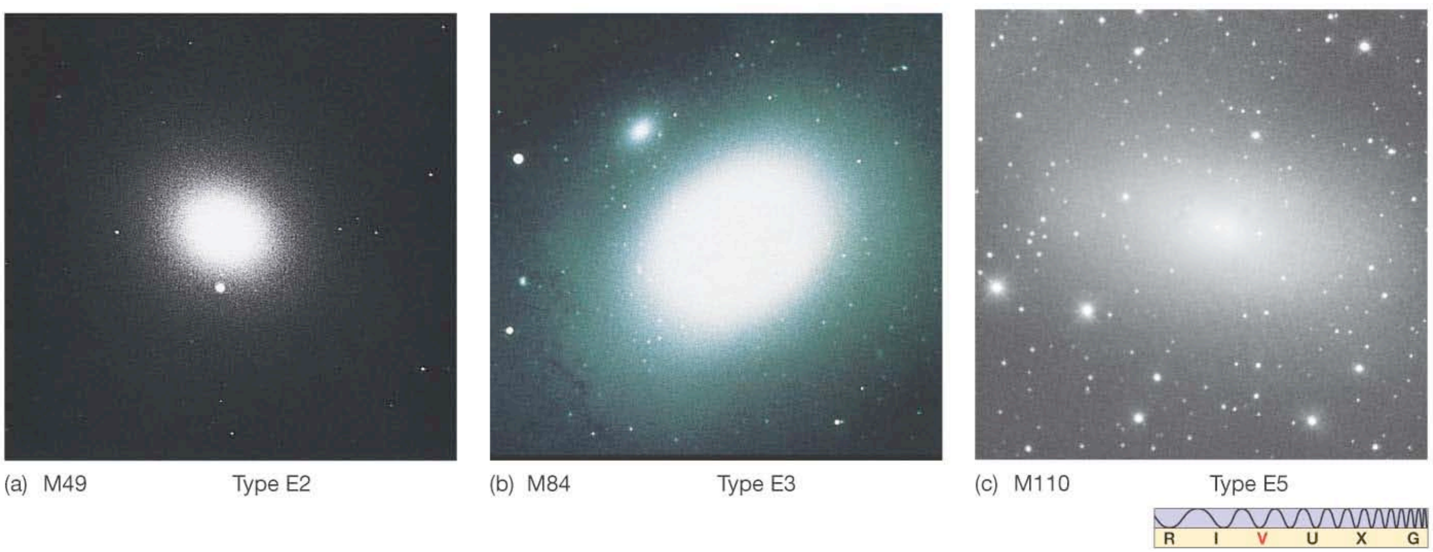
24.1 Hubble's Galaxy Classification

Elliptical galaxies have no spiral arms and no disk. They come in many sizes, from giant ellipticals of **trillions** of stars, down to dwarf ellipticals of less than a **million** stars.

Ellipticals also contain very little, if any, cool gas and dust, and they show no evidence of ongoing **star formation**.

Many do, however, have large clouds of **hot gas**, extending far beyond the visible boundaries of the galaxy.

Ellipticals are classified according to their shape from E0 (almost spherical) to E7 (the most elongated):

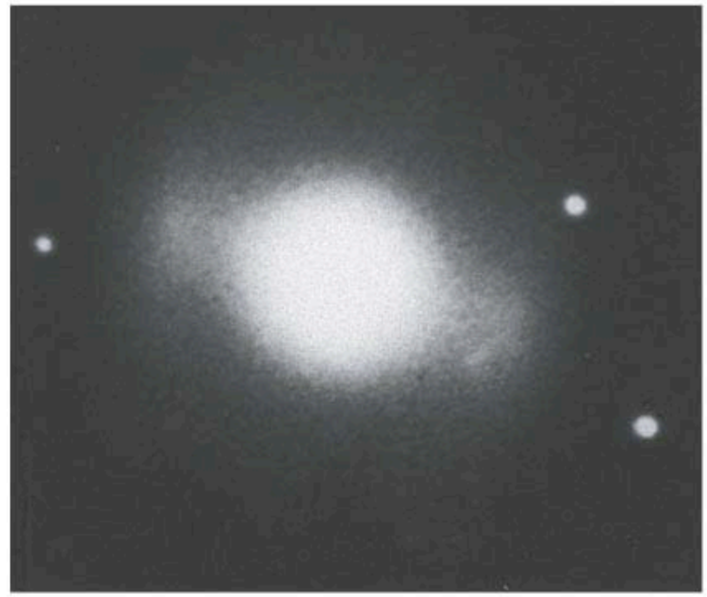


(a) M49 Type E2 (b) M84 Type E3 (c) M110 Type E5

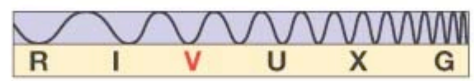
24.1 Hubble's Galaxy Classification

S0 (lenticular) and **SB0** galaxies have a disk and bulge, but no spiral arms and no interstellar gas:

(a) NGC 1201 Type S0



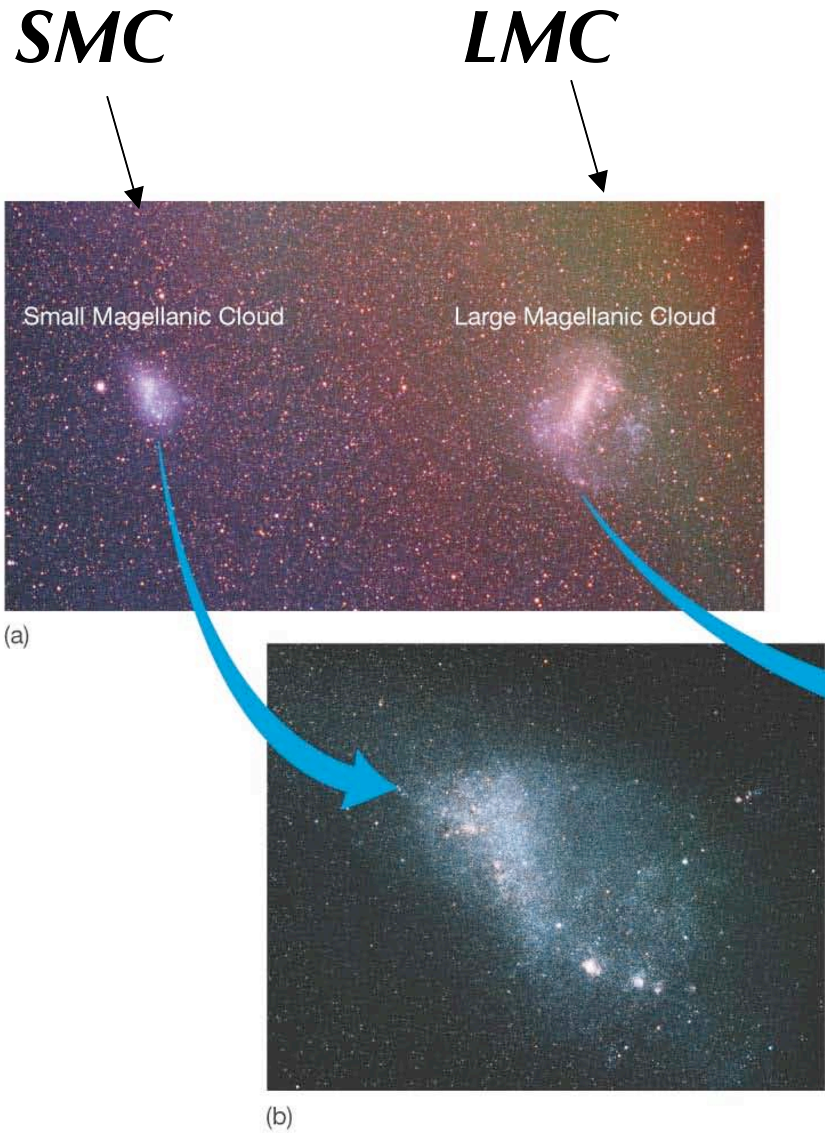
(b) NGC 2859 Type SB0



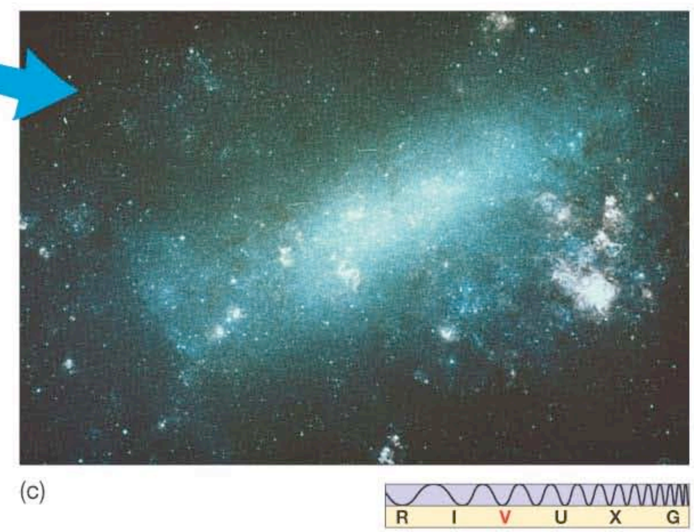
S0 is intermediate between E7 and Sa in properties. Note large bulge but no arms in the faint disk.

This SB0 galaxy is similar to the S0 galaxy except for the bar coming out of the central bulge.

24.1 Hubble's Galaxy Classification



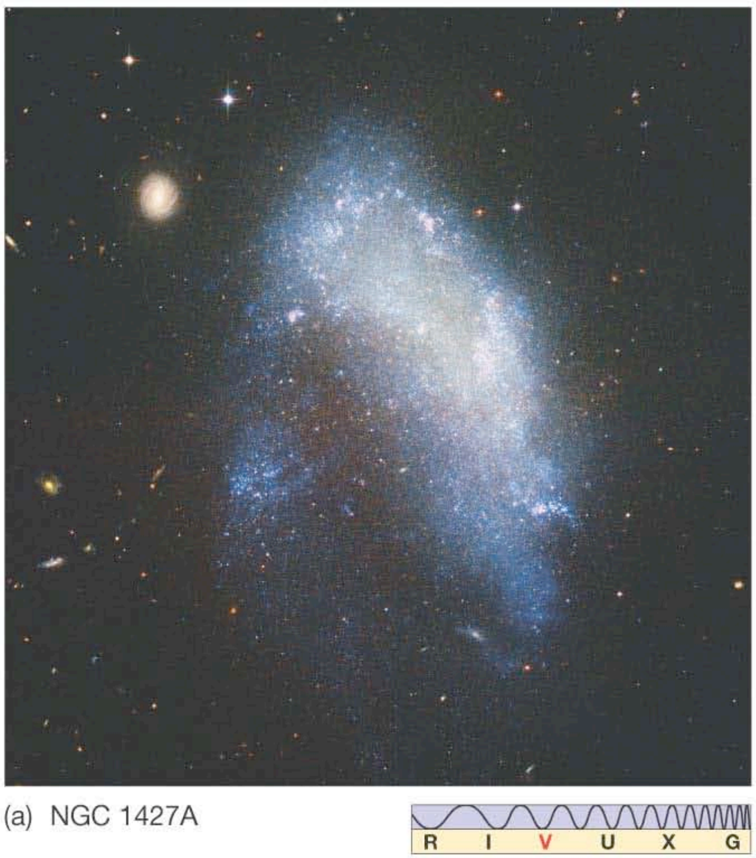
The **irregular** galaxies have a wide variety of shapes. The **small** and **large Magellanic Clouds** are close neighbors to our own Milky Way. They are satellites of our Galaxy. Note that they are blue and contain patches of light that are huge very young star clusters.



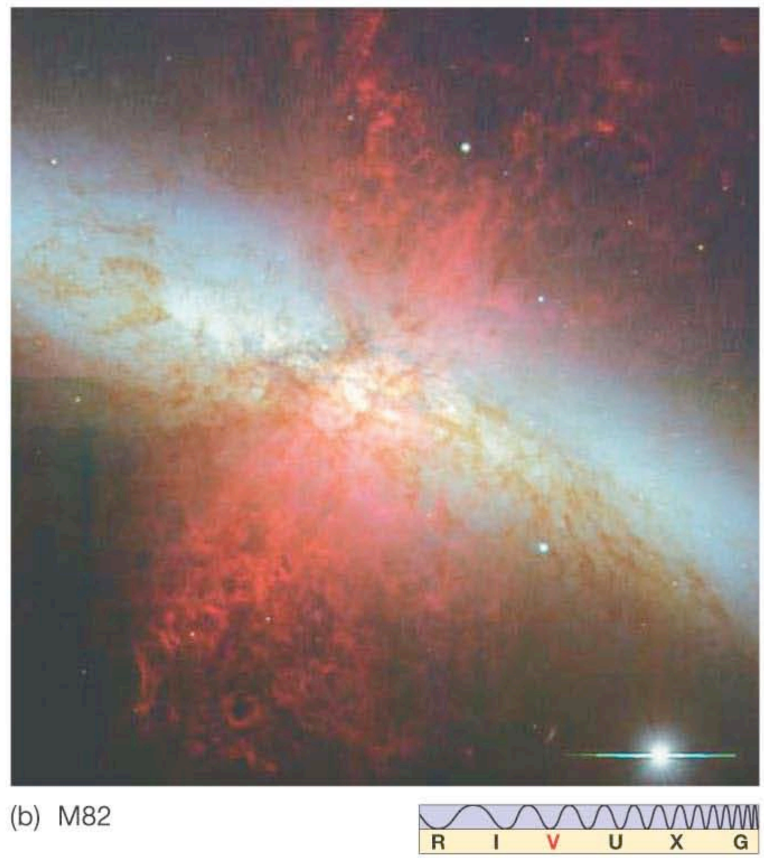
24.1 Hubble's Galaxy Classification

Here are three other irregular galaxies: NGC 4485 and NGC 4490 on the left, and M82 on the right.

The strangely shaped galaxy NGC 1427A is probably plunging headon into a group of several other galaxies (not shown), causing huge rearrangements of its stars, gas, and dust. (b) The galaxy M82 seems to show an explosive appearance, probably the result of a recent galaxywide burst of star formation (a “starburst galaxy.”



(a) NGC 1427A



(b) M82

24.1 Hubble's Galaxy Classification

A summary of galaxy properties by type: Notice correlation between "stellar content," "gas and dust," and "star formation." We want to make sense out of this in terms of whether one type formed earlier than another, or only just started forming stars, or stopped forming stars long ago, or is driven by its internal structure or by collisions, etc. That is "galaxy evolution."

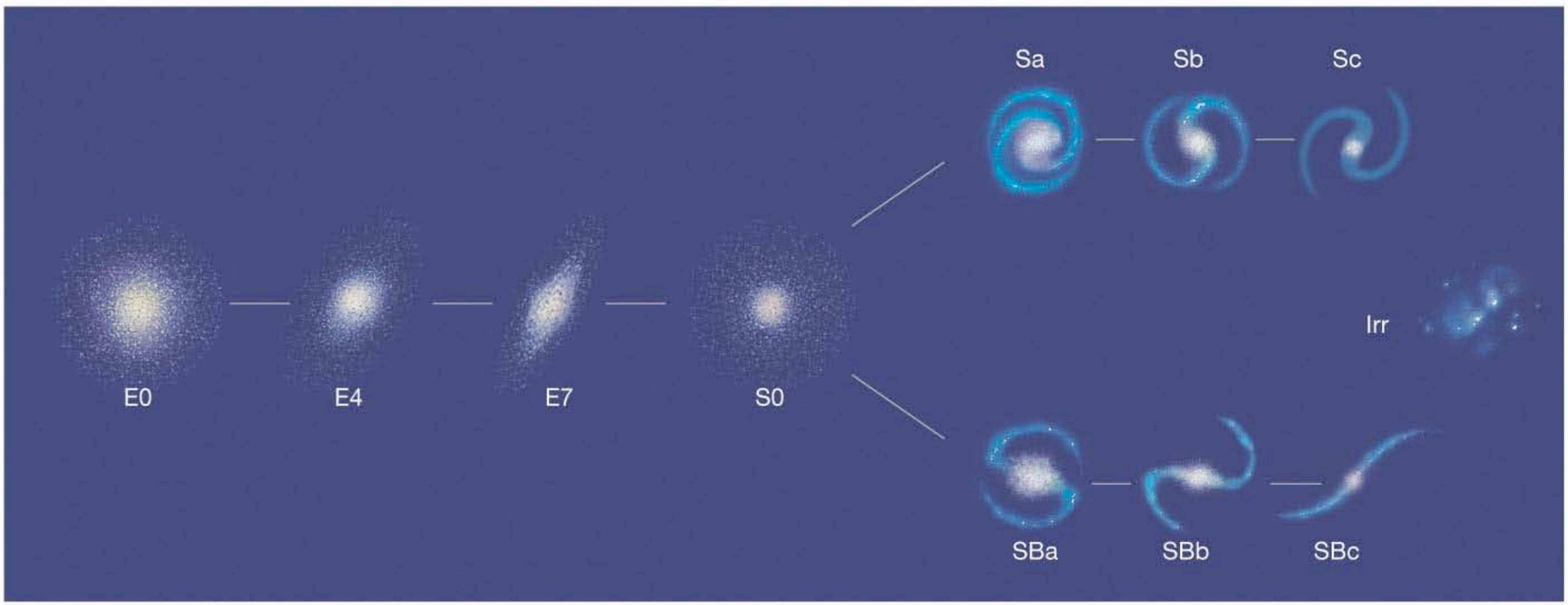
TABLE 24.1 Galaxy Properties by Type

	Spiral/Barred Spiral (S/SB)	Elliptical* (E)	Irregular (Irr)
Shape and structural properties	Highly flattened disk of stars and gas, containing spiral arms and thickening central bulge. Sa and SBa galaxies have the largest bulges, the least obvious spiral structure, and roughly spherical stellar halos. SB galaxies have an elongated central "bar" of stars and gas.	No disk. Stars smoothly distributed through an ellipsoidal volume ranging from nearly spherical (E0) to very flattened (E7) in shape. No obvious substructure other than a dense central nucleus.	No obvious structure. Irr II galaxies often have "explosive" appearances.
Stellar content	Disks contain both young and old stars; halos consist of old stars only.	Contain old stars only.	Contain both young and old stars.
Gas and dust	Disks contain substantial amounts of gas and dust; halos contain little of either.	Contain hot X-ray emitting gas, little or no cool gas and dust.	Very abundant in gas and dust.
Star formation	Ongoing star formation in spiral arms.	No significant star formation during the last 10 billion years.	Vigorous ongoing star formation.
Stellar motion	Gas and stars in disk move in circular orbits around the galactic center; halo stars have random orbits in three dimensions.	Stars have random orbits in three dimensions	Stars and gas have highly irregular orbits.

* *As noted in the text, some giant ellipticals appear to be the result of collisions between gas-rich galaxies and are exceptions to many of the statements listed here.*

24.1 Hubble's Galaxy Classification

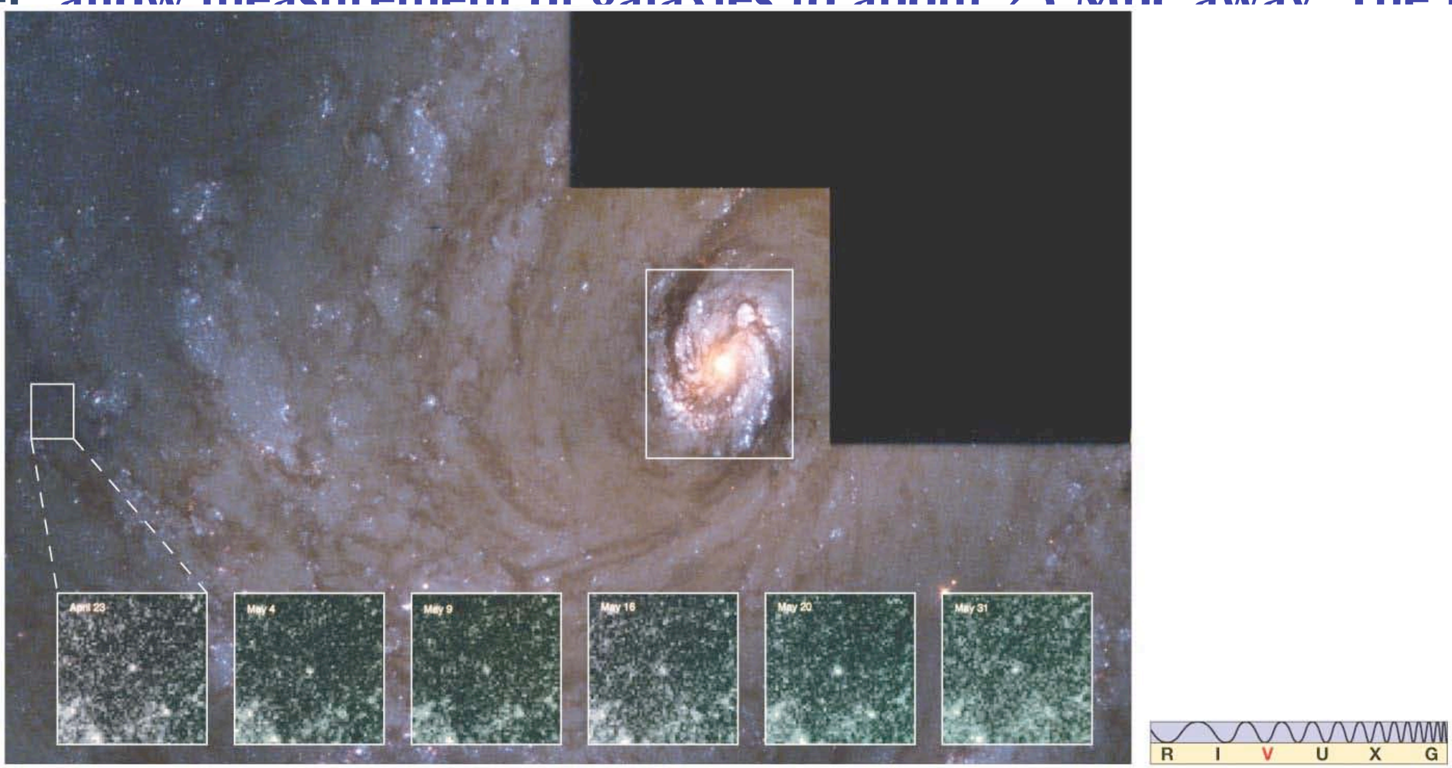
Hubble's "**tuning fork**" is a convenient way to remember the galaxy classifications, although it has no deeper meaning:



24.2 The Distribution of Galaxies in Space

In order to find how galaxies are distributed in the universe, we have to be able to estimate their distances. We therefore need to understand which "standard candles" can be used for this purpose.

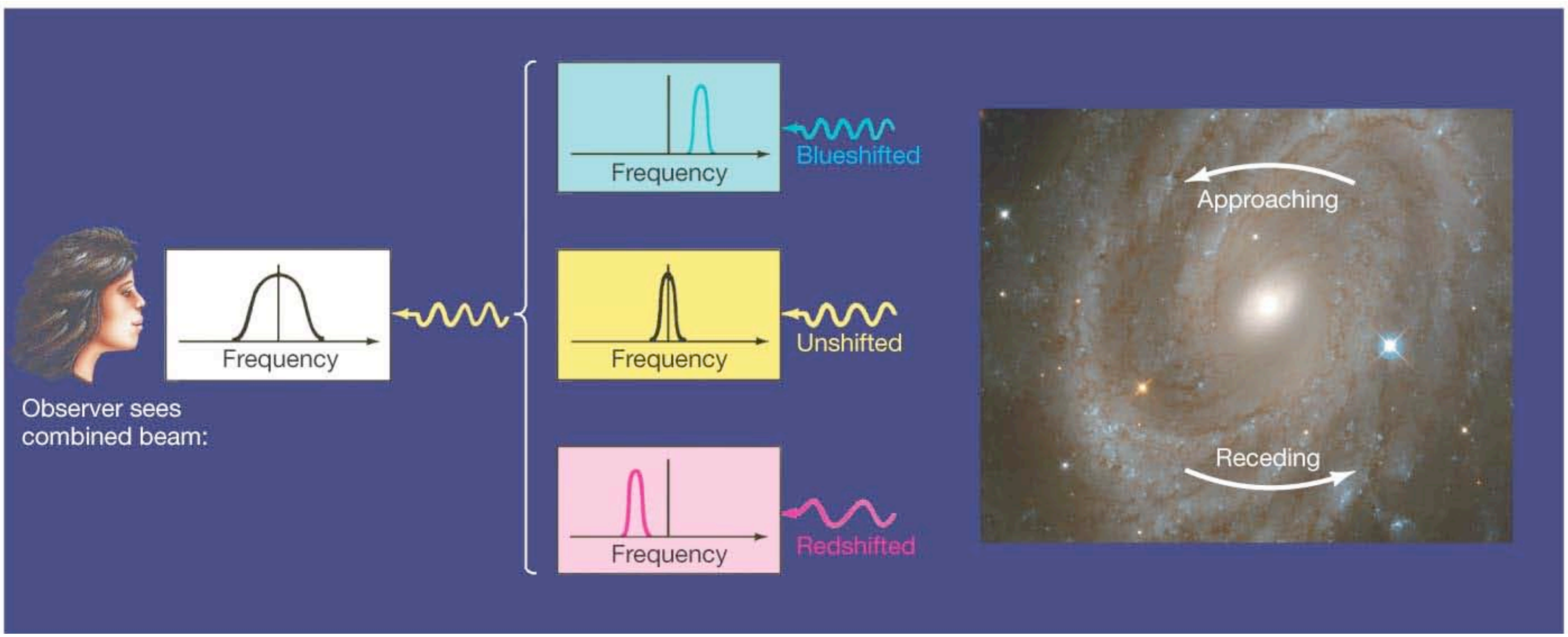
Recall that RR Lyrae variables allowed us to get distances to the globular clusters in the halo of our Galaxy, while **Cepheid variables,** being so much brighter, allow measurement of galaxies to about 25 Mpc away. The image below ... ter of galaxie...



24.2 The Distribution of Galaxies in Space

However, some galaxies have no Cepheids, and most are farther away then 25 Mpc. New distance measures are needed.

The **Tully–Fisher relation** correlates a galaxy's **rotation speed** (which can be measured using the Doppler effect) to its **luminosity**.
In hindsight this makes sense, since faster rotation means more galaxy mass, means (on average) a more luminous galaxy. In the example below the Galaxy is spatially resolved, but you could get this from the width of a spectral line if you couldn't resolve the galaxy. This galaxy is NGC 4603, about 30 Mpc away.



24.2 The Distribution of Galaxies in Space

Another standard candle, only used in the past decade:

Type I supernovae (carbon detonation supernovae) all have about the same luminosity at the peak of their light curve (see Ch.21), because the process by which they explode (luckily) doesn't allow for much variation. They can be used as "standard candles"—objects whose absolute magnitude is known, and which can therefore be used to determine distance using their apparent magnitude.

This is no different from saying that if you see an RR Lyrae star, you know its absolute luminosity because all RR Lyrae stars have the same luminosity, so you can obtain the distance. But here we use Type I supernovae, which are enormously brighter, *and so can be used to very large distances.*

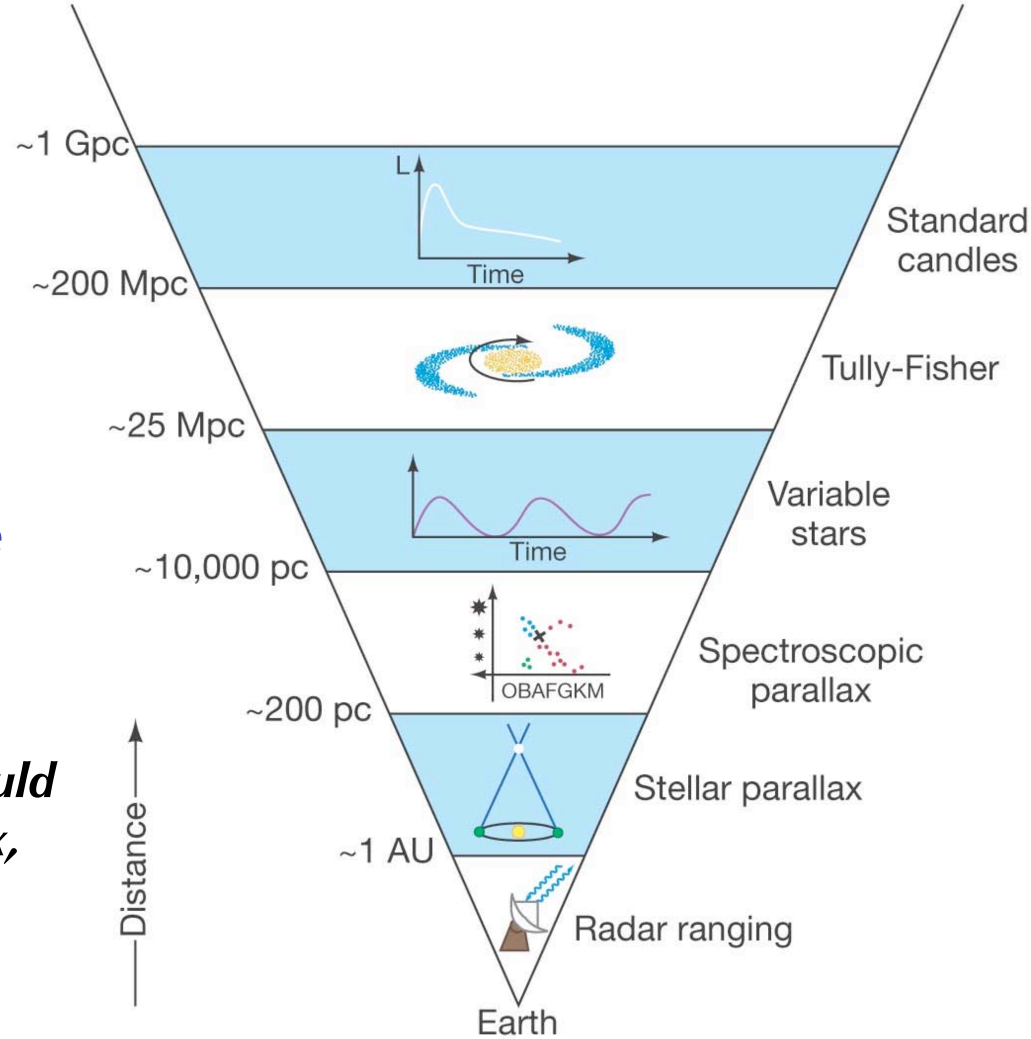
24.2 The Distribution of Galaxies in Space

With these additions, the **cosmic distance ladder** has been extended to about

1 Gpc = 1000 Mpc

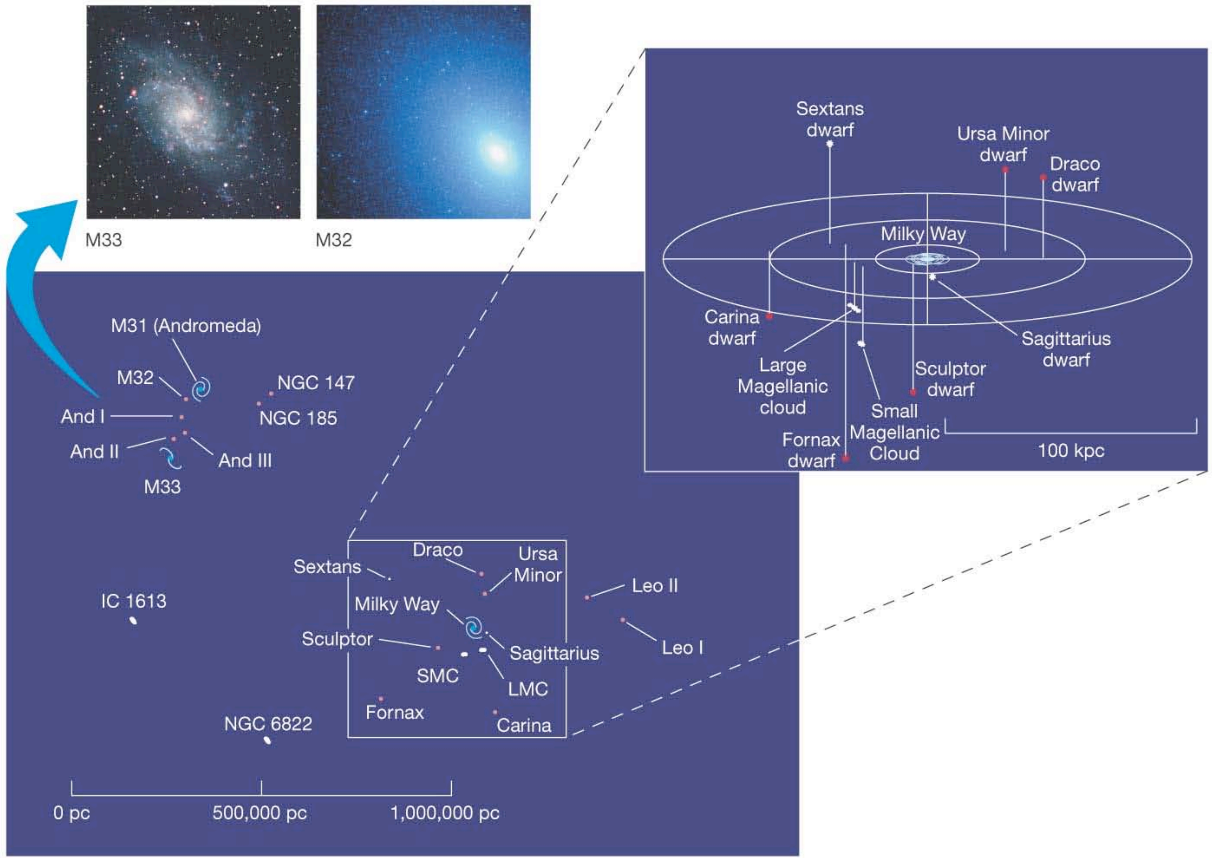
Think about this. Size of our Galaxy is about 0.03 Mpc, distance to Andromeda is only about 1Mpc. Also, this is about 300 million light years, so we are seeing light emitted when the universe was 0.3 Gyr younger than it is now.

Study this inverted triangle. You should be able to explain why stellar parallax, spectroscopic parallax, and variable stars only took us out as far as the nearest galaxies.



24.2 The Distribution of Galaxies in Space

This is the Local Group of galaxies, about 45 galaxies within about 1 Mpc of the Milky Way.

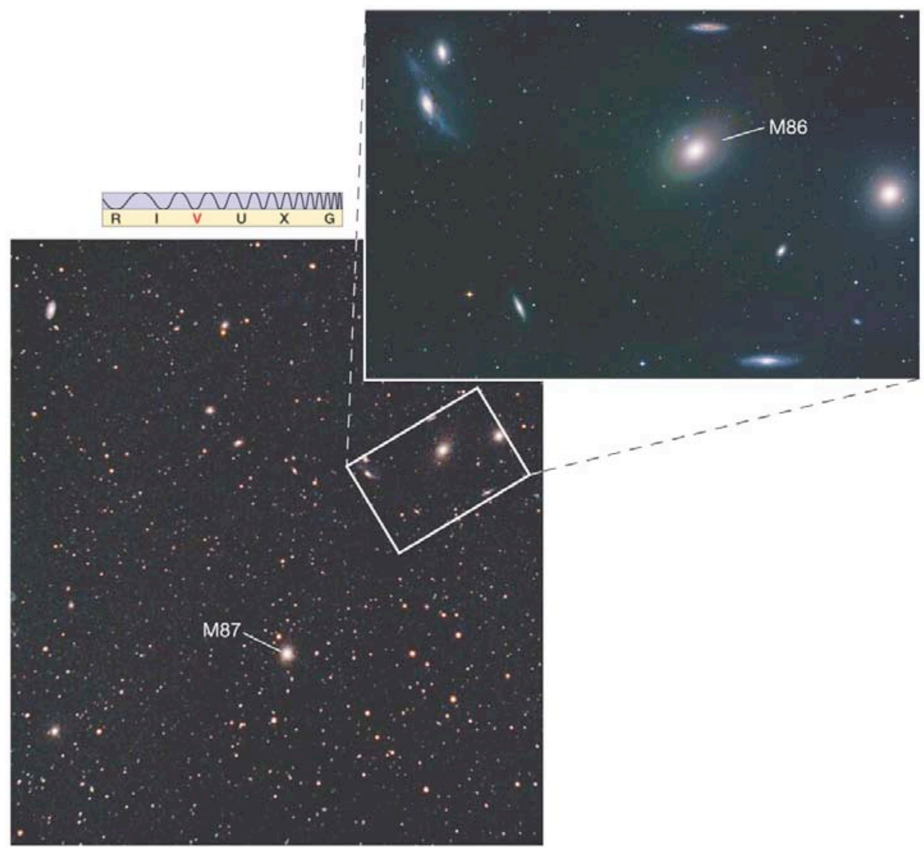


There are three spirals in this group—the **Milky Way**, **Andromeda**, and **M33**. These and their satellites—about 45 galaxies in all—form the **Local Group**. Notice that most of the galaxies are dwarfs or satellites of the three largest.

Such a group of galaxies, held together by its own gravity, is called a galaxy cluster.

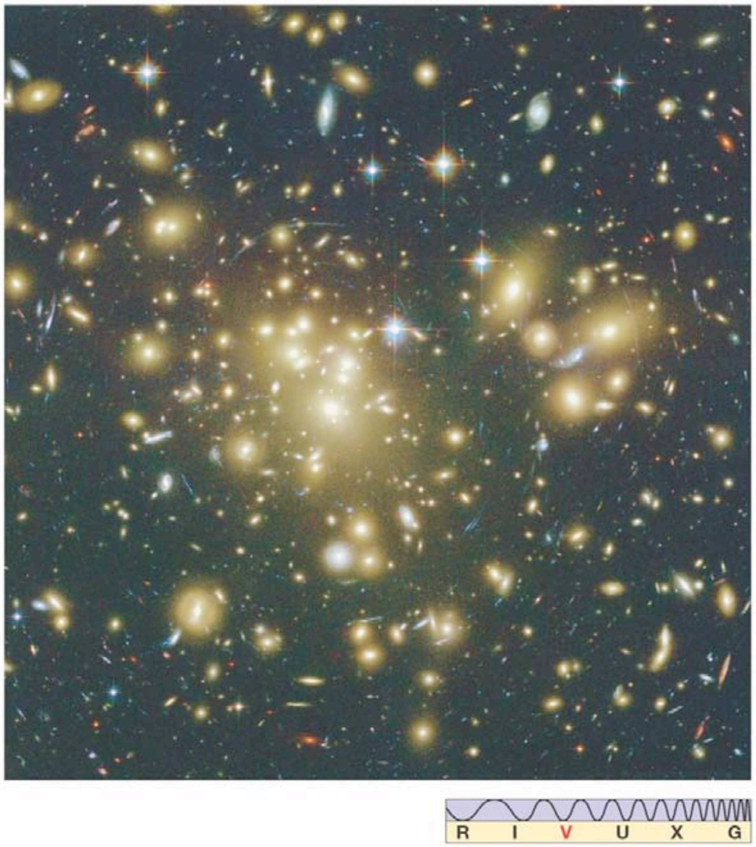
24.2 The Distribution of Galaxies in Space

A nearby galaxy cluster is the **Virgo** cluster; it is much larger than the Local Group, containing about **3500** galaxies.



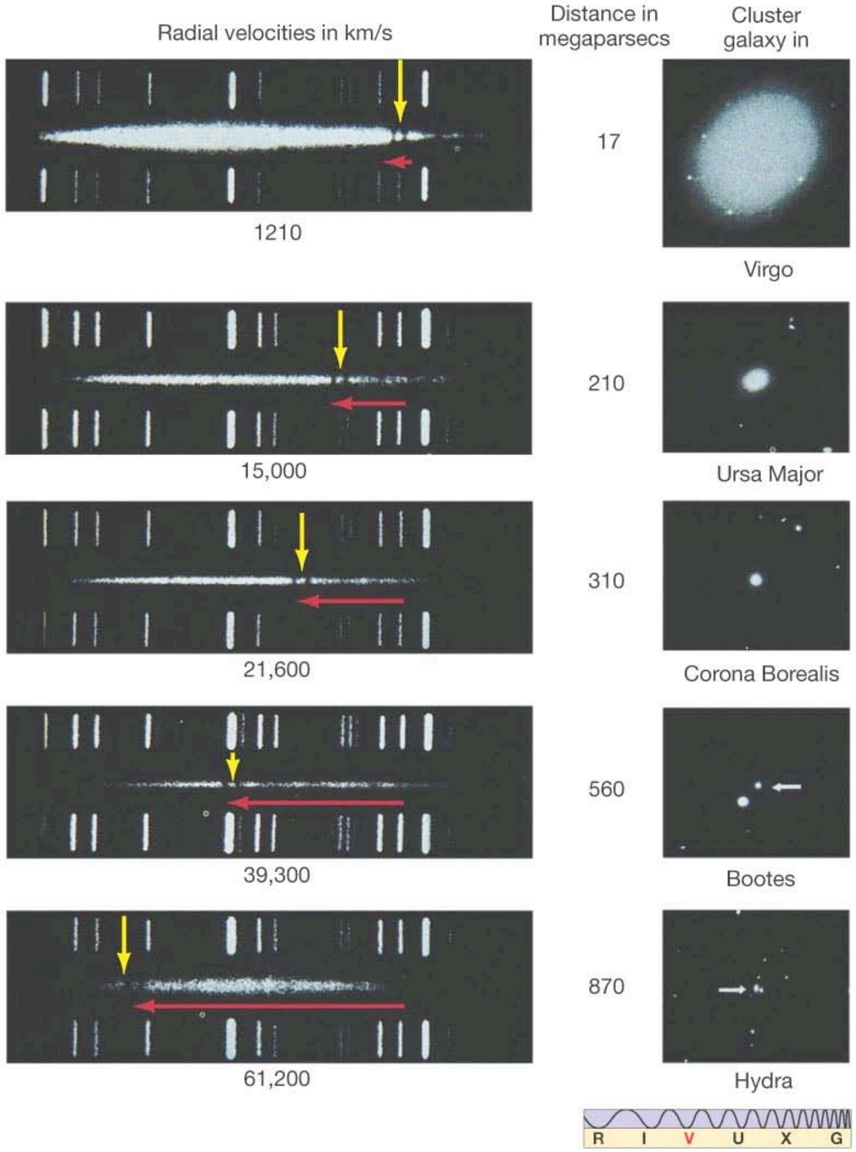
24.2 The Distribution of Galaxies in Space

This image shows the Abell 1689 cluster of galaxies, a very large cluster almost 1 billion parsecs away:



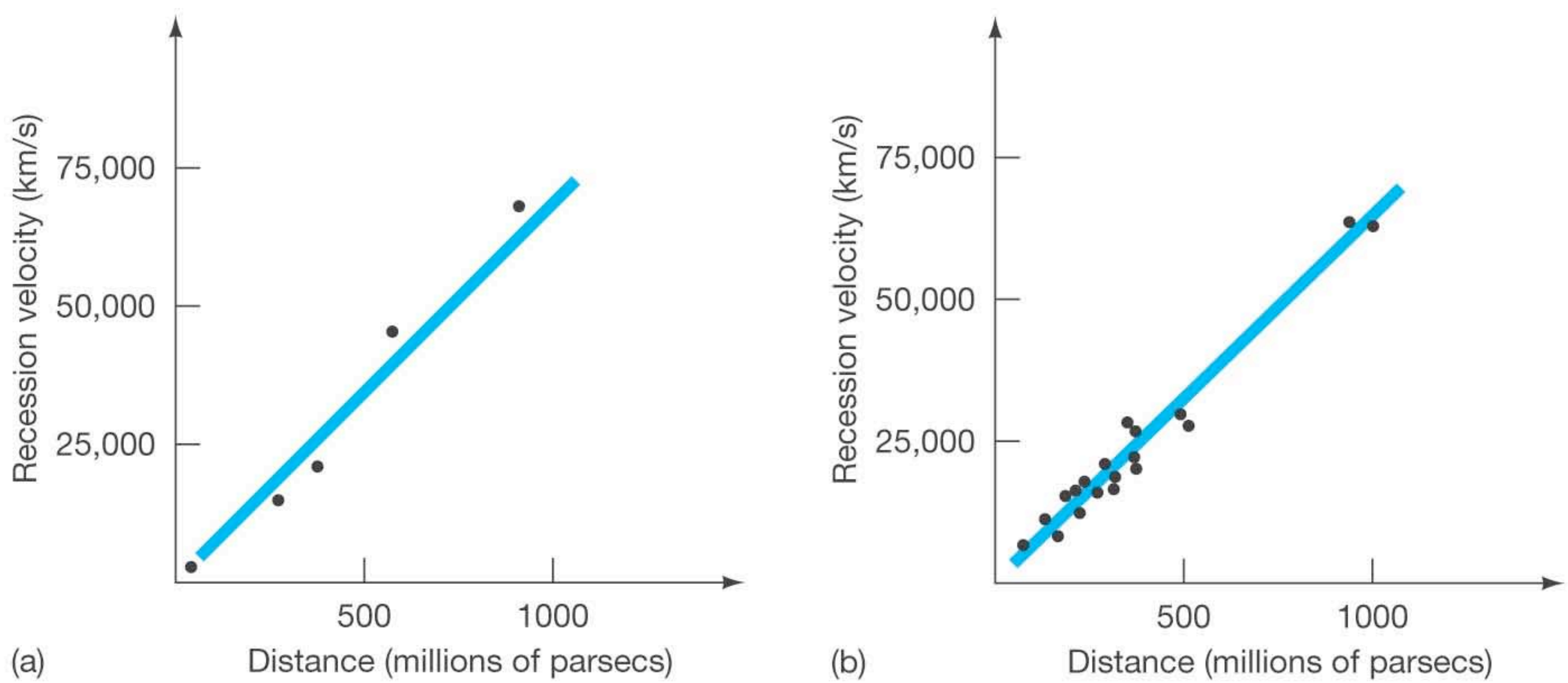
24.3 Hubble's Law

Universal recession: all galaxies (with a couple of nearby exceptions) seem to be moving away from us, with the **redshift** of their motion correlated with their **distance**.



24.3 Hubble's Law

These plots show the relation between distance and recessional velocity for the five galaxies in the previous figure, and then for a larger sample:



24.3 Hubble′s Law

The relationship (slope of the line) is characterized by **Hubble′s constant** H_0:

$$\text{recessional velocity} = H_0 \times \text{distance}$$

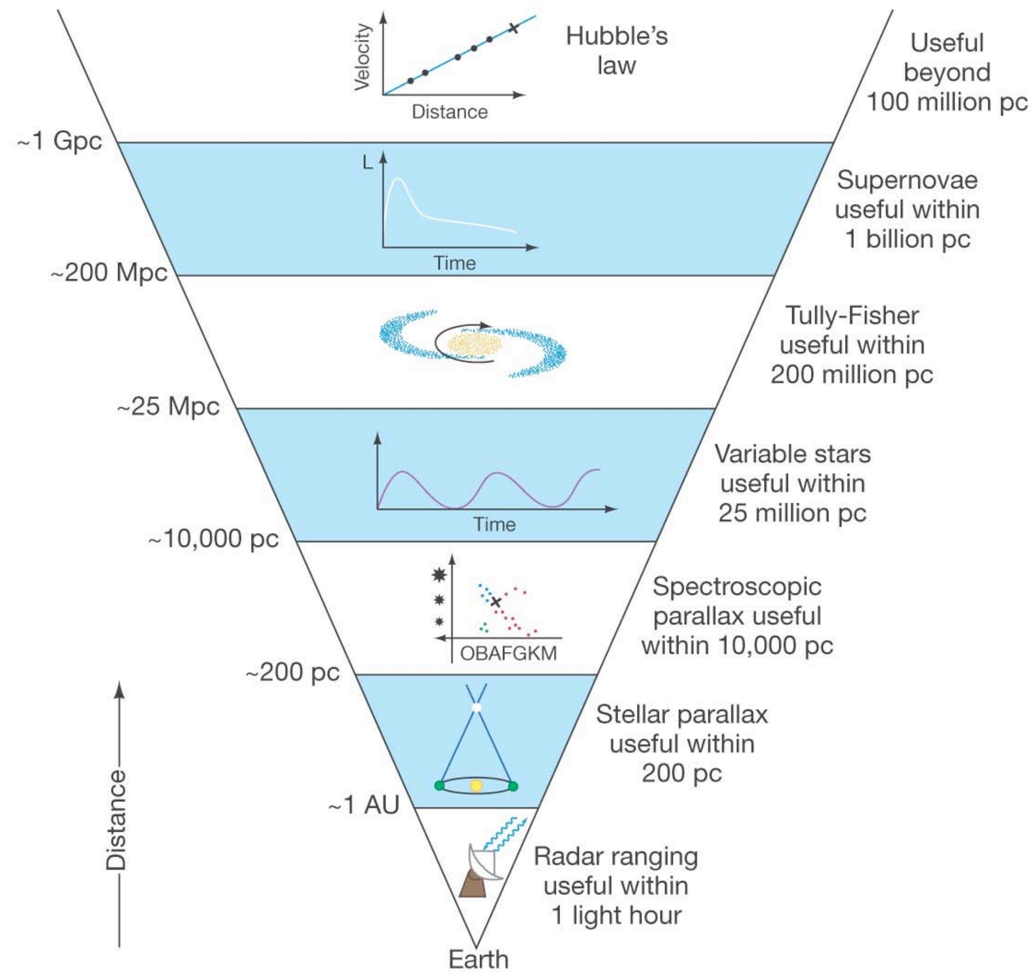
The currently accepted **value** for Hubble′s constant:

$$H_0 = 70\ \text{km/s/Mpc}$$

Measuring distances using Hubble′s law actually works better on farther away objects; **random motions** are overwhelmed by the **recessional velocity**.

24.3 Hubble's Law

This puts the final step on our **distance ladder**:



Summary of Chapter 24

- Hubble classification organizes galaxies according to shape.
- Galaxy types: spiral, barred spiral, elliptical, irregular
- Objects of relatively uniform luminosities are called "standard candles"; examples include RR Lyrae stars and Type I supernovae.
- The Milky Way lies within a small cluster of galaxies called the Local Group.
- Other galaxy clusters may contain thousands of galaxies.

Summary of Chapter 24 (cont.)

- Hubble's Law: Galaxies recede from us faster the farther away they are.
- Active galaxies are far more luminous than normal galaxies, and their radiation is nonstellar.
- Seyfert galaxies, radio galaxies, and quasars all have very small cores; many emit high-speed jets.
- Active galaxies are thought to contain supermassive black holes in their centers; infalling matter converts to energy, powering the galaxy.