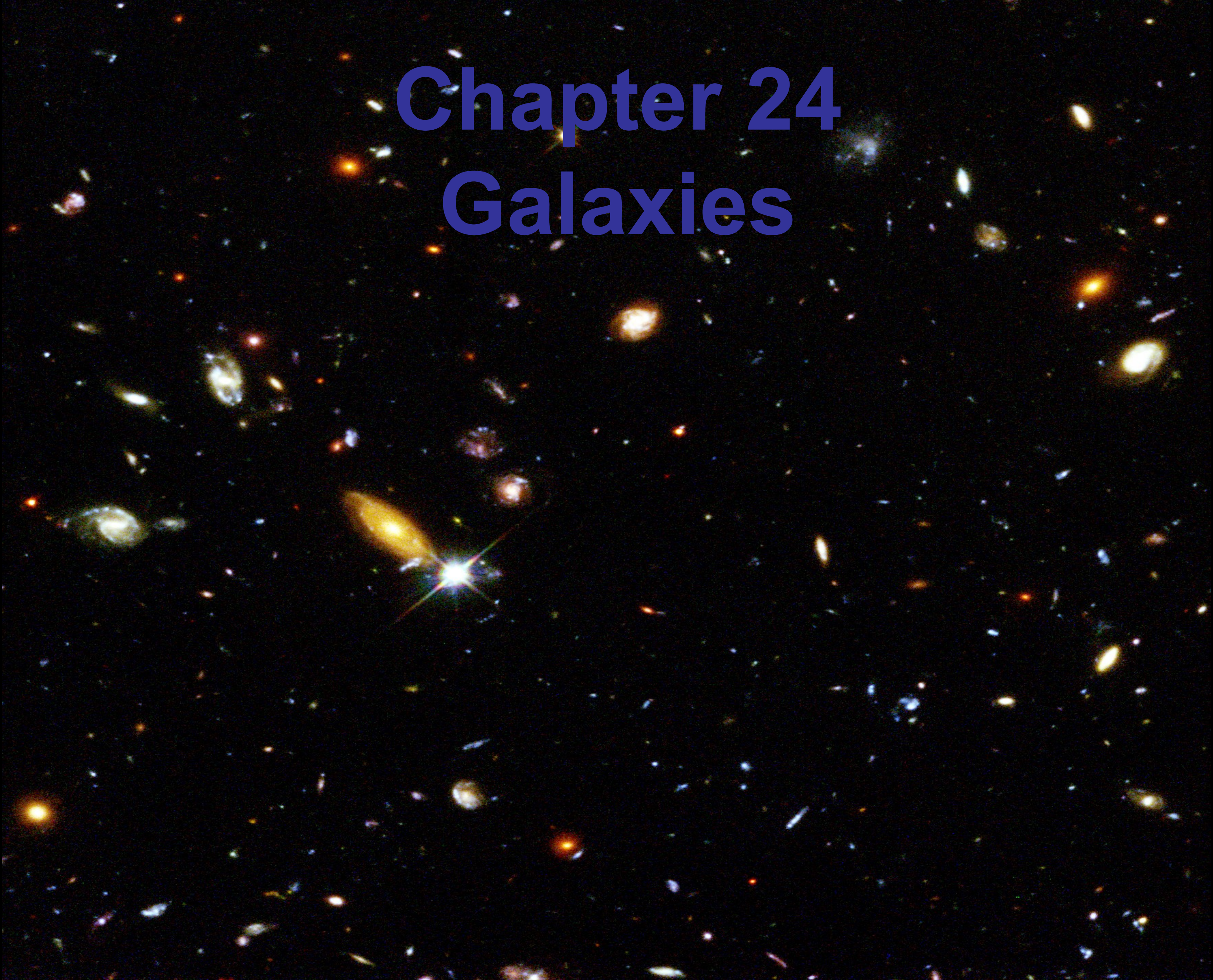
Chapter 24
Galaxies



Units of Chapter 24

24.1 Hubble's Galaxy Classification

The Coma cluster of galaxies.

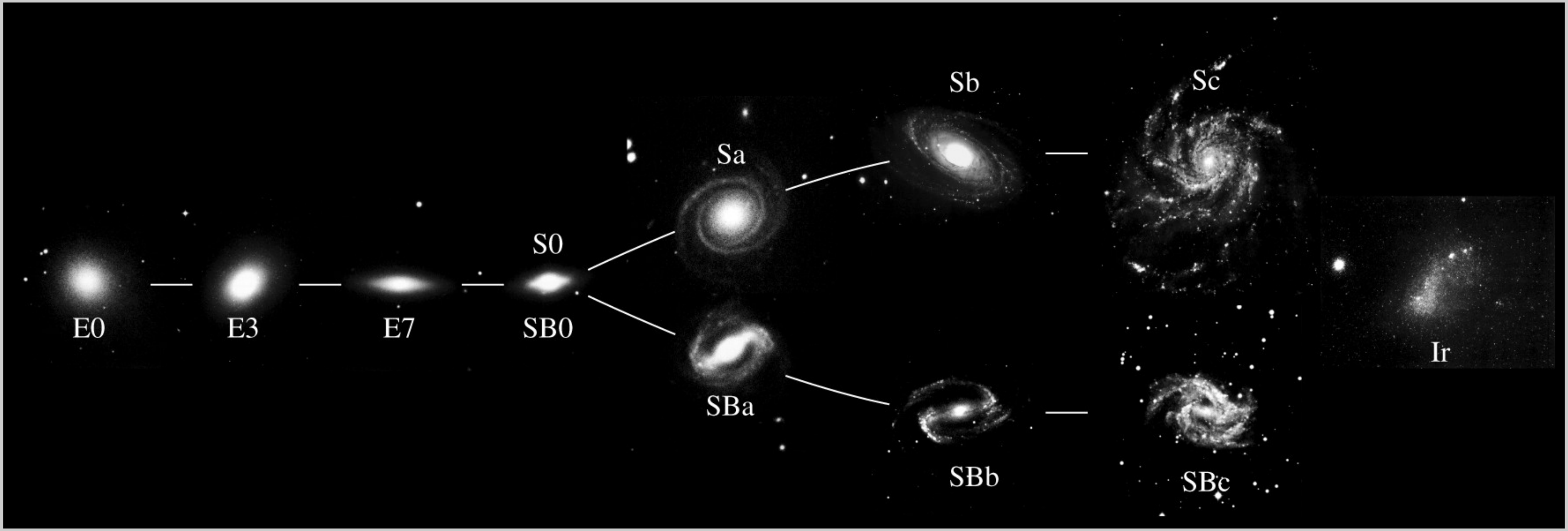
(b)

Clusters have many galaxies at the <u>same distance.</u>

The wide range in sizes, luminosities, colors, and shapes is obvious.

24.1 Hubble's Galaxy Classification

Hubble "tuning-fork" diagram.



The Types: **S0, Sa, Sb, Sc**

E0, E1, ..., E7 **IrI, IrII**

SB0, Sba, Sbb, Sbc

"Early Types" <-----------------------> "Late Types"

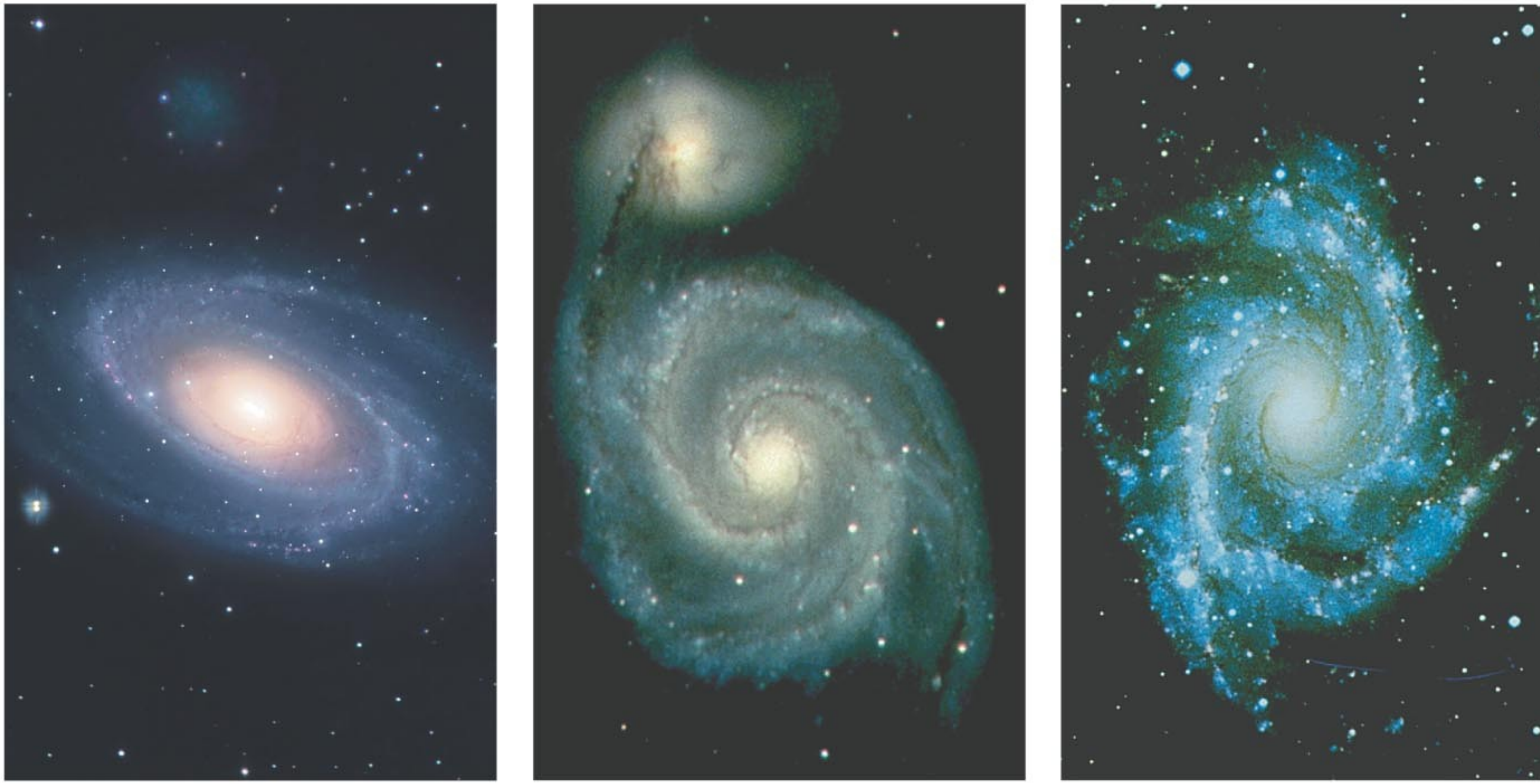
(Now we know evolution does not occur along this sequence.)

24.1 Hubble's Galaxy Classification

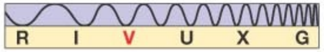
Spiral subtypes (a,b,c,d) are based on ...

1) the size of their central bulge relative to their disk. (Sa's have big bulges, Sc small.)
2) how tightly bound are the spiral arms. (Sa are tight, Sc loose).
3) how "clumpy" the arms appear. Types Sb and Sc are progressively clumpier.

24.1 Hubble's Galaxy Classification

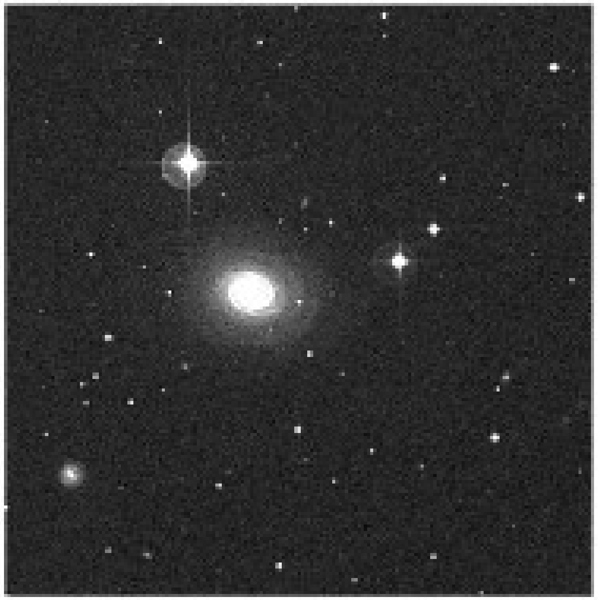


(a) M81 Type Sa (b) M51 Type Sb (c) NGC 2997 Type Sc



The components of spiral galaxies are the same as in our own galaxy: disk, halo, bulge, and spiral arms. Usually they also have nuclear clusters.

Spirals



Sa NGC 1357

Sb M81

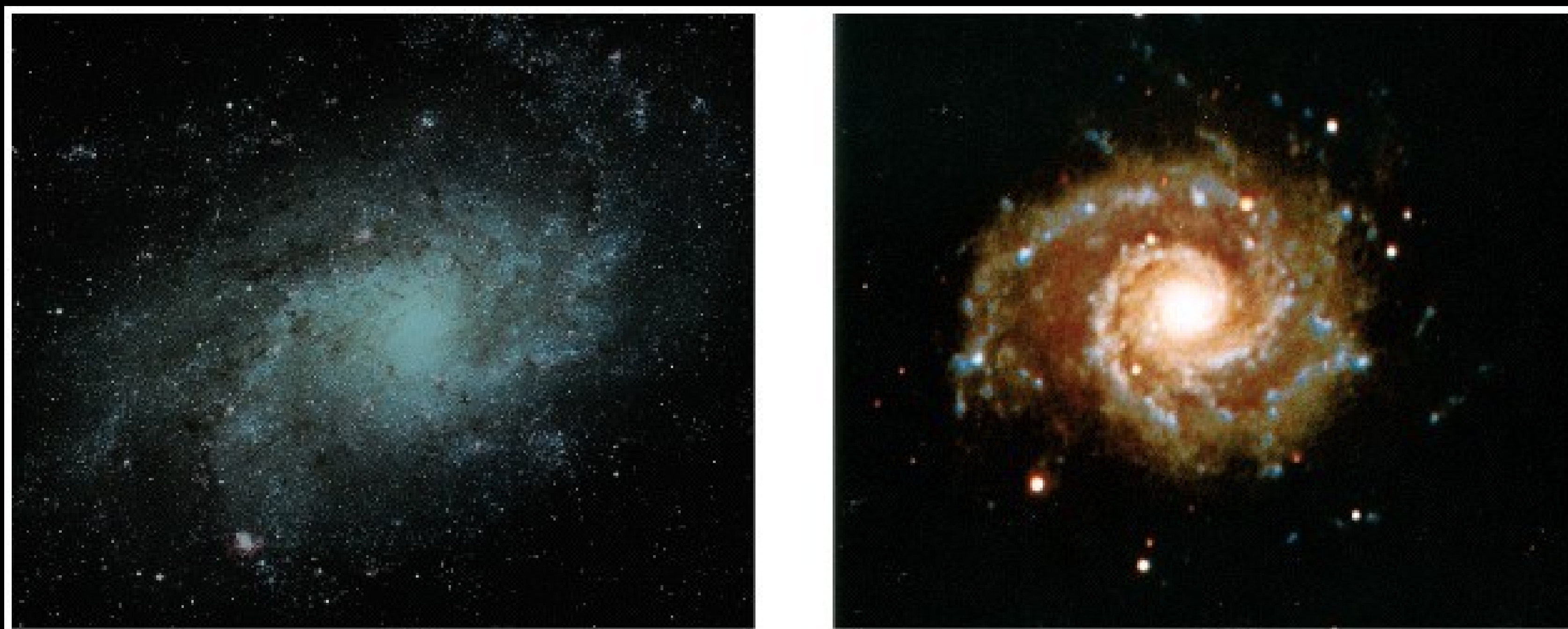
Sc NGC 4321

a M104

b NGC891

c NGC4631

Variety of Spiral Arms



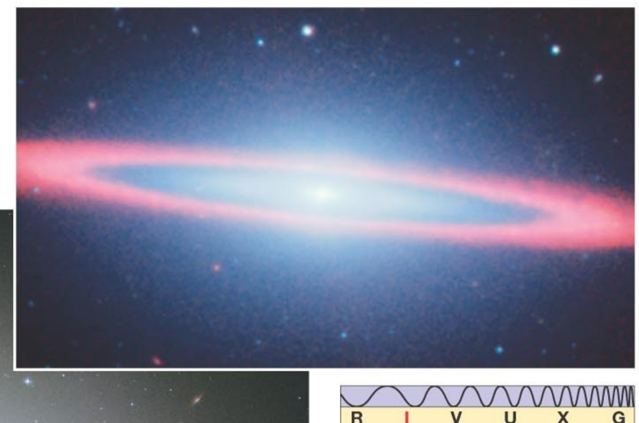
a M33 b M74

Flocculent spirals
(*fleecy*)

Grand-design spirals
(*highly organized*)

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.



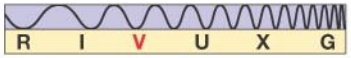
24.1 Hubble's Galaxy Classification

Similar to the spiral galaxies are the barred spirals:

(a) NGC 1300 Type SBa

(b) NGC 1365 Type SBb

(c) NGC 6872 Type SBc



24.1 Hubble's Galaxy Classification

Elliptical galaxies

- have no spiral arms and no obvious disk.
- come in many sizes, from giant ellipticals of **trillions** of stars, down to dwarf ellipticals of less than a **million** stars.
- contain very little cool gas and dust, and they show little evidence of ongoing **star formation**.
- Many are immersed in a large cloud of **hot gas**, visible in x-rays

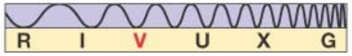
24.1 Hubble's Galaxy Classification

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

(a) M49 Type E2

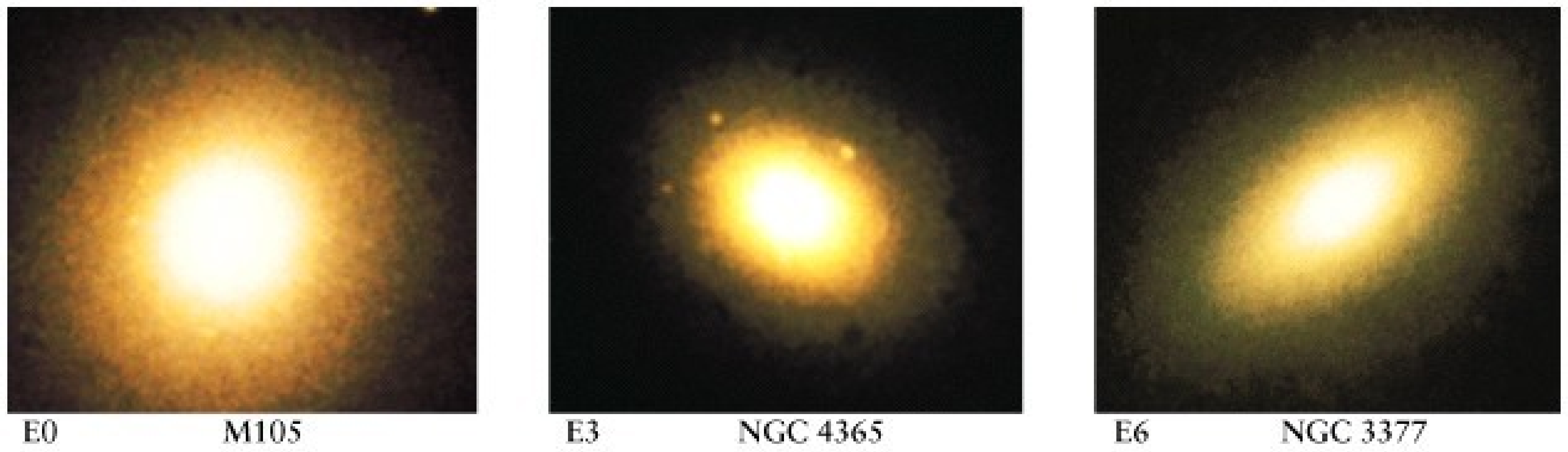
(b) M84 Type E3

(c) M110 Type E5

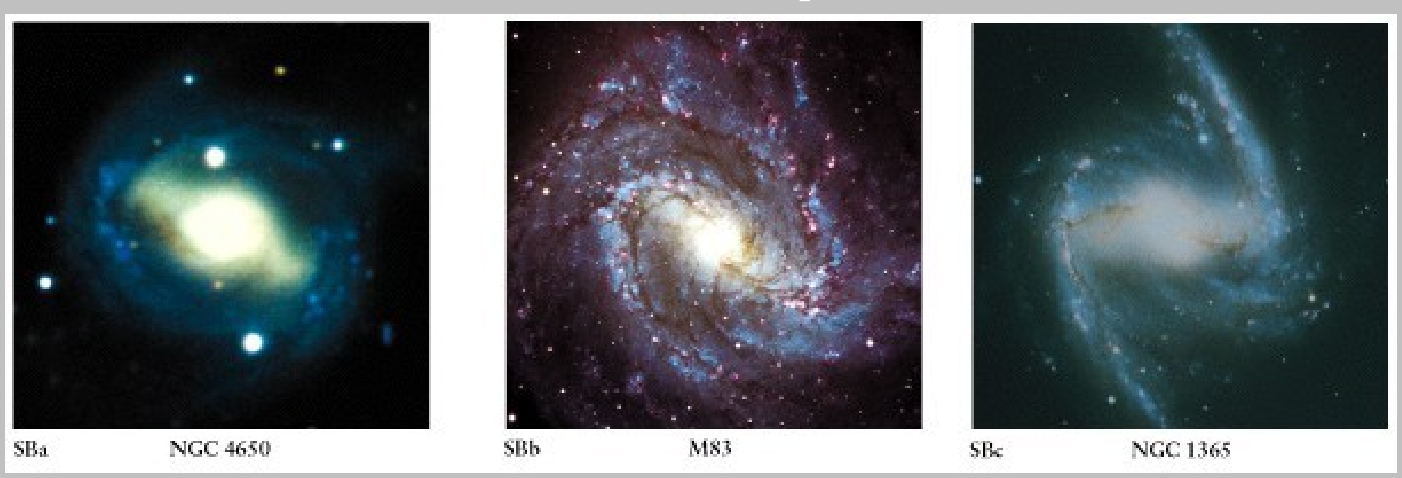


ellip = 10 (1 - b/a)

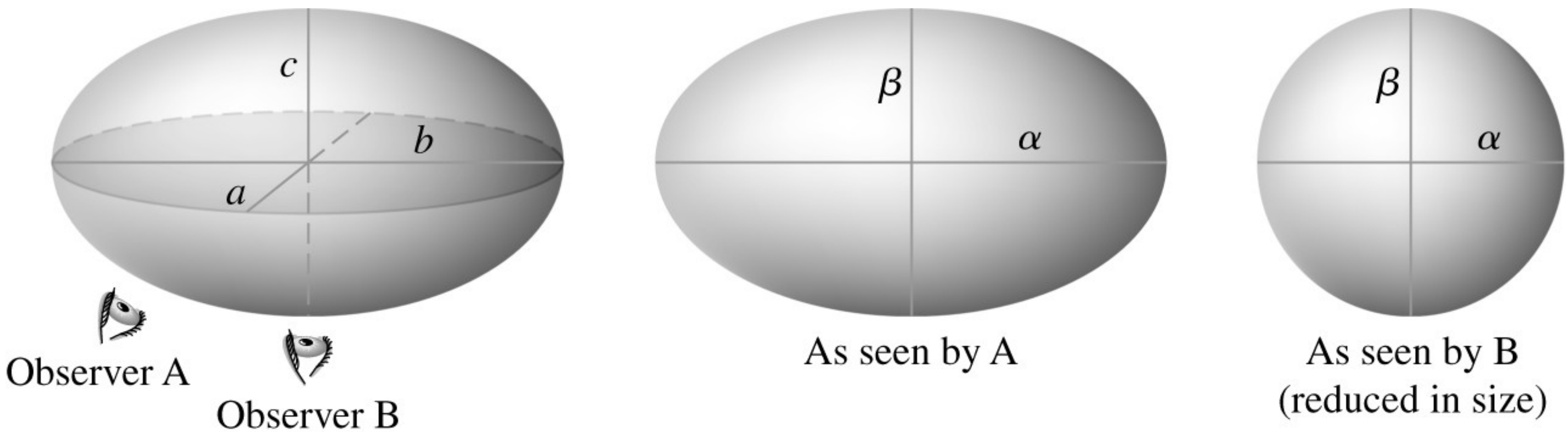
Elliptical galaxies



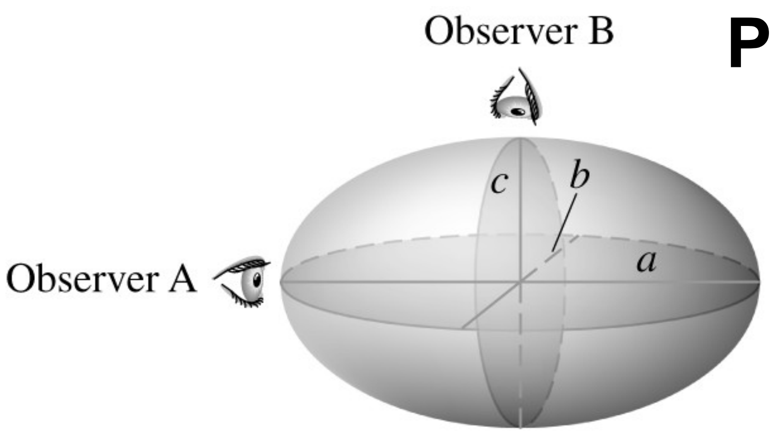
Barred Spirals

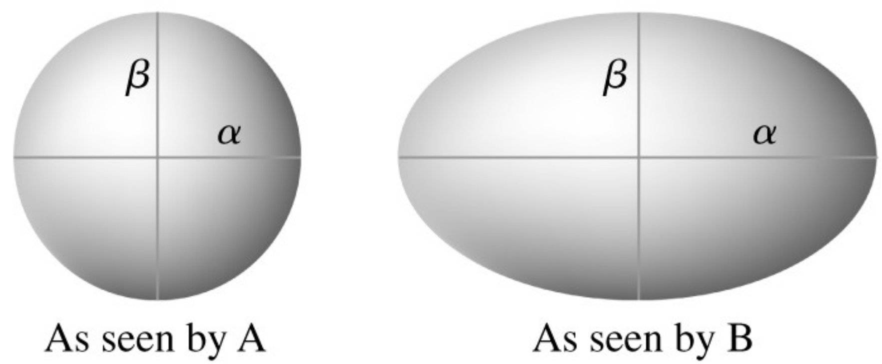


Oblate spheroids.   a=b>c



Prolate spheroids. a>b=c



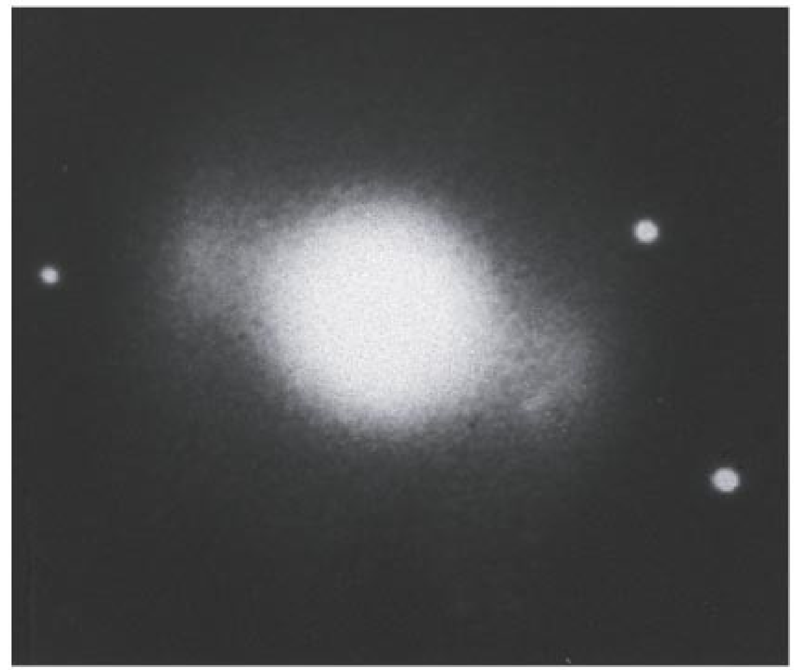


(Not shown: Triaxial. a>b>c)

24.1 Hubble's Galaxy Classification

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

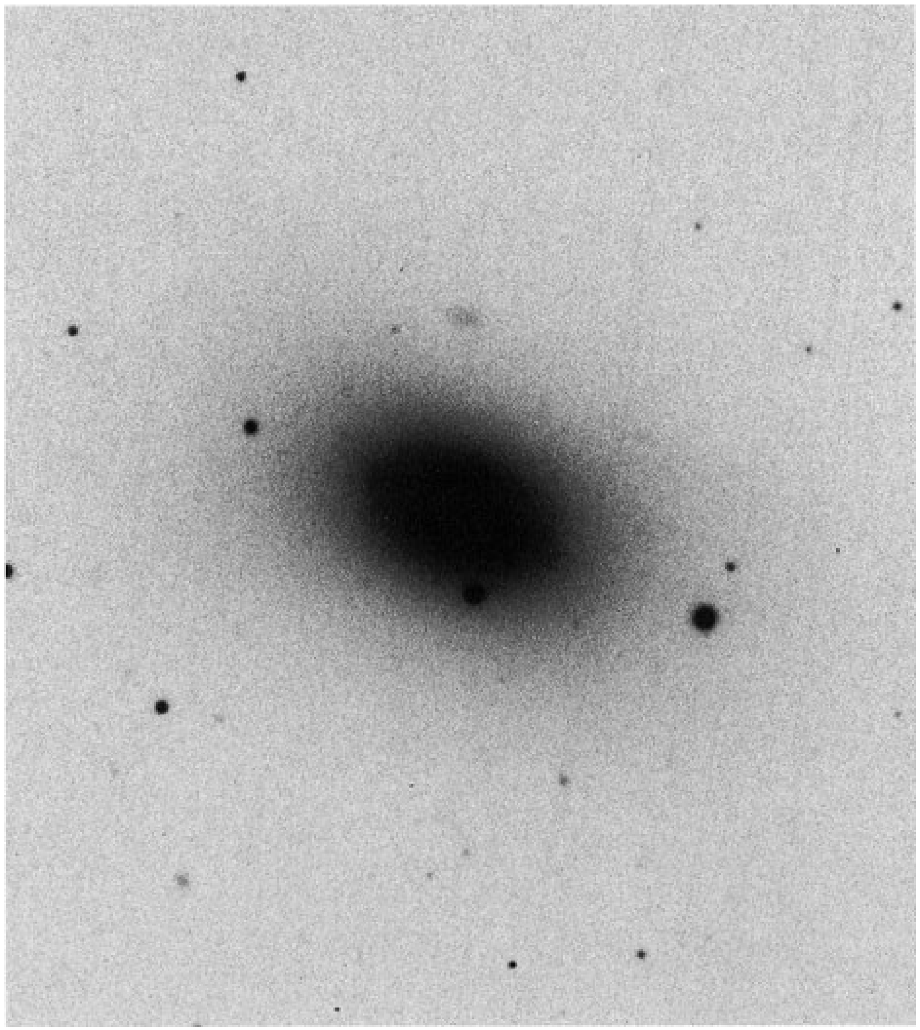
(a) NGC 1201 Type S0



(b) NGC 2859 Type SB0

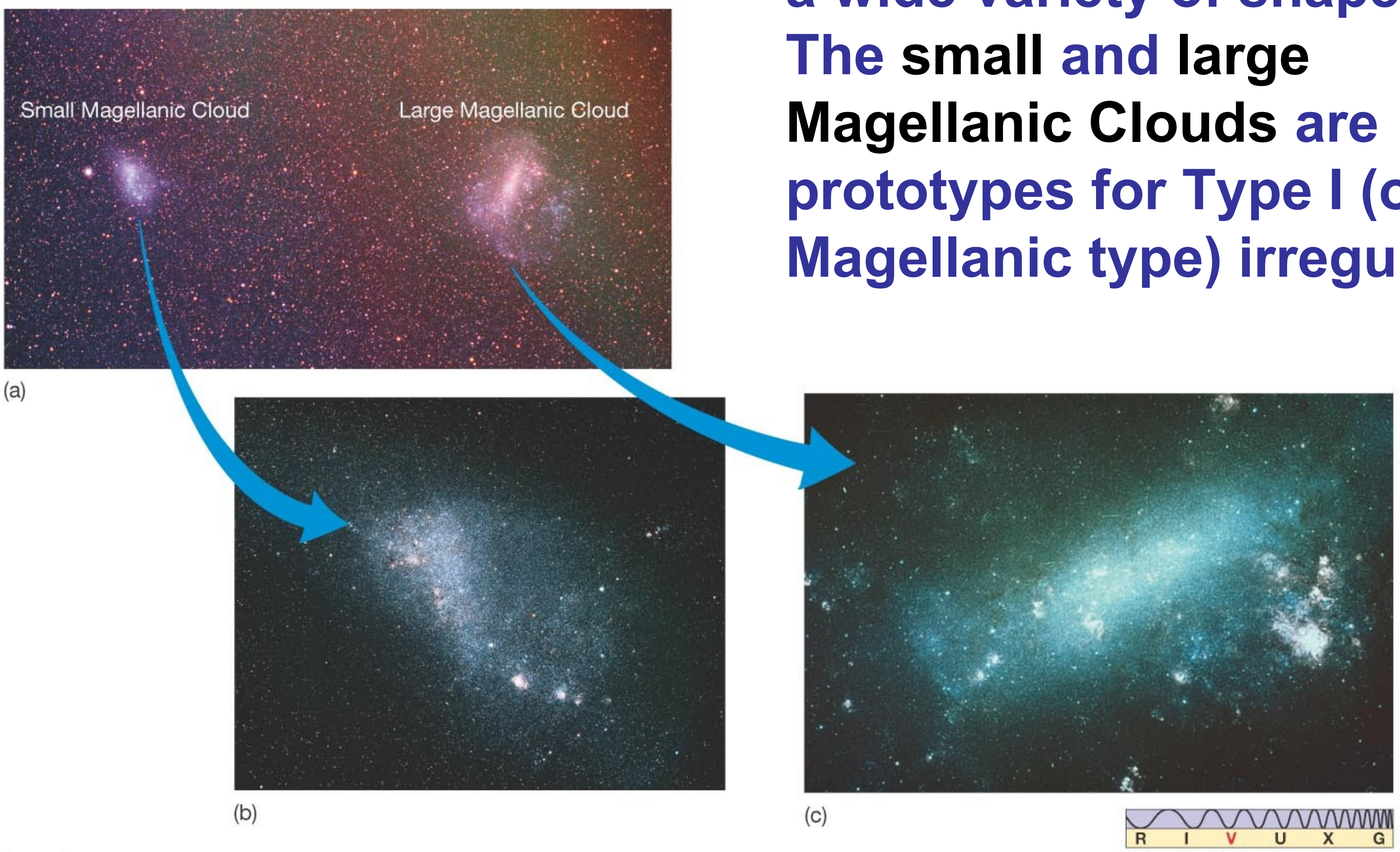
24.1 Hubble's Galaxy Classification

NGC 7049



24.1 Hubble's Galaxy Classification

The **irregular** galaxies have a wide variety of shapes. The **small** and **large Magellanic Clouds** are prototypes for Type I (or Magellanic type) irregulars.



24.1 Hubble's Galaxy Classification

Here are two contrasting **irregular** galaxies: Type I on the left, and Type II (smooth) on the right.

(a) NGC 1427A

(b) M82

24.1 Hubble's Galaxy Classification

A summary of galaxy properties by type:

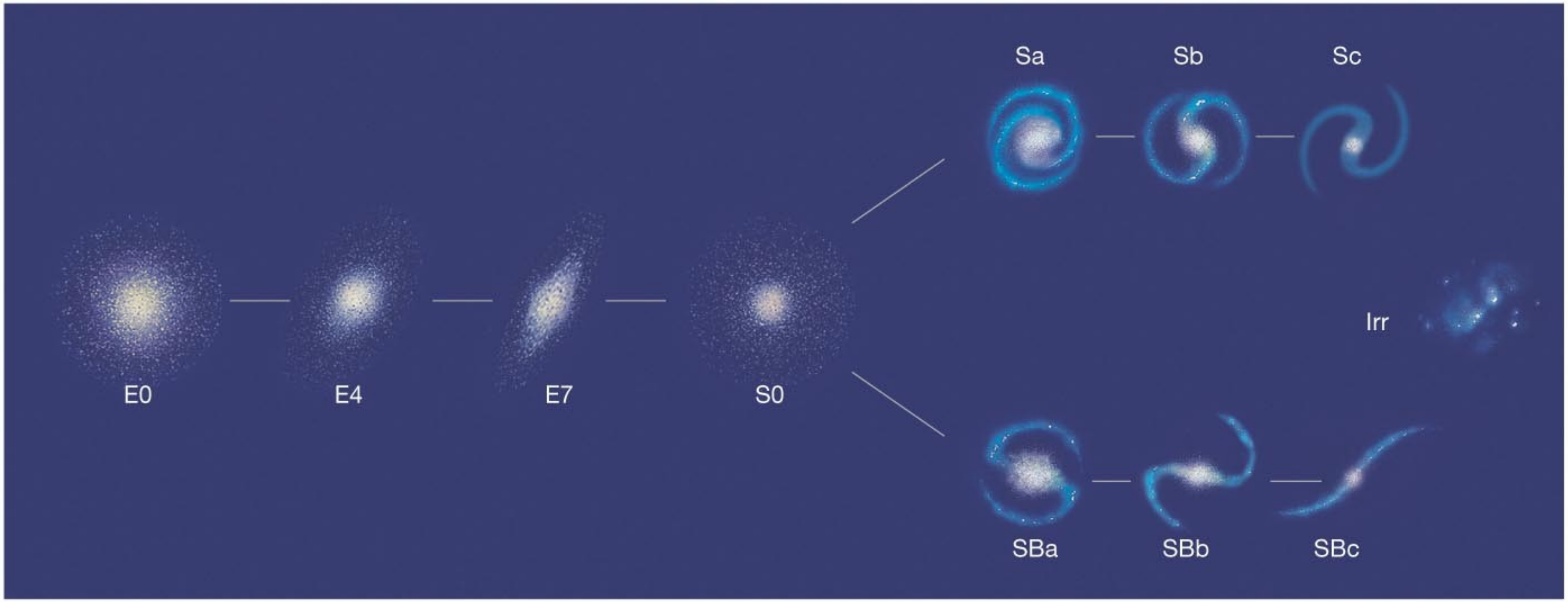
TABLE 24.1 Galaxy Properties by Type

	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 logical ordering of the galaxy classifications. But galaxies do NOT evolve along the fork.



See my "Galaxies along the Hubble Sequence" web page.

24.1 Galaxy Classification

Hubble's scheme has limitations:

“Bandwidth bias” – galaxies look different in different wavelength ranges

“Resolution” – different types cannot be distinguished if the image is too blurry. HST showed that about half of E's had inner dust.

It doesn't take into consideration rings (inner and outer), inner spirals, different light profiles, kinematics, LSB disks, dwarf spheroidals, size ranges, colors, mergers (peculiar), looking back in time, etc.

24.1 Galaxy Classification

Consequently, others have built classification schemes which usually elaborated upon the Hubble scheme. Most notably ...

G. de Vaucouleurs' scheme used these spiral types:

SA, SAB, SB,

SA(r), SA(rs), SA(s)

Saa,SAab,SAb,SAbc,

SAc,SAcd,SAd,SAdm,SAm

NGC 6782 SB(r)0/a

24.1 Galaxy Classification

"Galaxy Zoo" project http://www.galaxyzoo.org/

A good example of "Citizen Science".

(Others include SETI@home and Einstein@home)

- up to 18 questions about each galaxy (see "How to take part")

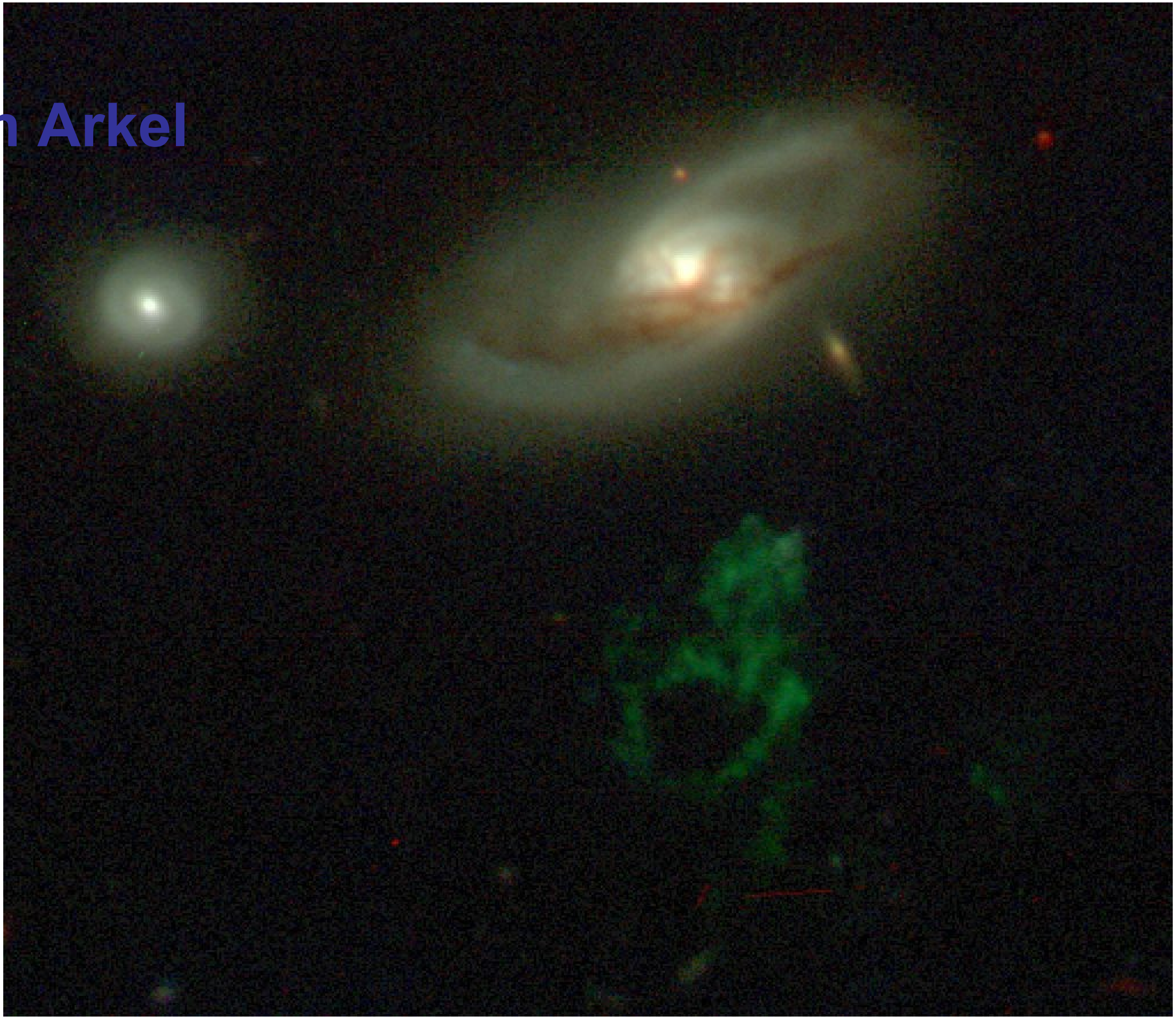
- amateurs turn up "green peas" and "Hanny's Voorwerp"

Hanny's “Voorwerp” (object in Dutch). Found by

Hanny van Arkel

in 2007.

Near Seyfert IC 2497



Galaxy Evolution

Classification in science is important because it can tell us about the nature of things and how they EVOLVE. Astronomers know:

- Galaxies do not really evolve along the Hubble Sequence, although spirals can combine to form Irr 2's, peculiars, and eventually E's.
- More irregular, clumpy galaxies are seen at high redshifts (back in time).
- Red ellipticals exist way back to ~10 Gyrs ago.
- More ellipticals are found in denser regions.
- Quasars at $z=2-3$ and black holes play a role.

Galaxy Evolution

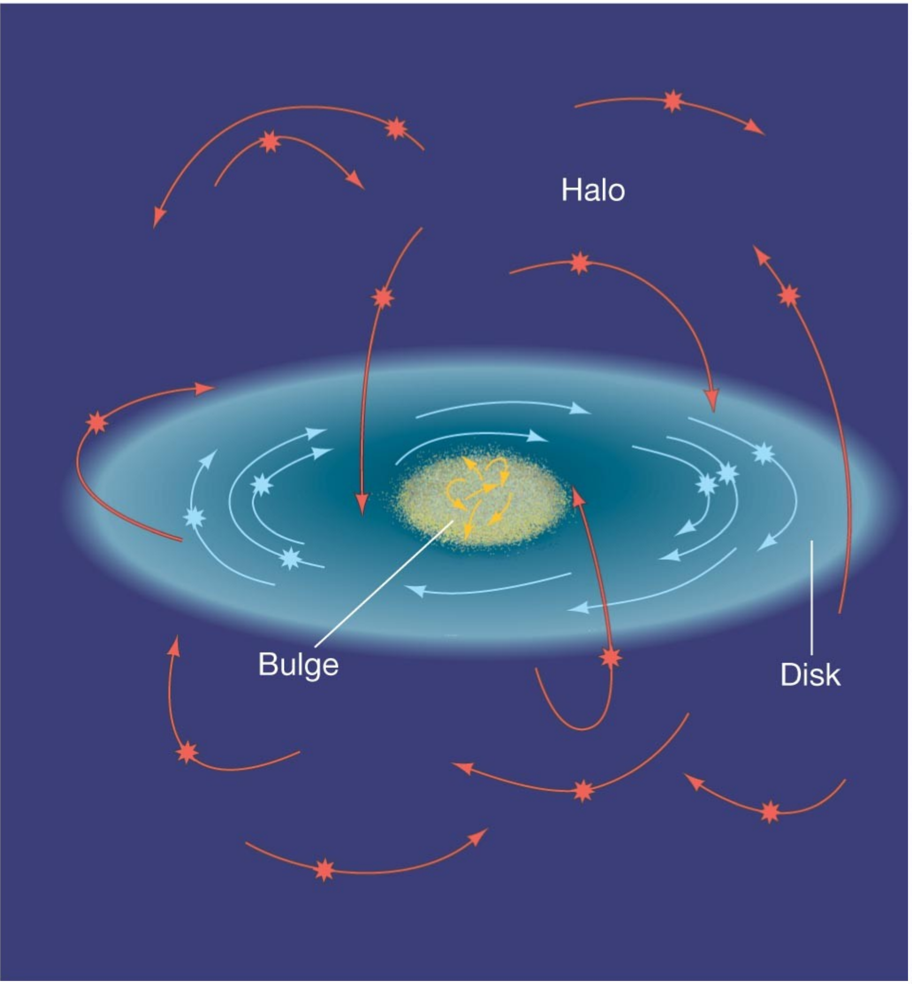
How did our galaxy (the Milky Way) form?

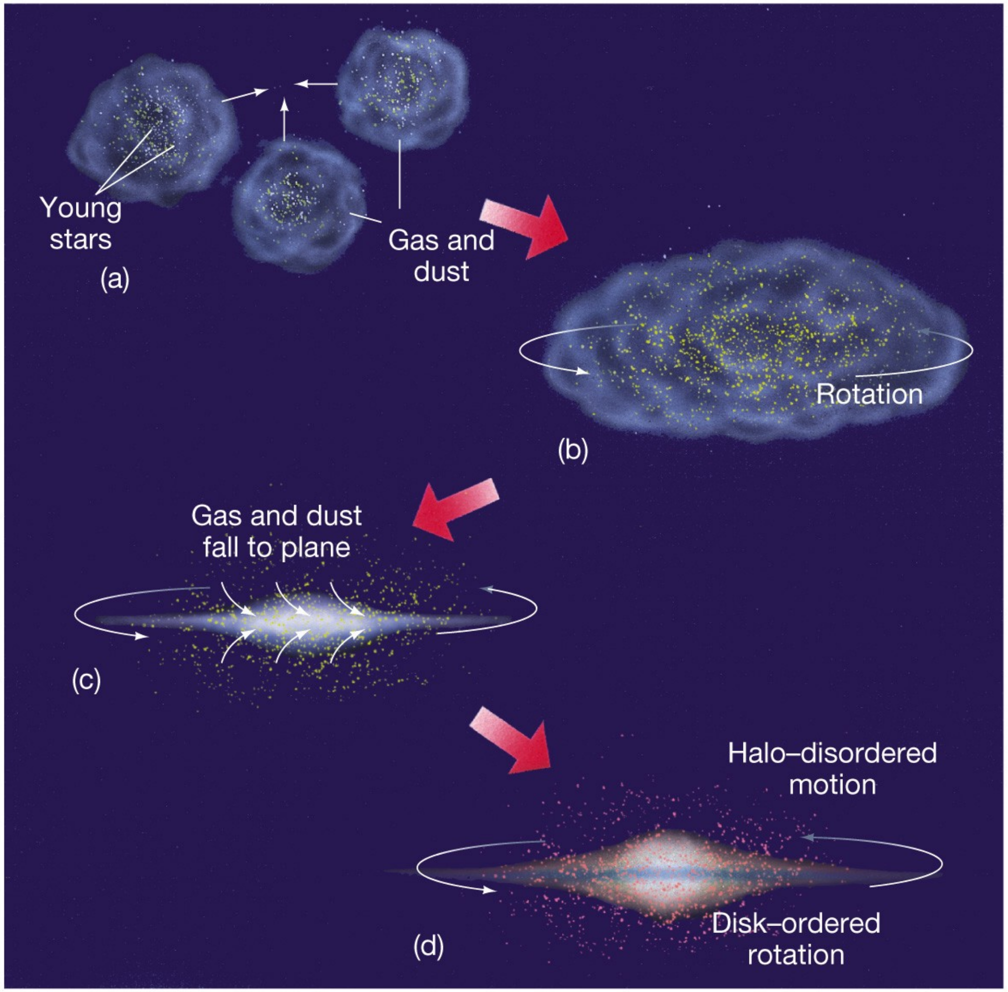
These questions point to a theory...

- **Where are the oldest and youngest stars found?**
- **How do the kinematics of the youngest and oldest stars differ?**
- **What can you say about the order of formation of the halo stars (and globular clusters), the disk, the bulge?**

Galaxy Evolution

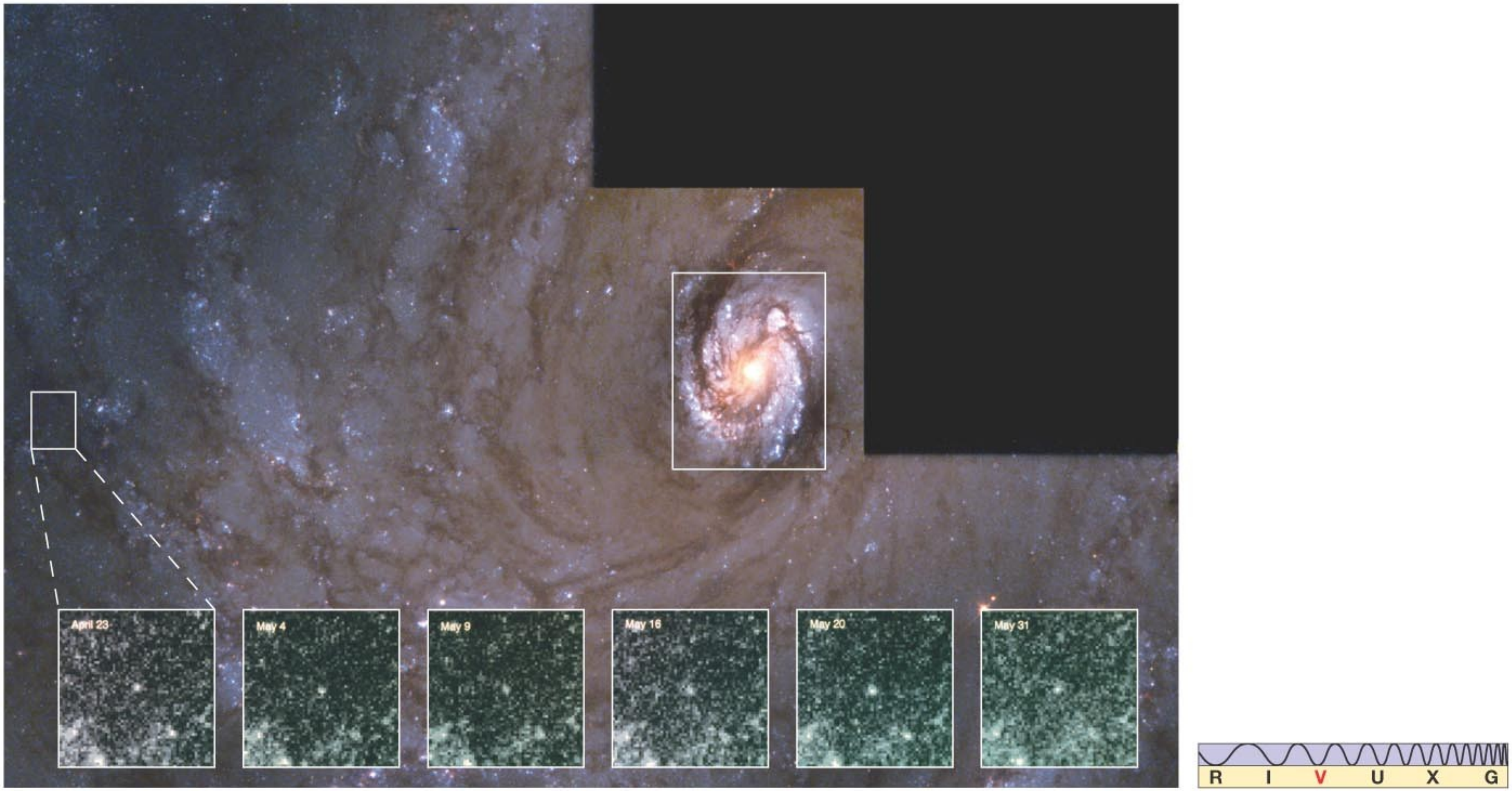
How did our galaxy (the Milky Way) form? (Ch. 23)





24.2 The Distribution of Galaxies in Space

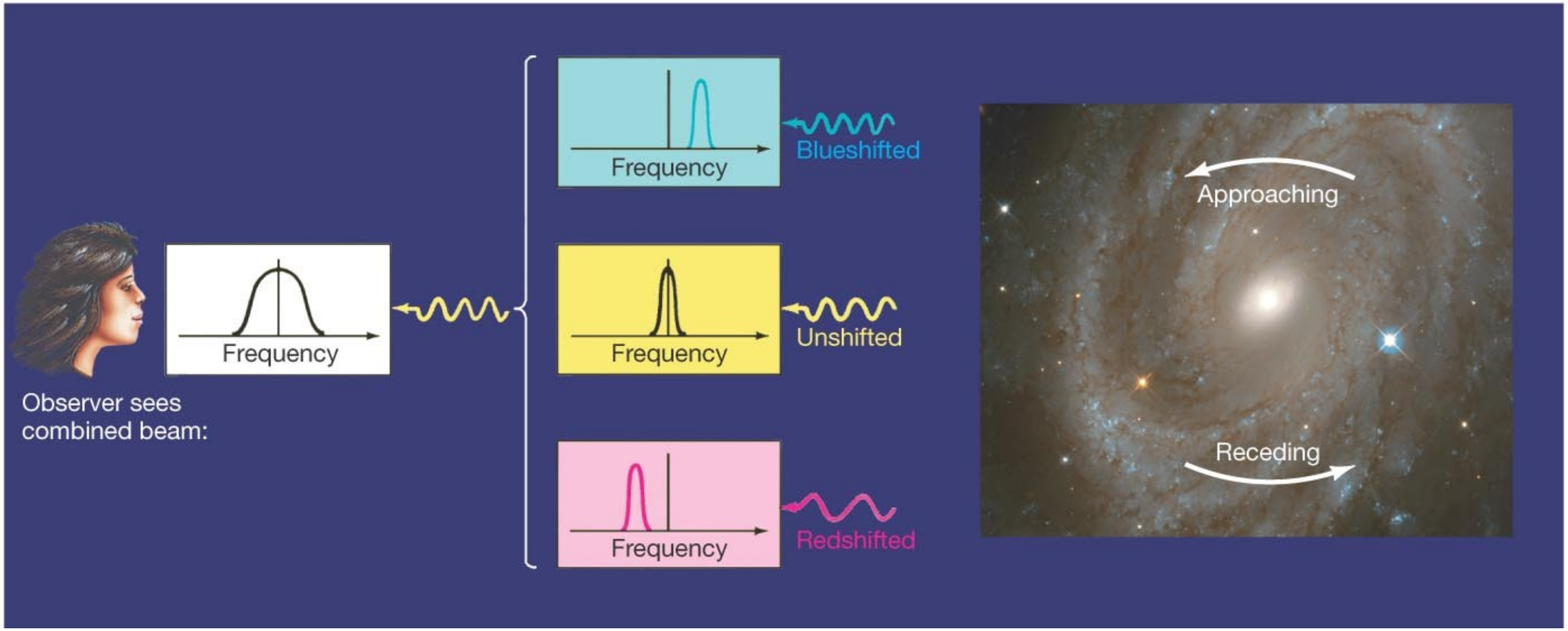
Cepheid variables allow measurement of galaxies to about 25 Mpc away.



24.2 The Distribution of Galaxies in Space

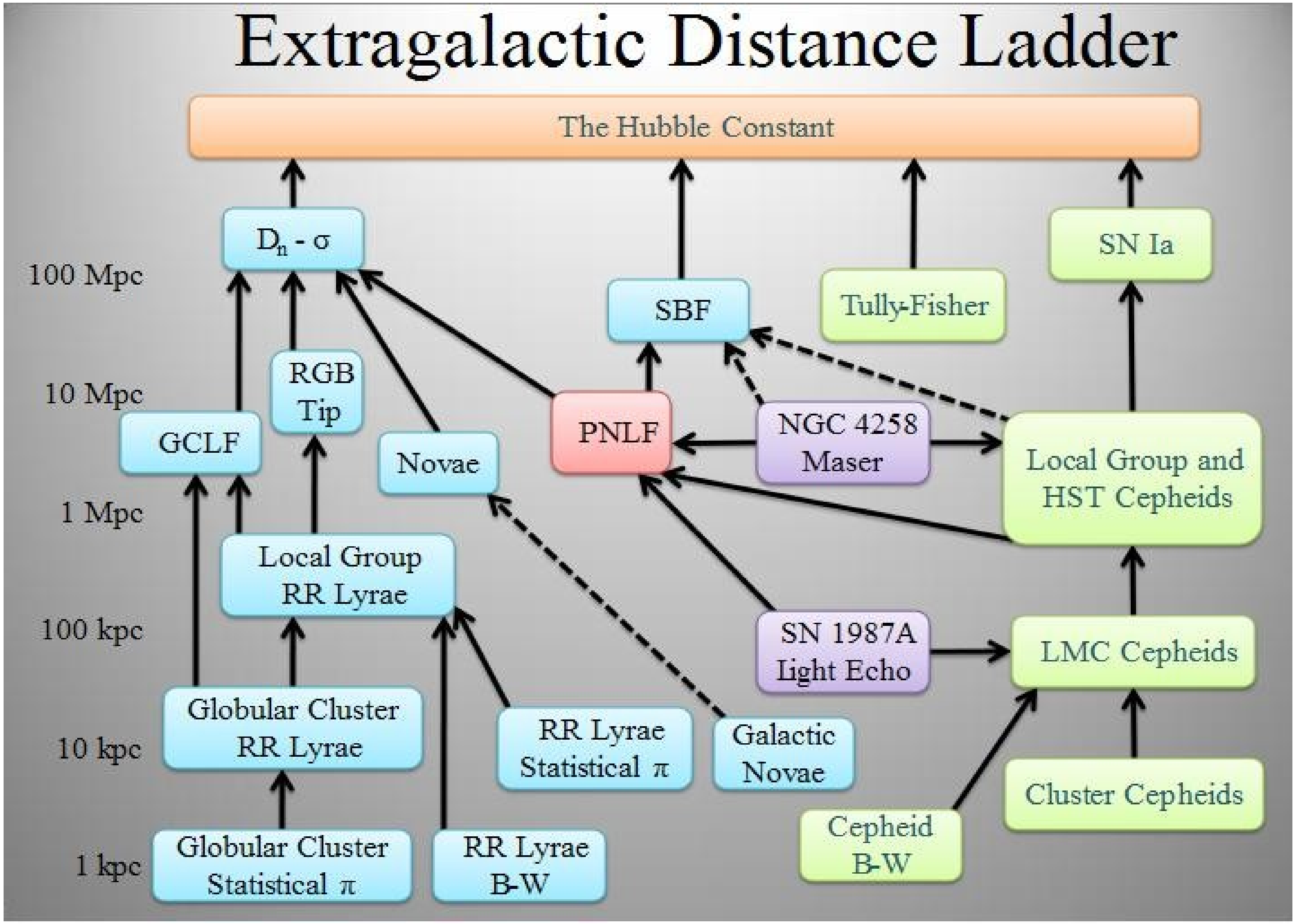
However, some galaxies have no Cepheids, and most are farther away then 25 Mpc. New distance measures are needed.

- **Tully–Fisher relation** correlates a galaxy's **rotation speed** (which can be measured using the Doppler effect) to its **luminosity**.



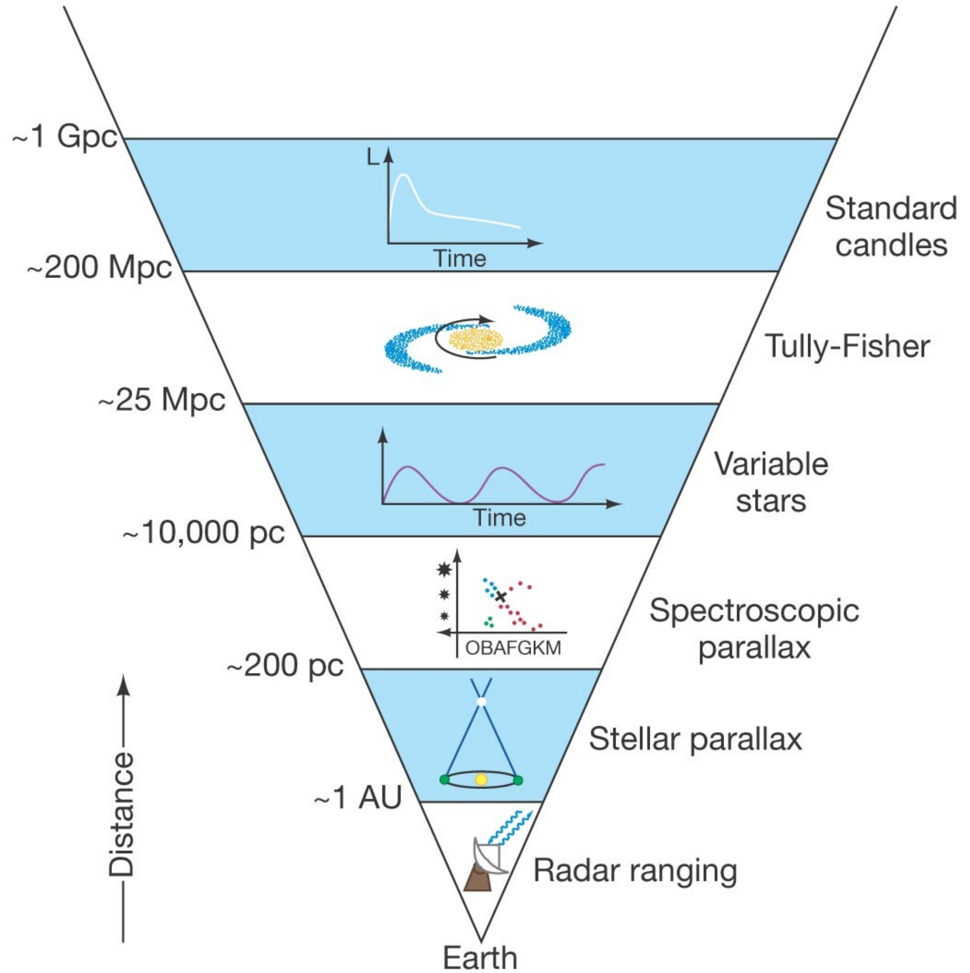
24.2 The Distribution of Galaxies in Space

Actually, about 3 other methods were used to obtain distances out beyond 30 Mpc. This chart shows how they depended upon other methods.



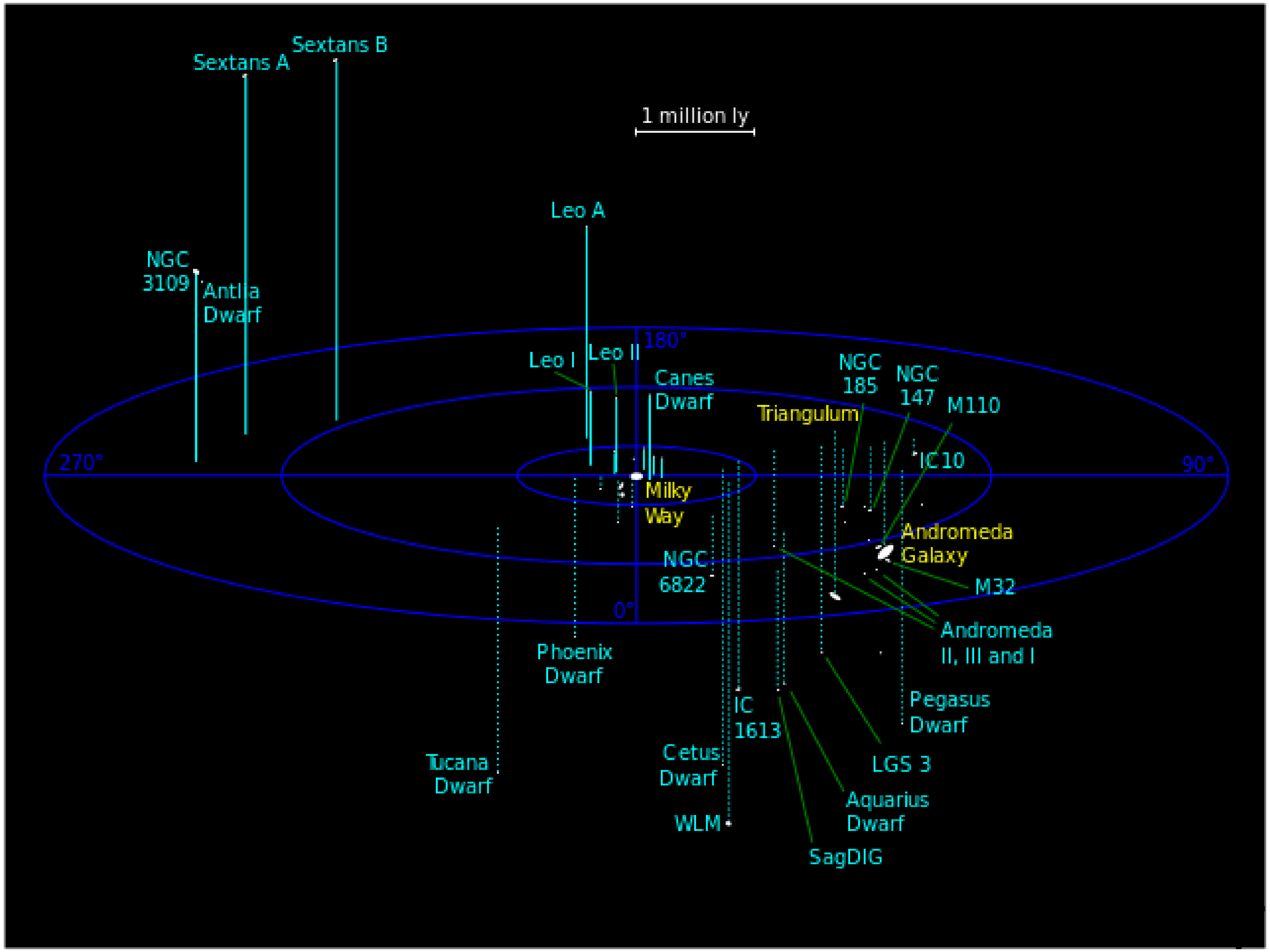
24.2 The Distribution of Galaxies in Space

With these additions, the cosmic distance ladder has been extended to about 1 Gpc:



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.



from wikipedia

24.2 The Distribution of Galaxies in Space

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**.

Aggregates of galaxies, held together by gravity, are named according to their size / number of galaxies:

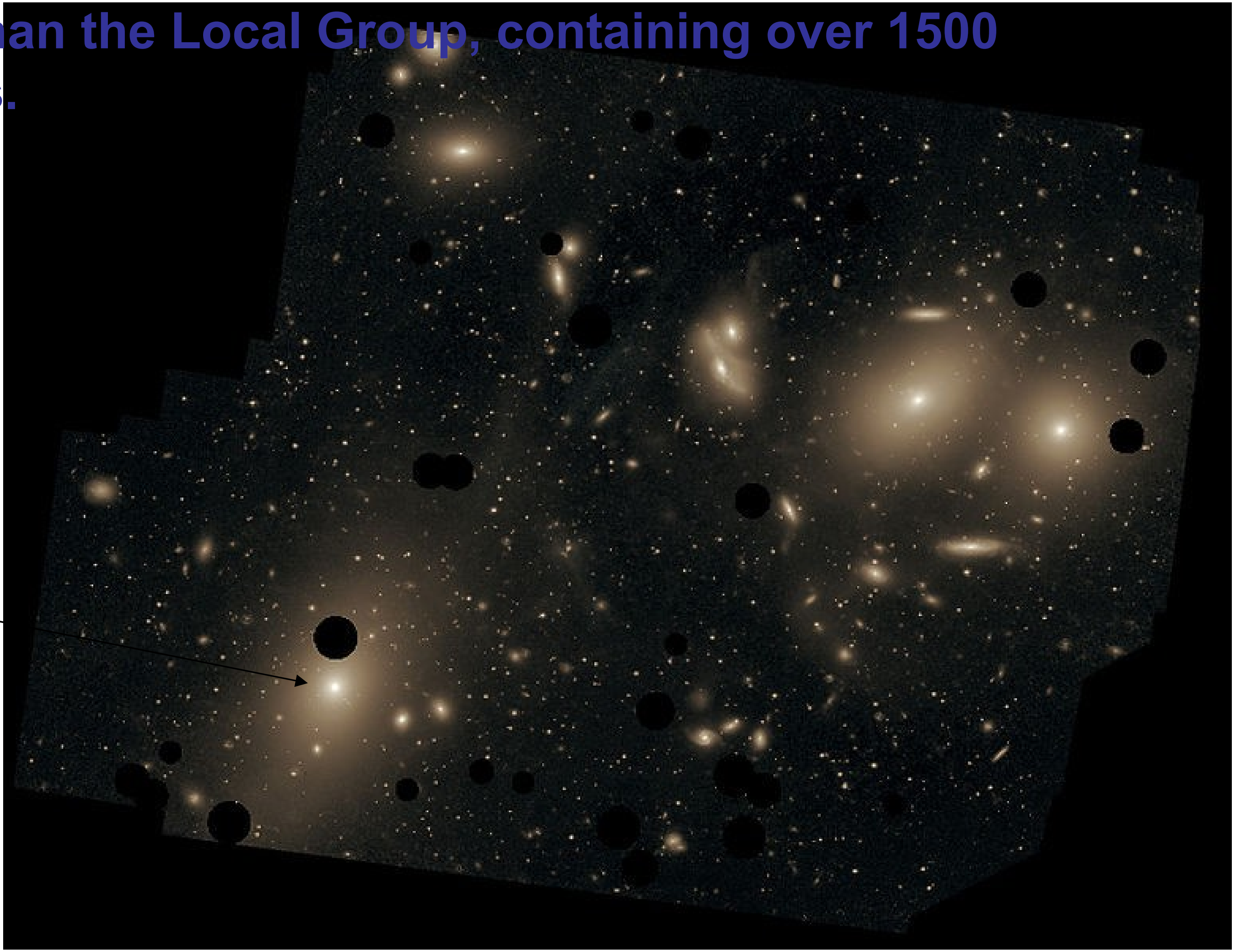
3-10 Poor groups

10-30 Groups

30-50 Poor Clusters >50 Rich Clusters

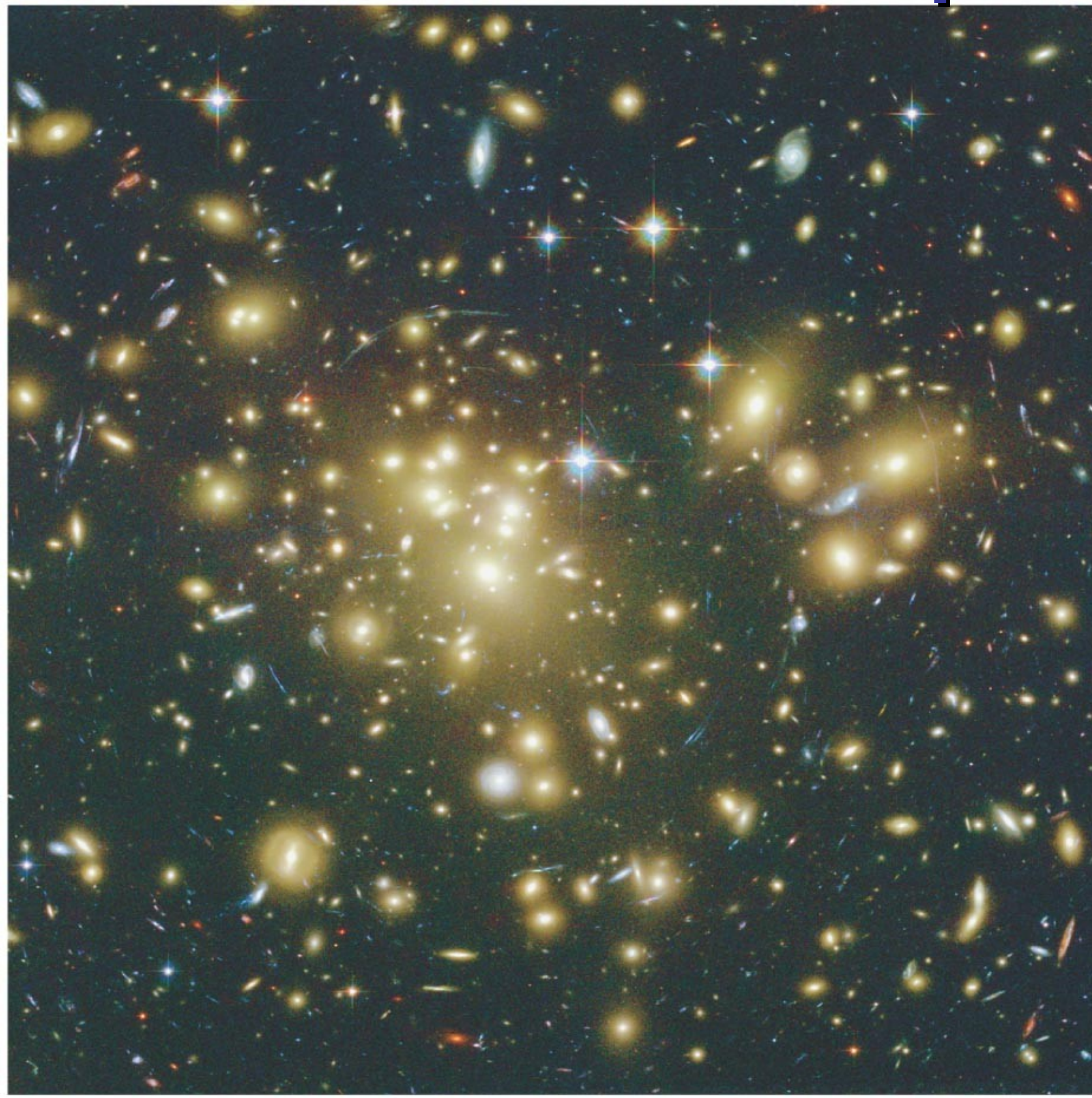
24.2 The Distribution of Galaxies in Space

A nearby galaxy cluster is the Virgo cluster; it is much larger than the Local Group, containing over 1500 galaxies.

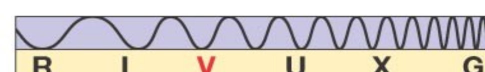


24.2 The Distribution of Galaxies in Space

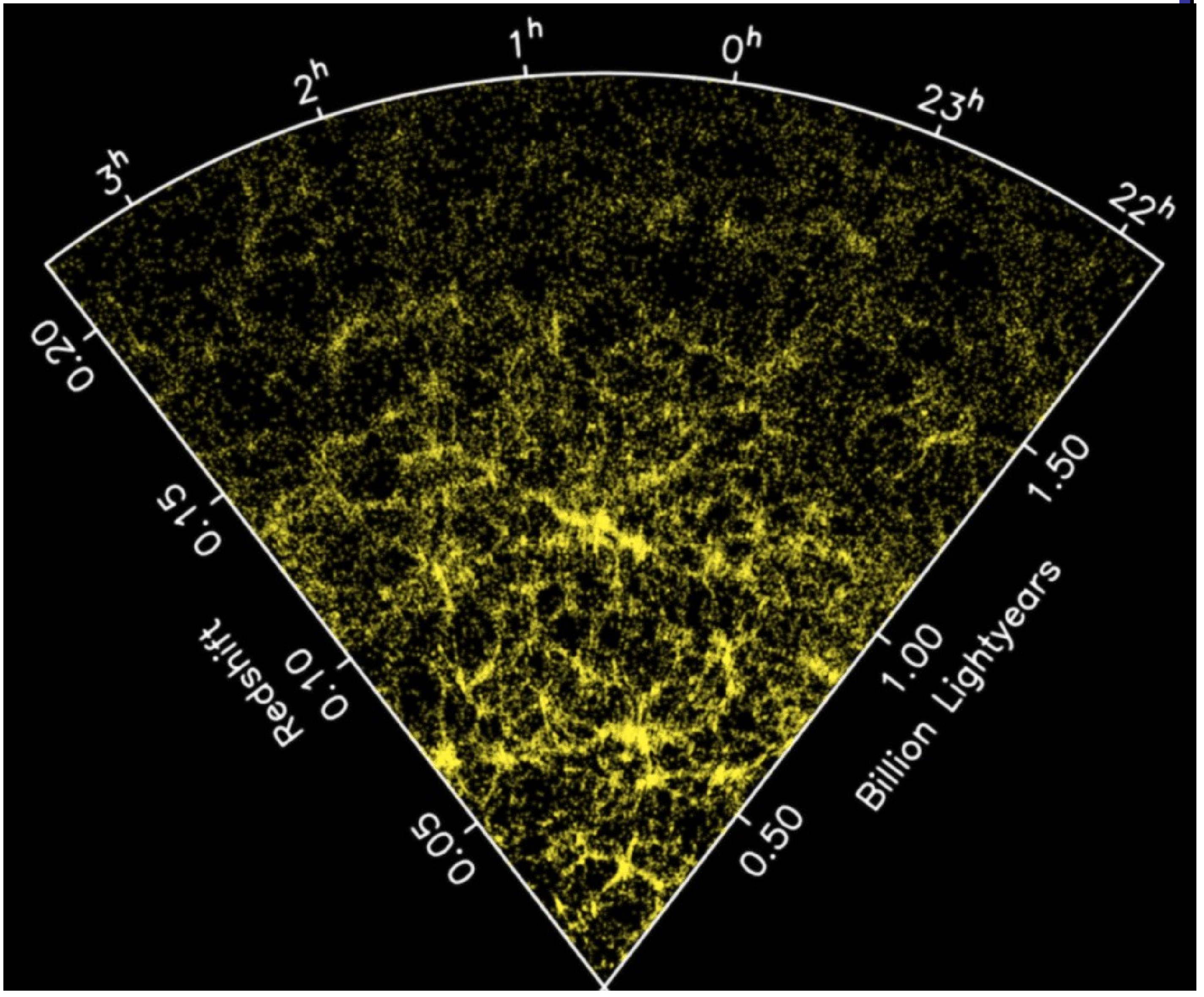
This image shows the Abell 1689 cluster of galaxies, a very large cluster almost 1 billion parsecs away:



See the blue arcs?



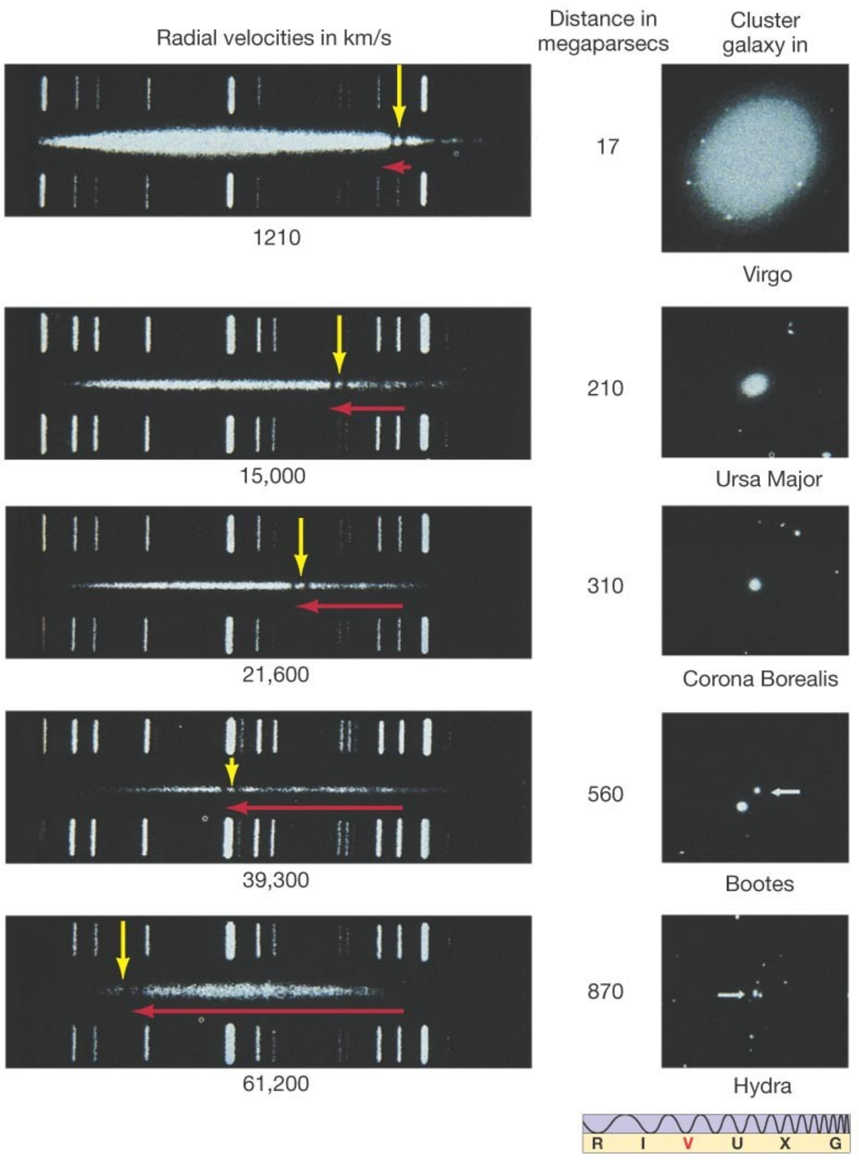
24.2 The Distribution of Galaxies in Space



See a “universe in a bottle”

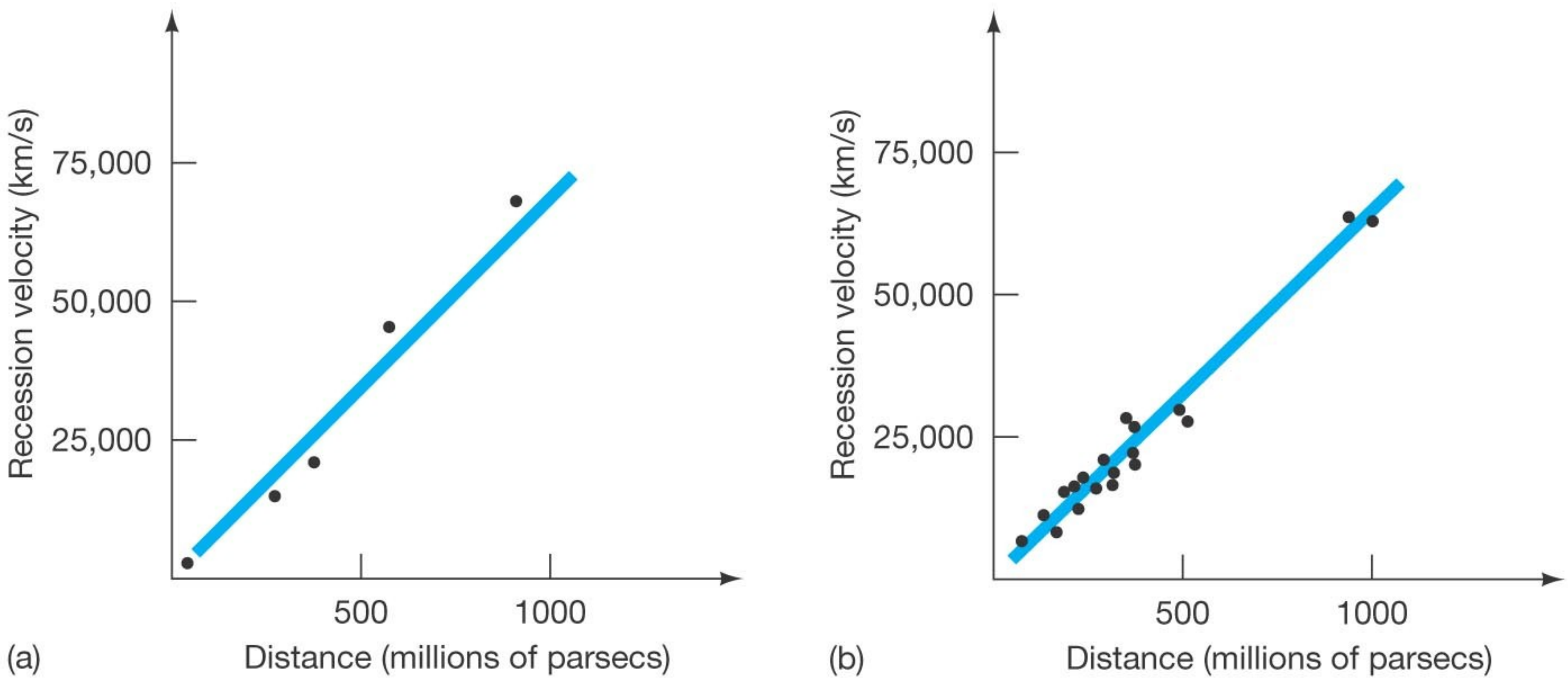
24.3 Hubble's Law

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:

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

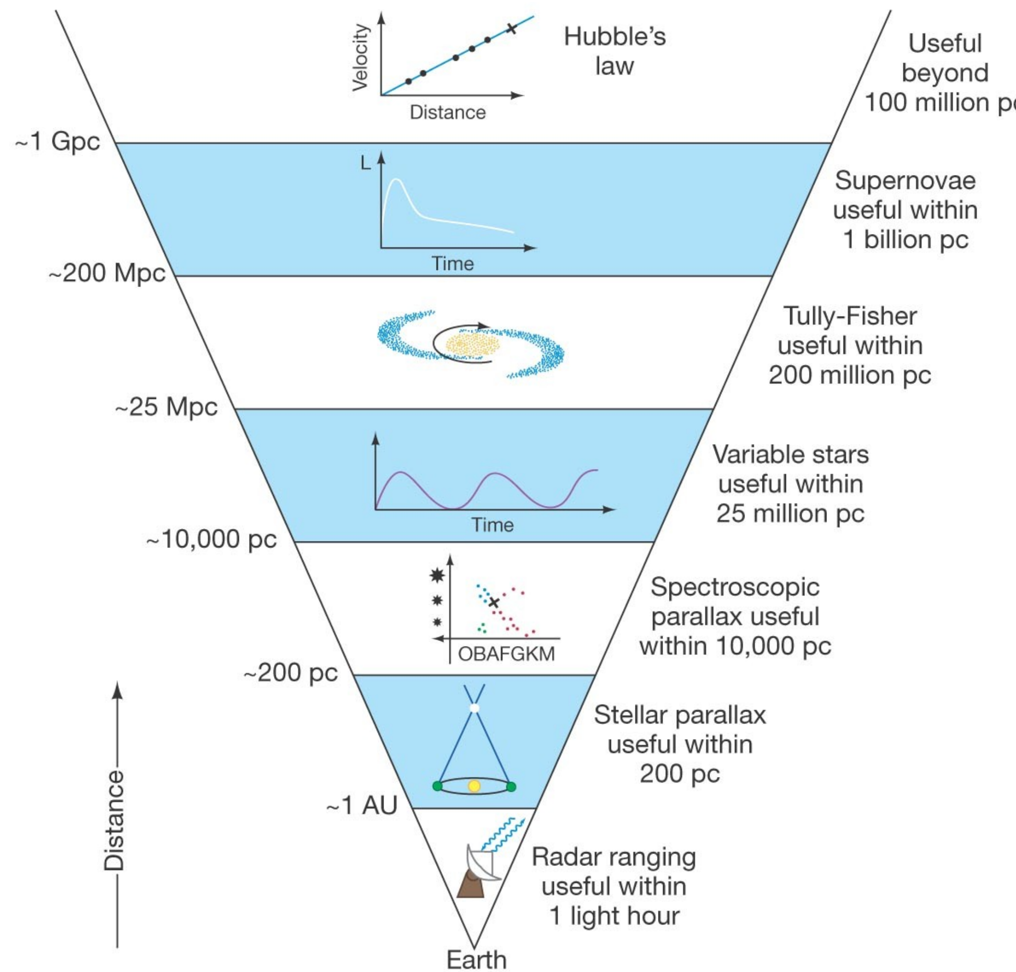
The currently accepted **value** for Hubble's constant:

$$H_0 = 72\ \text{km/s/Mpc}$$

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

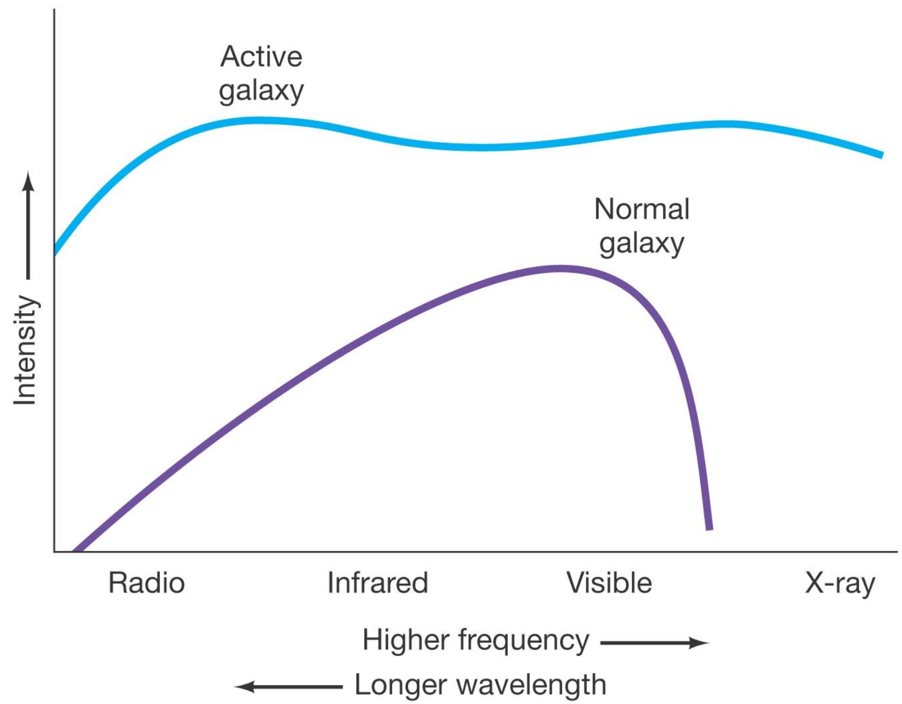
This puts the final step on our distance ladder:



24.4 Active Galactic Nuclei

About 2% of galaxies have unusually **luminous nuclei**.

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



24.4 Active Galactic Nuclei

Some include **starburst galaxies** in with the AGN because they have intense star formation going on near their center.

The rest of the AGN are so small that they are unresolved. Types include:

Seyferts

Radio Galaxies

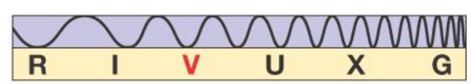
Quasars

Blazars

LLAGN – low luminosity (e.g., LINERS)

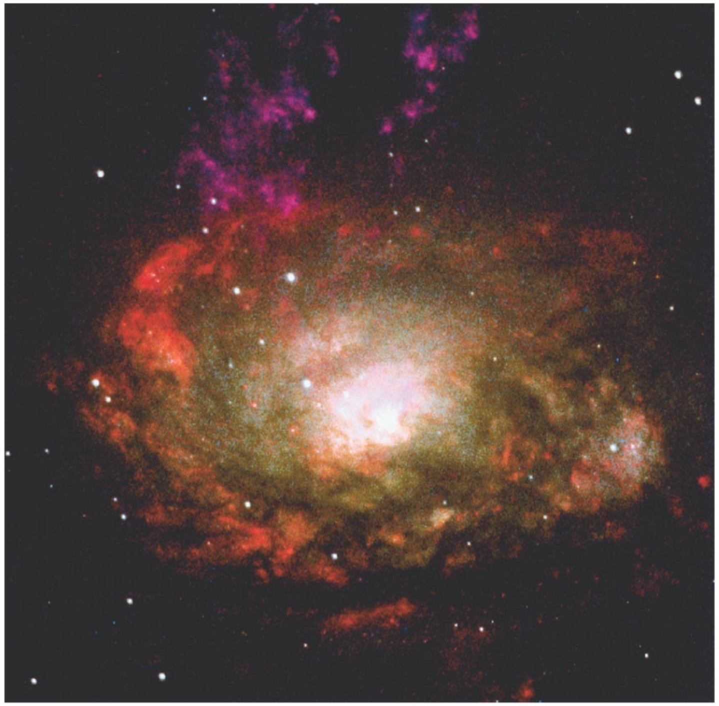
24.4 Active Galactic Nuclei

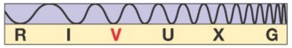
This active galaxy has **star-formation rings** surrounding a very **luminous** core:



24.4 Active Galactic Nuclei

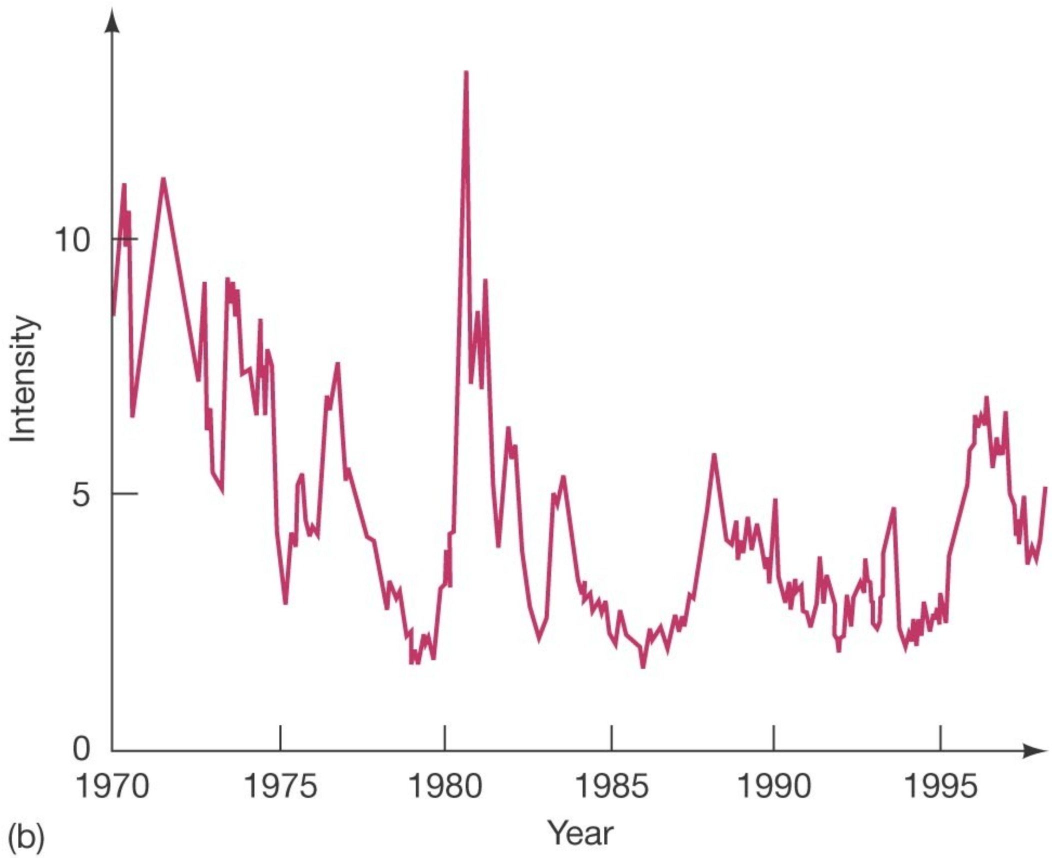
Seyfert galaxies resemble normal spiral galaxies, but their cores are **thousands** of times more luminous:


(a)

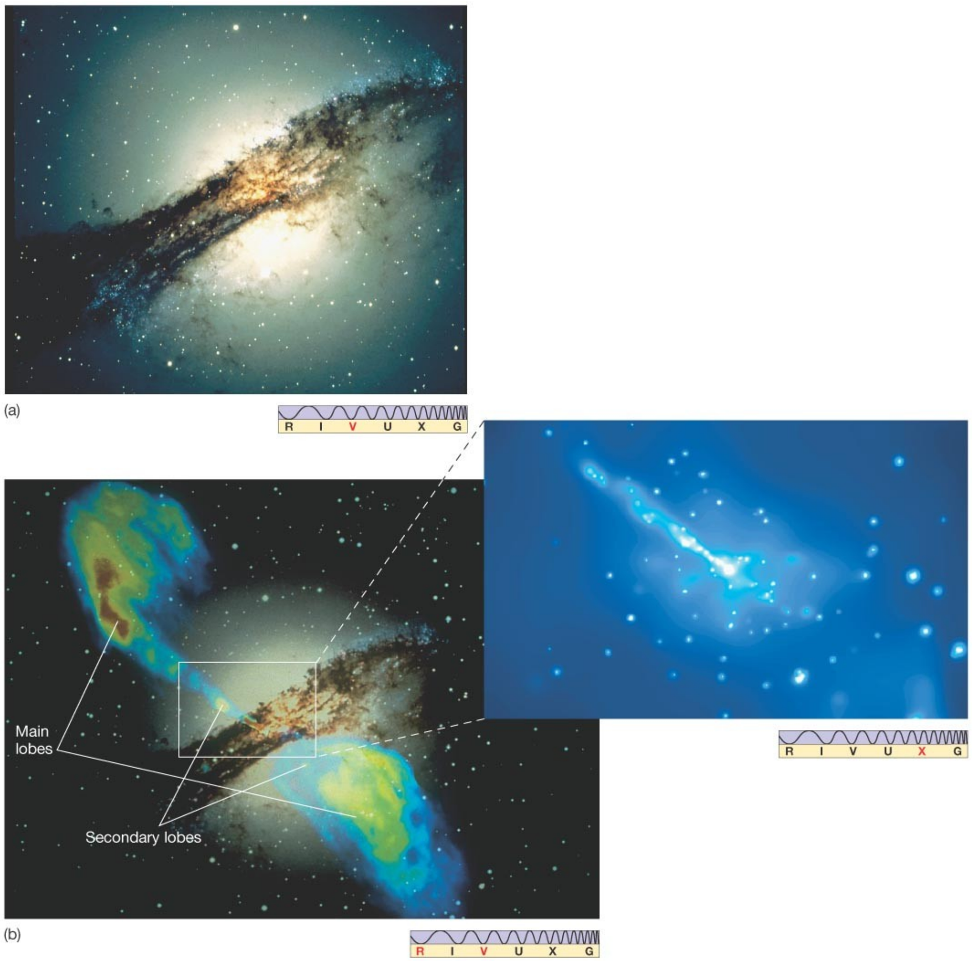


24.4 Active Galactic Nuclei

The **rapid variations** in the luminosity of Seyfert galaxies indicate that the core must be extremely **compact**:



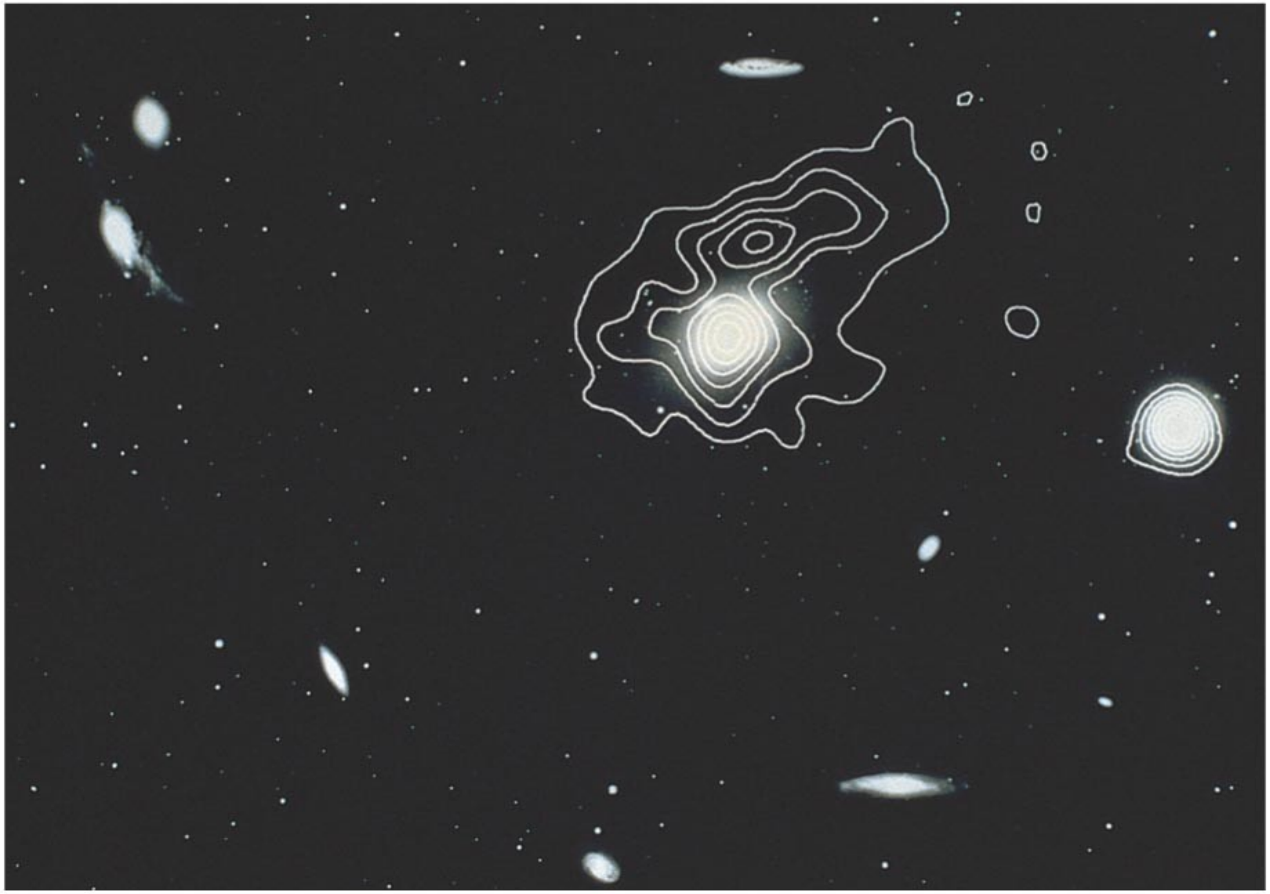
24.4 Active Galactic Nuclei

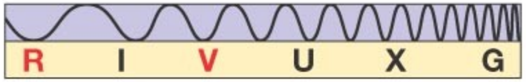


Radio galaxies emit very strongly in the radio portion of the spectrum. They may have enormous **lobes**, invisible to optical telescopes, perpendicular to the plane of the galaxy.

24.4 Active Galactic Nuclei

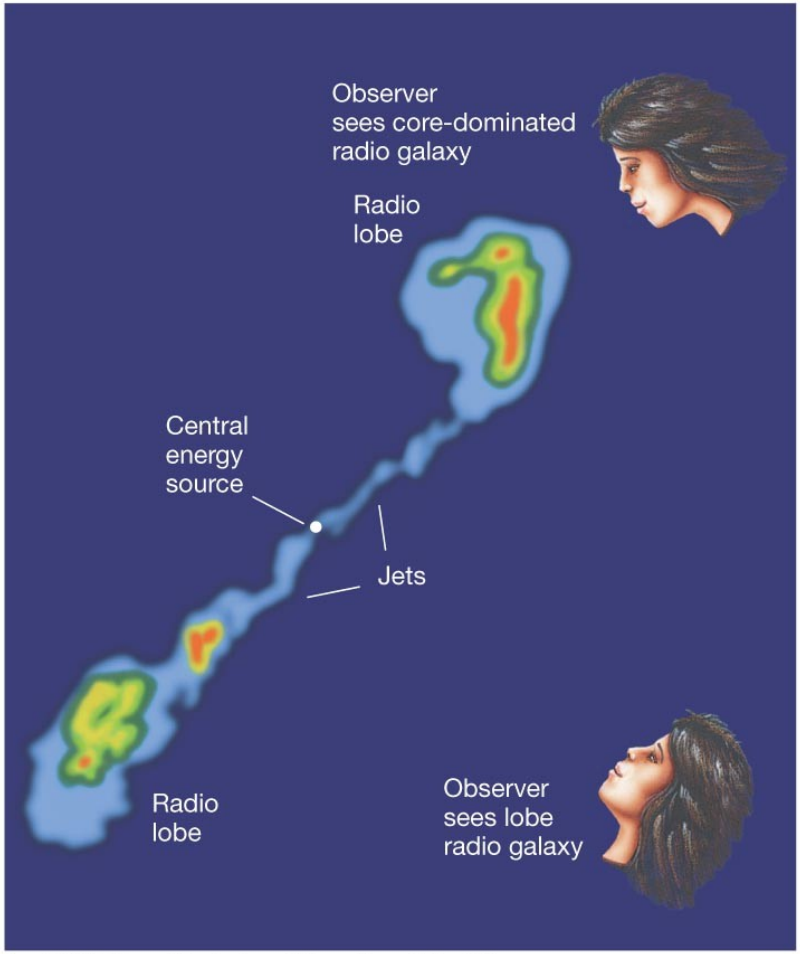
Radio galaxies may also be **core dominated:**



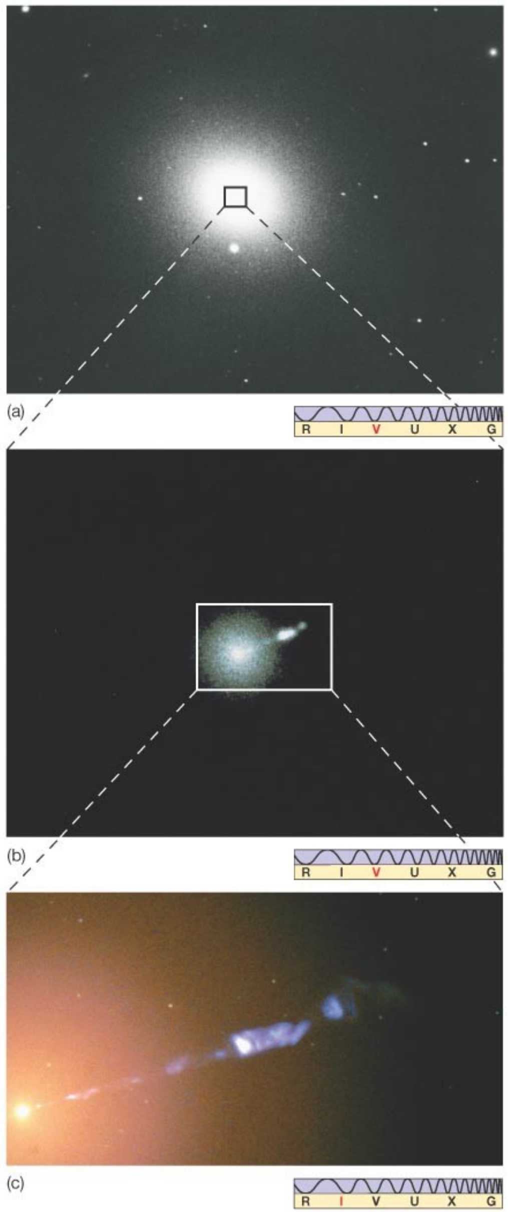


24.4 Active Galactic Nuclei

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



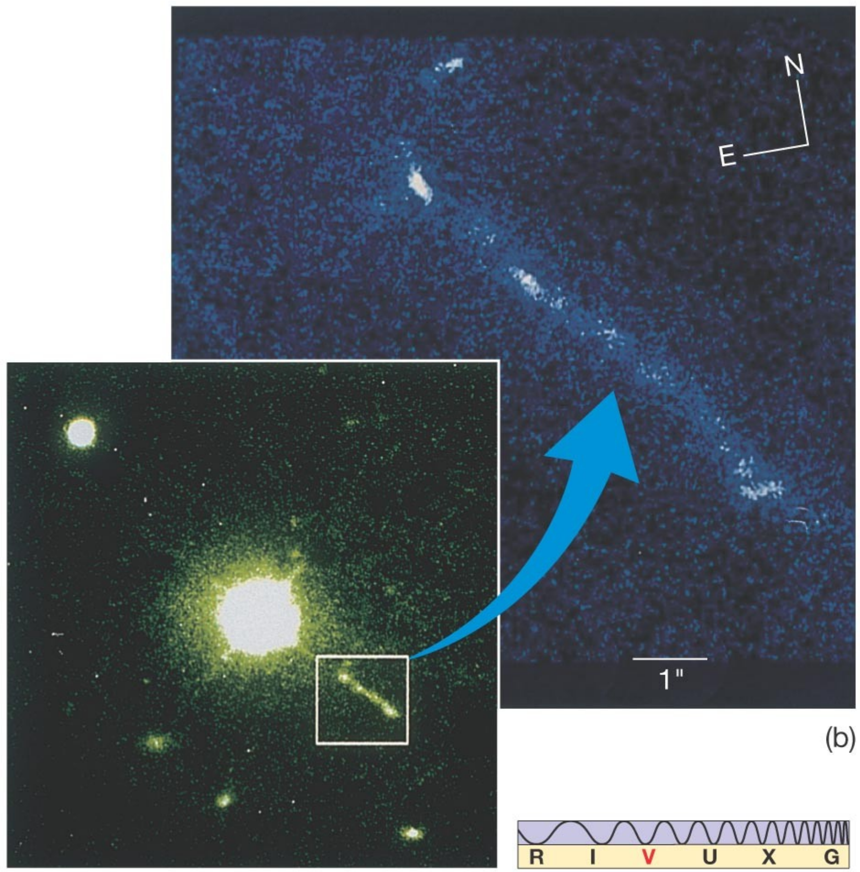
24.4 Active Galactic Nuclei



Many active galaxies have jets, and most show signs of interactions with other galaxies.

24.4 Active Galactic Nuclei

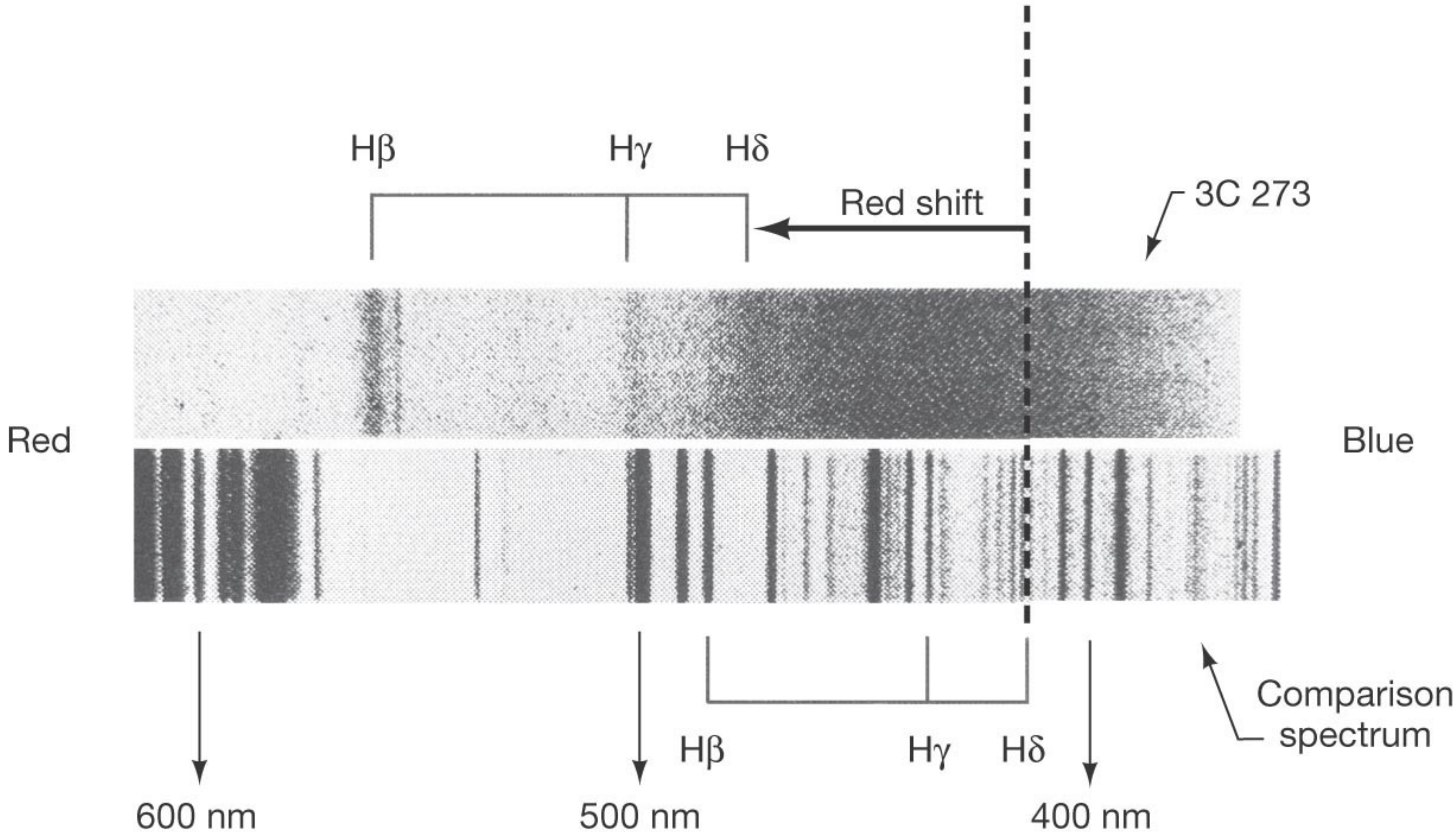
Quasars—quasi-stellar objects—are starlike in appearance, but have very unusual **spectral lines**:



(a)
(b)

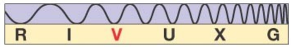
24.4 Active Galactic Nuclei

Eventually it was realized that quasar spectra were normal, but enormously **redshifted**:



24.4 Active Galactic Nuclei

Solving the spectral problem introduces a new problem—quasars must be among the most luminous objects in the galaxy, to be visible over such enormous distances.



More Precisely 24-1: Relativistic Redshifts and Look-Back Time

The redshift of a beam of light is its fractional increase in wavelength. Redshifts are measured directly; distances are calculated from them using Hubble's constant, which is uncertain. Astronomers therefore prefer to quote redshifts rather than distances.

The look-back time is the time when light was emitted from a distant object; for very distant objects it is less than the redshift would indicate, as the object has receded in the meantime.

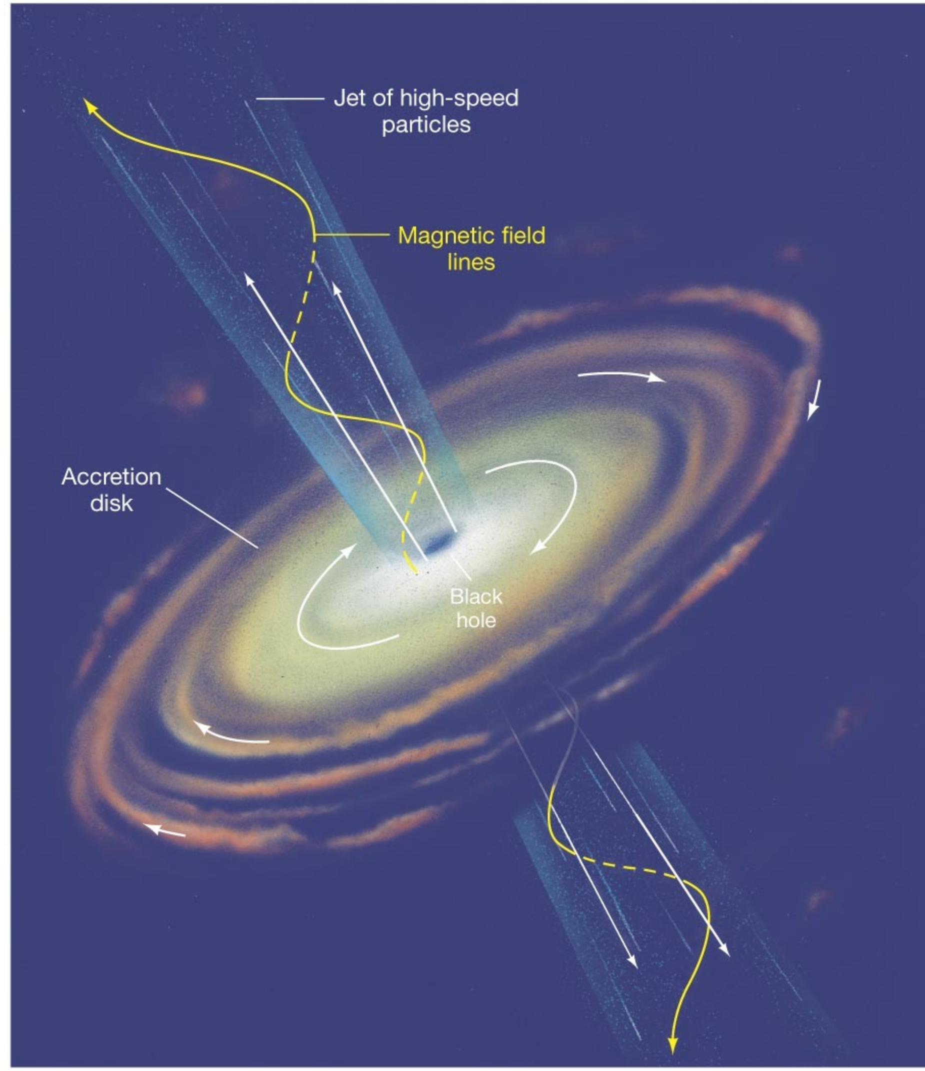
24.5 The Central Engine of an Active Galaxy

Active galactic nuclei have some or all of the following properties:

- high **luminosity**
- **nonstellar** energy emission
- **variable** energy output, indicating small nucleus
- **jets** and other signs of explosive activity
- broad **emission lines**, indicating rapid rotation

24.5 The Central Engine of an Active Galaxy

This is the leading theory for the energy source in an active galactic nucleus: a **black hole**, surrounded by an **accretion disk**. The strong **magnetic field lines** around the black hole channel particles into **jets** perpendicular to the magnetic axis.



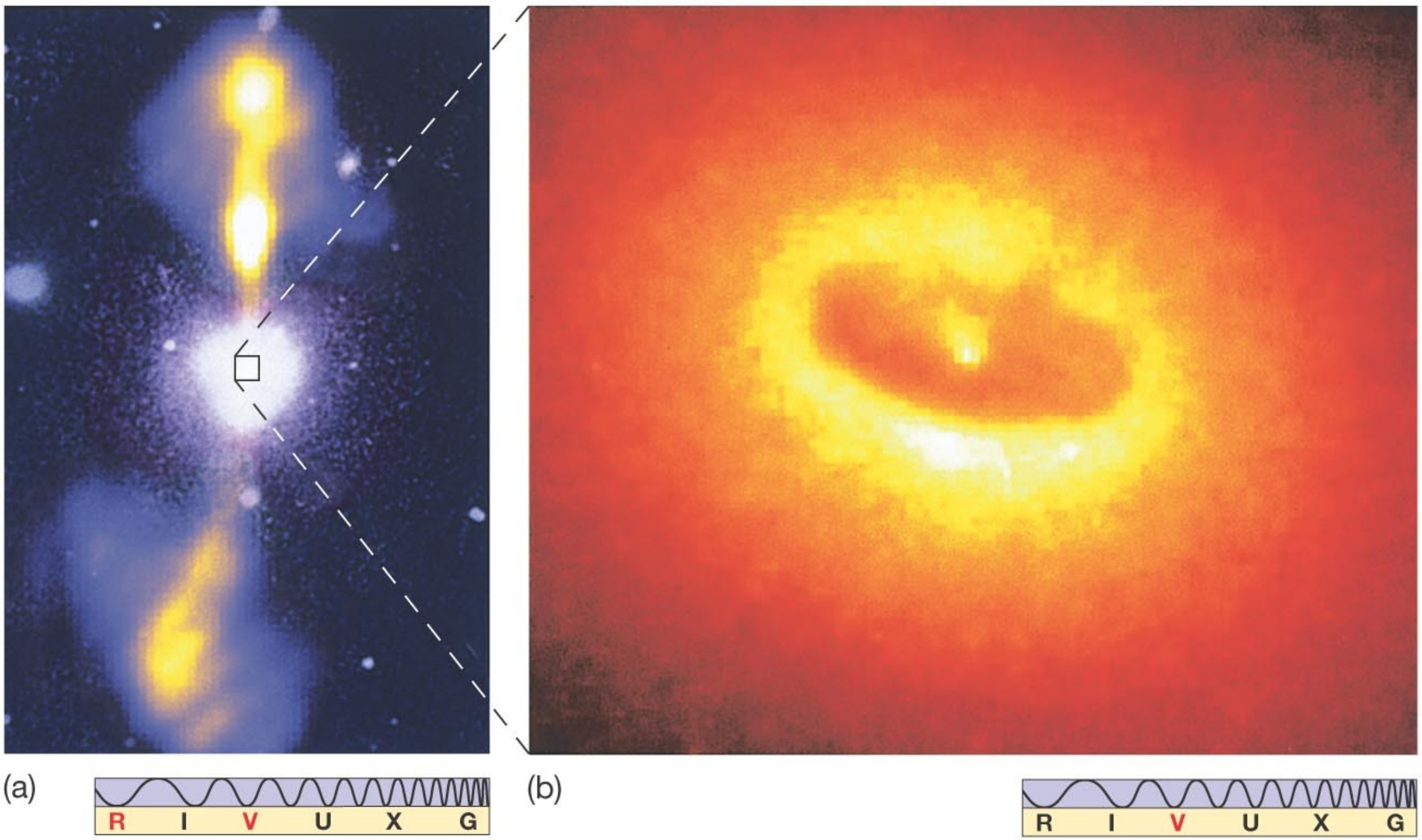
24.5 The Central Engine of an Active Galaxy

In an active galaxy, the central black hole may be **billions** of solar masses.

The accretion disk is whole clouds of interstellar gas and dust; they may radiate away as much as **10–20%** of their mass before disappearing.

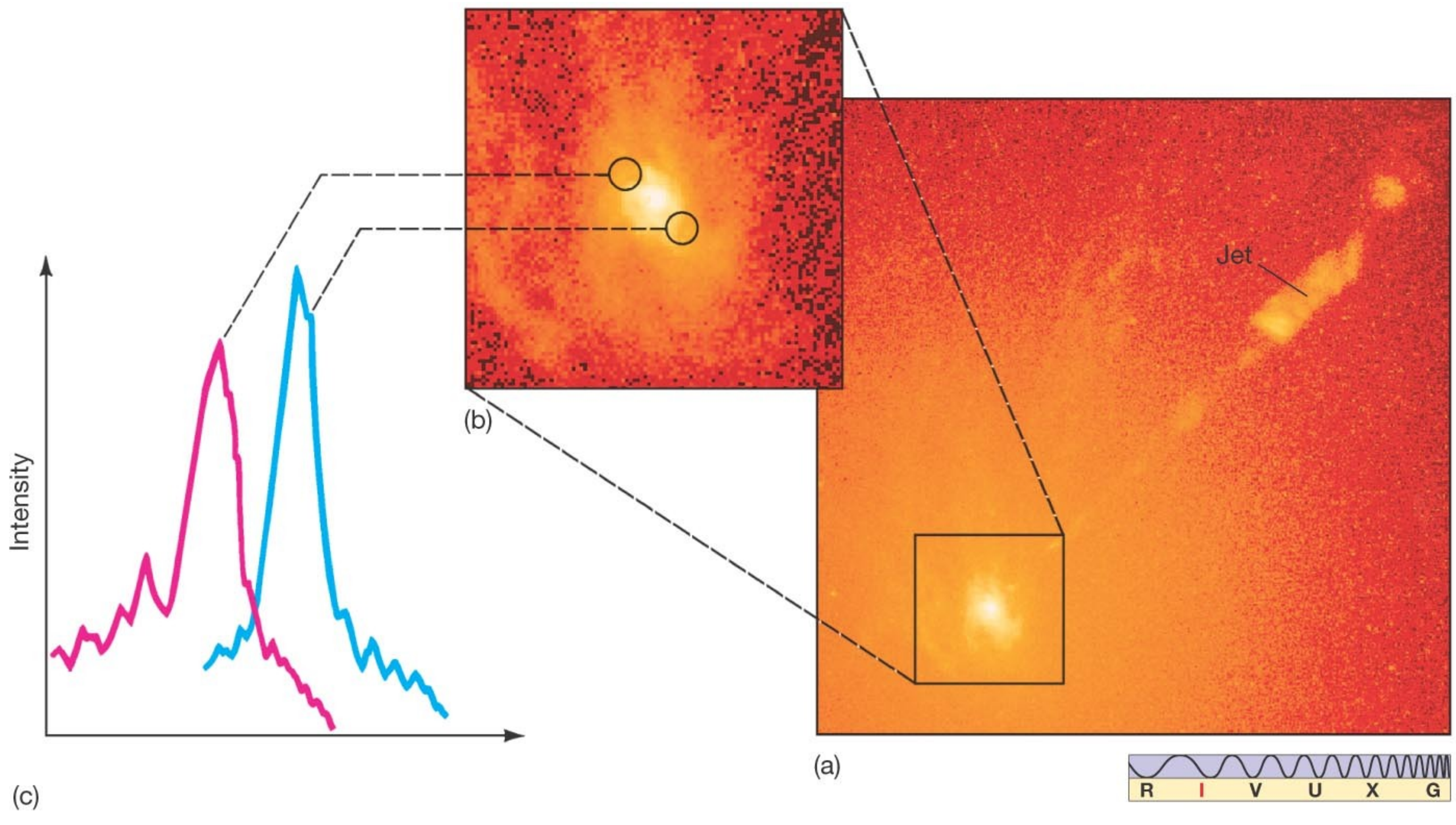
24.5 The Central Engine of an Active Galaxy

This pair of images shows evidence for a black hole at the center of NGC 4261.



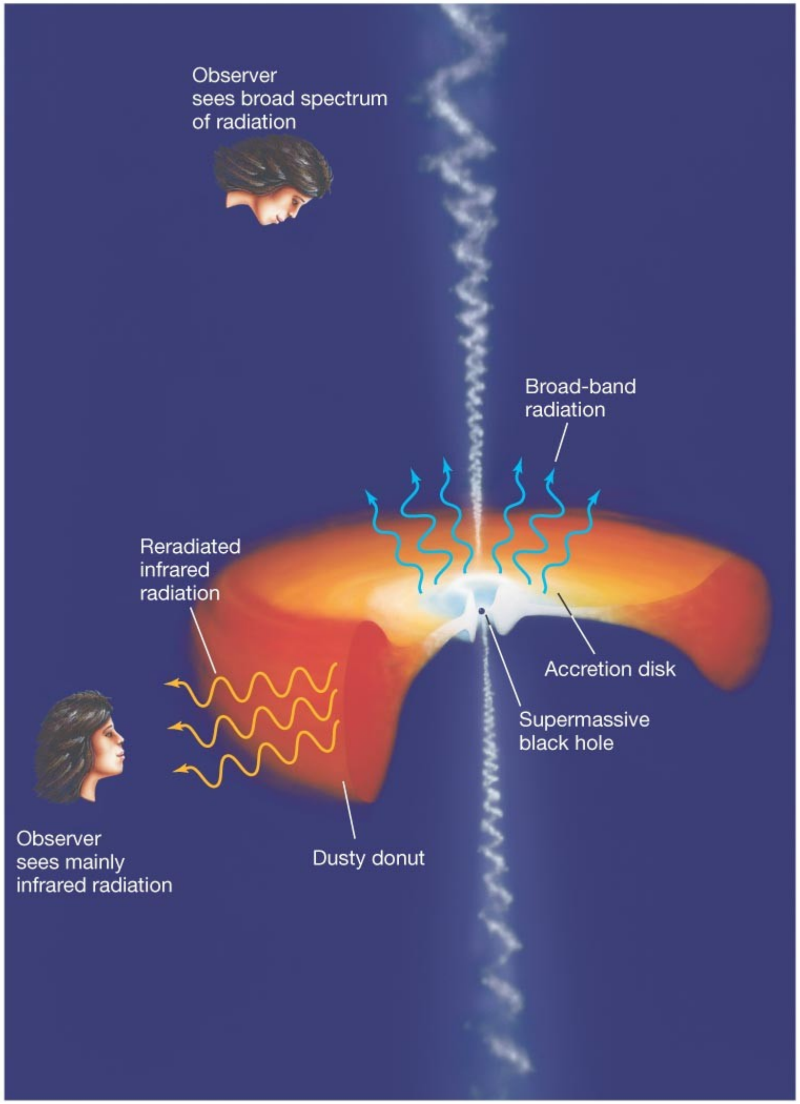
24.5 The Central Engine of an Active Galaxy

The central portion of M87 shows rapid motion and jets characteristic of material surrounding a black hole.



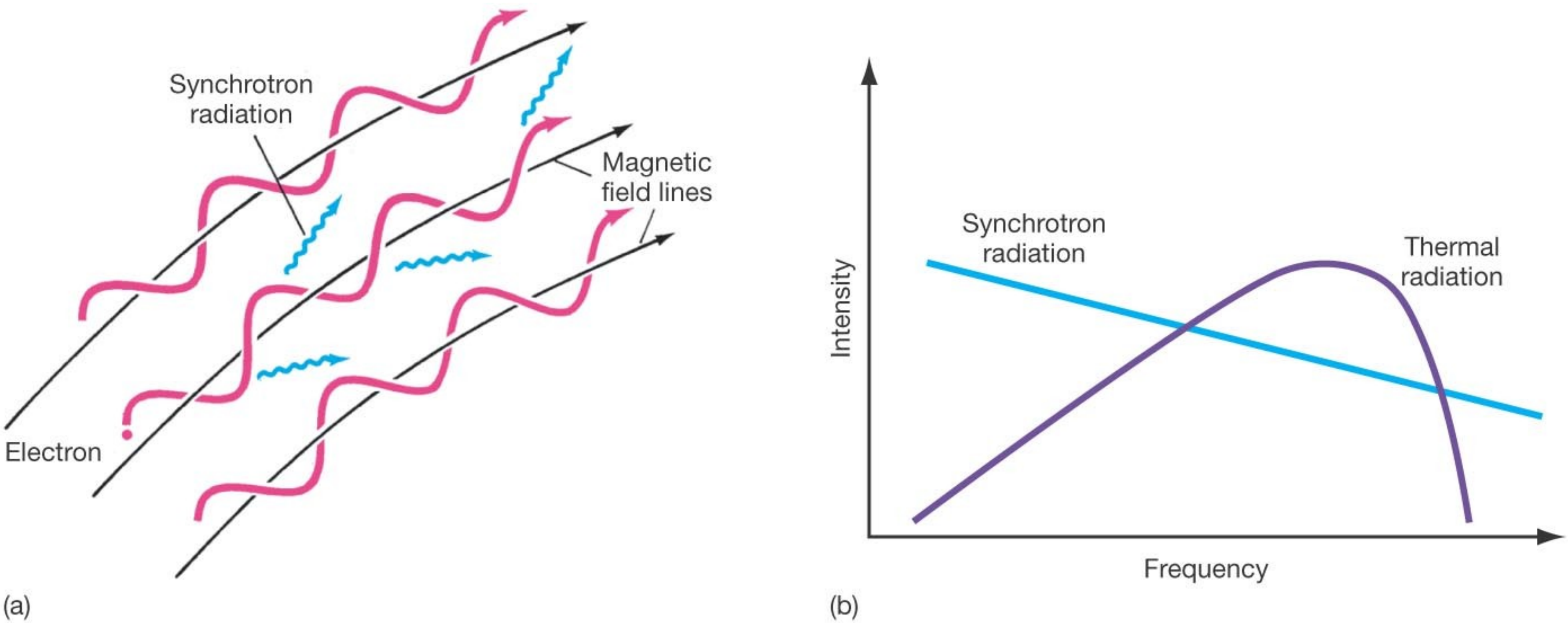
24.5 The Central Engine of an Active Galaxy

One might expect the radiation to be mostly X- and gamma-rays, but apparently it is often "**reprocessed**" in the dense clouds around the black hole and re-emitted at longer wavelengths.



24.5 The Central Engine of an Active Galaxy

Particles will emit **synchrotron radiation** as they spiral along the magnetic field lines; this radiation is decidedly **nonstellar**.



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.