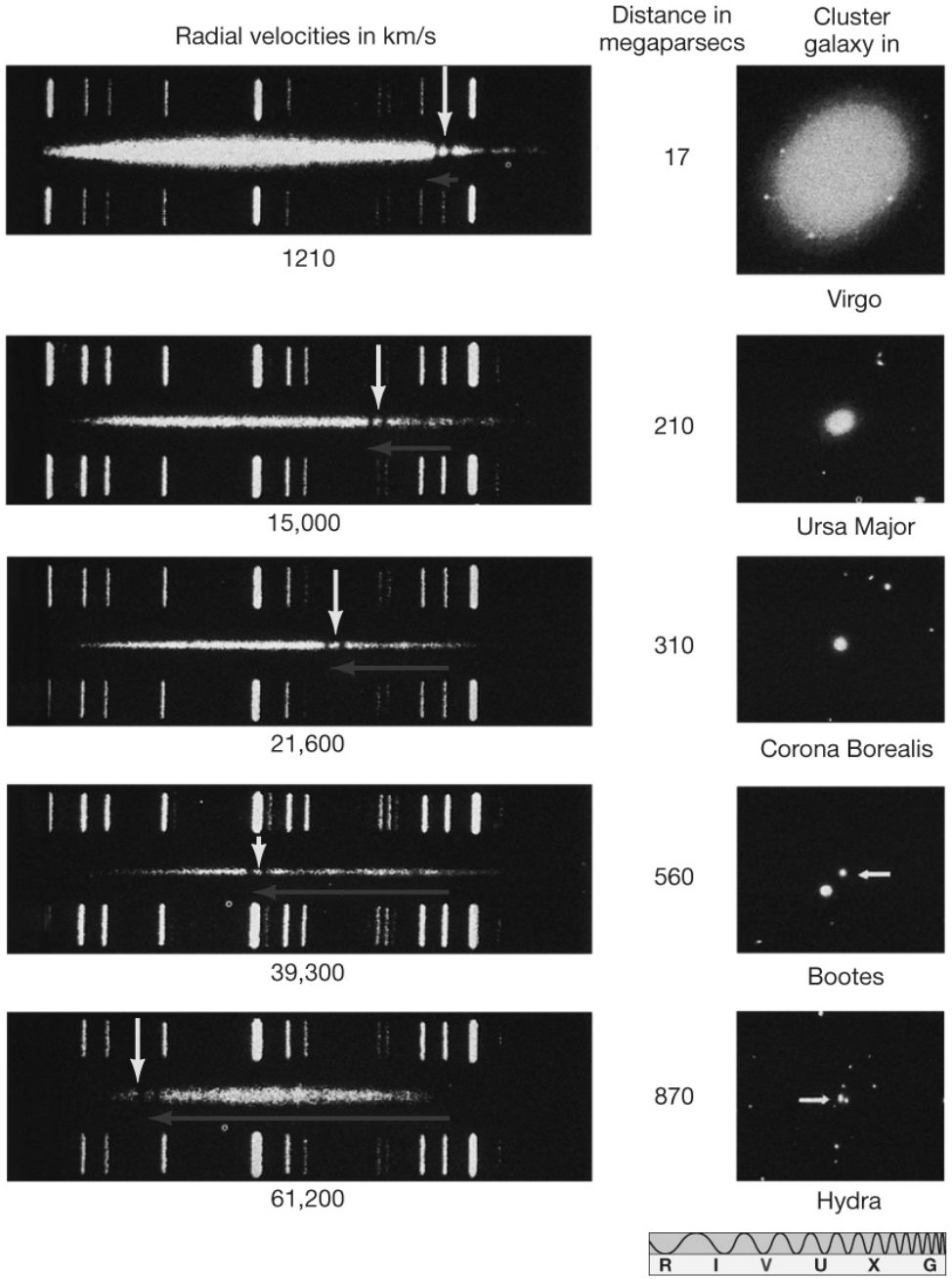
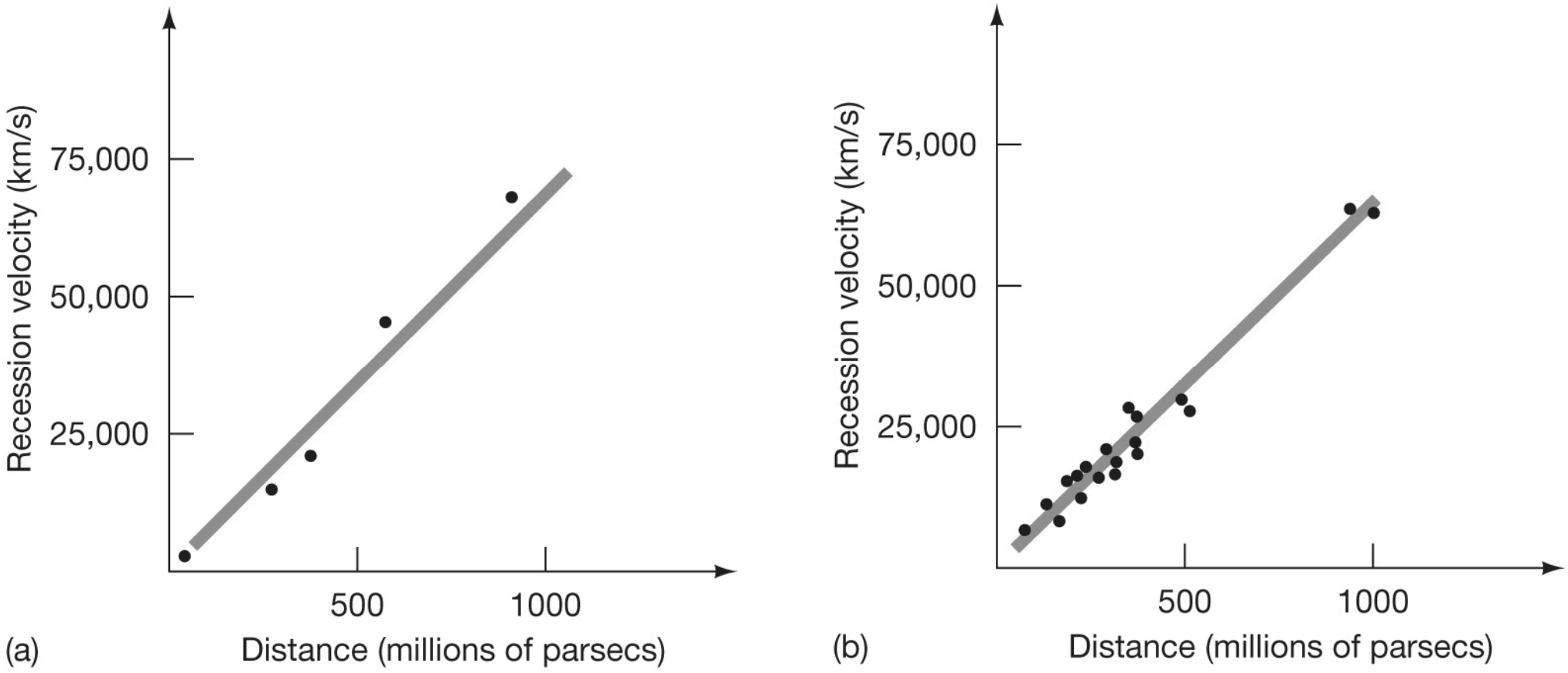
15.3 Hubble's Law

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:



15.3 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:



15.3 Hubble's Law

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

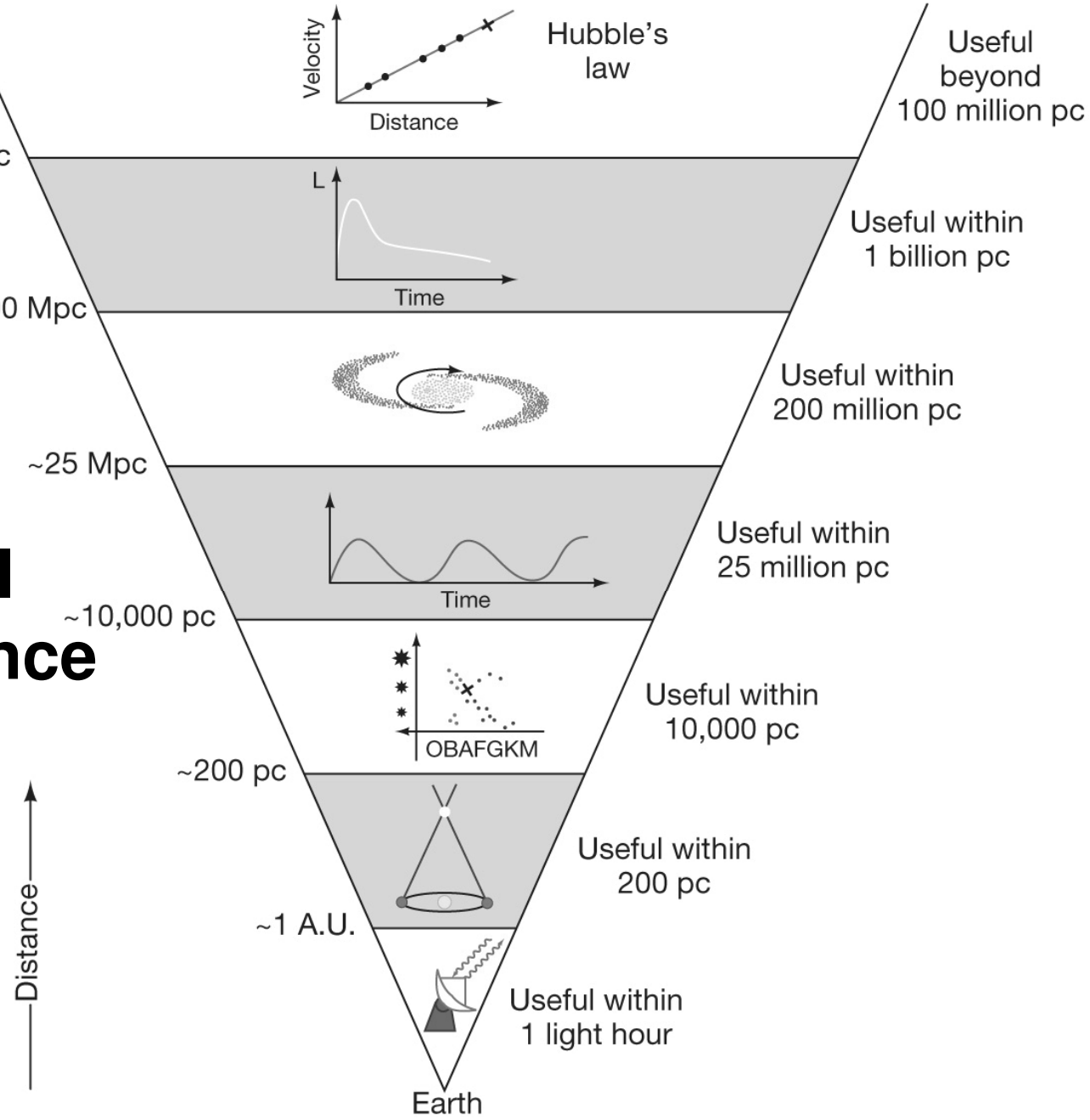
$$\text{recessional velocity} = H_0 \times \text{distance}$$

The value of Hubble's constant is currently uncertain, with most estimates ranging from 50 to 80 km/s/Mpc.

Measuring distances using Hubble's law actually works better the farther away the object is; random motions are overwhelmed by the recessional velocity.

15.3 Hubble's Law

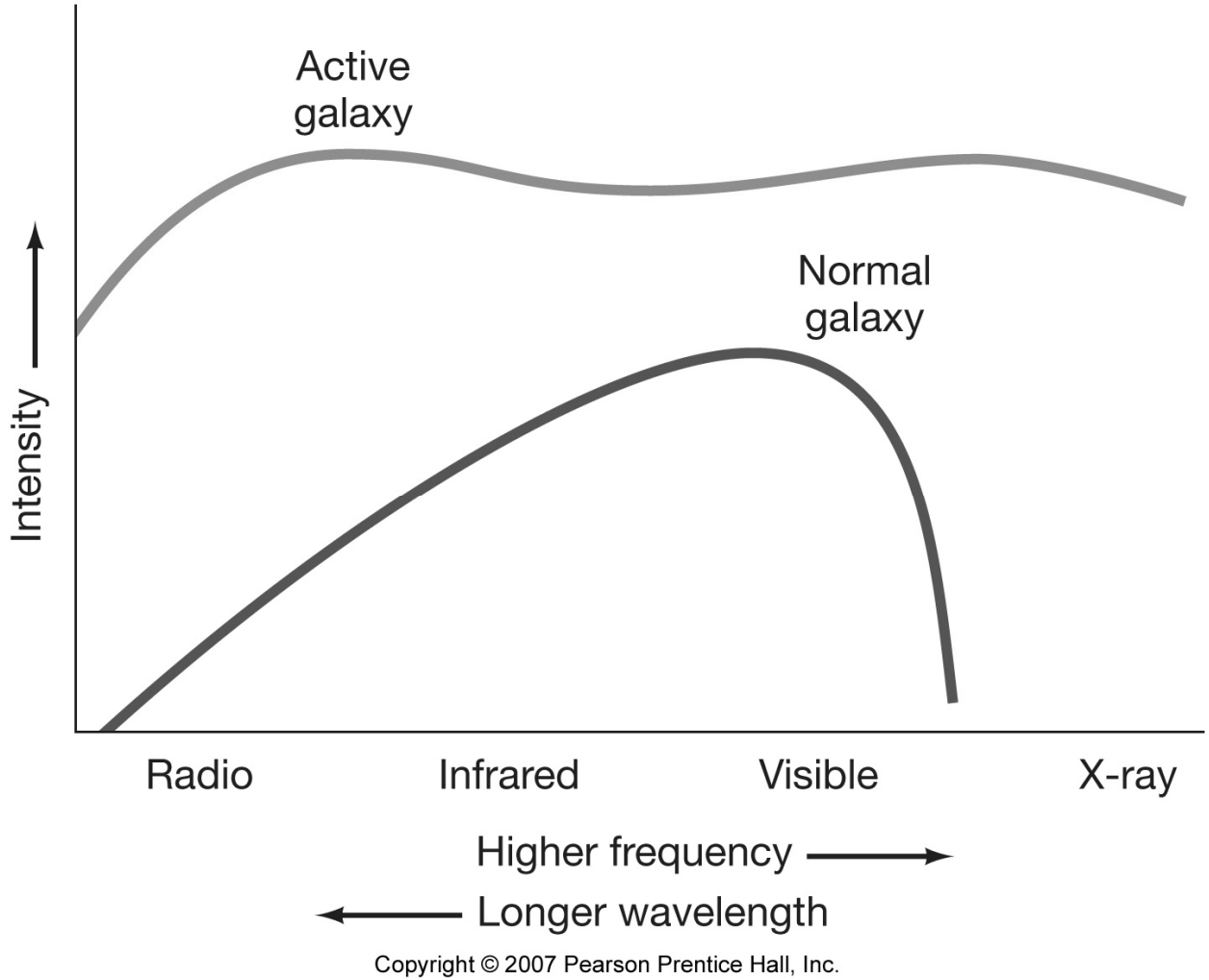
This puts the final step on our distance ladder:



15.4 Active Galactic Nuclei

About 20-25% 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 the luminosity and type of radiation they emit:



15.4 Active Galactic Nuclei

The radiation from these galaxies is called nonstellar radiation.

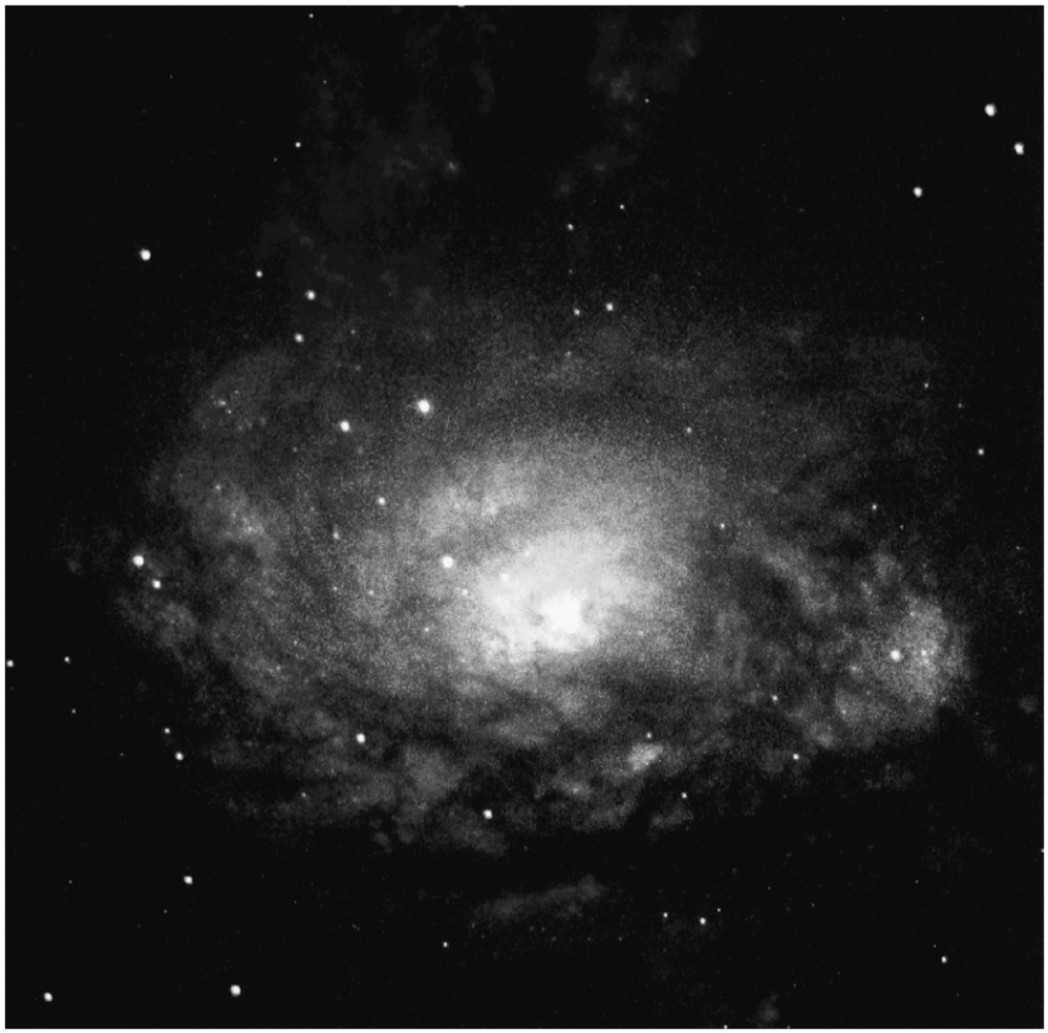
Many luminous galaxies are experiencing an outburst of star formation, probably due to interactions with a neighbor. These galaxies are called starburst galaxies, and we will discuss them later.

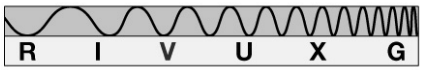
The galaxies we will discuss now are those whose activity is due to events occurring in and around the galactic center.

15.4 Active Galactic Nuclei

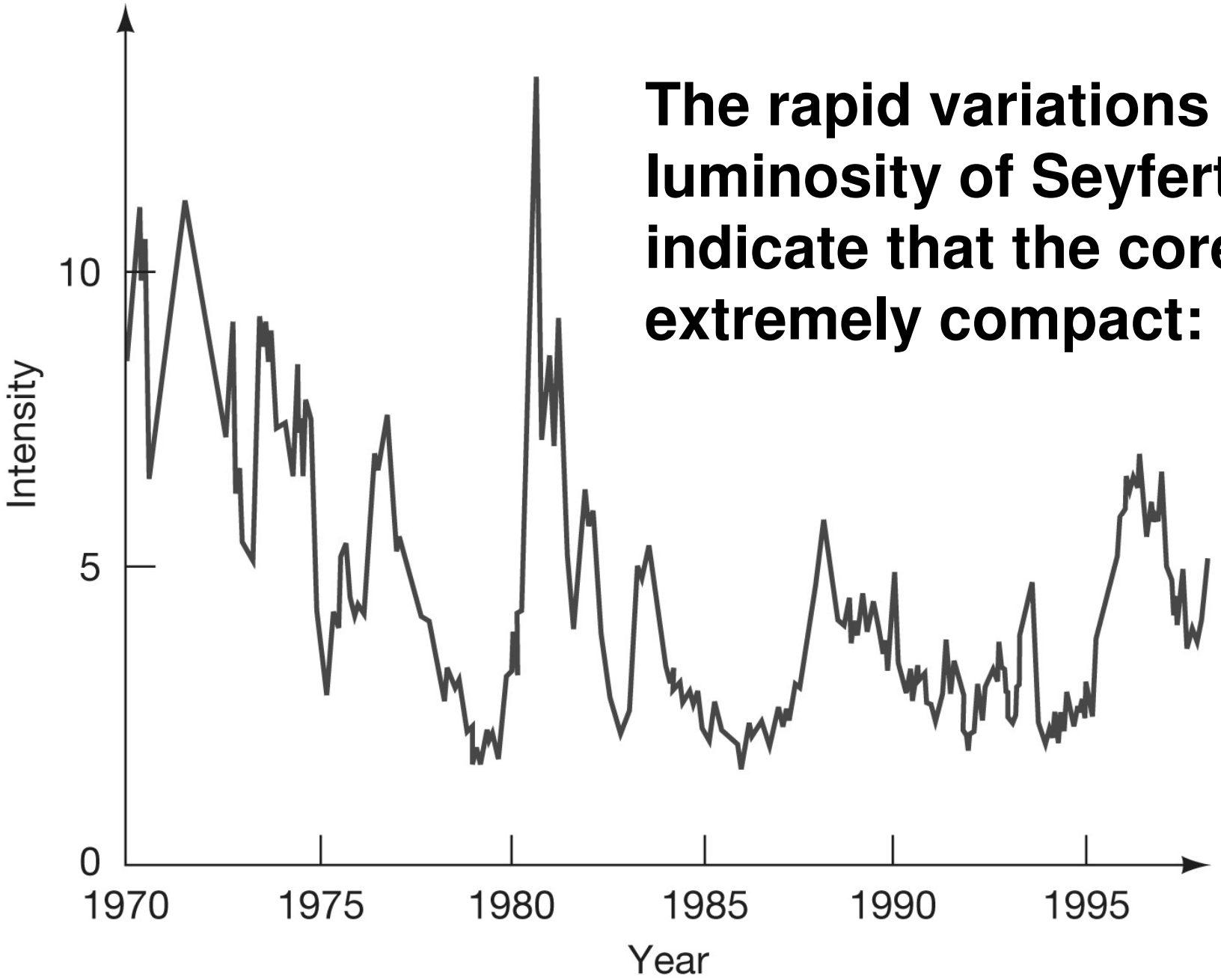
Active galaxies are classified into three types: Seyfert galaxies, radio galaxies, and quasars.

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





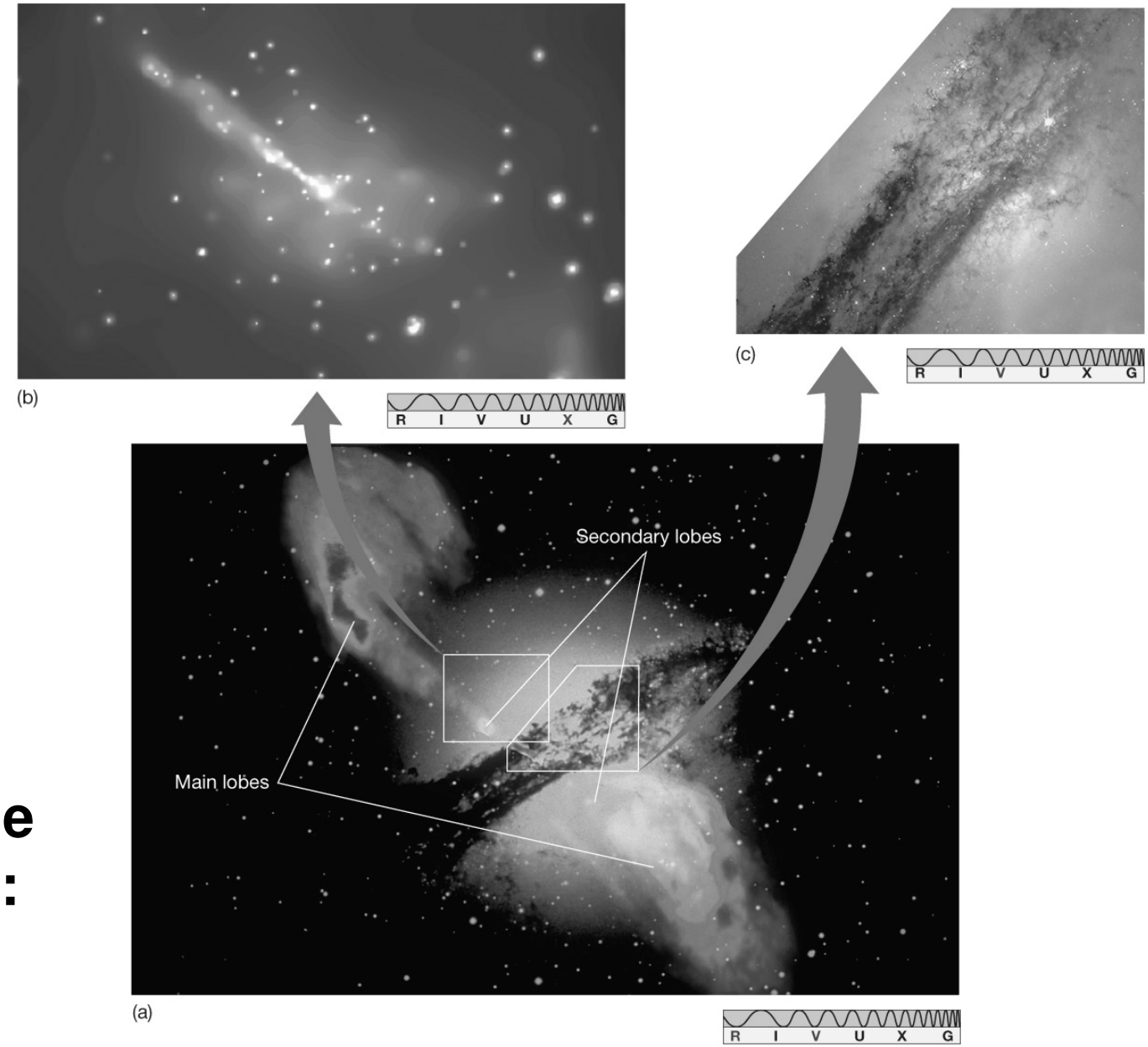
15.4 Active Galactic Nuclei



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

15.4 Active Galactic Nuclei

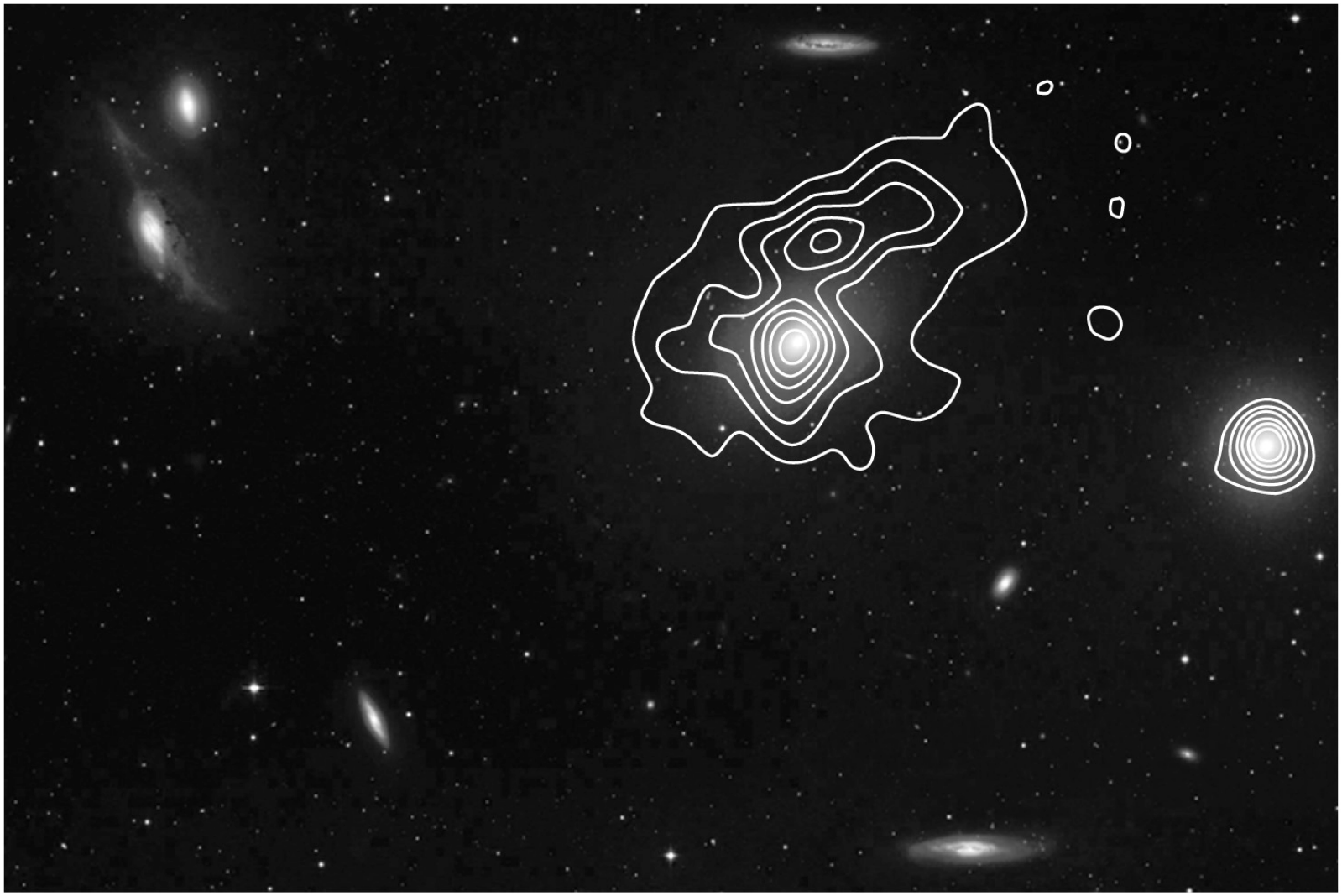
Radio galaxies emit very strongly in the radio portion of the spectrum.

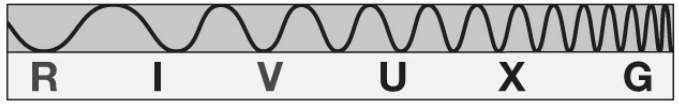


They may have enormous lobes, invisible to optical telescopes, perpendicular to the plane of the galaxy:

15.4 Active Galactic Nuclei

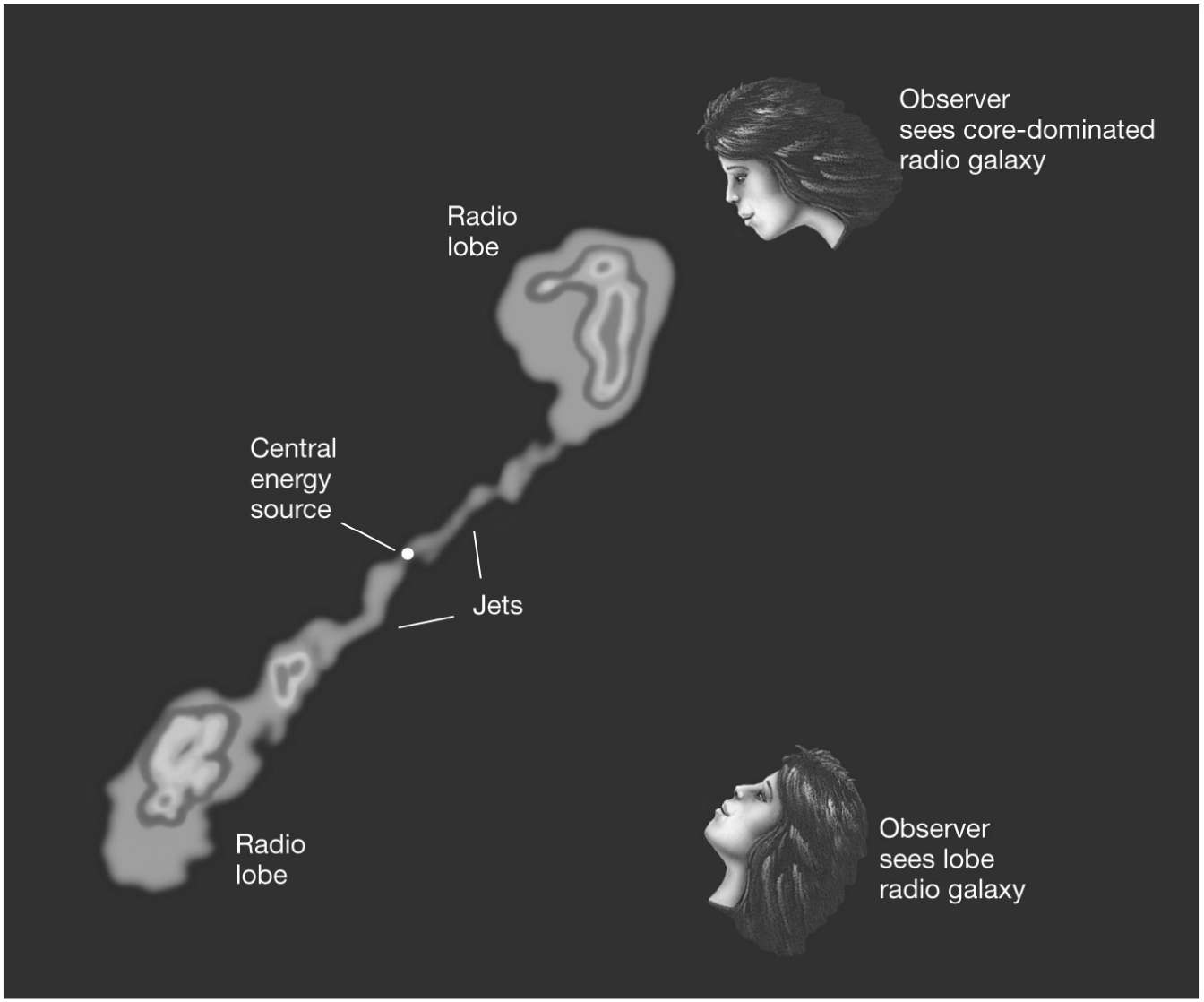
Radio galaxies may also be core-dominated:



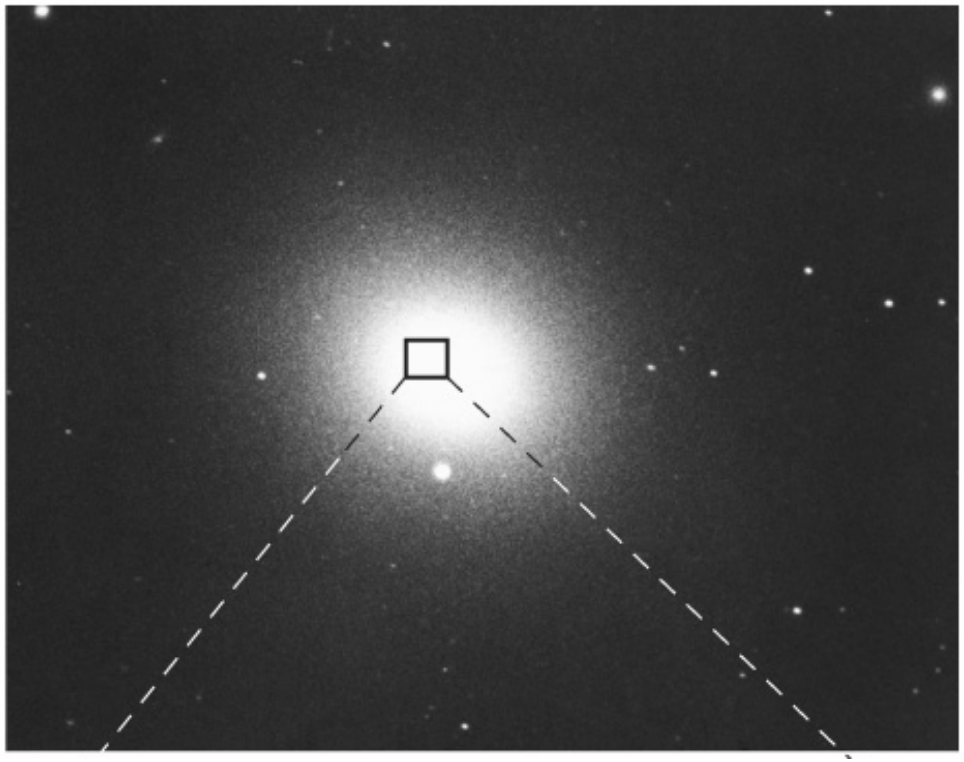


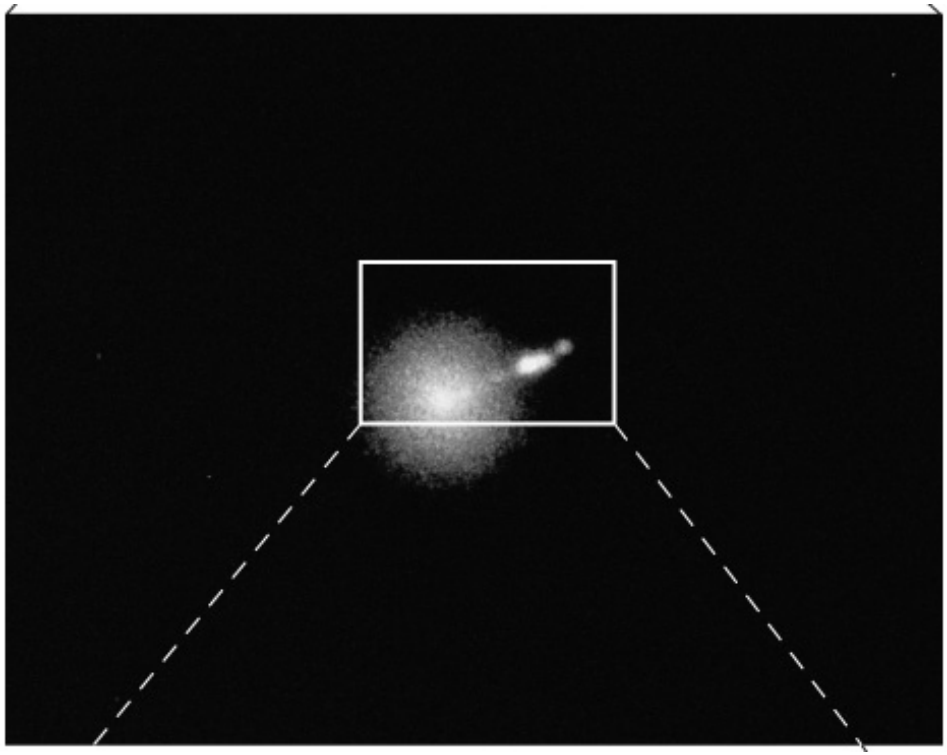
15.4 Active Galactic Nuclei

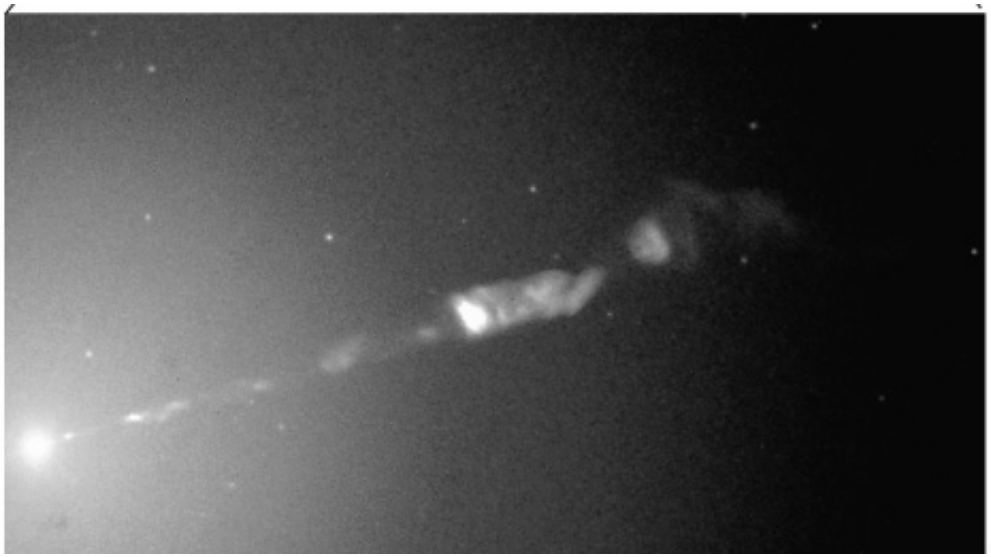
Core-dominated and radio-lobe galaxies are probably the same phenomenon viewed from different angles:



15.4 Active Galactic Nuclei



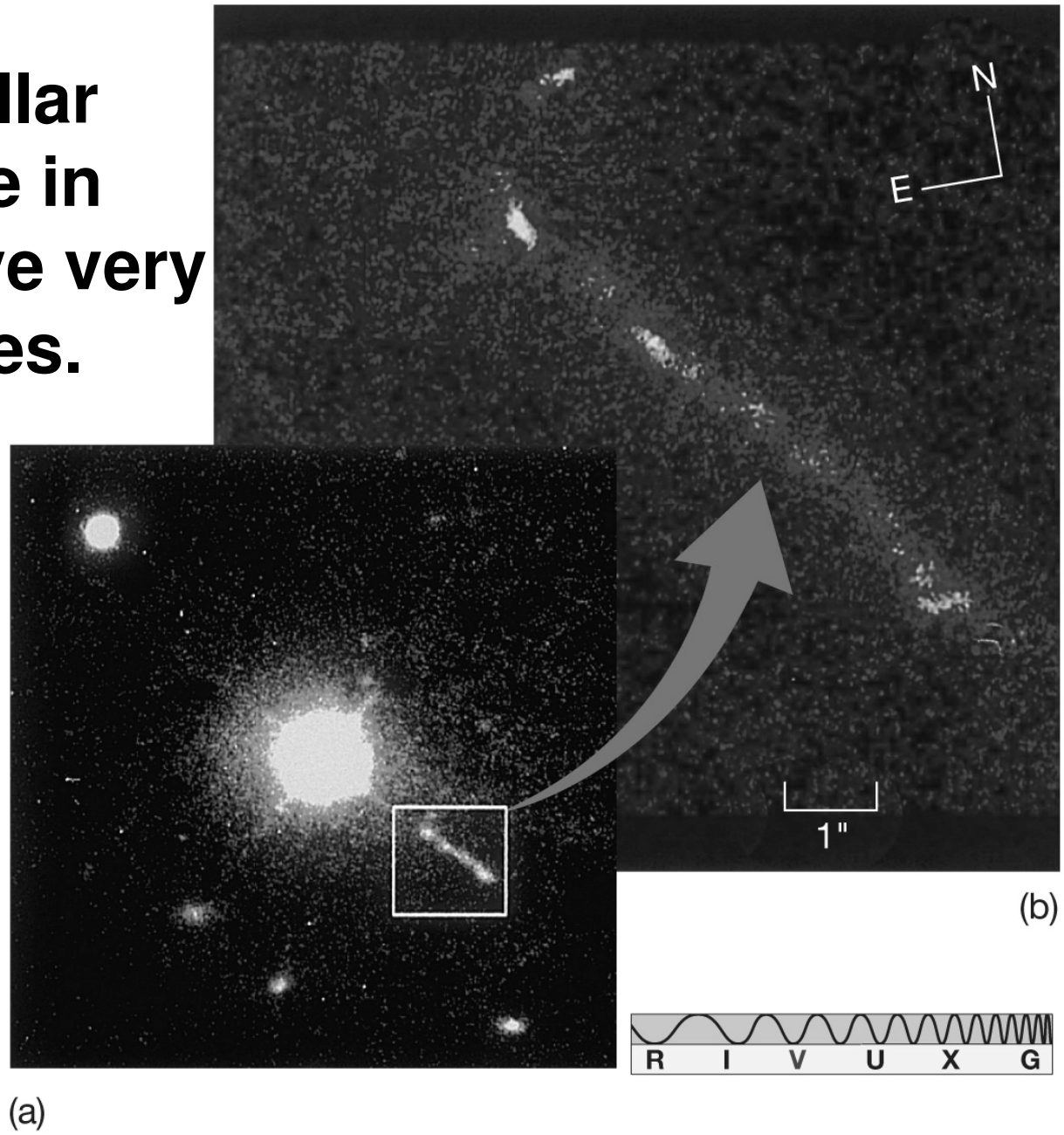




Many active galaxies have jets, and most show signs of interactions with other galaxies.

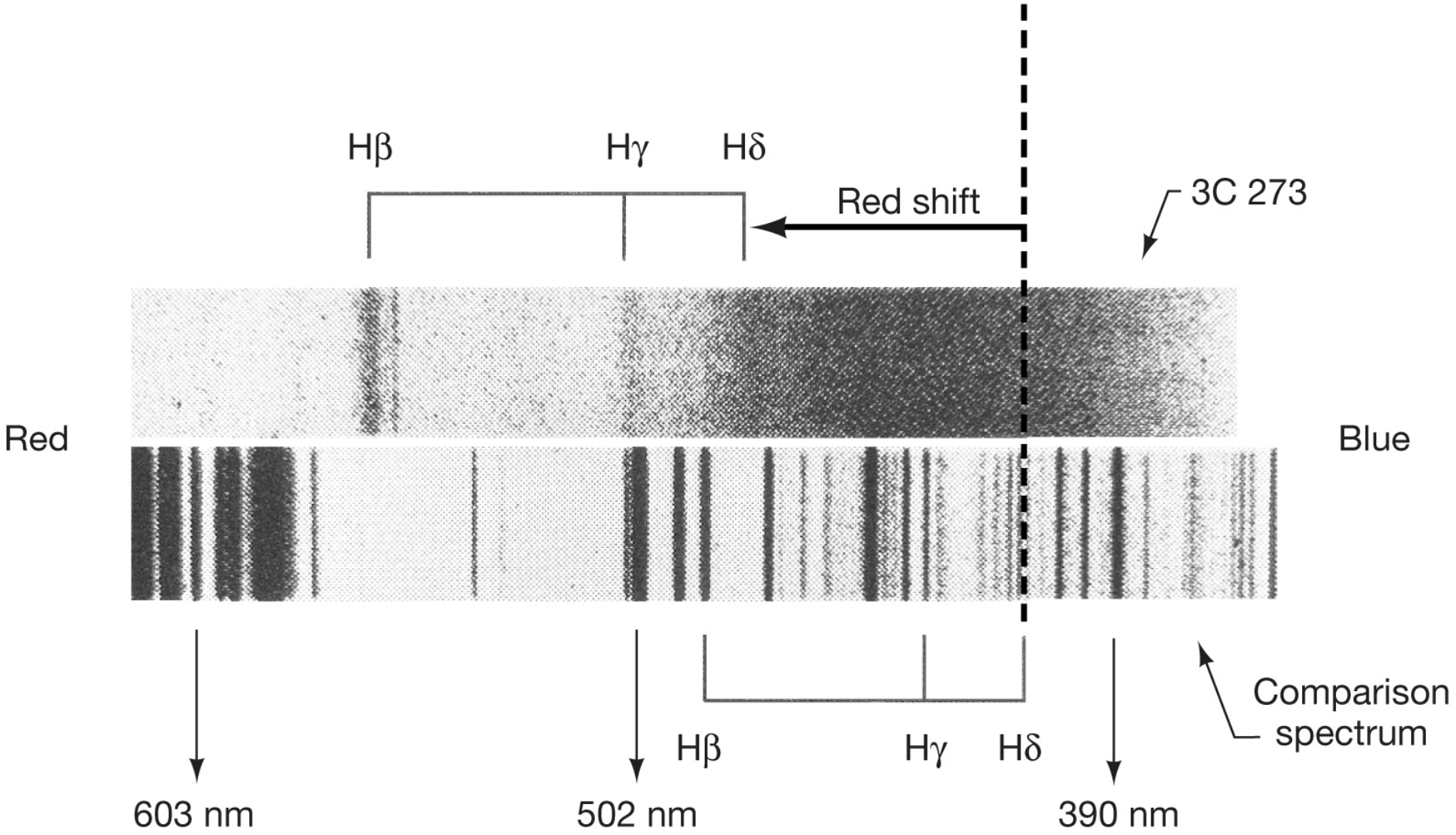
15.4 Active Galactic Nuclei

Quasars – quasi-stellar objects – are starlike in appearance, but have very unusual spectral lines.



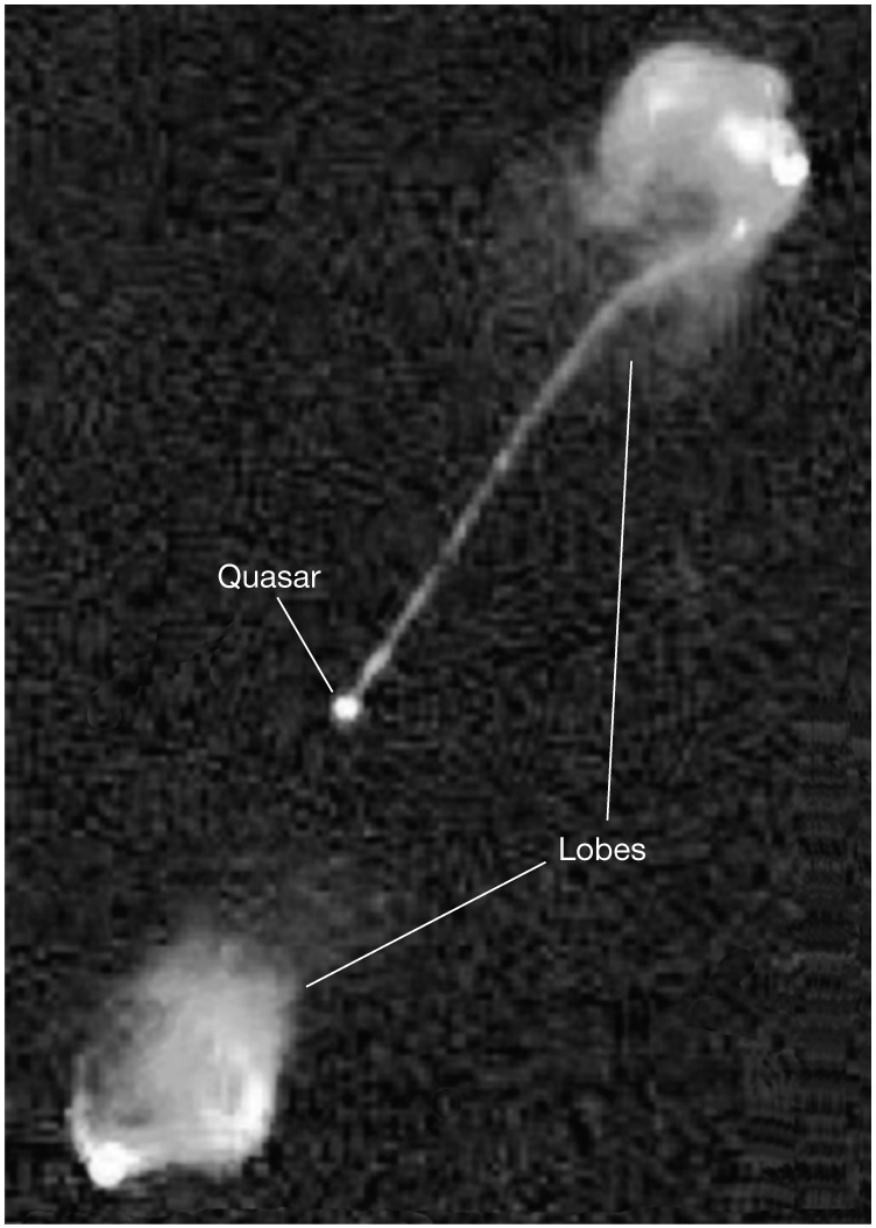
15.4 Active Galactic Nuclei

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



15.4 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.



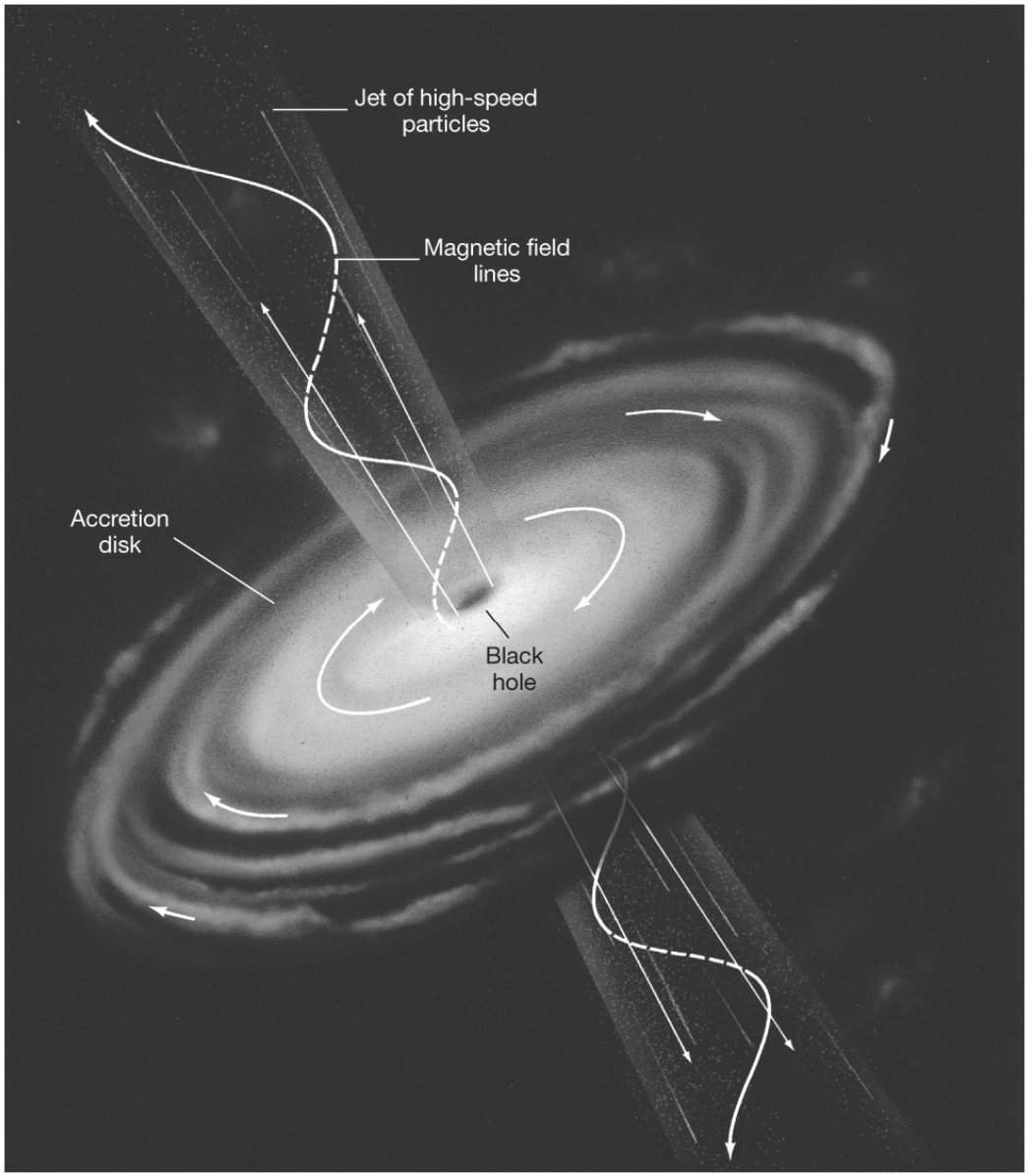
15.5 The Central Engine of an Active Galaxy

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**

15.5 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.



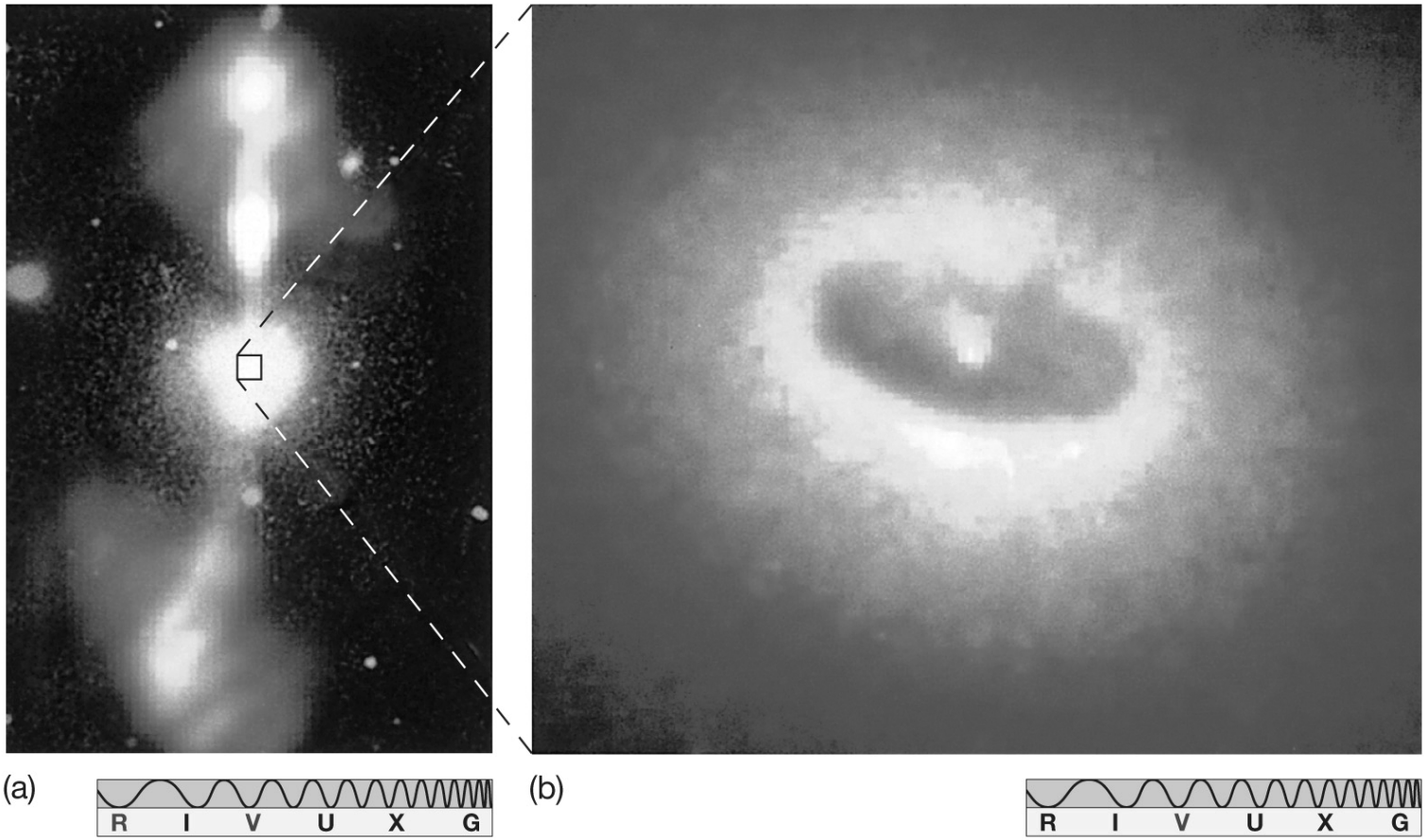
15.5 The Central Engine of an Active Galaxy

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.

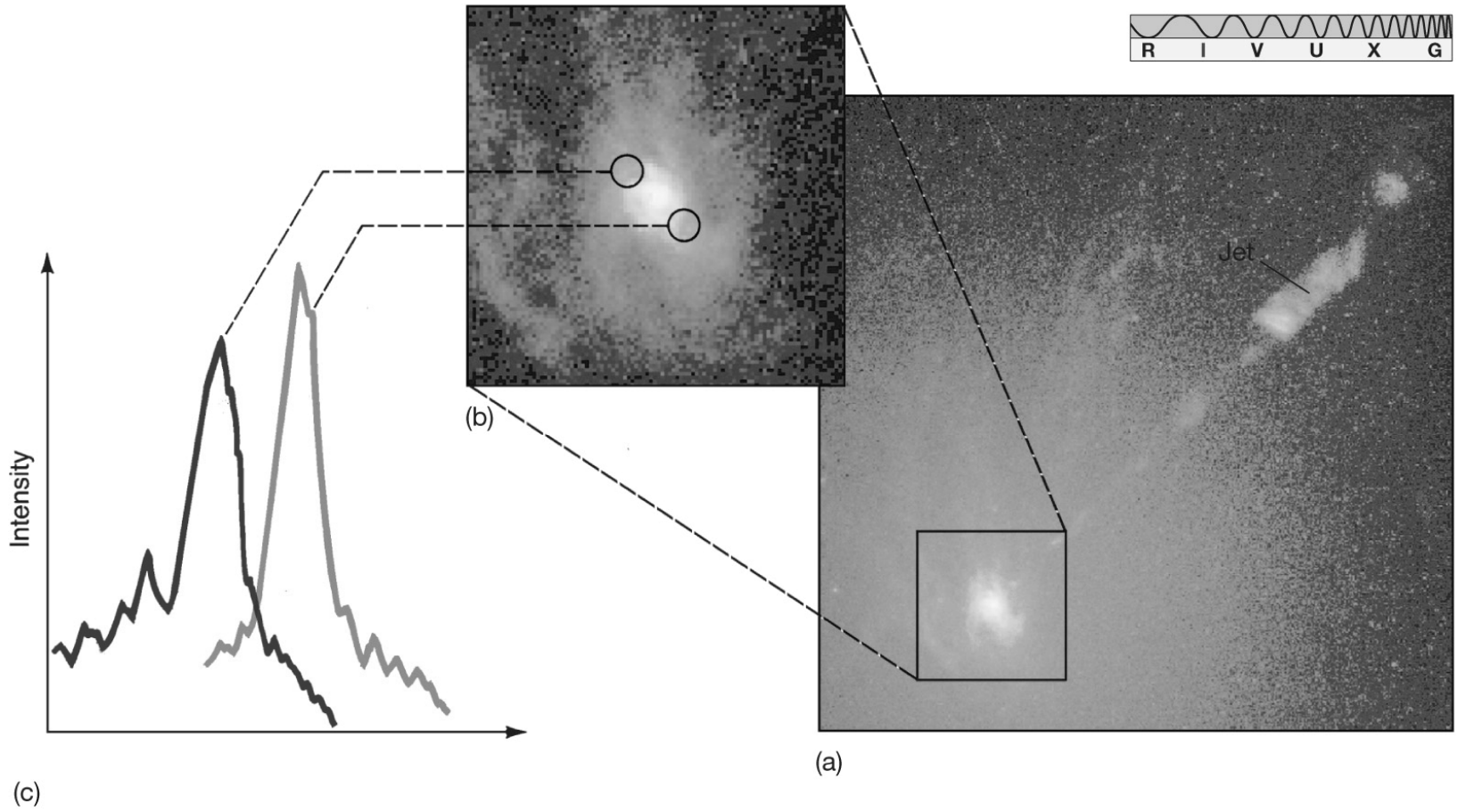
15.5 The Central Engine of an Active Galaxy

The jets emerging from an active galaxy can be quite spectacular:



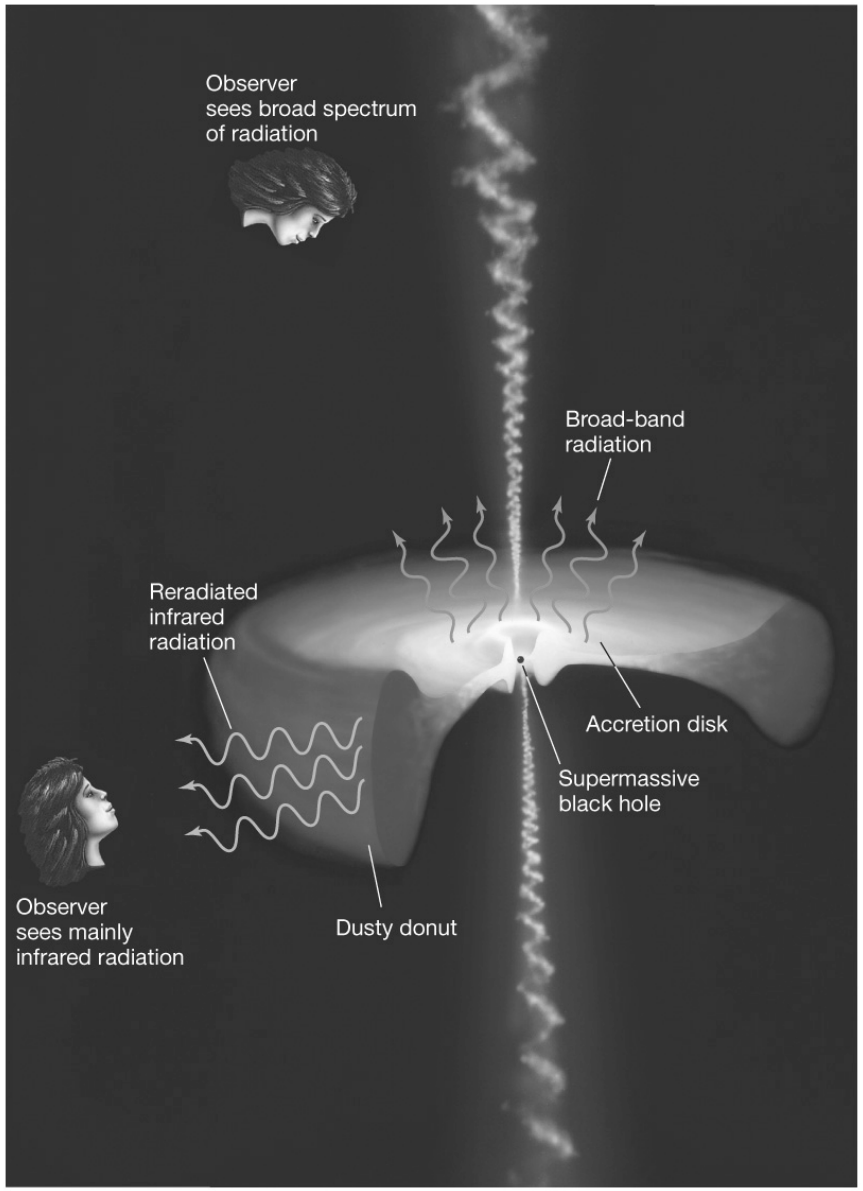
15.5 The Central Engine of an Active Galaxy

Recent measurements of the core of the galaxy M87 indicate that it is rotating very rapidly.



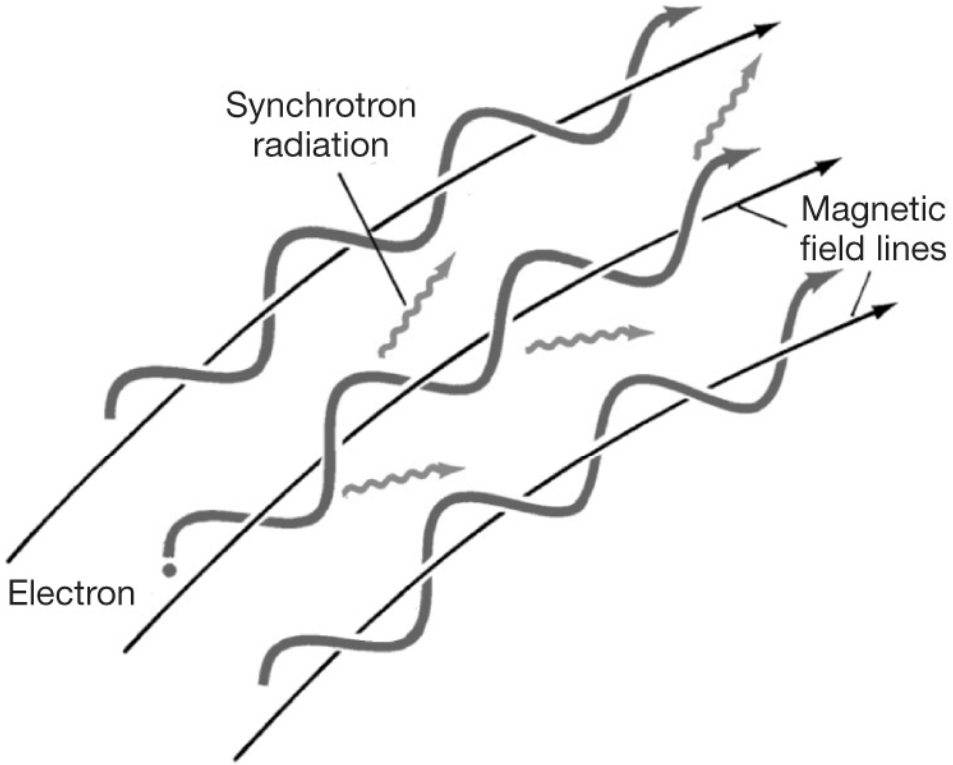
15.5 The Central Engine of an Active Galaxy

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.

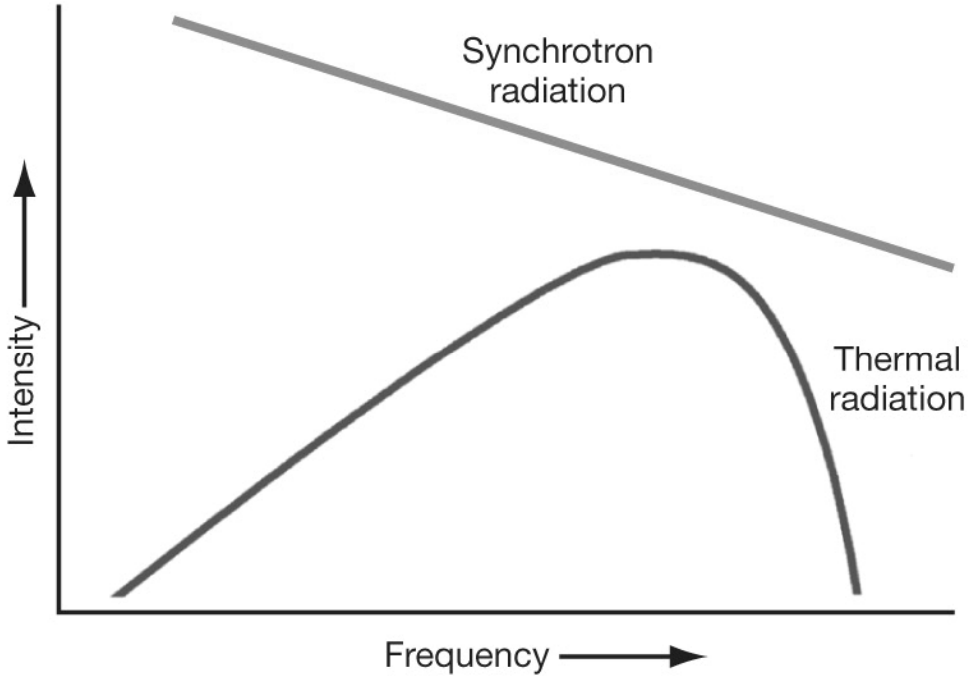


15.5 The Central Engine of an Active Galaxy

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



(a)



(b)

Summary of Chapter 15

- 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 15

- **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**