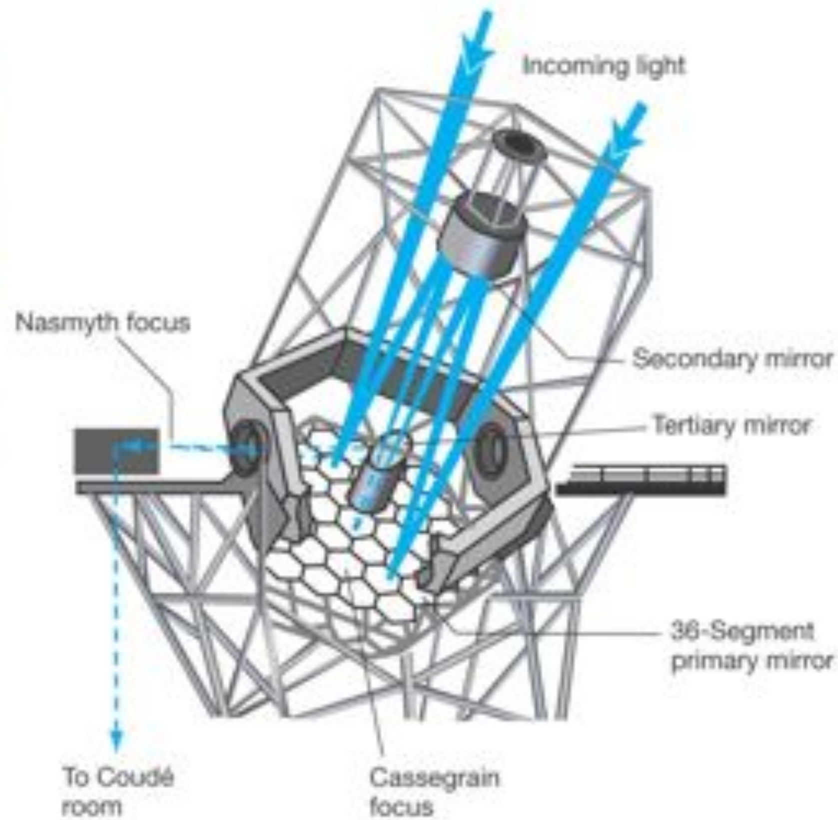
Chapter 5: Telescopes

You don’t have to know different types of reflecting and refracting telescopes.

(c)

(a)



(b)

Why build bigger and bigger telescopes? There are a few reasons. The first is:

Light-gathering power:

Obviously bigger telescopes can collect more light, because the amount gathered just depends on the area of the telescope (diameter squared).

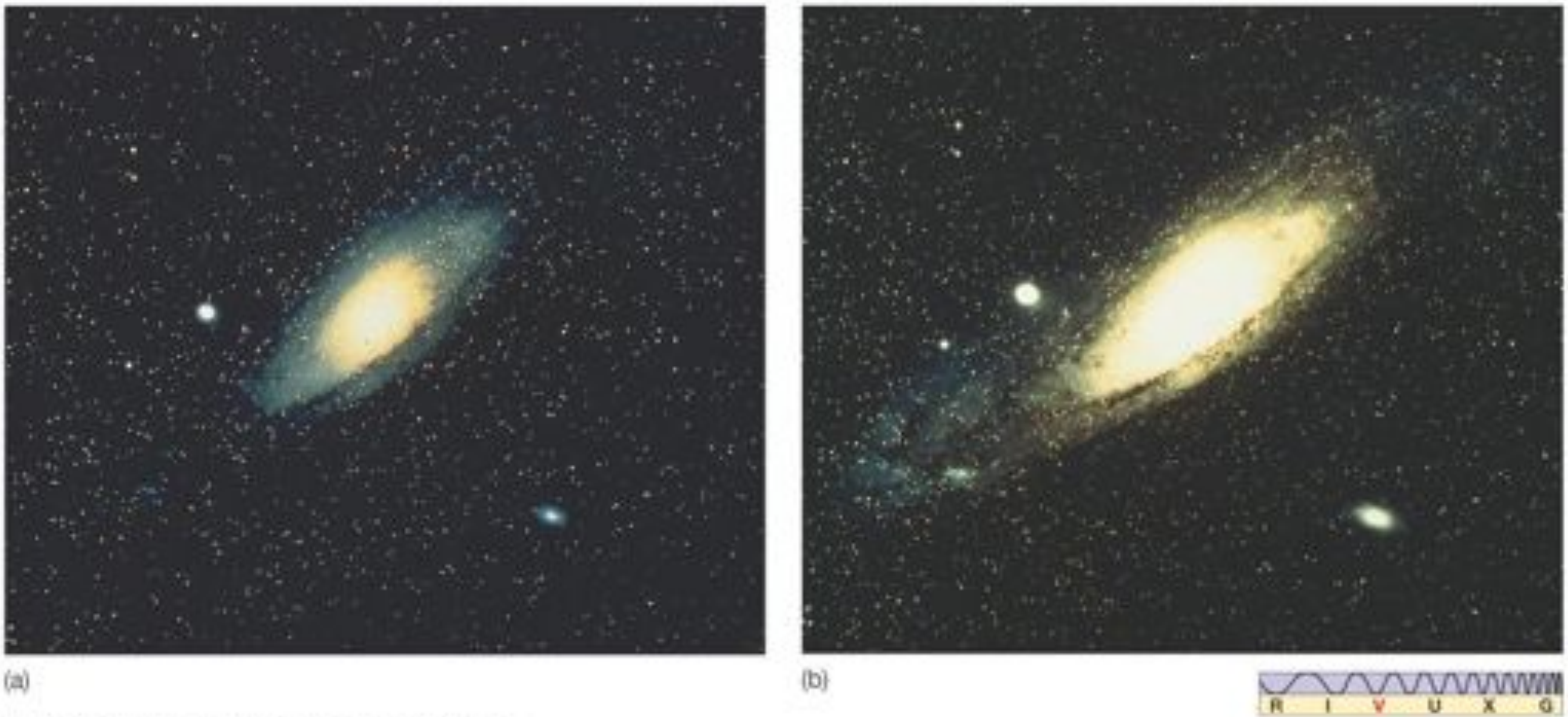
This property determines the ability to see faint objects. Faint objects might not be nearby, but could be very distant. So need a large telescope to see the faintest, nearby objects in the universe, and the most distant.

You also need a LOT of light to obtain spectra with high enough *spectral* resolution to analyze spectral lines!

(Think about it--you're trying to study a tiny fraction of the entire spectrum of an object if you try to analyze a spectral line.)

Larger telescope means more photons collected:
Can see fainter objects, or parts of objects.

Below: same galaxy but image from smaller telescope is on the left:
Outer regions (right) too faint to see.



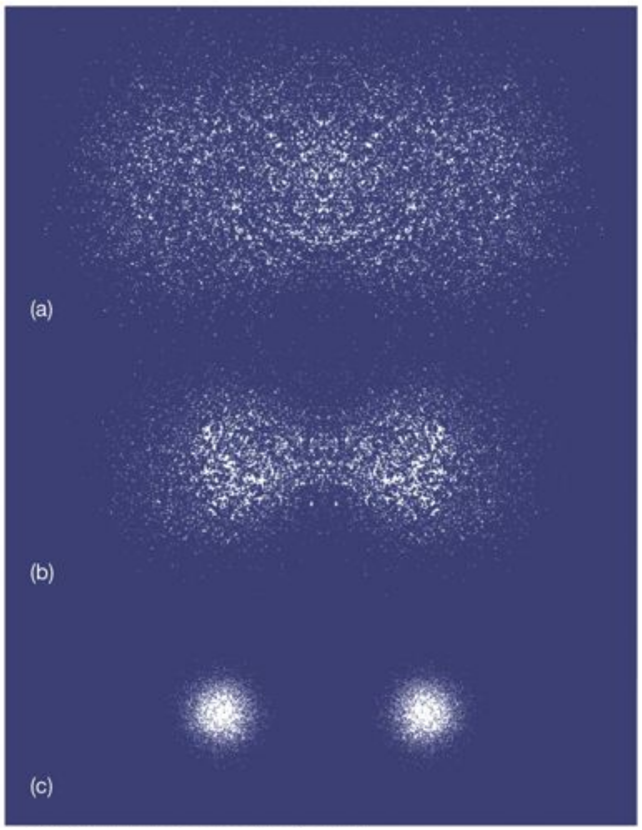
The largest telescopes are built at the highest altitudes, in order to avoid as much of the Earth's atmosphere as possible. This shows the collection of some of the world's largest telescopes on the same mountain in Hawaii.

(a)

European counterpart

Resolution: how well you can distinguish two objects, or detail in a single object. It is an *angle*, usually in arcseconds.

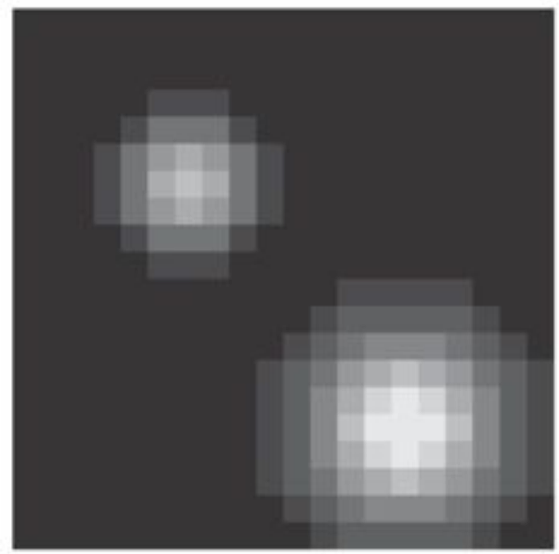
Increasing resolution from top to bottom. *High* resolution is good, means sharp image.



Images are pixels with brightnesses, 0,1, 2,… in the image below. Notice that with only a few brightness levels and only a few hundred pixels (resolution is very poor), only gross features can be seen.

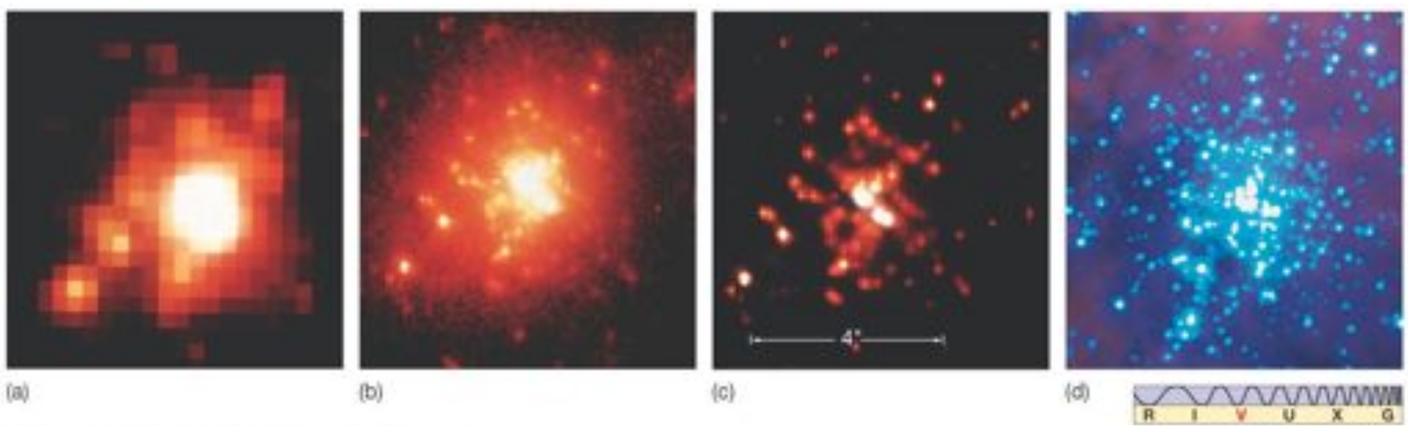
At higher resolution these two round objects might turn out to have intricate detail, or be pictures of human faces, or anything!

0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	1	3	3	3	1	0	0	0	0	0	0	0	0	0	0	0
0	0	0	1	3	5	6	5	3	1	0	0	0	0	0	0	0	0	0	0
0	0	0	1	3	6	7	6	3	1	0	0	0	0	0	0	0	0	0	0
0	0	0	1	3	5	6	5	3	1	0	0	0	0	0	0	0	0	0	0
0	0	0	0	1	3	3	3	1	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	0	0	0
0	0	0	0	0	0	0	0	0	0	0	1	2	2	2	2	2	1	0	0
0	0	0	0	0	0	0	0	0	0	1	2	3	4	4	4	3	2	1	0
0	0	0	0	0	0	0	0	0	1	2	3	5	6	7	6	5	3	2	1
0	0	0	0	0	0	0	0	0	1	2	4	6	8	9	8	6	4	2	1
0	0	0	0	0	0	0	0	0	1	2	4	7	9	9	9	7	4	2	1
0	0	0	0	0	0	0	0	0	1	2	4	6	8	9	8	6	4	2	1
0	0	0	0	0	0	0	0	0	1	2	3	5	6	7	6	5	3	2	1
0	0	0	0	0	0	0	0	0	0	1	2	3	4	4	4	3	2	1	0
0	0	0	0	0	0	0	0	0	0	0	1	2	2	2	2	2	1	0	0



Example: we want to resolve individual stars in galaxies.

With increasing resolution, the "blob" on the left is seen to be a cluster of thousands of stars (right)



Resolution (continued)

Note: if you have trouble remembering "resolution", remember that poor resolution means "blurry," and is equivalent to being nearsighted, or having a digital camera with only 0.2 megapixels.

How to enhance resolution? First must understand the limitations, which are

1. **The "seeing limit" (Earth's atmosphere), and**
2. **The "diffraction limit" (inherent in observing through an instrument)**

The diffraction limit

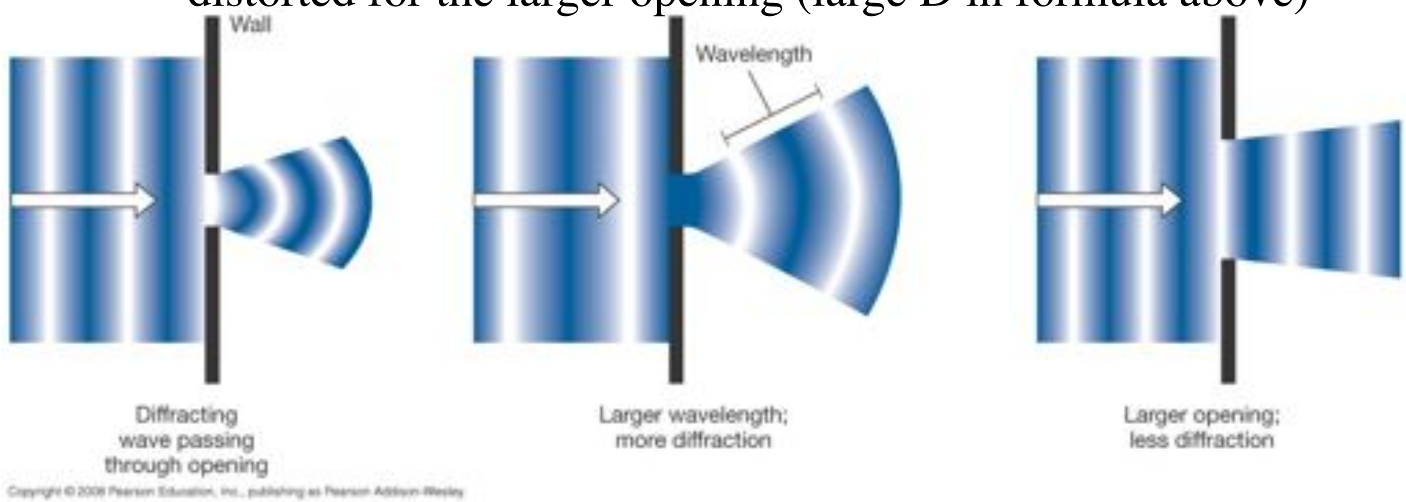
<u>Diffraction limit</u> λ/D (just due to the fact that you're using an instrument with edges and boundaries—see text)

(λ = wavelength, D = diameter of telescope)

(Remember: poor resolution means a large number, like 7 arcsec compared to 2 arcsec.) So resolution is poorer at radio wavelengths than, say, optical wavelengths for a given telescope diameter D; i.e. **D *has* to be huge for radio telescopes. (see next slide)**

But even optical telescopes must deal with this effect.

Drawing from textbook illustrates how diffraction distorts a wave passing through an opening. Notice the image is less distorted for the larger opening (large D in formula above)



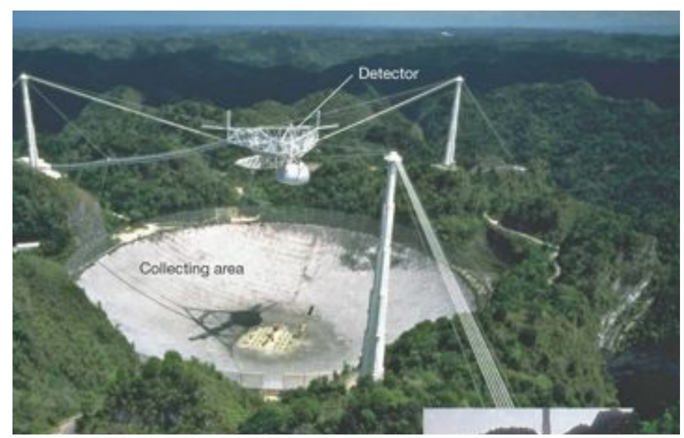
Diffraction limit requires huge radio telescopes

Radio waves can get into the atmosphere without being blocked. But a problem is that their wavelengths are so large that their diffraction limit on resolution is also very large.

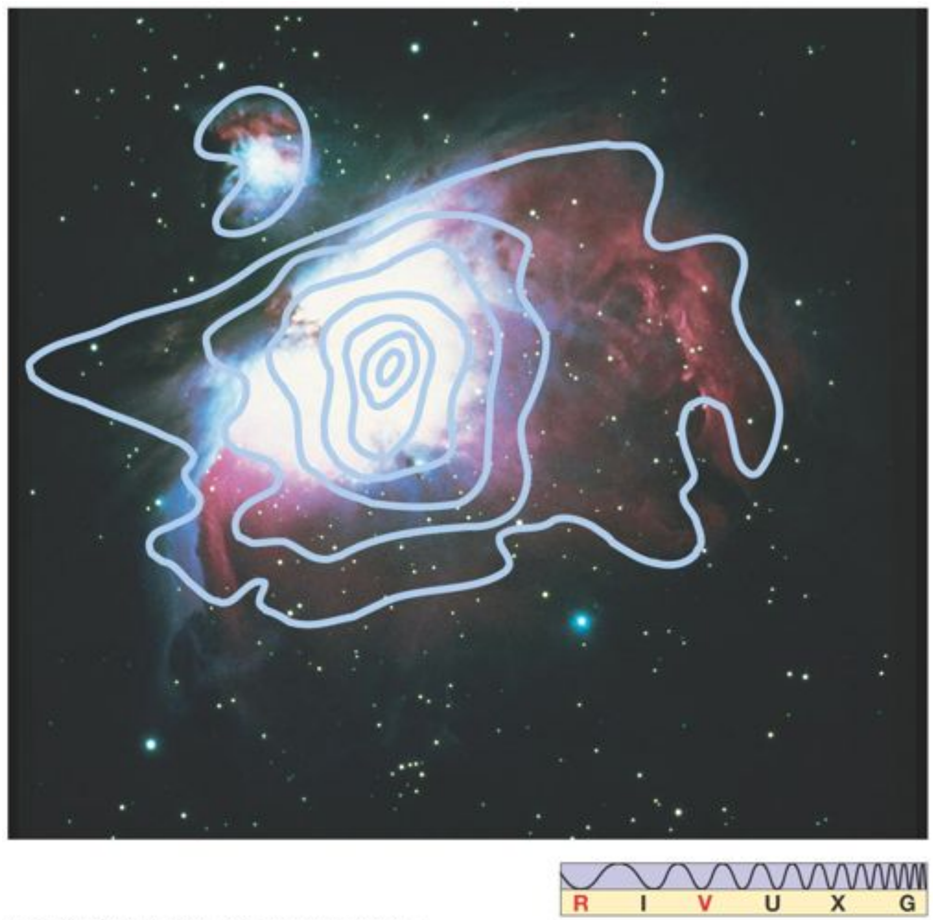
If radio telescopes were the size of optical telescopes, the radio sky would look like one big blur.

(a) (b)

World's largest: Arecibo (1,000 ft. dish)



The “contours” show the low resolution image that a radio telescope was able to produce for this object. The rest of the image is from an optical telescope, so much higher resolution.



A solution: Interferometers


(a)

One way around the diffraction limit, which has almost entirely been used for radio telescopes so far, is to use <u>interferometers</u>—
several radio telescopes used to simulate one huge telescope in order to get great resolution. Biggest interferometers can get amazing resolutions of 0.001 arc sec or better!
(Read sec. 5.6)

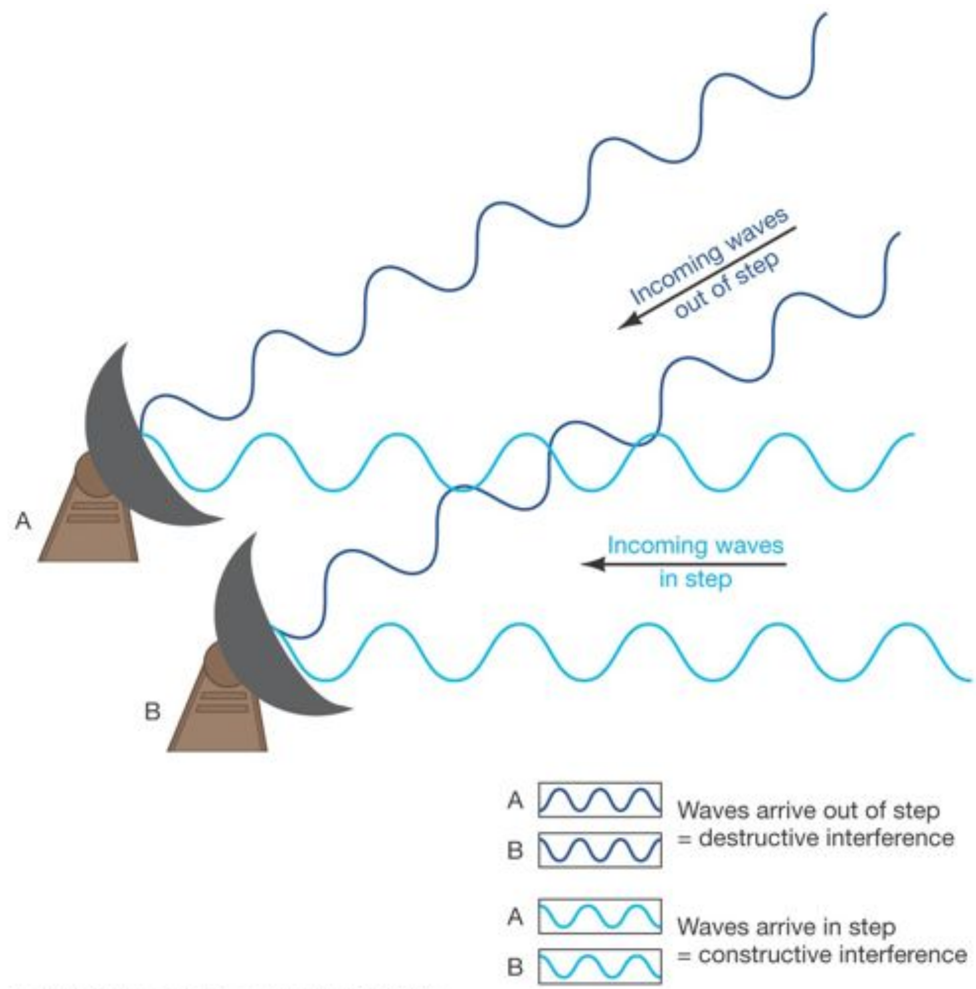
To the right are some pictures of present-day large-baseline interferometers: The VLA and the VLBA

The "Very Large Array" (VLA)

FIGURE 5.18
The Very Long Baseline Array A map showing the distribution of the ten antennas that constitute an array or radio telescopes stretching across the United States. *(National Radio Astronomy Observatory)*

VLBA=effective size ~ half of U.S.

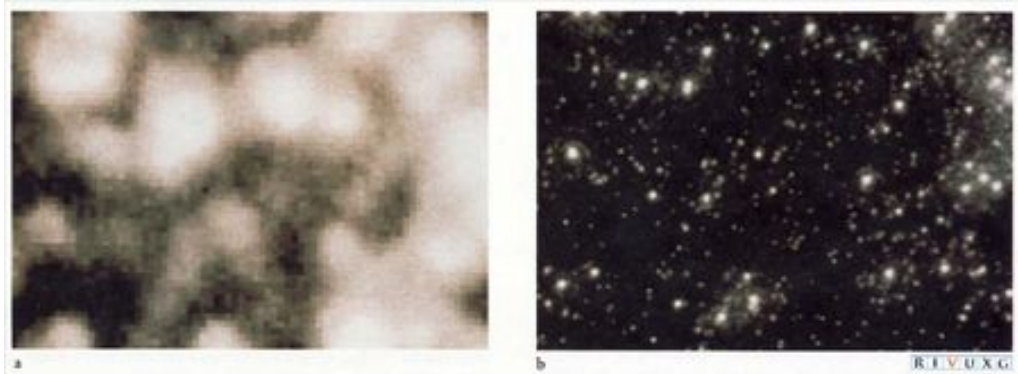
How an interferometer works



The Seeing Limit

2. **Seeing limit**: due to scintillation in the Earth’s atmosphere

“***Scintillation***” caused by scattering of light as it passes through the Earth’s atmosphere. Images become “smeared out” over 1-5 arcsec, depending on altitude, weather, … because they are “twinkling.” (see example)



Effects of Twinkling The same star field photographed with **(a)** a ground-based telescope, which is subject to twinkling, and **(b)** the Hubble Space Telescope, which is free from the effects of twinkling.

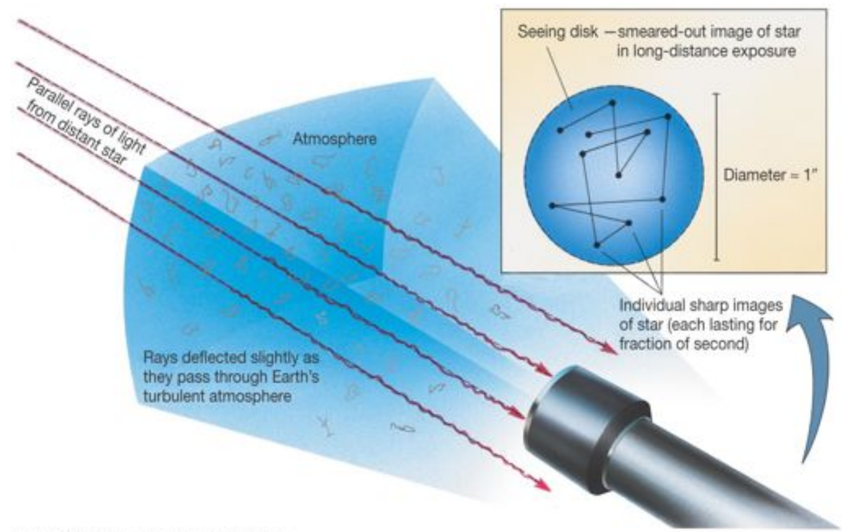
For a ground-based optical telescope the best res. ≈ **1 arc sec** because of this effect.

Two ways around seeing:

1. Adaptive optics in which the mirror constantly
and rapidly adjusts its orientation and shape (sometimes thousands of times per second!) in order to compensate for scintillation. (See discussion sec. 5.4)

2. Space telescopes (Hipparcos, IRAS, HST, Spitzer,
Chandra,···Sec. 5.7)

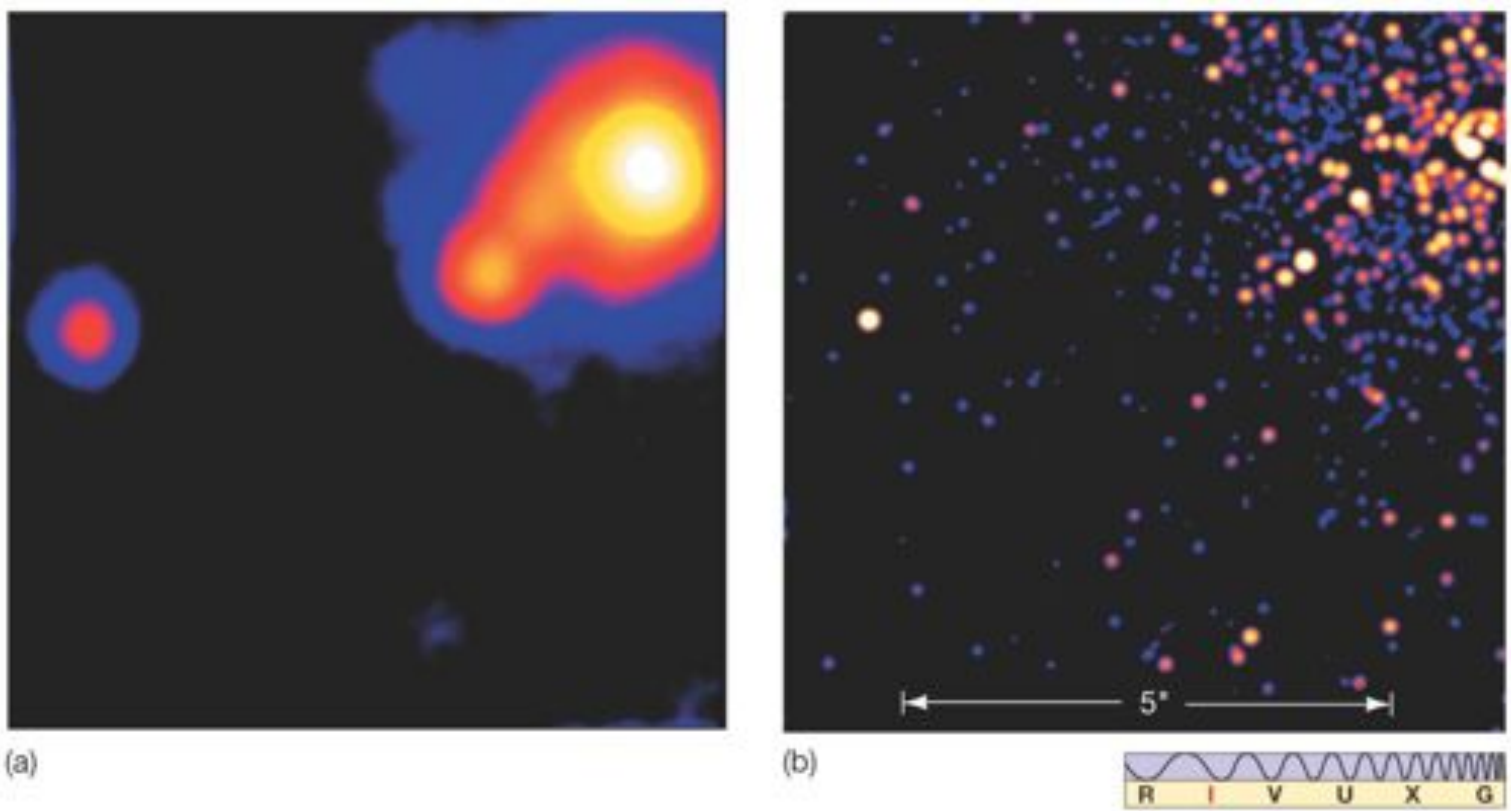
Both of these methods to beat the *seeing limit* can get resolutions approaching
0.05 arc sec or less.



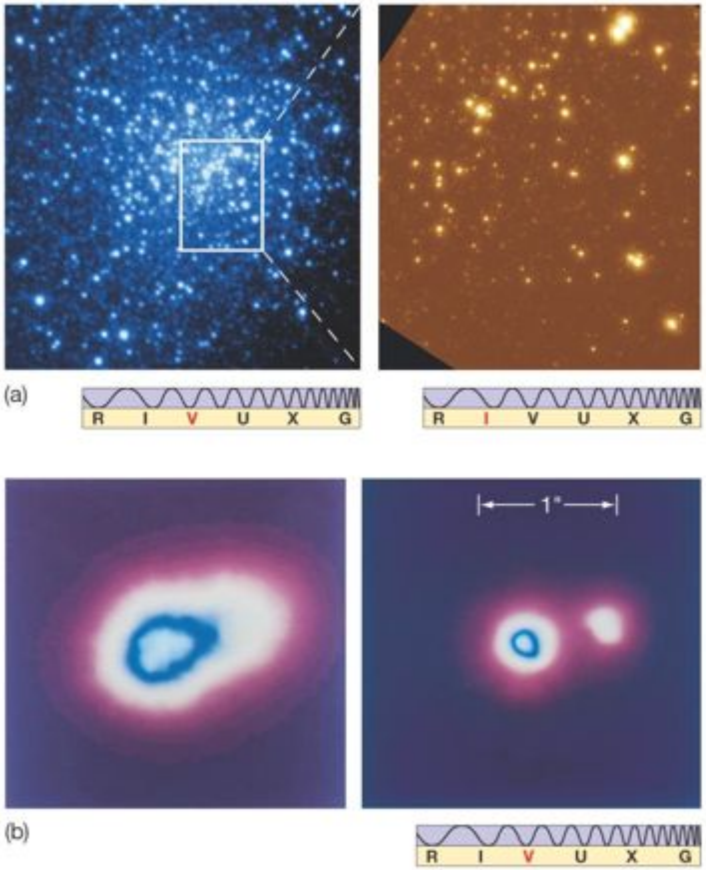
Adaptive optics at work

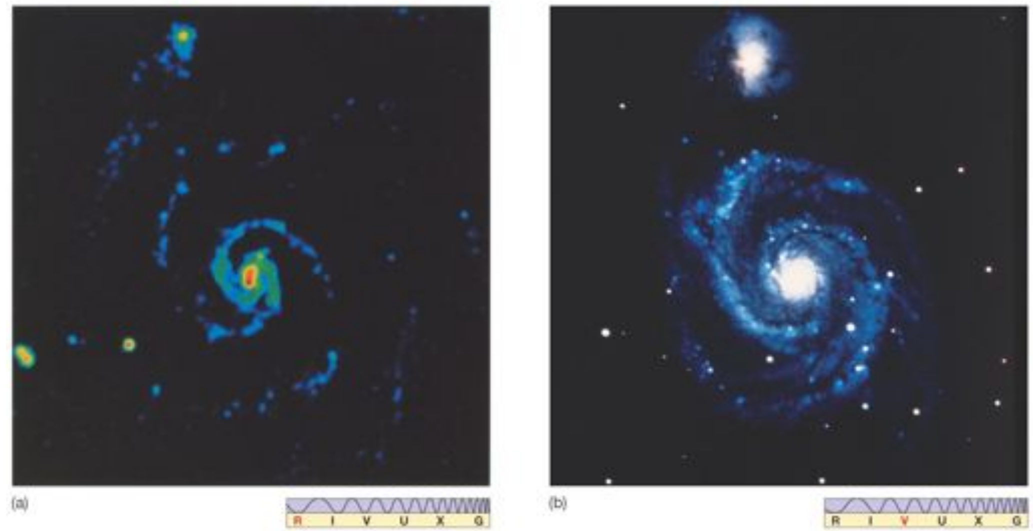
Left: Observation from ground, can see three blurred objects.
Right: Above atmosphere, or with adaptive optics, blurry object is *resolved* into a star cluster.

This is an important example: Based on the low-resolution image, people supposed there could be supermassive stars, 1000 times the Sun's mass. But the image on the right shows that, when the region is resolved, there just 100s of smaller normal mass stars.



Examples of resolution enhancement by adaptive optics





Important additional considerations

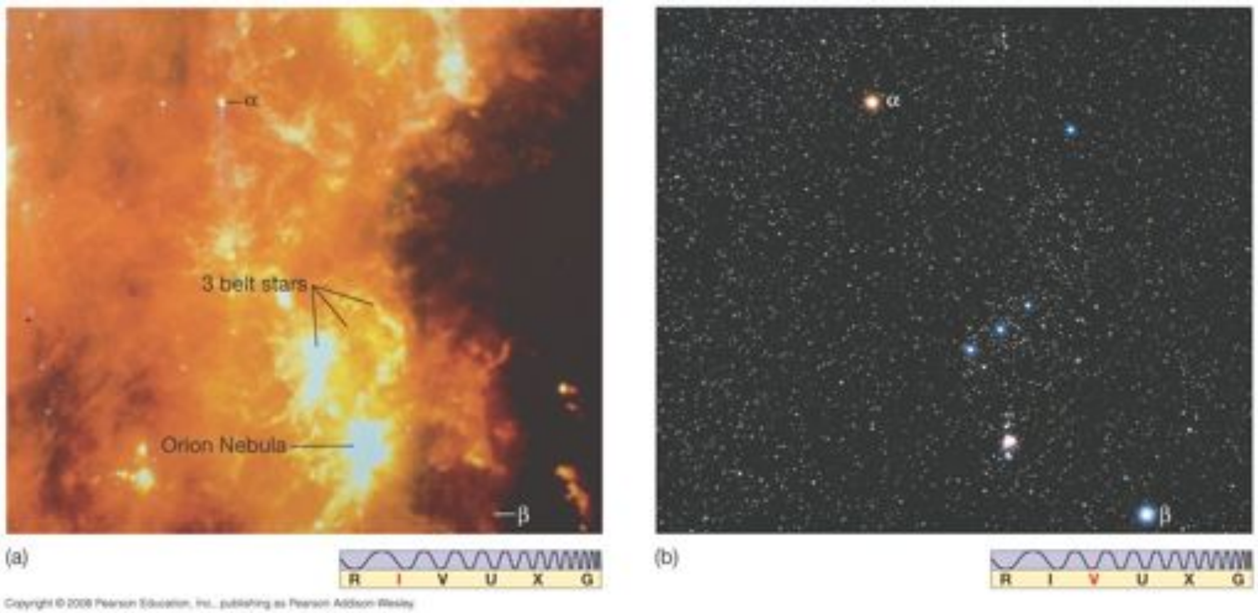
1. Atmospheric transmission--Besides being responsible for *seeing*, the Earth's atmosphere also just blocks out light. Visible and radio wavelengths are least affected (recall material from ch.3). For other wavelength regions, need satellite observatories or at least very high mountains (same for visible because of seeing). (Sec. 5.7)

2. CCDs—Photographic plates only capture about 1% of the light, while charge-coupled devices (CCDs) can get about 75% efficiency, *and* **extremely** accurate. (sec. 5.2 in text). For optical telescopes, photographic plates are no longer used.

3. Infrared telescopes—special problem: must be cold, because the telescope itself emits IR radiation (why?). Also, best when above the Earth's atmosphere to avoid molecular absorption (see 1 above). (Sec. 5.7)

4. X-ray and gamma-ray observations—All must be done far up in Earth's atmosphere because absorption is so strong. Need special telescopes, since these don't reflect off mirrors the way that longer-wavelength light does (why not?). See book sec. 5.7 for more details.

Infrared observations: Reveals the gas that is currently forming stars in regions like Orion (shown below). Right is optical photograph of Orion in the night sky. Left is infrared image of the region around Orion's "belt".



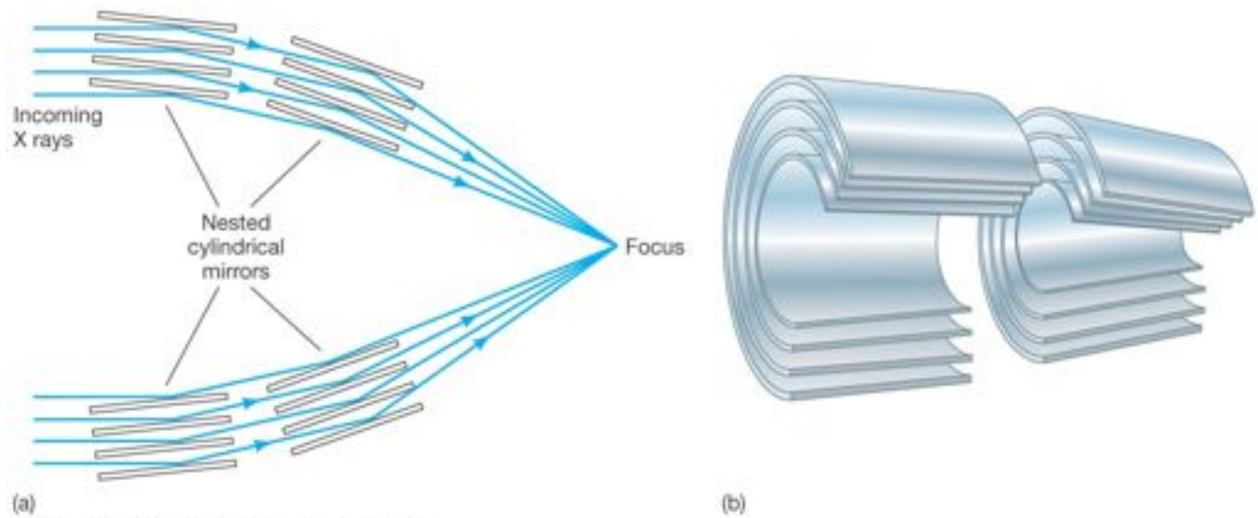
Why do star-forming regions glow in the infrared? Because the hot young stars heat the dust grains to a few hundred degrees, just as the Earth is heated by the Sun.

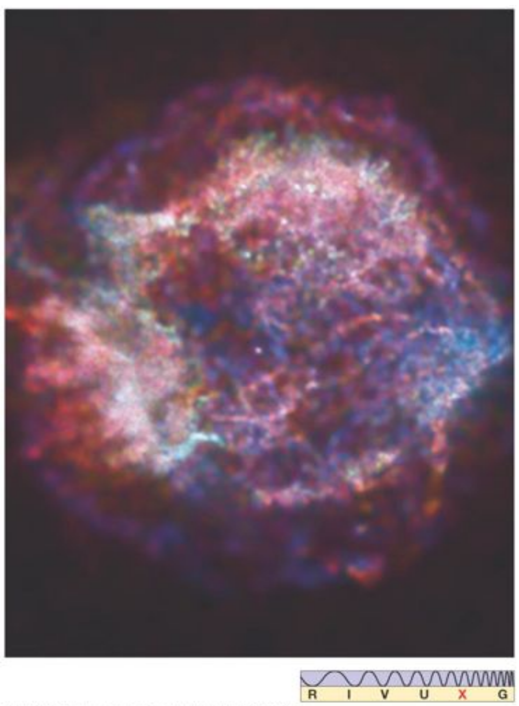
- 1984: IRAS satellite IR telescope gave the first full IR view of the entire sky.
- At the time of writing of your textbook, the premier infrared observatory was the **Spitzer Space Telescope** (see text).
- **Homework question** (to appear on exam 2):

What is the latest infrared space telescope that went into operation in 2009?

X-ray and gamma-ray telescopes: Require completely different design
(see textbook)

This is one of the most important advances in astronomy in the past half-century: The ability to observe the universe as it appears in X-rays and gamma-rays. You have to be above the Earth's atmosphere to do it!





A "supernova" explosion observed in X-rays

Views of the entire sky at different wavelengths.
Horizontal band in center is the disk of our galaxy, the Milky Way

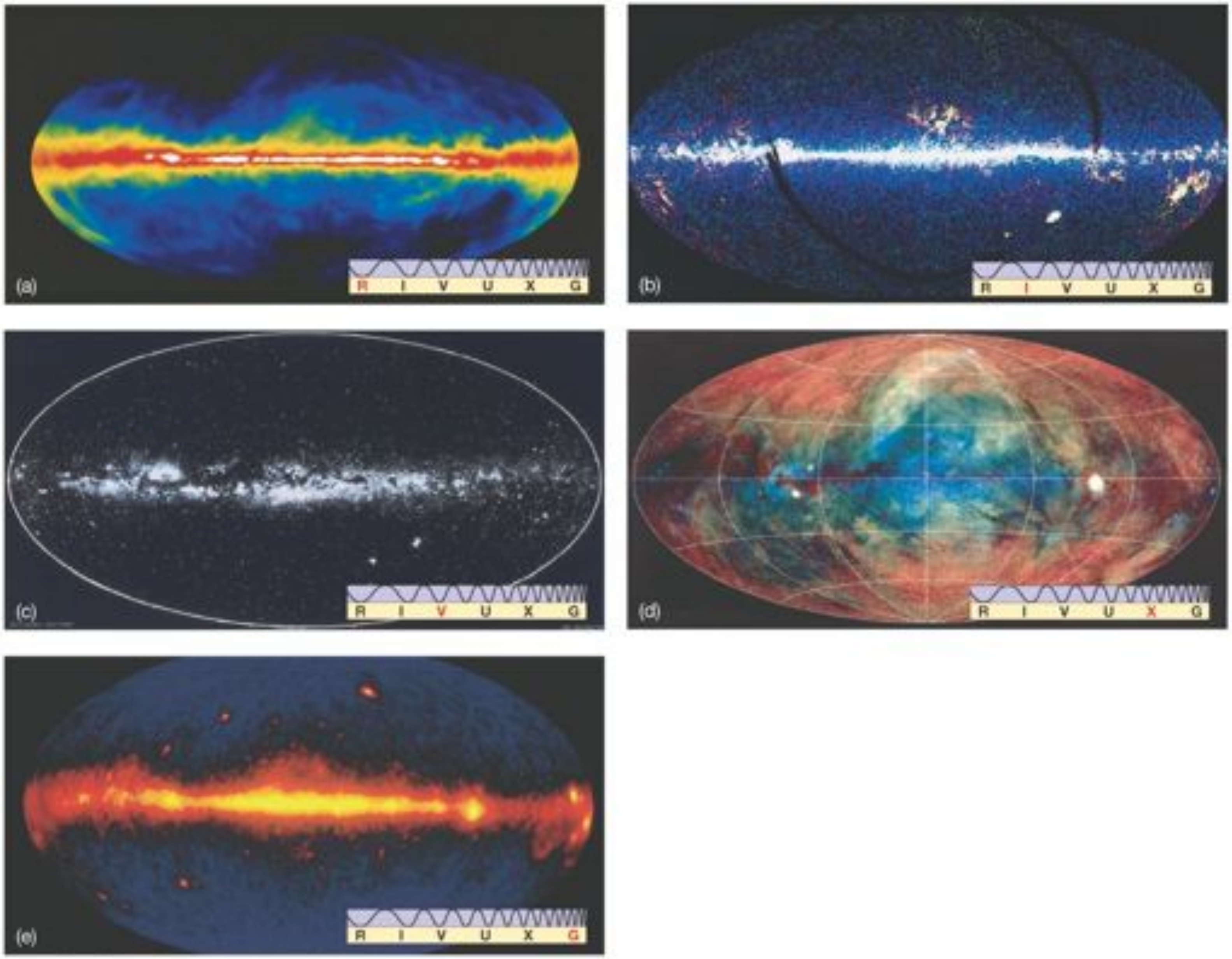


Table 5.1 from textbook: A useful way to review—see "general considerations." The "Common Applications" are an indication of how often we will be encountering observations in these wavelength regions in future chapters.

TABLE 5.1 Astronomy at Many Wavelengths

	General Considerations	Common Applications (Chapter Reference)
Radio	Can penetrate dusty regions of interstellar space Earth's atmosphere largely transparent to these wavelengths Can be detected in the daytime as well as at night High resolution at long wavelengths requires very large telescopes or interferometers	Radar studies of planets (2,9) Planetary magnetic fields (11) Interstellar gas clouds and molecules (18) Galactic structure (23, 24) Galactic nuclei and active galaxies (23, 24) Cosmic background radiation (27)
Infrared	Can penetrate dusty regions of interstellar space Earth's atmosphere only partially transparent to infrared radiation, so some observations must be made from space	Star formation (19,20); cool stars (20) Center of the Milky Way Galaxy (23) Active galaxies (24) Large-scale structure of the universe (25, 27)
Visible	Earth's atmosphere transparent to visible light	Planets (7–14) Stars and stellar evolution (17, 20, 21) Normal and active galaxies (23, 24) Large-scale structure of the universe (25)
Ultraviolet	Earth's atmosphere is opaque to ultraviolet radiation, so observations must be made from space	Interstellar medium (19) Hot stars (21)
X-ray	Earth's atmosphere is opaque to X-rays, so observations must be made from space. Special mirror configurations are needed to form images	Stellar atmospheres (16) Neutron stars and black holes (22) Active galactic nuclei (24) Hot gas in galaxy clusters (25)
Gamma ray	Earth's atmosphere is opaque to gamma rays, so observations must be made from space. Cannot form images	Neutron stars (22) Active galactic nuclei (24)