

Telescopes (Chapter 6)

Based on Chapter 6

- This material will be useful for understanding Chapters 7 and 10 on “Our planetary system” and “Jovian planet systems”
- Chapter 5 on “Light” will be useful for understanding this chapter

Goals for Learning

- How are cameras similar to eyes?
- What is angular resolution?
- What are refracting and reflecting telescopes?
- Why put telescopes in space?

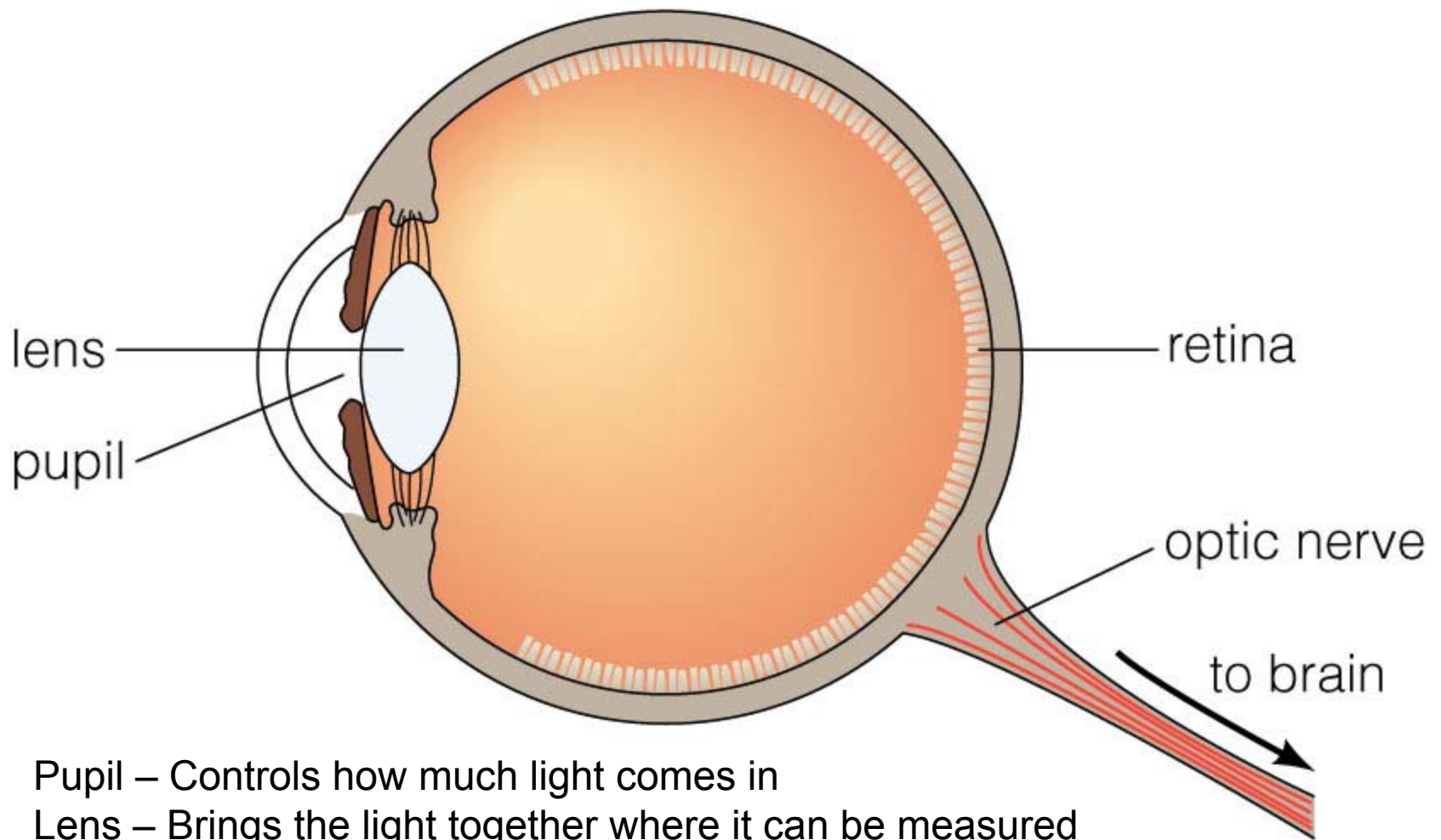
Measuring Light

- The light from other worlds contains vast amounts of information about those worlds.
- Why can't we just use our eyes to study this light?

Eyes?

- Visible only
- Eyes can't make records of what they see
- Can't see dim light, blinded by bright light
- Different eyes have different properties

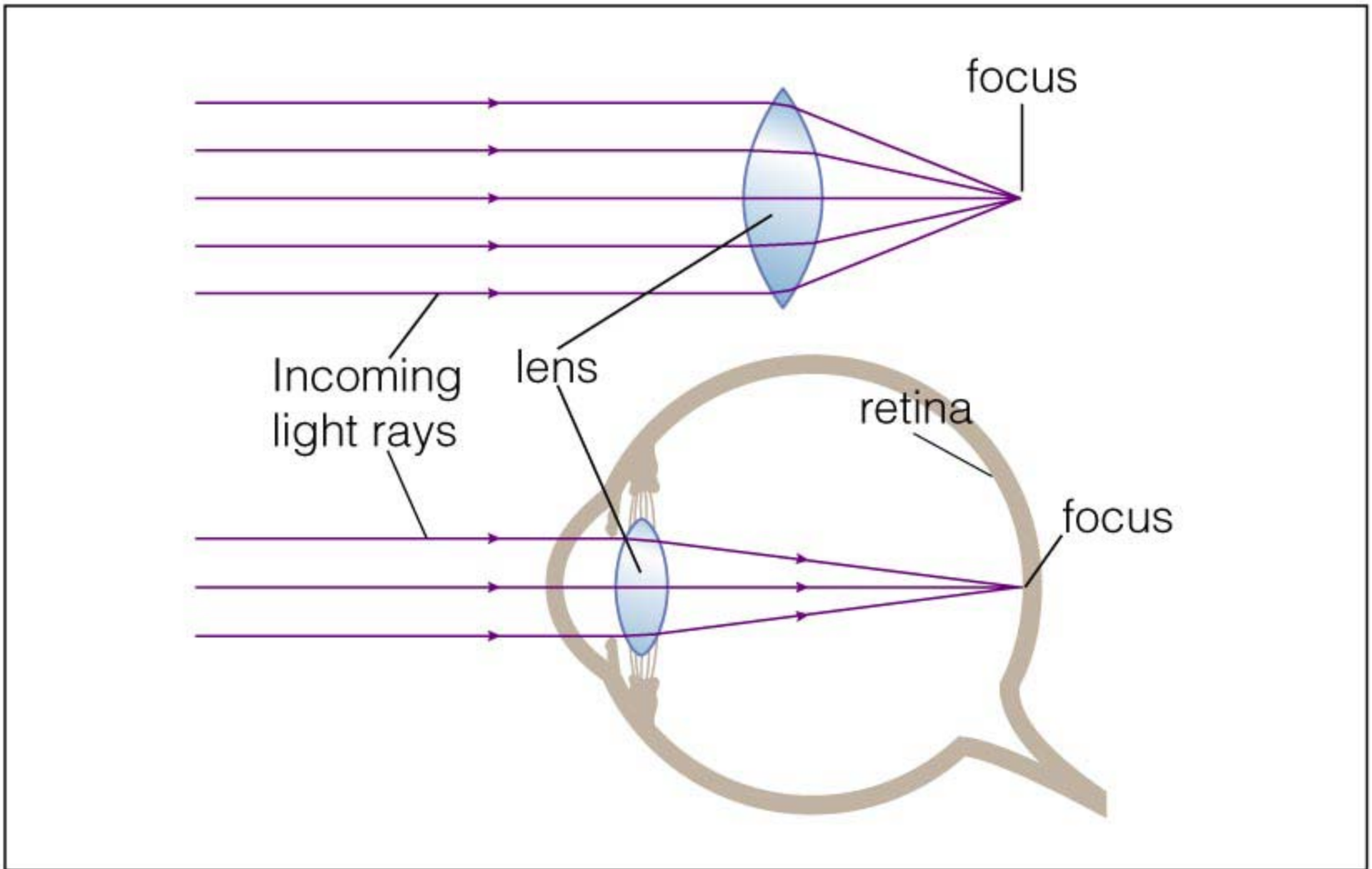
- But eyes are a good prototype for understanding cameras and telescopes



Pupil – Controls how much light comes in

Lens – Brings the light together where it can be measured

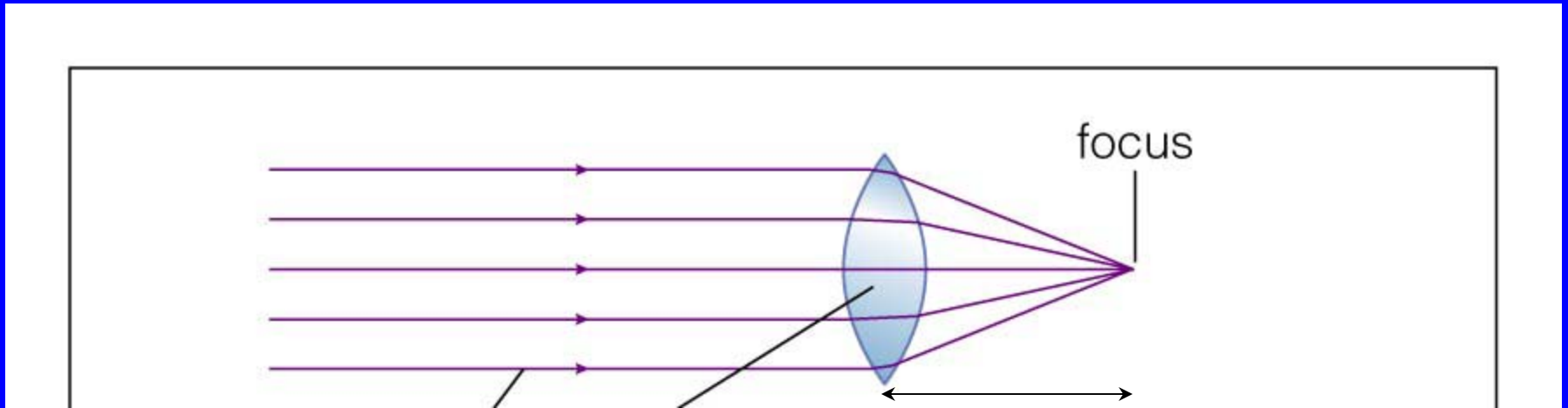
Retina – Measures the light, sends results to computer



A lens bends light

Compare a lens and a prism

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This diagram shows what happens for light emitted by a very distant object because the incoming light-rays are parallel

Discuss what happens for objects that are closer to the lens

$$1/u + 1/v = 1/f$$

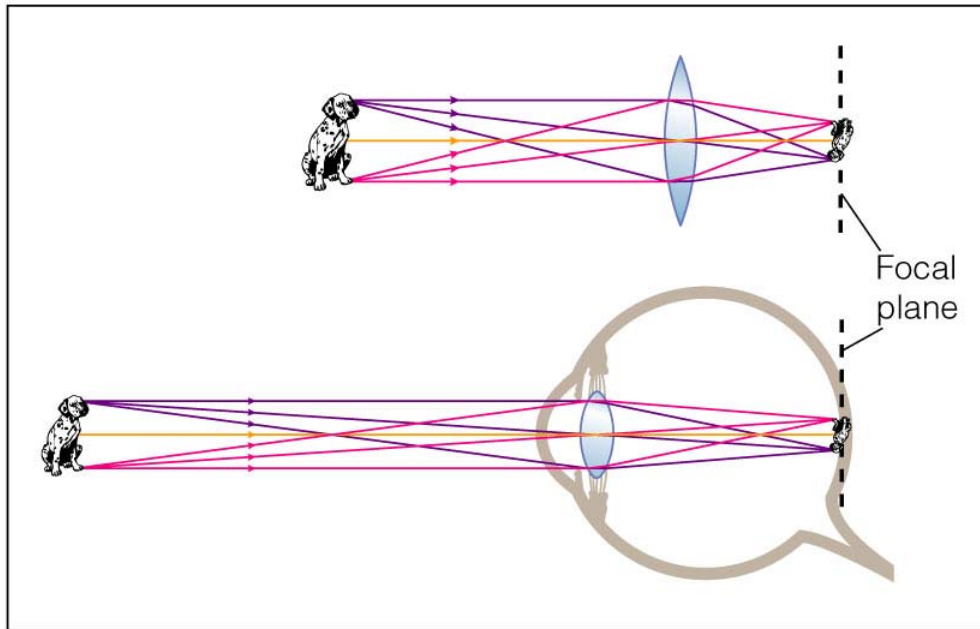
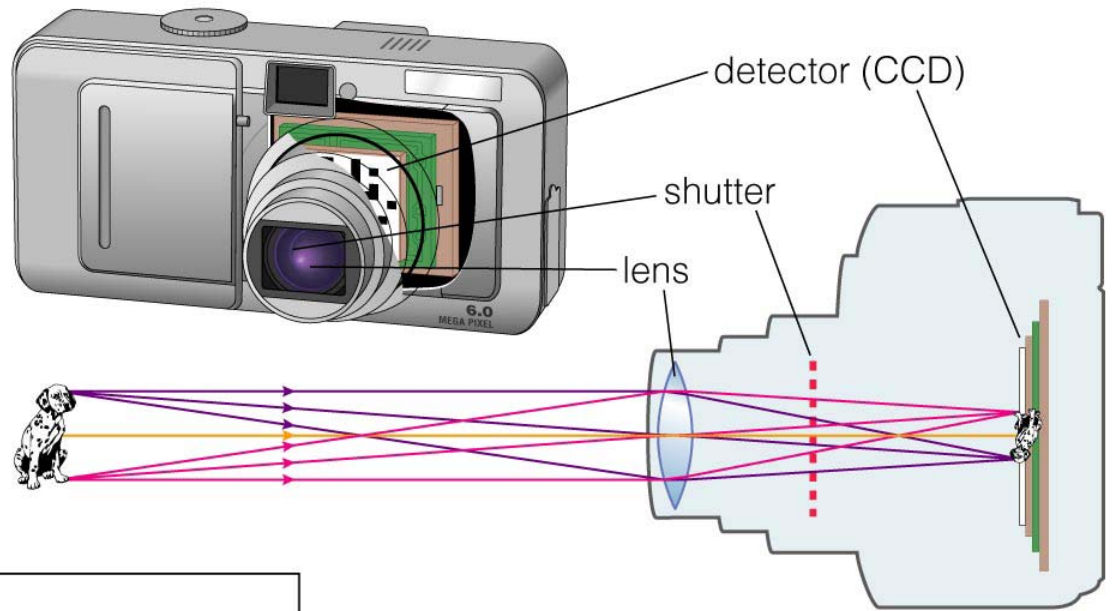
Distance between lens and focus is called the “focal length” or f

A property of the lens, not the image

Something to control how much light comes in

Something to focus the light

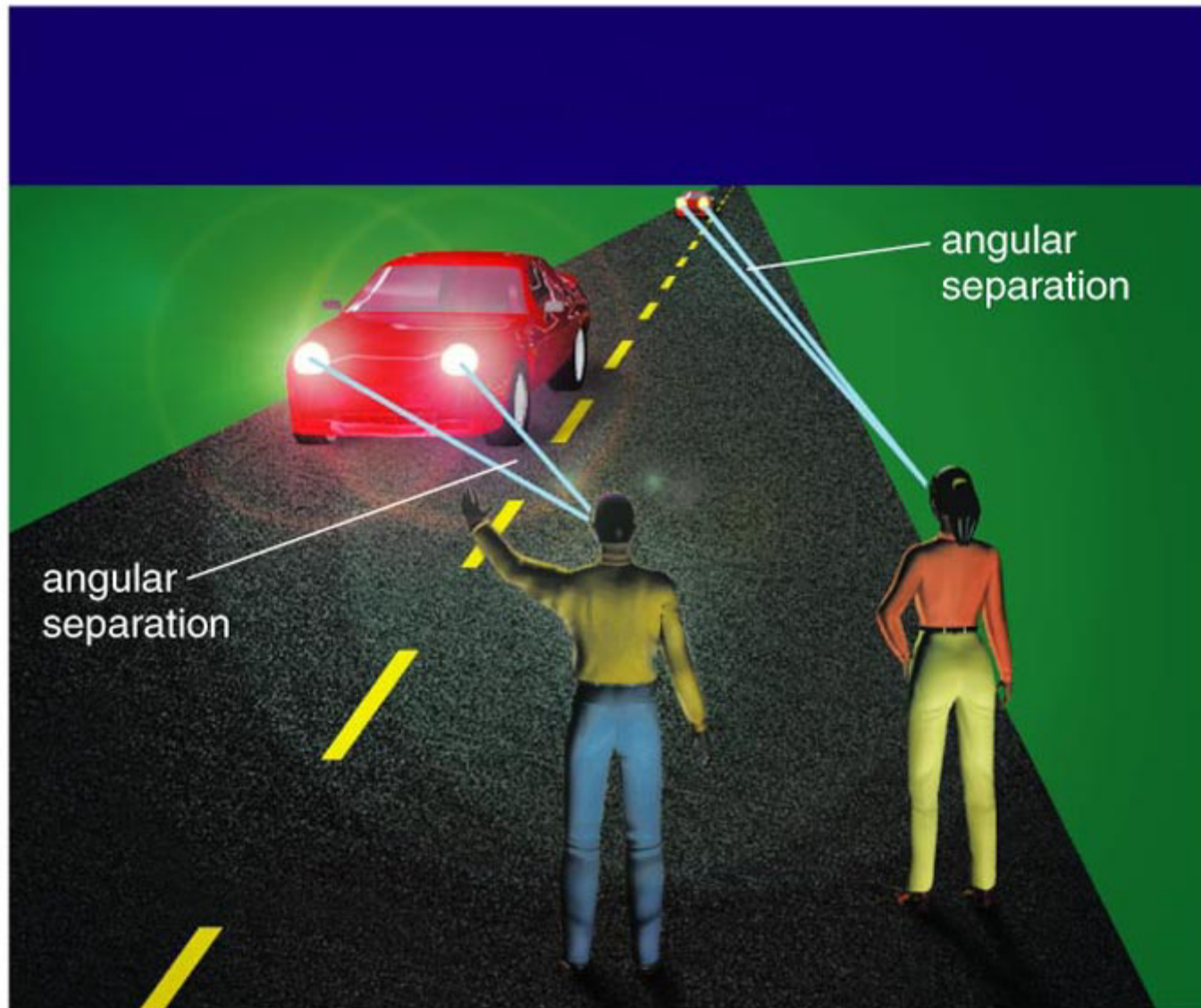
Something to detect the light

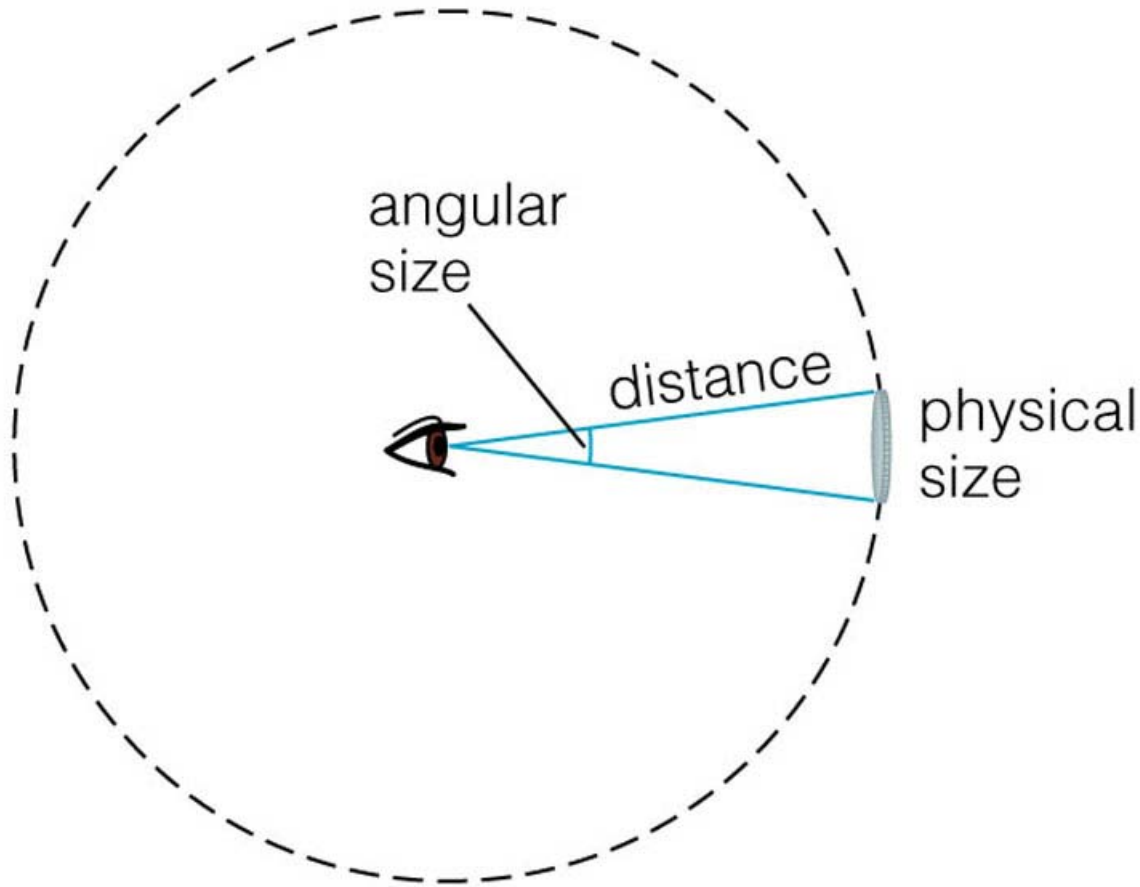


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Telescopes

- Light-collecting area. Should be large. Telescopes need to be able to see faint object
- Angular resolution. Should be able to resolve objects separated by a very small angle. Telescopes need to be able to take sharp pictures
- Interactive Figure 6.6





Angular size of object is same fraction of 360° as its physical size is of the circle's circumference

Circumference = $2 \times \pi \times \text{radius}$

Angular resolution =
Objects with an angular separation smaller than this appear as one joint object

$$\text{Angular size} / 360^\circ = \text{Physical size} / (2\pi \times \text{distance})$$

Angular Resolution

- Atmospheric turbulence blurs images, very hard to get better angular resolution than 0.5 arcseconds
- Steadiness of telescope and its foundations also affect angular resolution
- Also a physical limit due to behaviour of light
 - Diffraction limit in arcseconds = $2.5 \times 10^5 \times$
(wavelength of light) / (diameter of telescope)

Types of Telescopes

- Bend light with a lens – refraction
- Bend light with a curved mirror – reflection
- Early telescopes used refraction because lens makers had lots of experience
- Today's telescopes use reflection



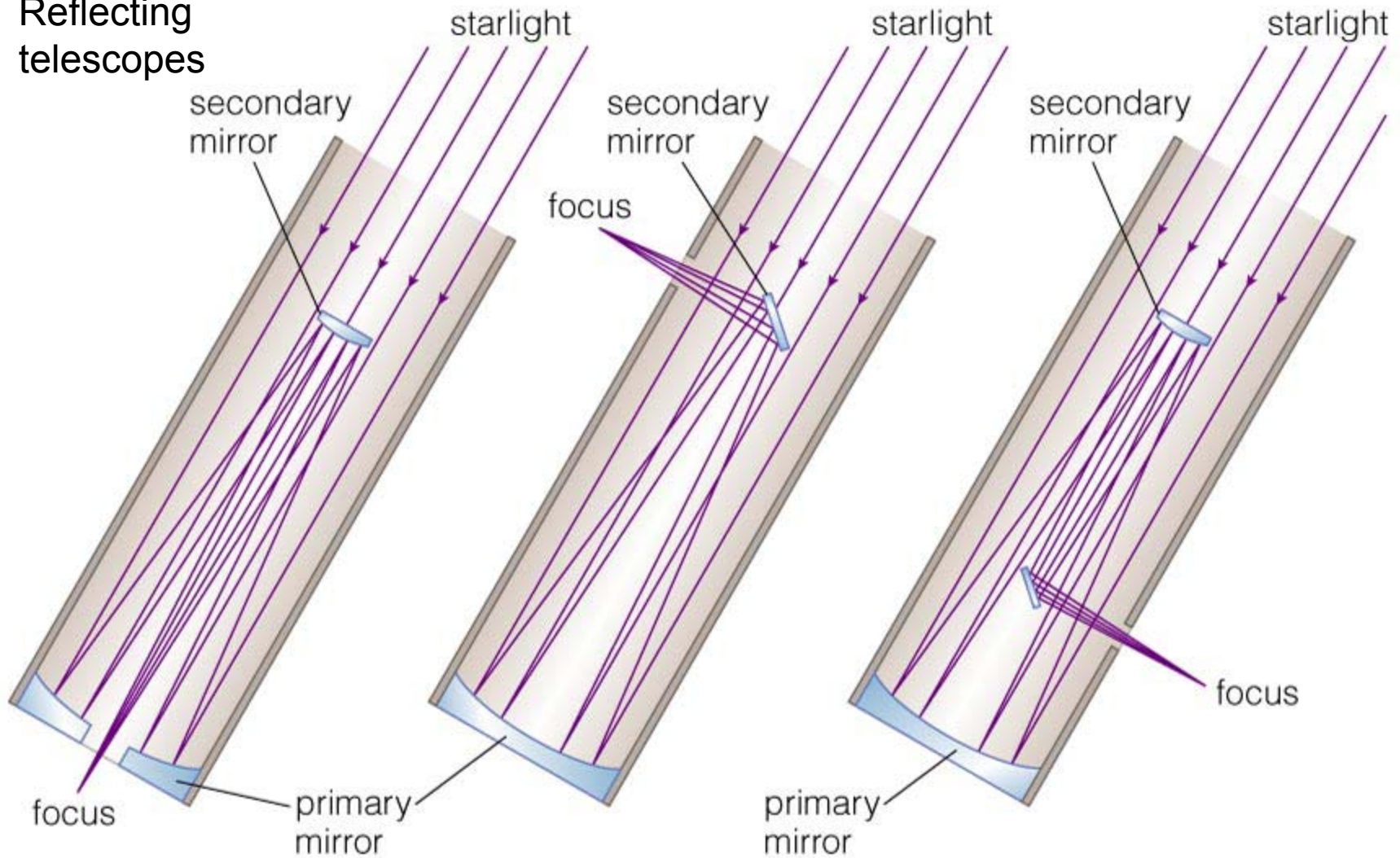
Refracting telescope

Problems

Entire lens must be perfect

Heavy lens causes long tube to bend

Reflecting telescopes



Cassegrain Focus

Newtonian Focus

Nasmyth/Coudé Focus

Only surface of mirror must be perfect

Heavy mirror at base of telescope



Reflecting telescopes often have a hole in the centre of their large primary mirror

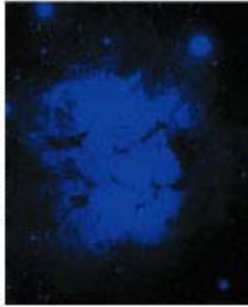
This is not a problem

Imaging

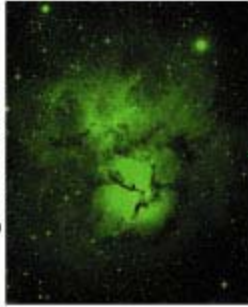
- A black and white photograph
- Often a filter is used to block the light so that only a narrow range of wavelengths are allowed to reach the detector.
Example: a red piece of transparent plastic
- Most colour photographs are basically fake

The actual light collected ...

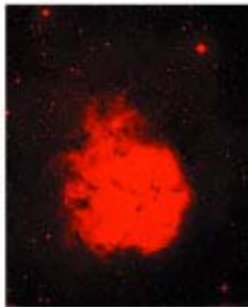
blue filter



green filter



red filter



... is combined to show a full-color image.



This colour image is made by combining an image made with blue light, an image made with green light, and an image made with red light

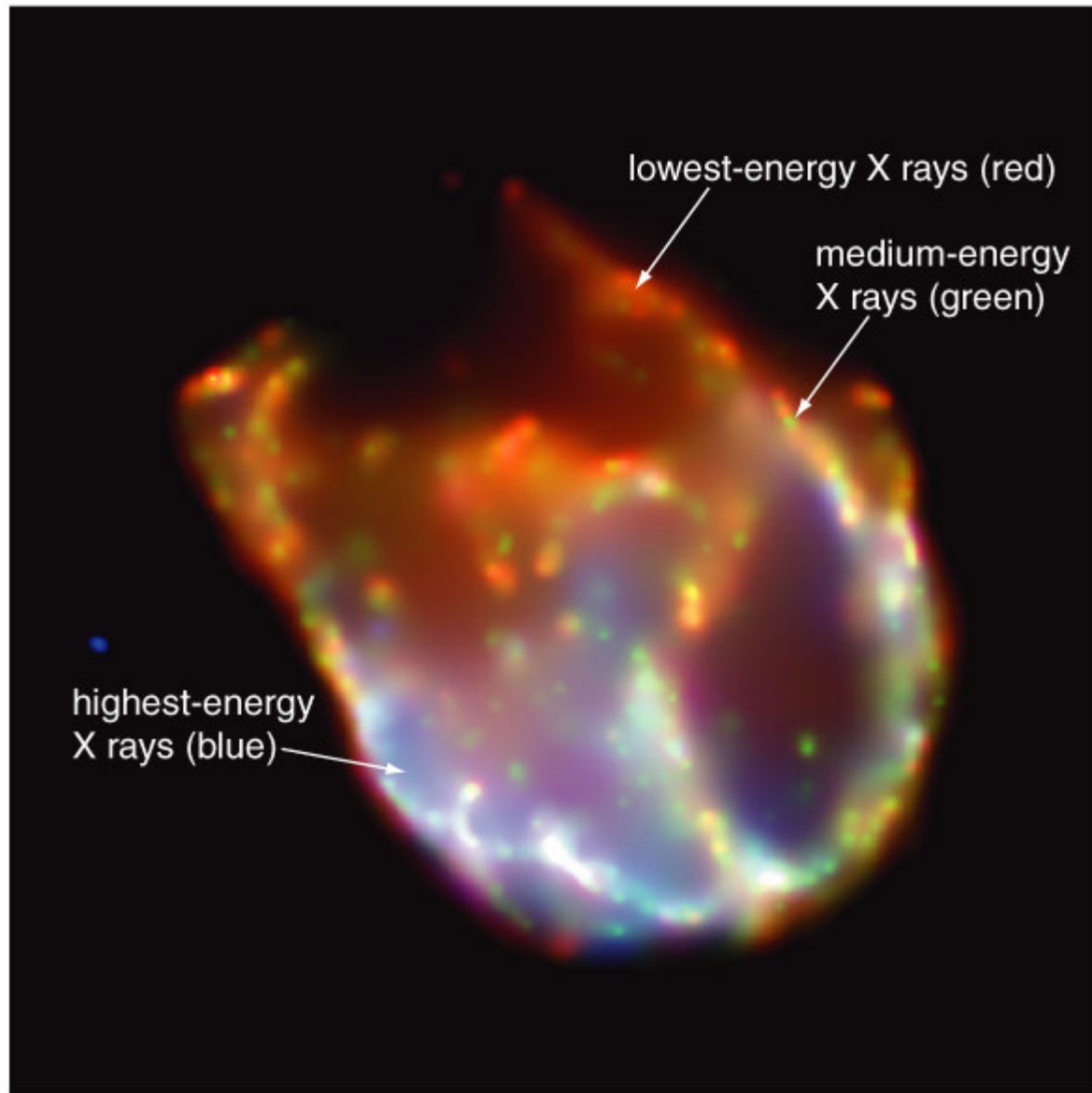
Your eye does the same thing

Astronomers often combine a blue, red, and infra-red image to make a "colour" image

Or they can combine different wavelengths of X-rays

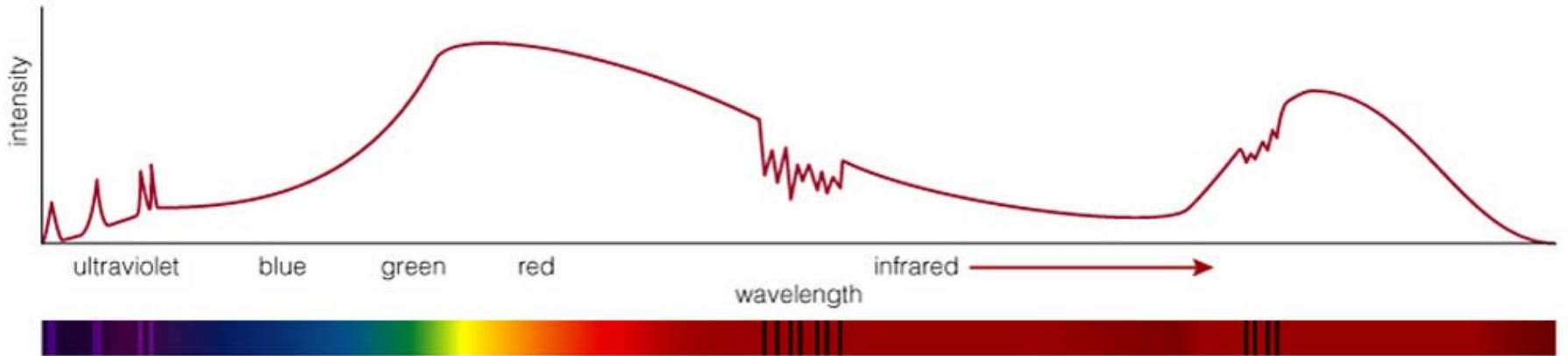
Why make colour images?
Why not just show three black and white images?

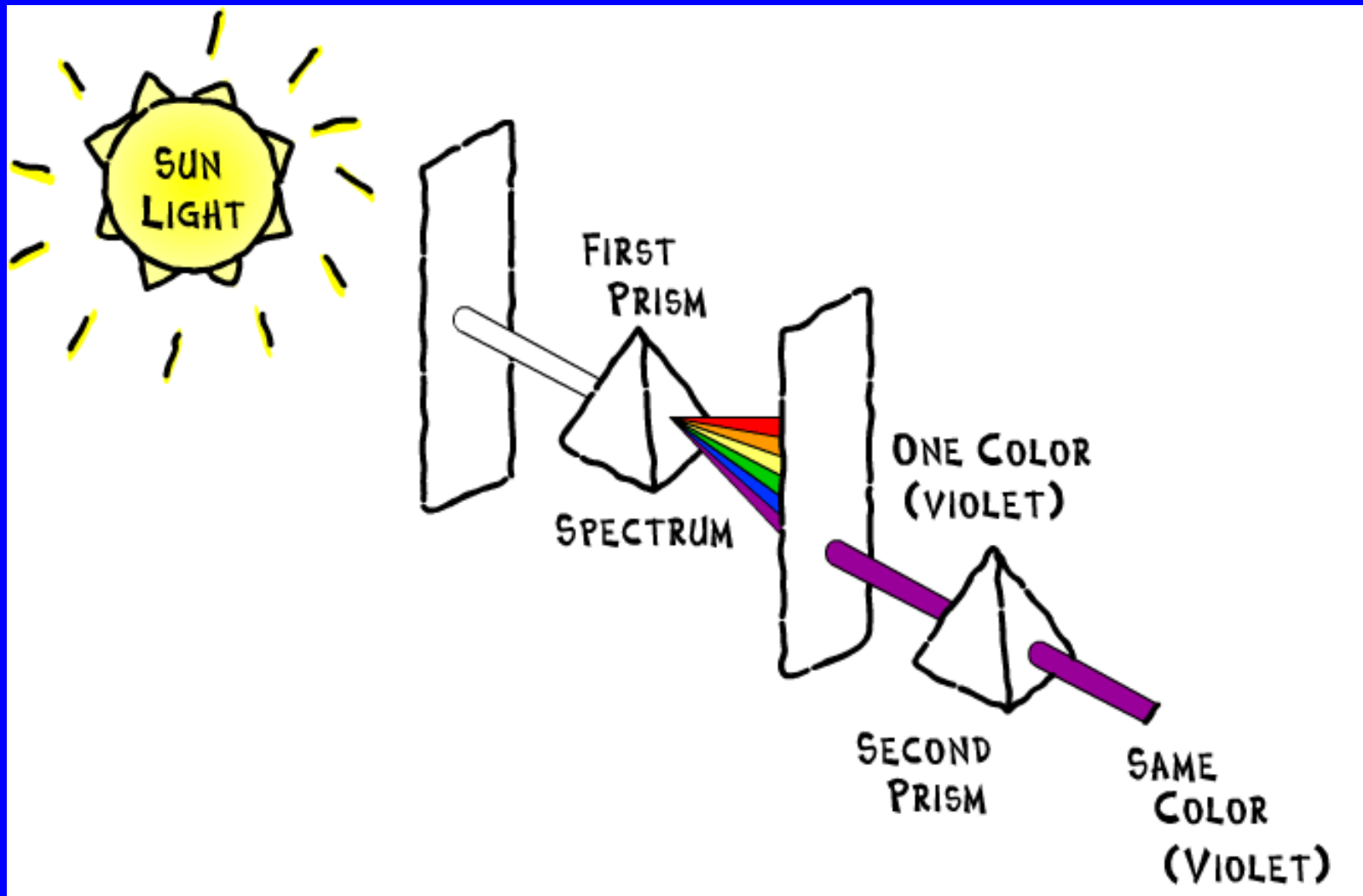
Interactive Fig 6.13



Spectroscopy

- Measure the intensity of light from an object at many different wavelengths
- Don't get an image of the object

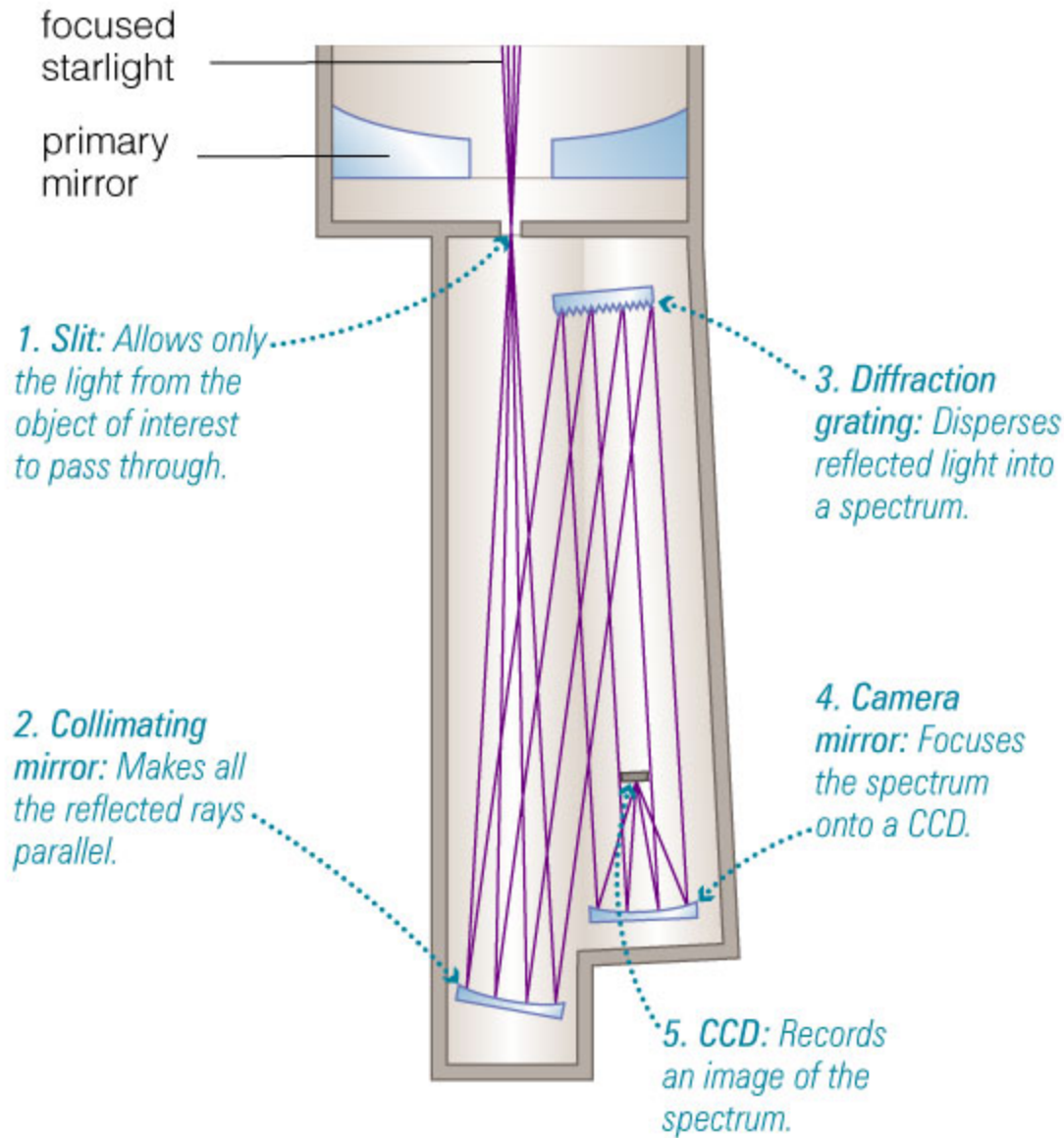




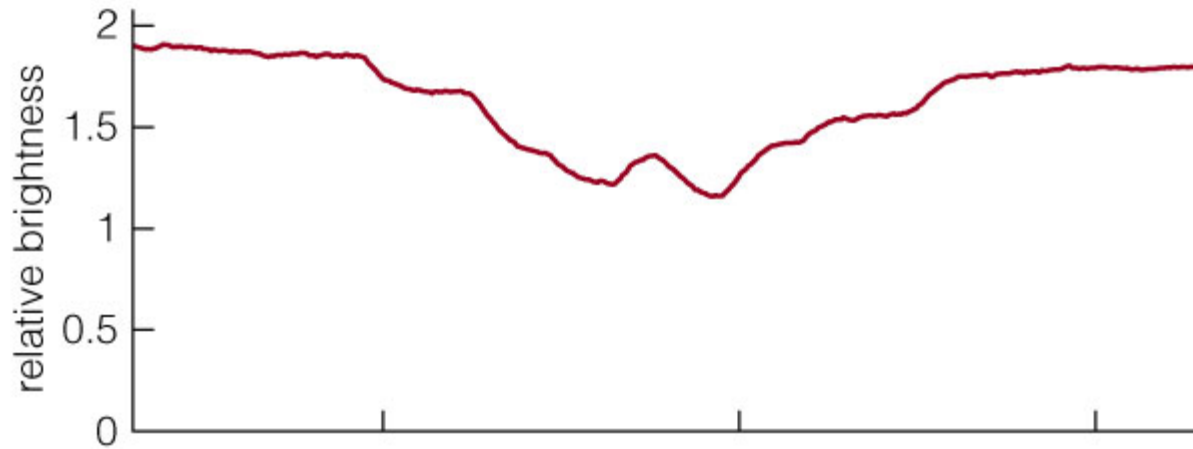
To measure a spectrum, astronomers need to isolate one wavelength of light. They measure the object's intensity at that wavelength, then move on to the next wavelength

A diffraction grating does the same job as a prism

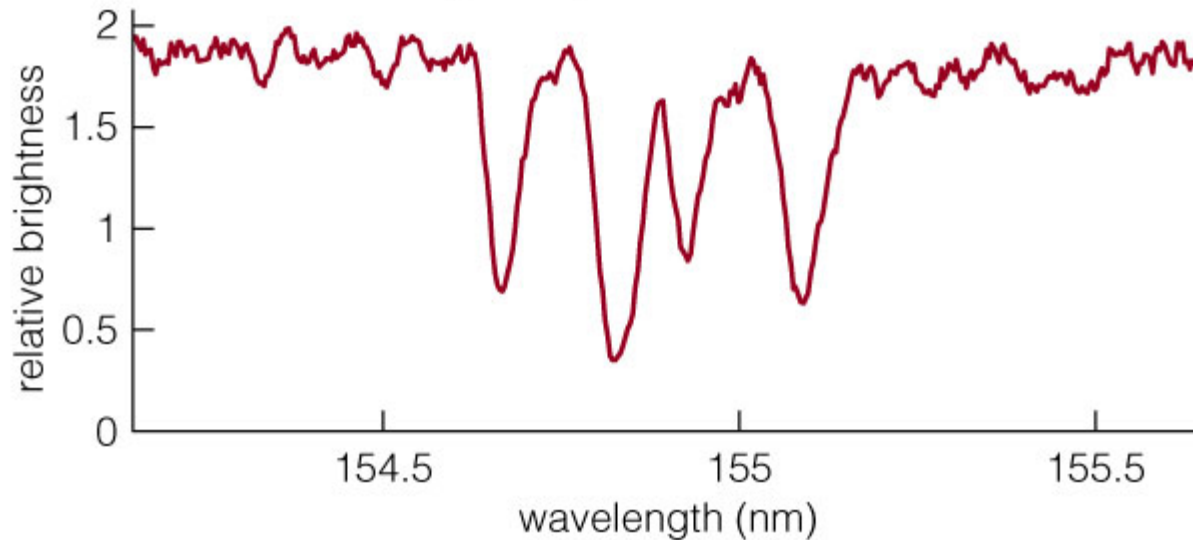
It separates the different wavelengths of light



Lower Spectral Resolution



Higher Spectral Resolution

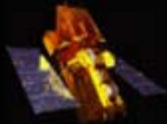


- Spectral resolution is usually given as a wavelength
- If a spectrograph can separate light at 599 nm from 600 nm, then it has a spectral resolution of 1 nm
- Better spectral resolution means more detail and more information in the spectrum

Telescopes in Space

- Telescopes don't need to get closer to stars
- Atmosphere absorbs many wavelengths of light and stops it reaching ground-based telescopes at all
- Atmospheric turbulence disturbs light as it passes through the atmosphere, making images blurry

major space observatories



Swift



Integral



Chandra



Hubble



Spitzer



WMAP

gamma ray

X ray

ultraviolet

visible

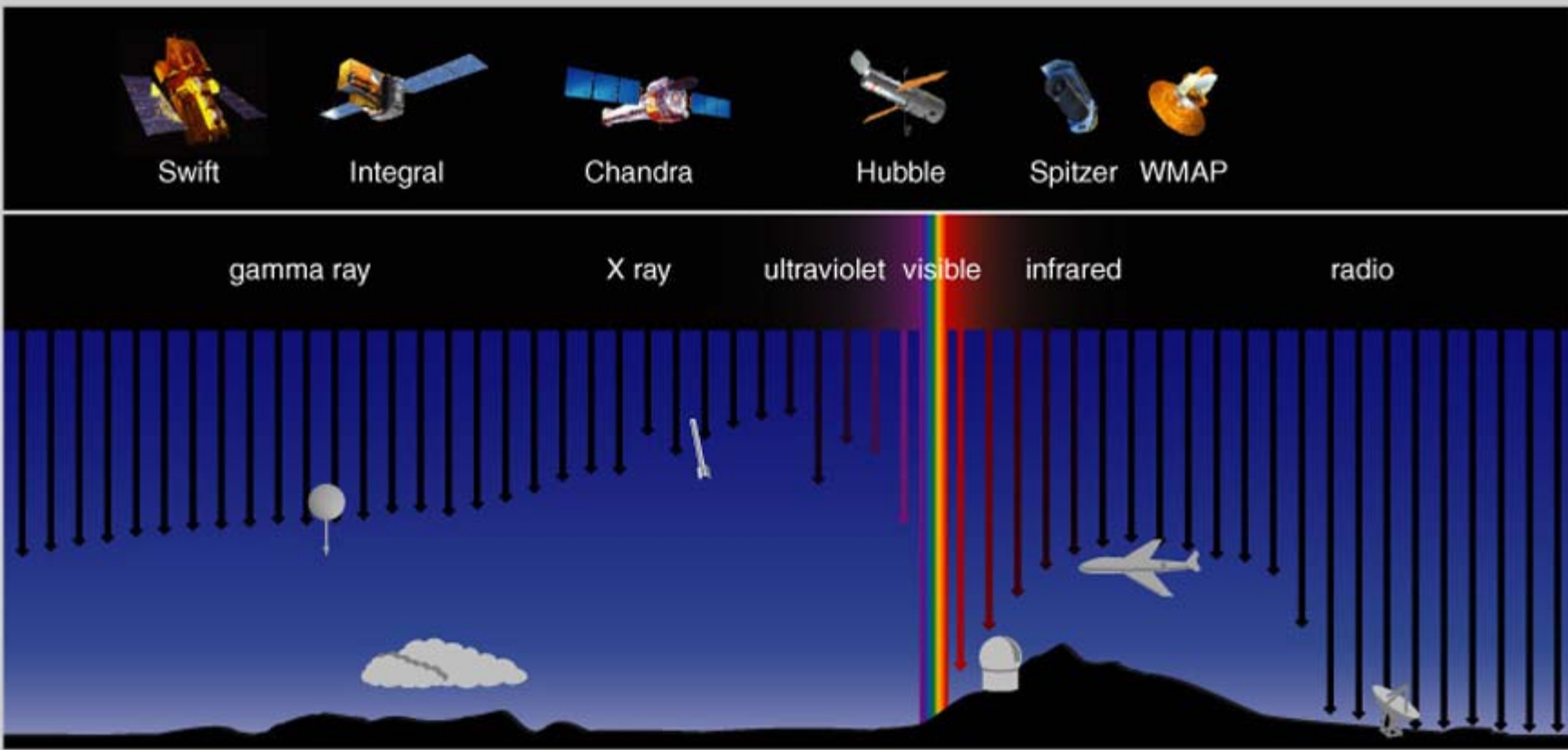
infrared

radio

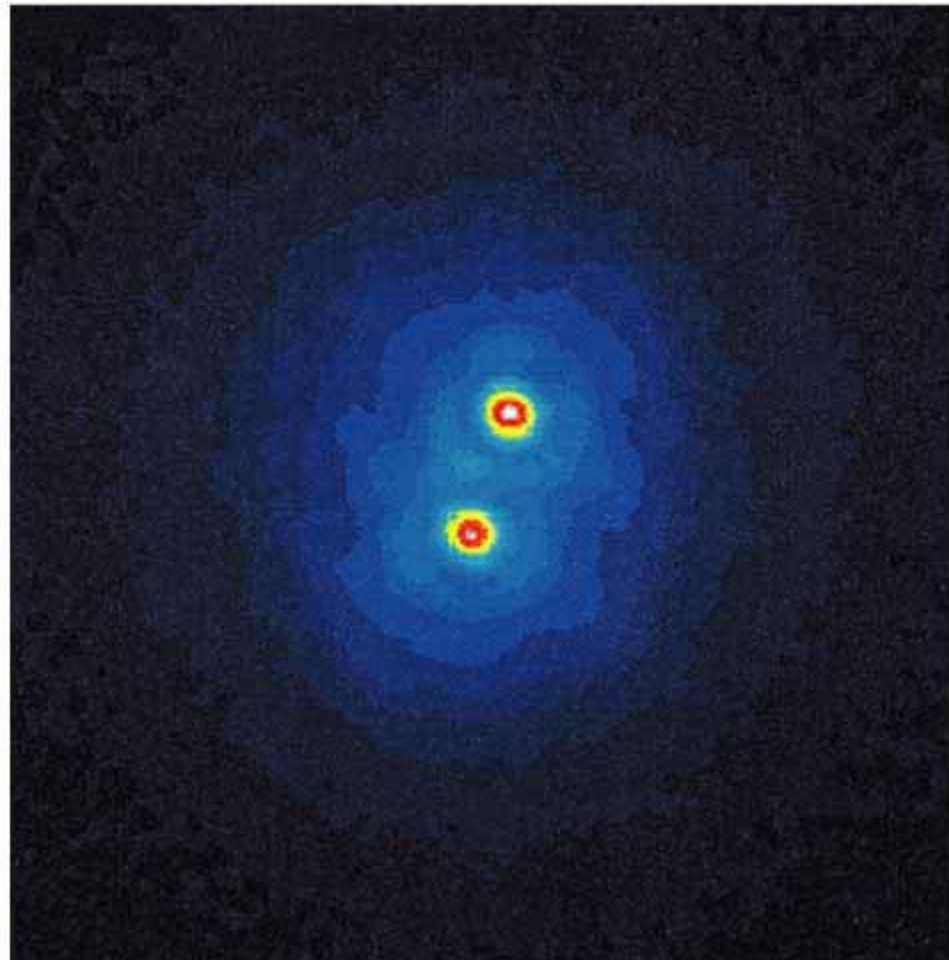
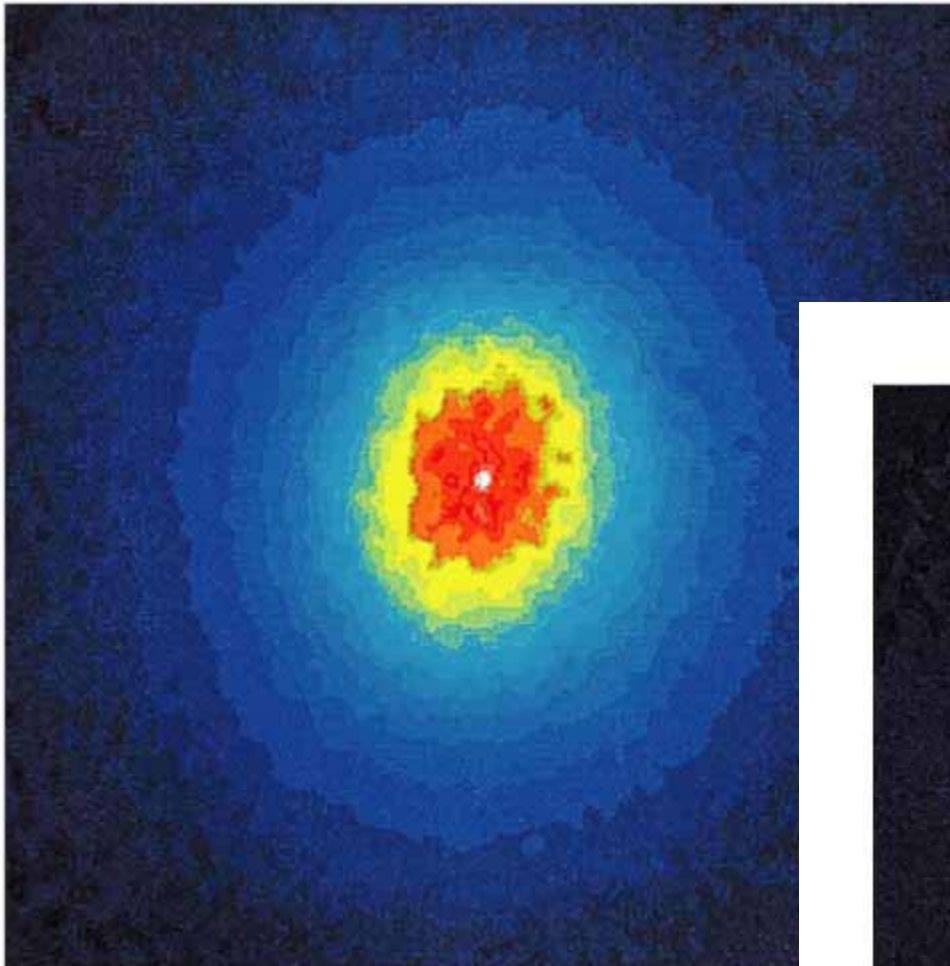
100 km

10 km

sea level



Removing the effects of atmospheric turbulence

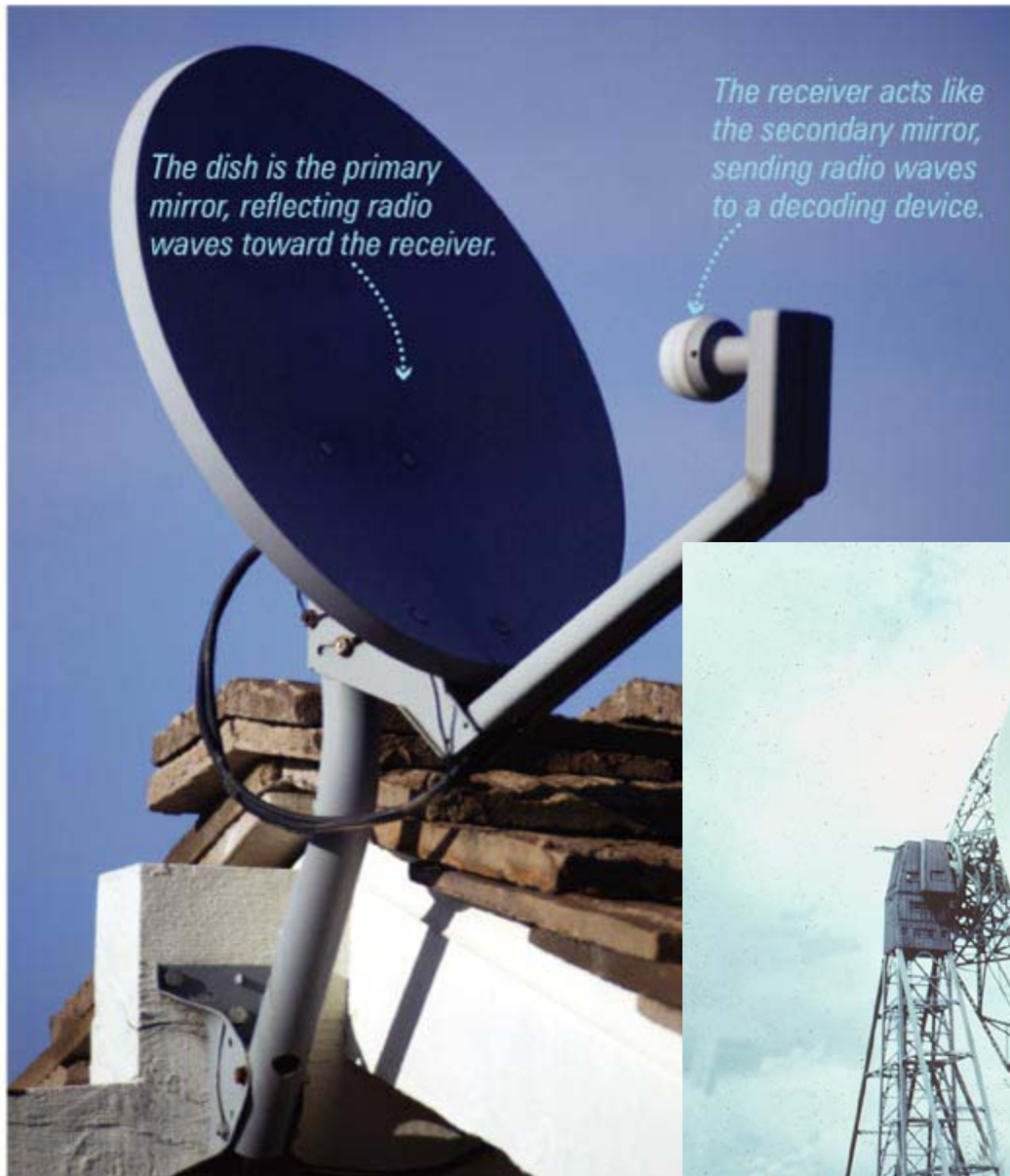


Observing Light at other Wavelengths

- Radio Telescopes
- Infra-red Telescopes
- Ultraviolet Telescopes
- X-ray Telescopes
- Gamma Ray Telescopes

Radio Telescopes

- Mirrors reflect light, metal reflects radio waves
- Radio telescopes look like big optical telescopes with metal mirrors



The dish is the primary mirror, reflecting radio waves toward the receiver.

The receiver acts like the secondary mirror, sending radio waves to a decoding device.

Larger size than satellite dish
(fainter objects and
better angular resolution)

The metal mirror is not as smooth
as an optical mirror, but it is
larger

Reason – long wavelength





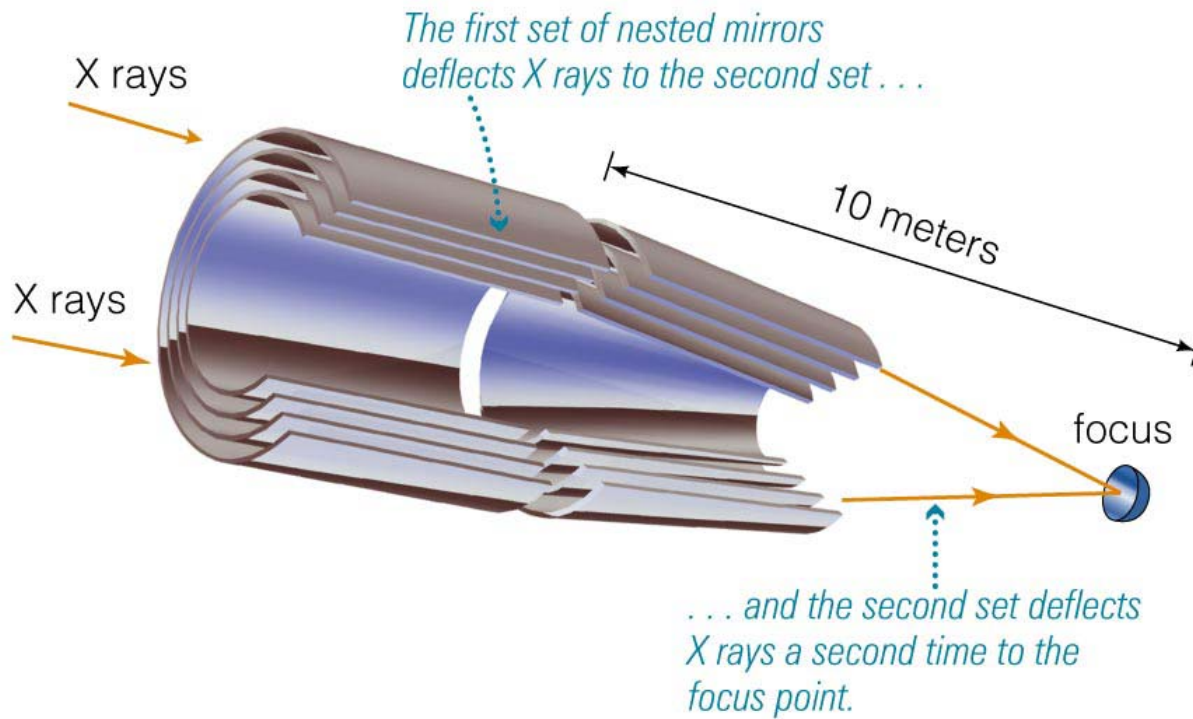
- Telescopes on the ground don't see much infra-red light, but telescopes on a plane do
- Warm objects emit infra-red thermal radiation. Telescopes looking at these wavelengths must be very cold (tens of Kelvin)

Ultraviolet

- Very similar wavelength to optical light, so optical telescopes can be used
- BUT the atmosphere absorbs ultraviolet light, so UV telescopes must fly in space

X-ray telescopes

- Optical light reflects off mirrors
- X-ray photons, which are very energetic, penetrate directly into mirrors



How can you
focus X-rays?

Grazing incidence

Gamma Ray Telescopes

- Gamma rays can't be focused because gamma rays are so energetic that they penetrate anything
- Gamma ray telescopes need thick shielding around almost all sides of the detector
- Only photons coming from one side can reach the detector
- Not an image, but some sense of direction

Multiple Telescopes

- The angular resolution of a group of telescopes can exceed the angular resolution of the individual telescopes
- This is commonly done with radio telescopes
- It is much harder for shorter wavelengths, such as visible light
- Don't worry about the details of how this works



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Goals for Learning

- How are cameras similar to eyes?
- What is angular resolution?
- What are refracting and reflecting telescopes?
- Why put telescopes in space?

Goals for Learning

- How are cameras similar to eyes?
 - Both have something to control how much light comes in, something to focus the light, and something to detect the light
 - But cameras can make permanent images, can “see” at other wavelengths, and can see very dim or very bright light

Goals for Learning

- What is angular resolution?
 - Objects with an angular separation smaller than this appear as one joint object
 - Diffraction limit in arcseconds = $2.5 \times 10^5 \times$
(wavelength of light) / (diameter of telescope)

Goals for Learning

- What are refracting and reflecting telescopes?
 - Making an image requires bending light rays
 - Refracting telescopes bend light as it passes through a lens
 - Reflecting telescopes bend light as it bounces off a mirror
 - Today, most telescopes are reflectors

Goals for Learning

- Why put telescopes in space?
 - The atmosphere absorbs many wavelengths of electromagnetic radiation, including UV and X-ray
 - Telescopes above the atmosphere can study light at wavelengths that don't reach Earth's surface
 - Light is not affected by atmospheric turbulence, so images are sharper

- <http://www.jb.man.ac.uk/public/story/mk1.jpg>