Light and motion

- This means that if you know what wavelength some radiation was emitted at (as you would for, say, a hydrogen Balmer line), then the observed wavelength tells you the velocity of the object along the line of sight.
- The change in wavelength is related to the velocity by a simple equation:

$$\frac{\Delta\lambda}{\lambda} = \frac{v}{c}$$

Light and motion

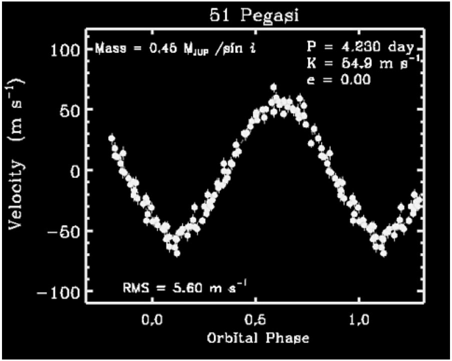
- So, for example, in the spectrum of Sirius, you see the Balmer alpha absorption line at 656.260 instead of 656.277 nm.

$$
\begin{aligned}
\frac{0.017}{656.277} &= \frac{v}{c} \\
v &= c \times \frac{0.017}{656.277} \\
&= 3 \times 10^8 \times \frac{0.017}{656.277}
\end{aligned}
$$

- This means that Sirius is moving towards us at 7.7km/s

Light and motion

- The Doppler effect is very important in astronomy. Some examples:
- The first planets outside our solar system were detected by looking for tiny ‘wobbles’ in the motions of stars, caused by the gravitational tug of planets orbiting them.



Light and motion

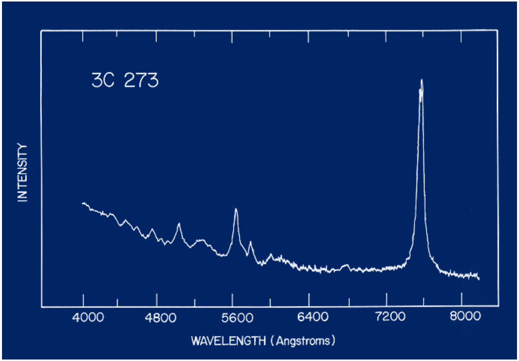
- If you look at a spiral galaxy, you can see that stars on one side are approaching us while stars on the other side are receding.
- The velocity of the stars far out is much larger than you would expect, from the amount of visible matter you see. This implies that there is dark matter.

Light and motion

- If you look at any galaxy beyond the Local Group, you find that it is receding from Earth. The Universe is expanding.
- Looking in more detail, you find that the more distant it is, the faster it is receding. Edwin Hubble discovered this, and the phenomenon is called the Hubble Flow.

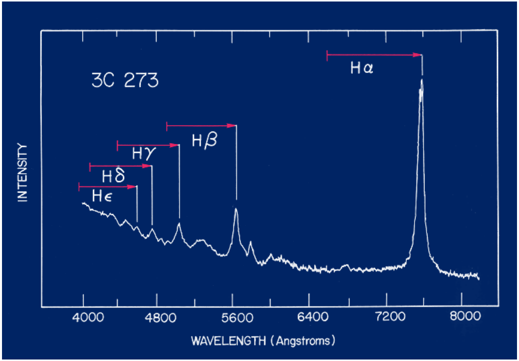
Light and motion

- Quasars are extremely bright galaxies, powered by supermassive black holes. They are all at great distances from Earth.
- First discovered was 3C273, in 1959 - its spectrum mystified astronomers.



Light and motion

- In 1963, Maarten Schmidt realised what was going on:



- 3C273 is moving away from us at 48,000 km/s. It is 2.4 billion light years away, and is 2 trillion (2×10^{12}) times brighter than the Sun

Optics and telescopes

- We have seen that the electromagnetic radiation from astronomical objects gives us a lot of information about them.
- So how do we collect and measure that light, coming from objects at colossal distances from Earth?

The eye

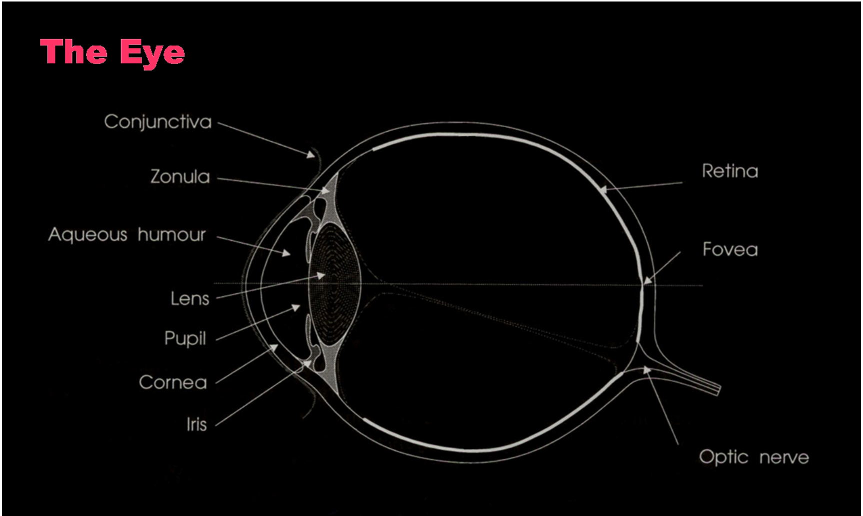
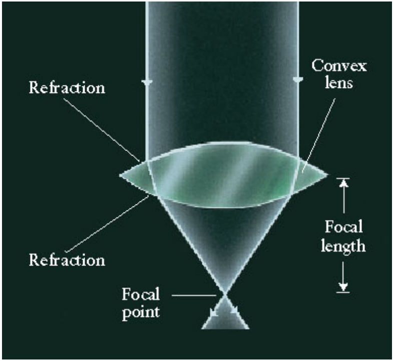


Figure 3: The human eye.

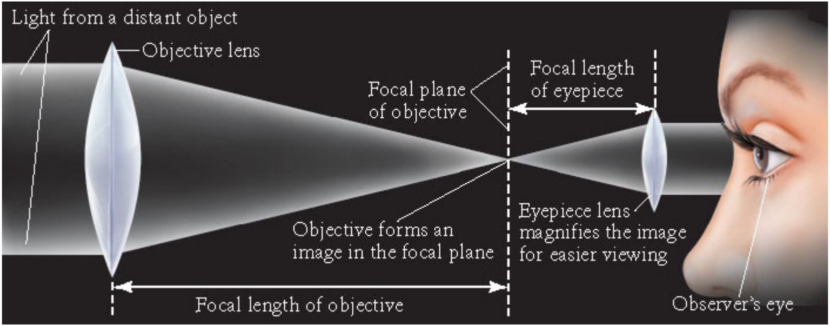
Lenses

- We learned earlier that EM radiation in a vacuum travels at **c**, the speed of light: 300,000 km/s. But it travels more slowly in a transparent substance like glass. This is called **refraction**.
- With the right shaped piece of glass, you can **focus** the light from a distant object, making it appear larger and brighter.



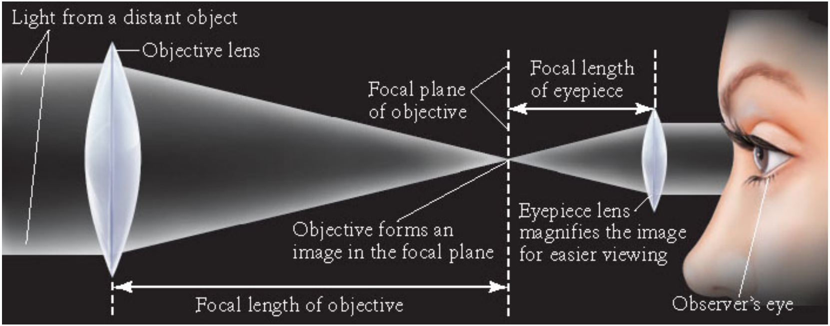
Telescopes - refractors

- If you put a piece of film, or a CCD, at the **focal plane**, you could record an image.
- Alternatively, you could put a second lens behind the first, to magnify the image and make it easy to view with the human eye. This is the principle of a **refracting telescope**.



Telescopes - refractors

- The first lens in the system is called the **objective** or **primary** lens. The magnifying glass is called the **secondary** or **eyepiece**.
- The amount of magnification is given by the ratio of the two focal lengths. So a secondary lens with half the focal length of the primary would give an image twice as large as seen with naked eye.

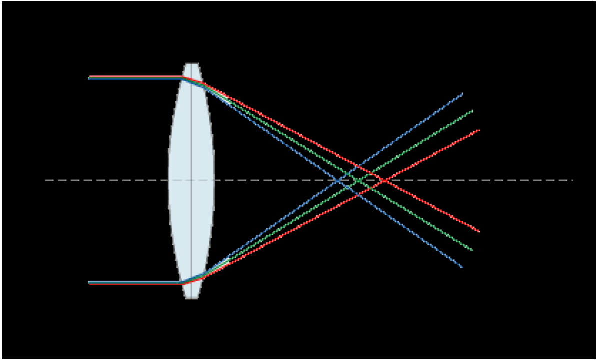


Telescopes - refractors

- The first telescopes, used in the early 1600s, were refractors. Galileo used a small refractor to stunning effect, discovering craters on the Moon, satellites around Jupiter, sunspots, and the phases of Venus and Mercury. Astronomy was revolutionised.
- Galileo's telescope had a lens 3cm across. The human eye has a lens about 5mm across.
- The **light-gathering power** of a telescope is proportional to the **area** of its lens, and therefore the **square** of the diameter. Galileo's telescope made things appear $(3/0.5)^2 = 36$ times brighter than the appear to the naked eye.

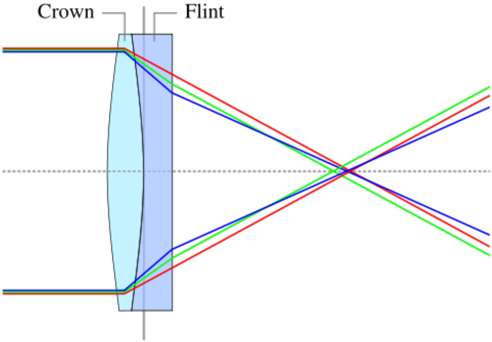
Refractors - disadvantages

- Refractors have a number of issues that ultimately limit their capabilties.
- First is the problem of **chromatic aberration**: when light is refracted, the amount of refraction depends on the wavelength of the light: blue light is refracted more than red light, so the focal point is different for different colours.



Chromatic aberration

- Chromatic aberration means that only one wavelength is in focus at a given position. With the addition of a second piece of glass with a slightly different refractive index, you can construct a lens which brings two wavelengths into focus at a given position:



Chromatic aberration

- A lens which brings two wavelengths into focus at the same point is called an **achromatic lens**. You can improve things still further with a third piece of glass, bringing three wavelengths into focus at the same time. Such a lens is called **apochromatic**.
- Better correction of chromatic aberration = more expensive.

Optical quality

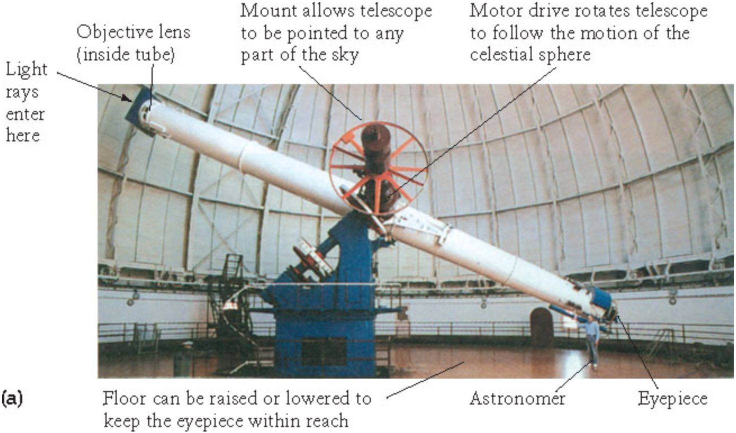
- Another problem with refracting telescopes is the quality of the glass. You want to lose as little light as possible when looking at astronomical objects, and this means you need very high quality glass, as free as possible from imperfections.
- Higher quality glass = more expensive.

Weight distribution

- Yet another problem with refractors is that the bigger the lens, the heavier it is. This means you need a very sturdy tube to hold it in place.
- A large lens will also be distorted by its own weight as it is moved around, compromising the optical quality.
- For this reason, the largest useful refractor ever built had a lens with a diameter of 40 inches / 1 metre. For comparison, the Radcliffe telescope at ULO has a diameter of 24 inches / 60 cm.
- I think the Radcliffe might be the second largest refractor in the UK. Not totally sure though...

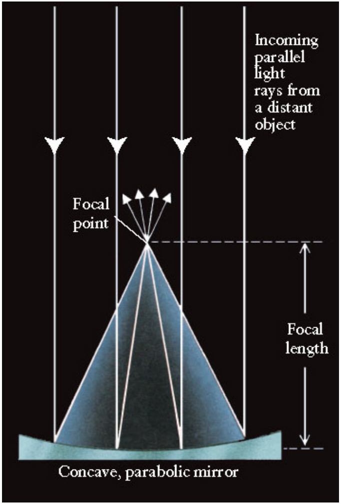
Weight distribution

- The lens of the Yerkes telescope weighs about two tonnes. The $\sim$20m tube needs to be seriously strong to avoid terrible flexure problems.



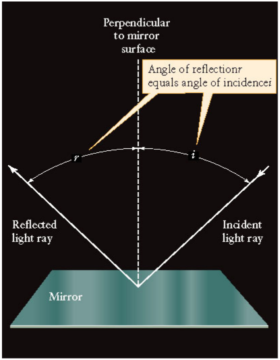
Reflecting telescopes

- Another way to bring light to a focus is with a curved mirror. This is the principle behind **reflecting telescopes**.



Reflectors - advantages

- Reflecting instead of refracting light has many advantages:
- 1. Reflection is not wavelength-dependent. All light, no matter what its wavelength, is reflected at an angle which is the same as the **angle of incidence**.
- This means there is no chromatic aberration.



Reflectors - advantages

- 2. While a refracting lens needs to be of extremely high quality throughout its volume, a reflecting mirror only needs to be of high quality on its surface.
- What you put behind the mirror to support it makes no difference, so it's much cheaper to construct a large, very high quality mirror, than it is to construct a large very high quality lens.

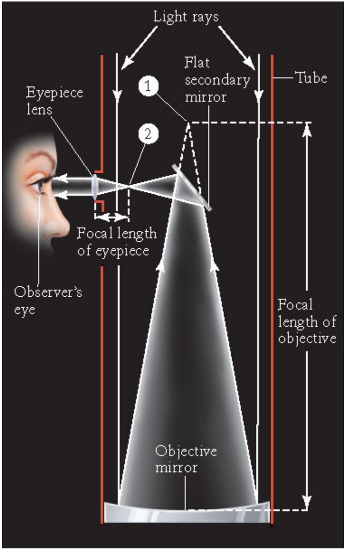
Reflectors - advantages

- 3. Unlike a lens which has to sit at the end of a tube, far from the pivot, a mirror can be positioned close to the pivot.
- Also, while internal flexure of a lens gets more and more difficult to avoid for larger lenses, mirrors do not suffer so much from this.
- For these reasons, all the telescopes used today for professional astronomy, and most amateur telescopes as well, are reflectors.
- The largest optical telescope in the world is the Gran Telescopio Canarias on La Palma, with a 10.4m mirror. At about 10 times the diameter of the largest refractor, it has 100 times the light-gathering capability.

Reflectors - disadvantages

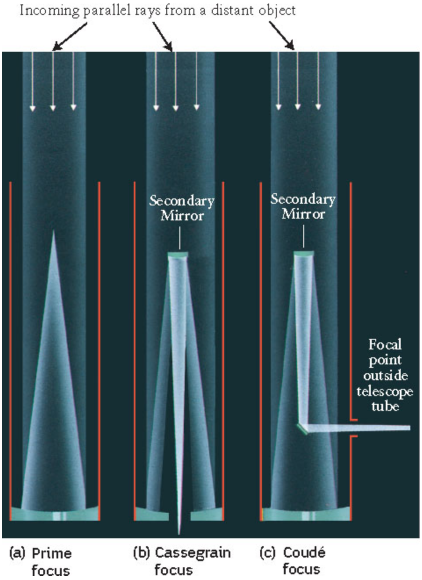
- But it’s not all good. From the diagram earlier, you can see that the focus point of a mirror is in front of it, not behind it as with a lens.
- To get your image into a useful position, you have to place either a detector or another mirror at the prime focus. This means you will lose some of the incoming light.
- There are many different ways of bringing the light to a focus in a useful position.

Reflectors - disadvantages



(a)

Reflectors - disadvantages



Reflectors - disadvantages

- Perhaps counterintuitively, the secondary mirror does not cause a hole in the image. It just reduces the effective light collecting area.
- It will not even noticeably affect the image quality unless its area is more than $\sim$25% of that of the primary.
- So, if you had a 2 metre primary mirror, you could have a secondary 1 metre across without degrading the image quality. The *effective* diameter of the telescope would be 1.73m

$$\begin{aligned} A_{\text{primary}} - A_{\text{secondary}} &= 4\pi \times 2^2 - 4\pi \times 1^2 \\ &= 37.7\text{square metres} \end{aligned}$$

$$\begin{aligned} \text{effective diameter} &= (37.7/4\pi)^{0.5} \\ &= 1.73 \end{aligned}$$