8. A Short Digression: Angular Size, Resolution, Spectra

Angles and Resolution

If we can see that an object is extended (not just a point), we say it is *resolved*.
An object of diameter l at distance D subtends an angle

$$\theta = \frac{l}{D} \text{ radians} = 206,265 \times \frac{l}{D} \text{ arc} - \text{seconds.}$$

(This formula assumes $D \gg l$, which is almost always a good approximation in astronomy because objects are so far away.)
There are 3600 arc-seconds in 1 degree (analogous to 3600 seconds in one hour).
With the naked eye, you can resolve objects about 60 arc-seconds across (1 arc-minute).
Because of blurring by the atmosphere, the sharpest images und-based telescope are about 1 arc-second across, so this is a useful unit of angle for astronomy.
1 arc-second is the angle subtended by a quarter at a distance of about 2.5 miles.
Hubble Space Telescope, above the earth's atmosphere, makes images with resolution of about 0.1 arc-seconds (limited by the size of its mirror).

The sun and the moon are both 1/2 degree across (1800 arc-seconds).
The diameter of the sun is 400 times the diameter of the moon, but it is also 400 times further away.
Other stars are much further than the sun (60,000 times further for the closest one), so their angular sizes are much less than one arc-second.
They are *unresolved*, appearing as points of light.

Other galaxies are very large (l of 10,000 light years or more), so they are resolved, extended sources even when they are very far away (many millions of light years).
Giant clouds of gas in our own galaxy (the Milky Way) are resolved, extended sources in telescopes because they are big (a few light years across) and not *so* far away (a few thousand light years).
But black holes are very compact, so any image of a black hole and its immediate surroundings will be unresolved.

What can we learn about unresolved objects?

How can we learn anything about objects that are just points of light?
We can measure:

- Apparent brightness. If we also know the distance, then we know the *intrinsic* brightness, how much energy the object is putting out.
- Motion on the sky. Nearby stars change position slightly as they move through space and as the earth goes around the sun. Limited to stars that are close or moving fast.
- Variability. Some stars (and some other objects) get brighter and fainter, irregularly or periodically. We can learn something from how they vary. Limited to variable objects.
- Color. For stars, this tells us about the temperature of the surface. Hotter stars put out more blue light (more energetic, shorter wavelength photons).

We get the most information about an object (unresolved or resolved) if we spread out its light by passing it through a prism (or a similar device that sends red and blue light in different directions) to measure its *spectrum*.

Information from spectra

The spectrum of an object is a plot of the intensity of its light against wavelength.

In addition to showing the overall amount of blue vs. red light, spectra show patterns of "missing" light or "extra" light at very specific wavelengths.

These are produced by atoms, which like to absorb or emit light at specific wavelengths.

These wavelengths can be measured in laboratory experiments, so we know (in many cases) what absorption or emission lines correspond to what atoms.

The spectrum of an object can tell us about:

- What kinds of atoms are present.
- The temperature and density of the gas, which determines which atoms will be emitting or absorbing light.
- The velocity of the object along the line of sight (towards us or away from us), from the Doppler shift.
- In some cases, the gravitational redshift.

In combination with the laws of physics, these seemingly limited observations can tell us an enormous amount about astronomical objects.

With the right kinds of telescopes, one can also measure spectra of objects in X-rays, ultraviolet light, infrared light, radio waves.

All of these play an important role in understanding black holes.