Summary of Lecture 16

Key points include:

1. When a light source moves toward us, the frequency of the light we receive is *higher* (and thus the wavelength is *smaller*) than when the light source is not moving with respect to us. This is called a *blueshift*. Conversely, when a light source moves away from us, the frequency of the light we receive is *lower* (and thus the wavelength is *larger*) than when the light source is not moving with respect to us. This is called a *redshift*. The change in frequency/wavelength with motion is called the *Doppler effect*.

2. Quantitatively, if $\lambda_{\rm em}$ is the emitted wavelength and $\lambda_{\rm obs}$ is the wavelength that we observe, then the change in wavelength $\Delta\lambda$, divided by the original wavelength λ, is given by
$$\frac{\Delta\lambda}{\lambda} = \frac{\lambda_{\rm obs} - \lambda_{\rm em}}{\lambda_{\rm em}} \approx v/c\ , \tag{1}$$
if the speed of the emitting source in our direction is v. Here c is the speed of light in a vacuum. **Important:** this formula applies *only* when $v \ll c$. In this formula, $v < 0$ means that the motion is toward us (and thus $\lambda_{\rm obs} < \lambda_{\rm em}$) whereas $v > 0$ means that the motion is away from us (and thus $\lambda_{\rm obs} > \lambda_{\rm em}$).

3. Thus if we know the rest wavelength of a spectral line, we can use the observed wavelength of that line to determine the speed of motion toward or away from us. We can't use this to determine the motion sideways to us, because (at this level of approximation) sideways motion does not produce a Doppler shift.

4. Applications of the Doppler shift include discovery and measurement of exoplanets, determination of the rotation of galaxies, and characterization of the expansion of the universe.

5. Telescopes greatly expand our ability to view the universe. Their three main advantages compared with our eyes are: (a) they collect more light than our eyes, i.e., they have greater *collecting area* than our eyes (and as a side note, they can accumulate data for much longer than our eyes), (b) they have greater *angular resolution* than our eyes, so they can see more detail, and (c) they can be designed to be sensitive to parts of the electromagnetic spectrum that we can't see (e.g., radio, infrared, ultraviolet, X-rays, and gamma rays).

6. For a telescope of diameter D, its collecting area is proportional to D^2 and its angular resolution is proportional to D^{-1} for a fixed wavelength λ.

7. There are two basic types of telescopes: refracting (which uses lenses) and reflecting (which uses mirrors; this type was invented by Isaac Newton). Reflecting telescopes are used almost exclusively for research.
8. *Interferometry* is where you combine the data from two or more separate telescopes. In the ideal case this gives you an angular resolution equal to what you would have with a single telescope with a diameter equal to the separation between the telescopes, but in terms of collecting area it's just the sum of the areas of the telescopes.
9. Telescopes in space have several advantages compared with telescopes on the ground: (a) space doesn't have light pollution (i.e., light from human sources), (b) the atmosphere causes stars to "twinkle", (c) the atmosphere absorbs most wavelengths of light.
10. The capabilities of telescopes can be increased even further using various instruments. For example, cameras are better than hand drawings! Cameras can add up light over a long time, and spectrographs can gather data with fine resolution in the wavelength of light.
11. Our Sun is by far the largest and most massive object in our Solar System. It has a mass about 300,000 times that of the Earth (and about 1,000 times that of Jupiter), and a luminosity of about 3.8×10^{26} Watts. Our Sun shines because of nuclear fusion in the Sun's core, where the nuclei of ordinary hydrogen (in that case, then, single protons) are combined to form helium nuclei.