Topics: Binary stars and stellar masses

Summary of reading:

- Read sections 5 and 6 of Ch. 13 before coming to class on Tuesday (pp. 322-332).
- Read section 3 of Ch. 12 as well. There is a lot of commonality between exoplanet and binary star studies, and some of the key concepts for both are discussed primarily or even solely in §12.3.

Summary of work to submit:

- Nothing to submit for Tuesday’s class.

Here are the things you should be thinking about:

Masses are all about Kepler’s third law. And the variety of binary categories and studies are mostly about how to find the period and either semi-major axis or orbital velocity in order to solve Kepler’s third law for the mass(es). Along the way, complications like the fact that the plane of the orbit will generally not be perpendicular to your line-of-sight (i.e. the orbit has a particular inclination) make it harder than you might naively think it would be to find those quantities from a given set of observations.

Also, in certain cases we can get information about the stars in a binary system that go beyond what we can find from Kepler’s laws. This is especially true for eclipsing binaries.

Commentary on the reading:

Visual binaries are those where (a) light from the two stars can be differentiated and measured (i.e. the binary components are spatially resolved) and (b) orbital motion can be seen over time via changes in the locations of one or both stars. Note that the first criterion implies that visual binaries (VBs) are those with large separation but the second criterion implies that their separations shouldn’t be too big, or their orbital periods will be long and orbital motion slow. The true, three-dimensional orbital trajectory is projected onto the two-dimensional sky, and from that, we can find the angular size of the orbit and thus the semi-major axis (e.g. Fig. 13.6, eq. 13.57) and knowing the distance (from parallax) the true semi-major axis and thus the combined masses can be found (eq. 13.58). If motion of both components can be seen, then the center of mass can be found and foci of the elliptical orbits located and the orbit de-projected – in principle. Bear in mind that the orbital motion that’s observed is combined with proper motion (linear space motion across the sky) and parallax motion (see Fig. 13.7).

The example of Sirius AB that’s used in the book shows how the masses of each component can be determined, and foreshadows the existence of white dwarfs (dead stars about as massive as the Sun but much dimmer). Note also that, at least in principle, a visual binary can be identified and studied even if the light of only one star can be seen (if the other star is too dim) as orbital motion of even just one component must be caused by something.

Spectroscopic binaries are those where the two stars generally can’t be spatially resolved (their separation is not large) and which have large orbital velocities that can be measured via the Doppler shift. (Note that small separation and large orbital velocities go together.) Spectral lines from the two different stars can be seen in the same spectrum (because the two components will likely have different Doppler shifts at any given time).
Kepler’s third law can be modified to incorporate measured orbital velocities (in exchange for the semi-major axis) – see eq. 13.62 and onward. Since the center of mass equation can be written $M_1v_1 = m_2v_2$ the individual Doppler shift amplitudes can be used to separately measure the masses of the two components in addition to their combined mass. Note that the key velocity is the actual orbital velocity and the Doppler shift measures only the radial component of the velocity. There are two aspects of this that are relevant: (1) even if we observe in the plane of a binary orbit, there are only two points in the orbit when a star is moving either directly away from or directly toward us; so it’s the maximum Doppler shift, the velocity amplitude (called $v_A$ and $v_B$ in the textbook; see p. 326 – and do look back at Fig. 12.5b, that’s referenced in that text), that we use in Kepler’s third law, but (b) even beyond that, if we are not lucky enough to be exactly in the orbital plane of a binary system, we will never see the full orbital velocity but rather will see the velocity reduced by a factor of the sine of the inclination angle, $i$ (look at Fig. 12.6 on p. 299). Note that spectroscopic binaries in which spectral lines from only one component are seen (because the other is too dim) are still quite useful – such single-lined spectroscopic binaries enable us to determine something called the mass function (eq. 13.75) which provides a lower limit on the mass of the dimmer, unseen component. This has proven to be quite useful for determining the existence of black holes orbiting regular stars. But if both sets of spectral lines can be seen, then both masses can be determined (modulo the inclination uncertainty).

Note that the inclination angle can never be definitively determined, unless it’s 90 degrees (edge on), in which case we see eclipses as one binary star passes periodically in front of the other (see Fig. 13.9). As a bonus, eclipsing binaries also allow us to measure the radii of the stars. So, double-lined spectroscopic binaries that are also eclipsing provide the most information of all types of binaries.

Finally – and importantly – once we can reliably measure the masses of some stars (those in binary systems), we can start to look for trends. See the two figures on p. 331. There are quite tight and strong correlations between the mass of a star and its radius and also its luminosity. These are strong observational clues about the physics of stars. And we’ll see when we read about stellar structure that these trends (the mass-radius and mass-luminosity relationships) can in fact be quite easily explained!