Binary Stars

More than 50% of all stars in our Milky Way are not single stars, but belong to **binaries**:

Pairs or multiple systems of stars which orbit their common center of mass.

If we can measure and understand their orbital motion, we can estimate the stellar masses.

The Center of Mass

center of mass = balance point of the system.

Both masses equal => center of mass is in the middle, \( r_A = r_B \).

The more unequal the masses are, the more it shifts toward the more massive star.

Estimating Stellar Masses

Recall Kepler’s 3rd Law:

\[
P_y^2 = a_{AU}^3
\]

Valid for the solar system: star with 1 solar mass in the center.

We find almost the same law for binary stars with masses \( M_A \) and \( M_B \) different from 1 solar mass:

\[
M_A + M_B = \frac{a_{AU}^3}{P_y^2}
\]

(\( M_A \) and \( M_B \) in units of solar masses)

Example:

a) Binary system with period of \( P = 32 \) years and separation of \( a = 16 \) AU:

\[
M_A + M_B = \frac{16^3}{32^2} = 4 \text{ solar masses.}
\]
Visual Binaries

The ideal case:

Both stars can be seen directly, and their separation and relative motion can be followed directly.

Spectroscopic Binaries

Usually, binary separation $a$ cannot be measured directly because the stars are too close to each other.

A limit on the separation and thus the masses can be inferred in the most common case:

Spectroscopic Binaries:

The approaching star produces blueshifted lines; the receding star produces redshifted lines in the spectrum.

Doppler shift $\rightarrow$ Measurement of radial velocities

$\rightarrow$ Estimate of separation $a$

$\rightarrow$ Estimate of masses

Typical sequence of spectra from a spectroscopic binary system
Eclipsing Binaries

Usually, inclination angle of binary systems is unknown → uncertainty in mass estimates.

Special case: Eclipsing Binaries

Here, we know that we are looking at the system edge-on!

Peculiar “double-dip” light curve

Example: VW Cephei

From the light curve of Algol, we can infer that the system contains two stars of very different surface temperature, orbiting in a slightly inclined plane.

Masses of Stars in the Hertzsprung-Russell Diagram

The higher a star’s mass, the more luminous (brighter) it is:

\[ L \sim M^{3.5} \]

High-mass stars have much shorter lives than low-mass stars:

\[ t_{\text{life}} \sim M^{-2.5} \]

Sun: \( \sim 10 \) billion yr.

10 \( M_{\odot} \): \( \sim 30 \) million yr.

0.1 \( M_{\odot} \): \( \sim 3 \) trillion yr.
The Mass-Luminosity Relation

More massive stars are more luminous.

$L \sim M^{3.5}$