Astronomy 404
September 6, 2013

Chapter 7. Binary Systems and Stellar Parameters

Parallax	➔	**distance**
Photometric magnitudes	➔	**brightness & color**
Distance + brightness	➔	**luminosity**
Spectrum (cont. + lines)	➔	**temperature, abundance**
Luminosity + temperature	➔	**radius (i.e. size)**
Binary stars	➔	**mass**
Eclipsing binaries	➔	**radii and ratio of temperatures**

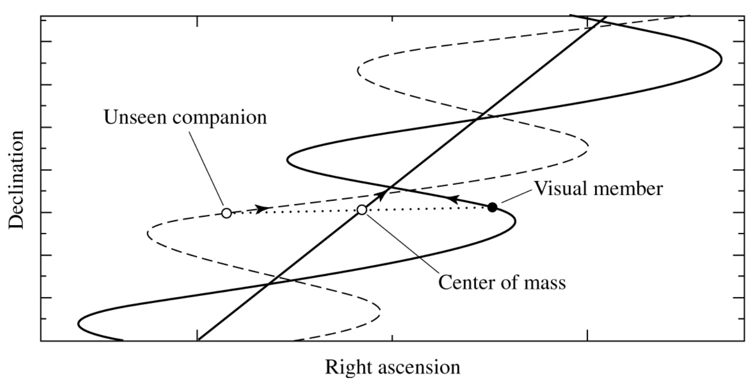
Classification of Binary Stars

Optical double

These are chance superposition of two stars; not real binary systems.

Visual binary

Both stars are resolved, and their orbital motion can be observed.

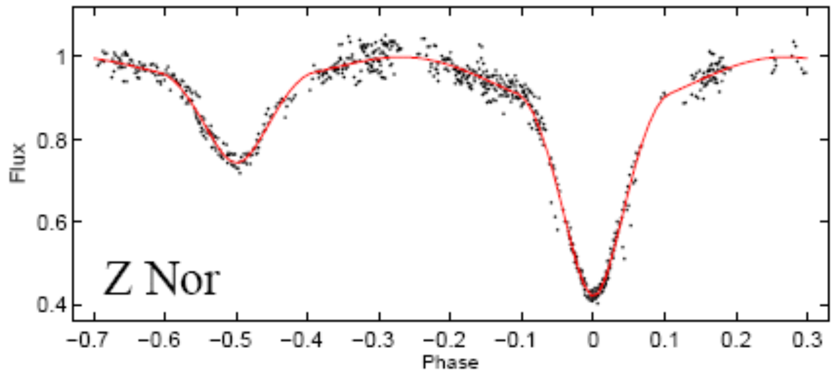


Astrometric binary

Only the brighter star is seen and shows orbital motion.

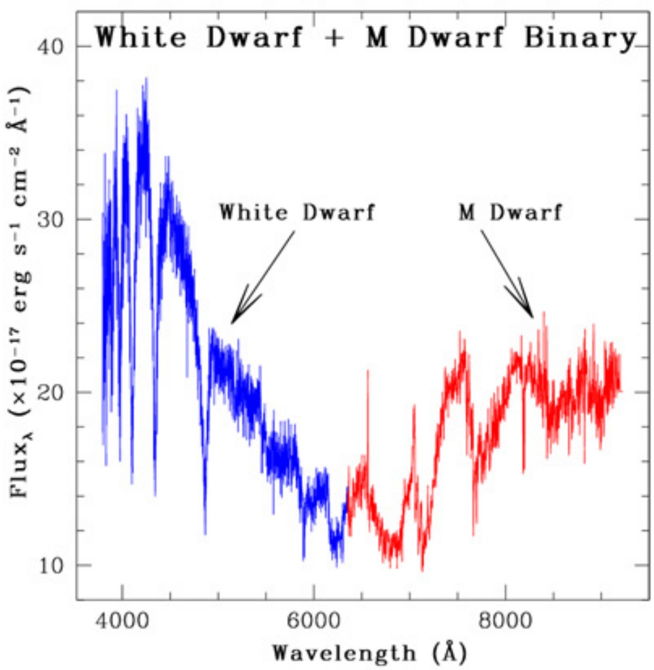
Eclipsing binary

The orbital plane is close to the line-of-sight for eclipses to occur.



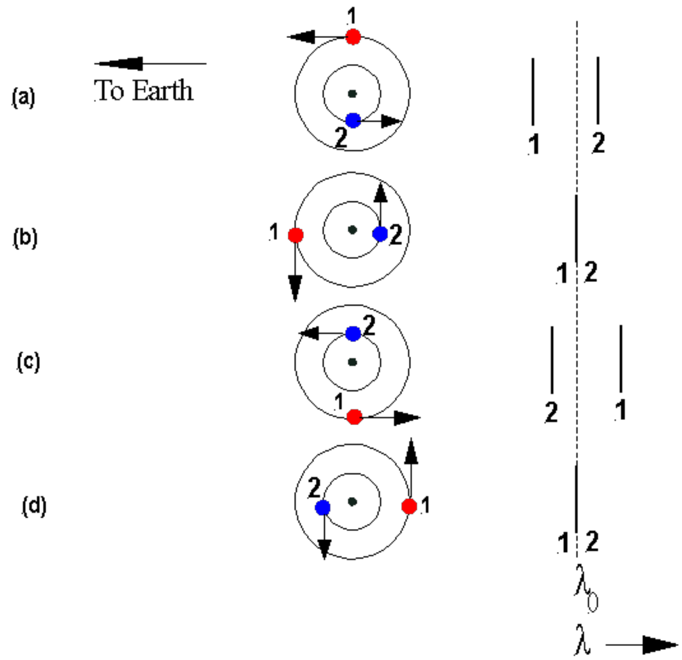
Spectrum binary

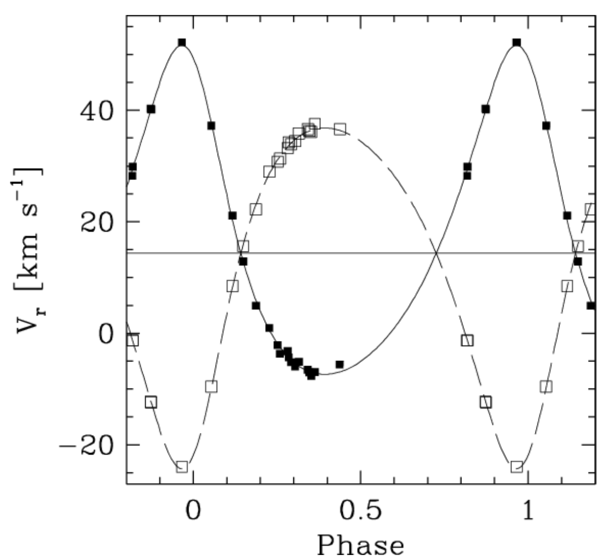
Two superimposed, independent, discernible spectra are seen.
For example, spectra of a red giant and a hot white dwarf, spectra of a WR star and an O star, etc.



Spectroscopic binary

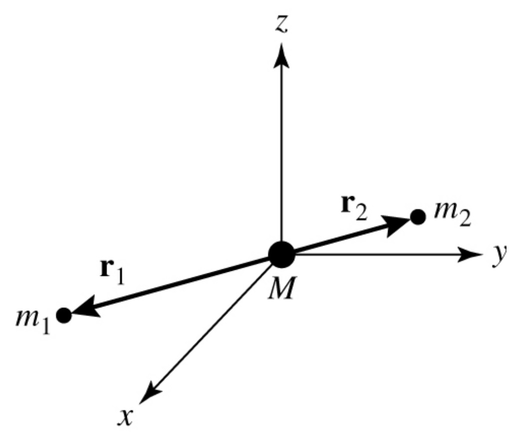
Spectral lines show Doppler shifts that reflect orbital motions. Either both stars or just the brighter star is seen.





Mass Determination Using Visual Binaries

In a visual binary system, both stars are observed to orbit around the center of mass. The semi-major axes of the elliptical orbits of stars 1 & 2 are a_1 and a_2.



$$\frac{m_1}{m_2} = \frac{r_2}{r_1} = \frac{a_2}{a_1}$$

a_2 / a_1 can be determined directly from the observed angular semi-major axes, even if the distance is unknown. **Mass ratio.**

Kepler's third law:

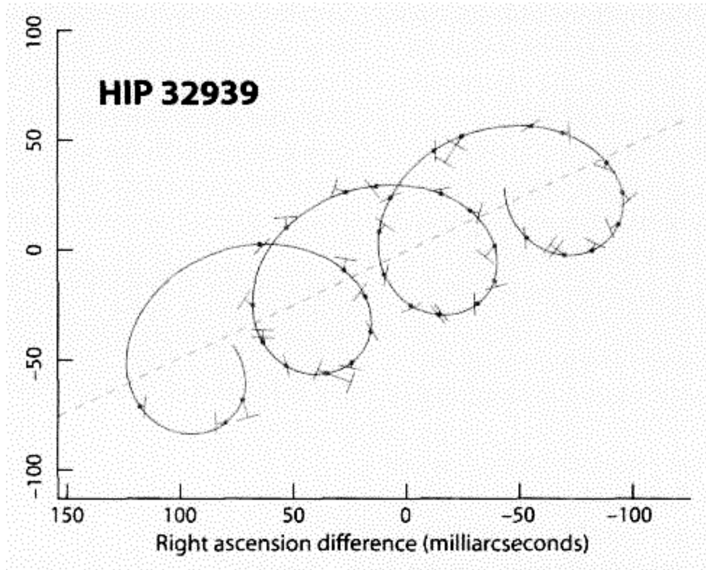
$$P^2 = \frac{4\pi^2}{G\,(m_1 + m_2)} a^3$$

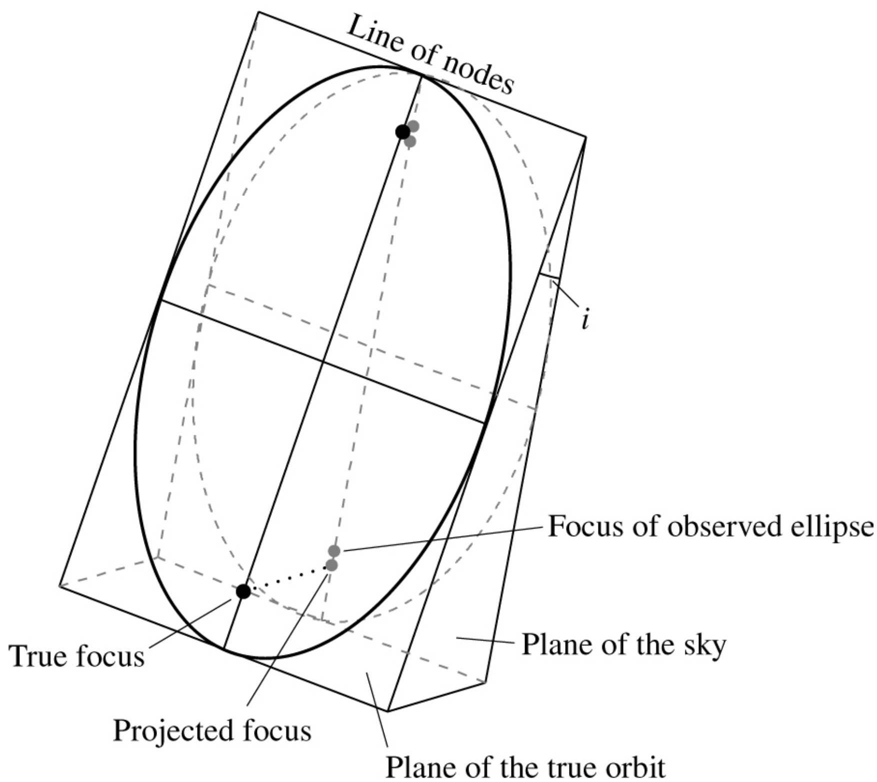
where P is the orbital period and $a = a_1 + a_2$.

The orbital period can be observed, and if the distance is known, a can also be determined, Kepler's third law can be used to determine the total mass ($m_1 + m_2$). **Total mass.**

Total mass and mass ratio → mass of each star.

Complications: proper motion and inclined orbital plane.


HIP 32939
100
50
0
−50
−100
150
100
50
0
−50
−100
Right ascension difference (milliarcseconds)


Line of nodes
i
Focus of observed ellipse
True focus
Plane of the sky
Projected focus
Plane of the true orbit

$m_1 / m_2 = a_2 / a_1 = (a_2 \cos i) / (a_1 \cos i)$

Even without knowing the inclination angle i, the mass ratio can still be determined.

To determine the total mass, we need to know the real a_1 and a_2, which are the apparent values divided by cos i.

$$m_1 + m_2 = \frac{4\pi^2}{G}\frac{(\alpha d)^3}{P^2} = \frac{4\pi^2}{G}\left(\frac{d}{\cos i}\right)^3 \frac{\tilde{\alpha}^3}{P^2},$$

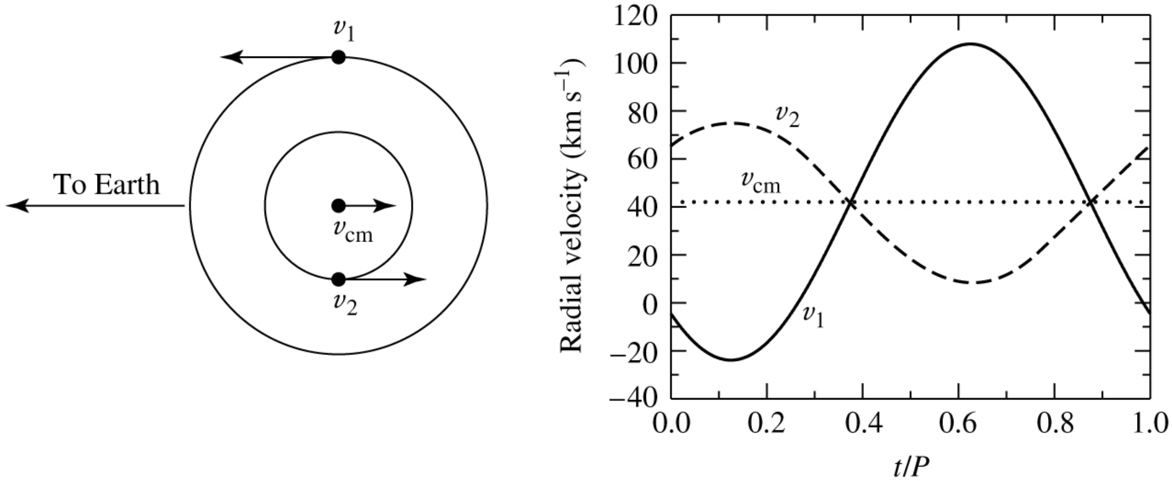
where d is the distance, i is the inclination angle, P is the period, α is the angular a in radian, and $\tilde{\alpha}$ is the apparent angular a in radian.

Basically, you need to correct the projection effect, and the observed length is equal to the real length x cos i.

Model the binary system with an inclination angle and fit data to determine all parameters.

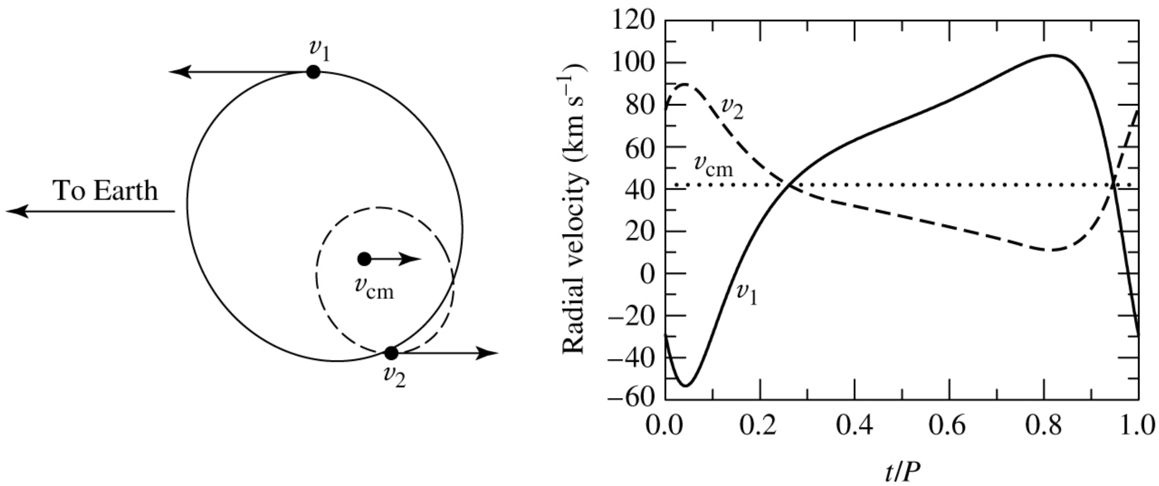
Spectroscopic Binaries

Two stars in circular orbits, $M_1 = 1\ M_{sun}$, $M_2 = 2\ M_{sun}$, $P = 30$ d, i=0.



(a) (b)

Two stars in elliptical orbits (e = 0.4), $M_1 = 1\ M_{sun}$, $M_2 = 2\ M_{sun}$, $P = 30$ d, i=0.



(a) (b)

$$\frac{m_1}{m_2} = \frac{v_2}{v_1}.$$

$$\boxed{\frac{m_1}{m_2} = \frac{v_{2r}/\sin i}{v_{1r}/\sin i} = \frac{v_{2r}}{v_{1r}}.}$$

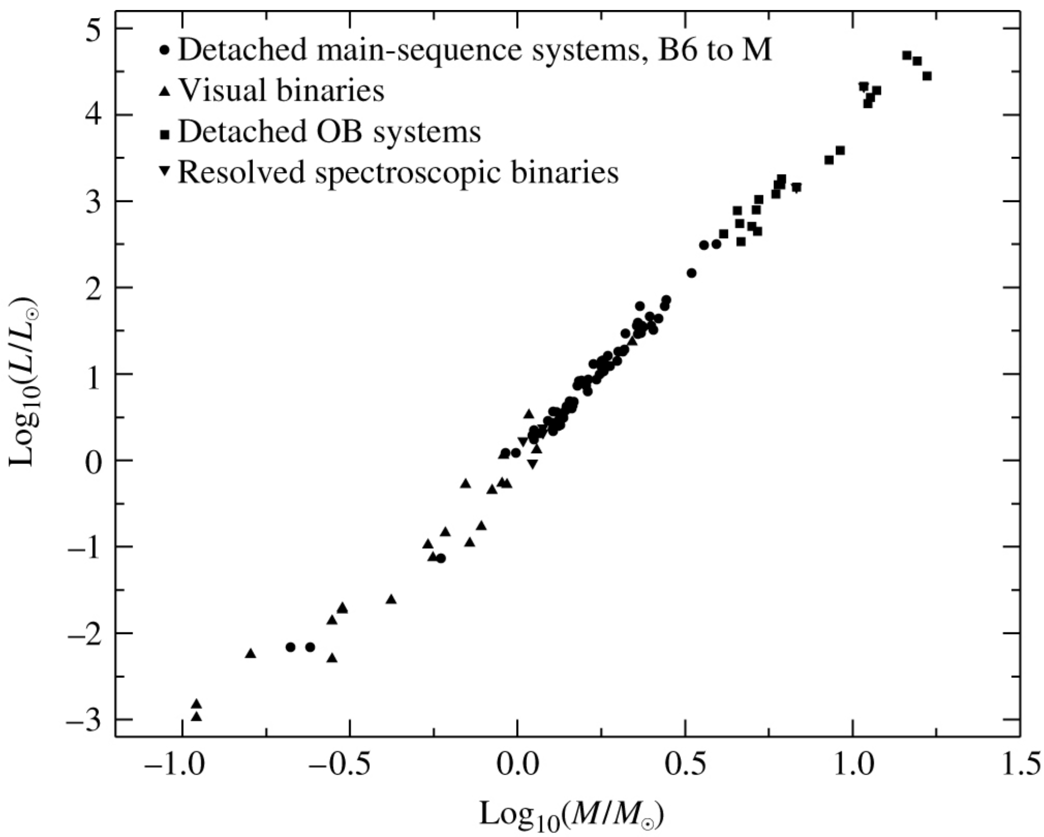
Recall that $P = 2\,\pi\,a\,/\,v$ and that

$$P^2 = \frac{4\pi^2}{G\,(m_1 + m_2)} a^3$$

$$m_1 + m_2 = \frac{P}{2\pi G}\,(v_1 + v_2)^3.$$

$$\boxed{m_1 + m_2 = \frac{P}{2\pi G}\frac{(v_{1r} + v_{2r})^3}{\sin^3 i}.}$$

Mass-luminosity relation of stars



Detached main-sequence systems, B6 to M
Visual binaries
Detached OB systems
Resolved spectroscopic binaries
5
4
3
2
1
0
−1
−2
−3
−1.0
−0.5
0.0
0.5
1.0
1.5
$\mathrm{Log}_{10}(L/L_\odot)$
$\mathrm{Log}_{10}(M/M_\odot)$