Binary Stars

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July 17,2020

What are Binary stars?

Binary stars

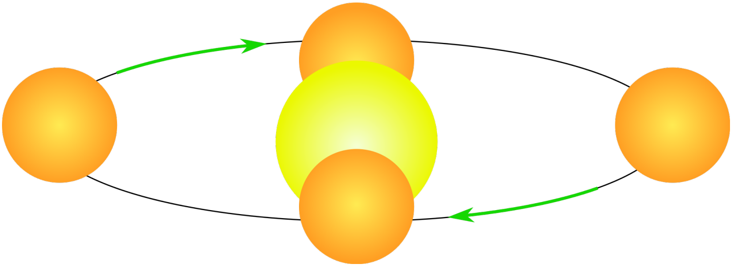


Figure: [By MesserWoland from WikiMedia]

Sirius

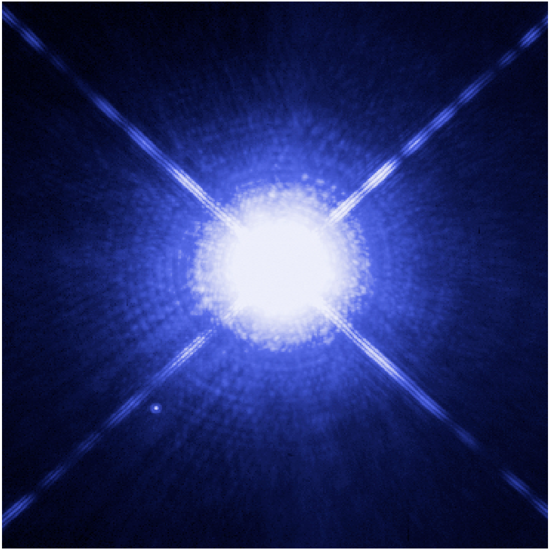
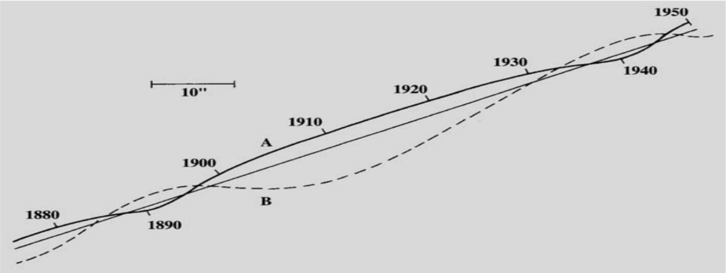
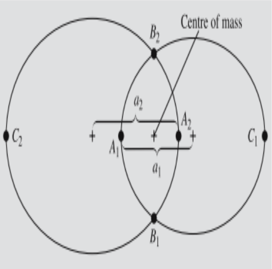


Figure: [By Dr. Andy Layden from Bowling Green State University]

Observing Sirius



Binary Orbits



Binary Orbits: Ellipses

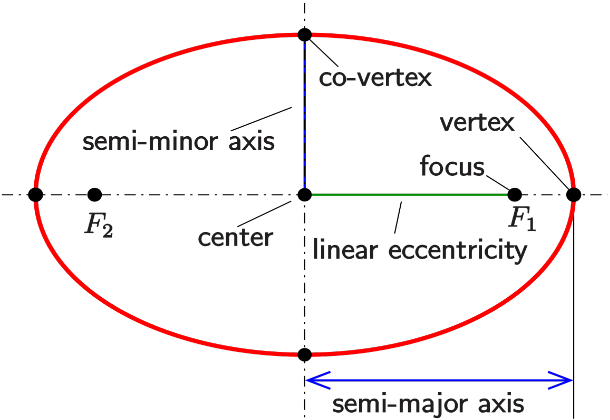


Figure: [By Ag2gaeh from WikiMedia]

Classifying Binaries

Optical Double

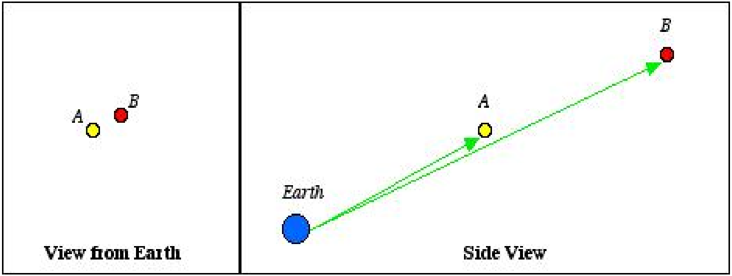


Figure: [By Dr. Andy Layden from Bowling Green State University]

Visual Binary

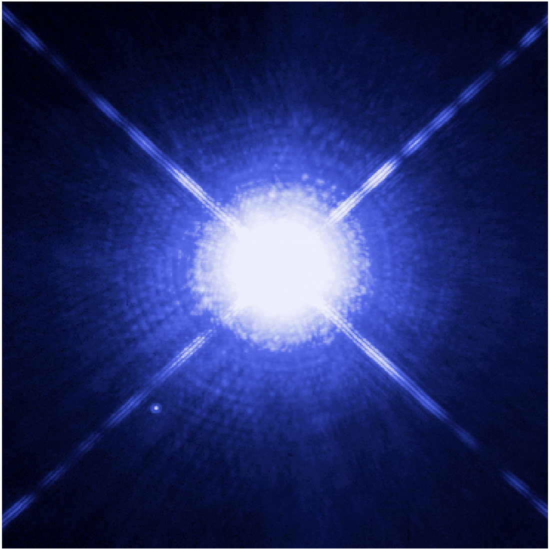
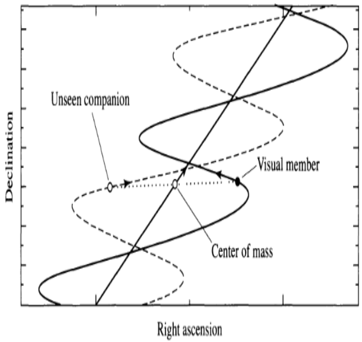
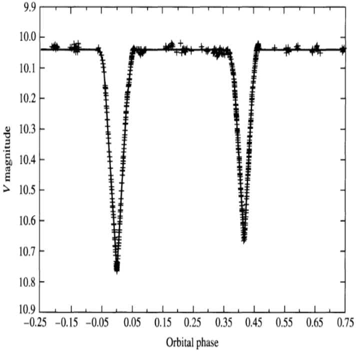


Figure: [By Wikimedia Commons contributors from WikiMedia]

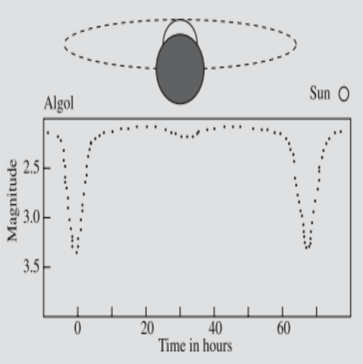
Astrometric Binary



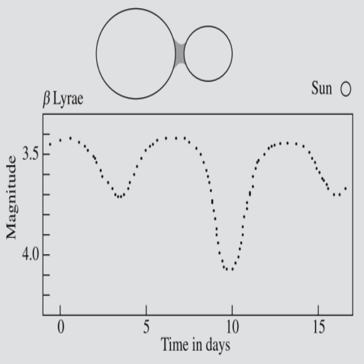
Eclipsing Binary



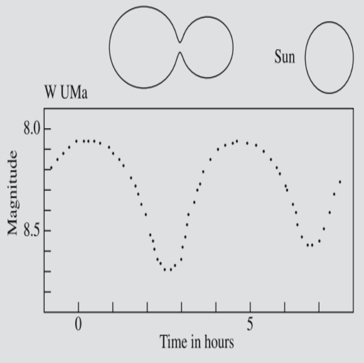
Algol Stars



β Lyrae



W Ursae Majoris



Spectrum Binary

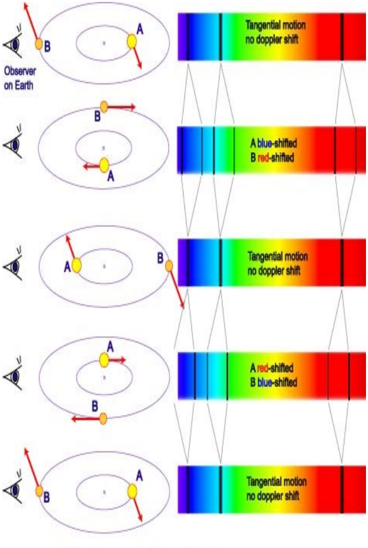


Figure: [From Australia Telescope National Facility]

Mass Determination Using Visual Binaries

Mass Determination Using Visual Binaries

$$\frac{m_1}{m_2} = \frac{r_2}{r_1} = \frac{a_2}{a_1} \tag{1}$$

Where a_1 and a_2 are the semimajor axes of the ellipses. If we suppose that the observer is at a distance d from the system, we can say that the angles subtended by the semimajor axes are:

$$\alpha_1 = \frac{a_1}{d}, \alpha_2 = \frac{a_2}{d}$$

$$\frac{m_1}{m_2} = \frac{\alpha_2}{\alpha_1} \tag{2}$$

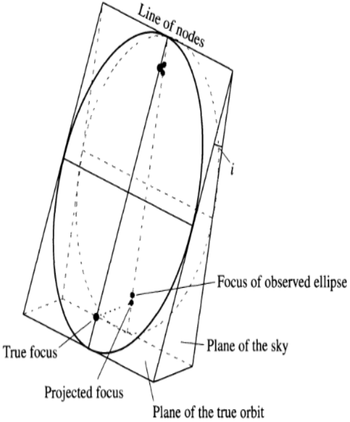
Mass Determination Using Visual Binaries

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

- Let i be the angle of inclination between the plane of an orbit and the plane of the sky note that the orbits of both stars are necessarily in the same plane
- As a special case, assume that the orbital plane and the plane of the sky defined as being perpendicular to the line of sight, intersect along a line parallel to the minor axis, forming a line of nodes
- The observer will not measure the actual angles subtended by the semimajor axes α_1 and α_2 but their projections onto the plane of the sky, $\tilde{\alpha}_1 = \alpha_1 \cos i$ and $\tilde{\alpha}_2 = \alpha_1 \cos i$
- This geometrical effect plays no role in calculating the mass ratios since the cos i term will simply cancel:

$$\frac{m_1}{m_2} = \frac{\alpha_2}{\alpha_1} = \frac{\alpha_2 \cos i}{\alpha_1 \cos i} = \frac{\tilde{\alpha}_2}{\tilde{\alpha}_1} \qquad (4)$$

Mass Determination Using Visual Binaries



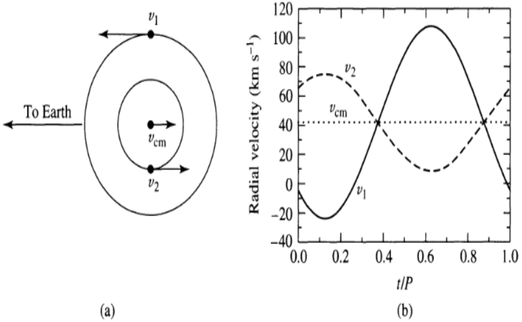
$$m_1 + m_2 = \frac{4\pi^2}{G} \frac{(\alpha d)^3}{P^2} = \frac{4\pi^2}{G} \left(\frac{d}{\cos i} \right)^3 \frac{\tilde{\alpha}^3}{P^2} \tag{5}$$

Where, $\tilde{\alpha} = \tilde{\alpha}_1 + \tilde{\alpha}_2$

Eclipsing, Spectroscopic Binaries

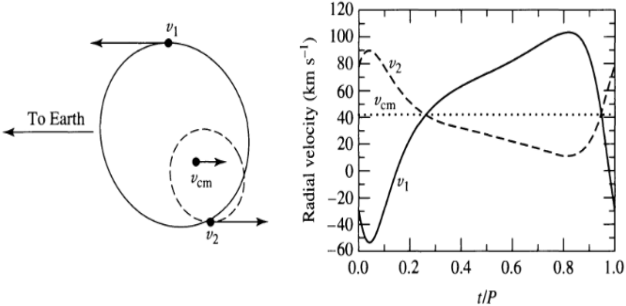
The Effect of Eccentricity on Radial Velocity Measurements

When $e = 0$,



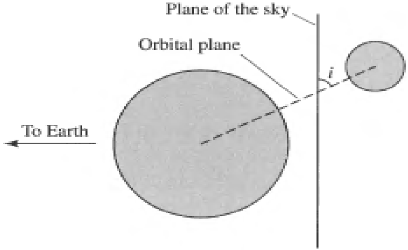
The Effect of Eccentricity on Radial Velocity Measurements

When $e \neq 0$,

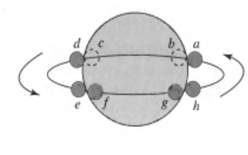


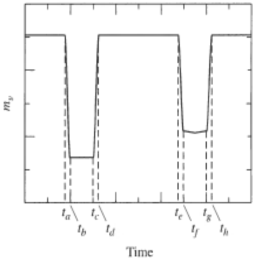
(a) (b)

Using Eclipses to Determine Radii and Ratios of Temperatures

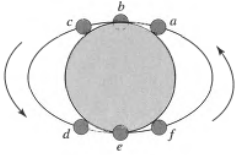


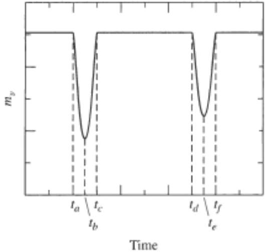
Using Eclipses to Determine Radii and Ratios of Temperatures





Using Eclipses to Determine Radii and Ratios of Temperatures





Using Eclipses to Determine Radii and Ratios of Temperatures

- If we assume that $i \approxeq 90^0$, the amount of time between first contact (t_a) and minimum light (t_b), combined with the velocities of the stars, leads directly to the calculation of the radius of the smaller component.
- If the semimajor axis of the smaller star's orbit is sufficiently large compared to either star's radius, and if the orbit is nearly circular, we can assume that the smaller object is moving approximately perpendicular to the line of sight of the observer during the duration of the eclipse
- In this case the radius of the smaller star is simply
$$r_s = \frac{v}{2}(t_b - t_a) \tag{6}$$
- where $v = v_s + v_l$ is the relative velocity of the two stars and v_s and v_l are the velocities of the small and large stars, respectively

Using Eclipses to Determine Radii and Ratios of Temperatures

- If we consider the amount of time between t_b and t_e , the size of the larger member can also be determined
- It can be quickly shown that the radius of the larger star is just

$$r_l = \frac{v}{2}(t_c - t_a) = r_s + \frac{v}{2}(t_c - t_b) \tag{7}$$

Using Eclipses to Determine Radii and Ratios of Temperatures

- The raiative surface flux is given by:
$$F_r = F_{surf} = \sigma T_e^4 \tag{8}$$

- Assuming for simplicity that the observed flux is constant across the disks, the amount of light detected from the binary when both stars are fully visible is given by
$$B_0 = k(\pi r_l^2 F_{rl} + \pi r_s^2 F_{rs}) \tag{9}$$

Using Eclipses to Determine Radii and Ratios of Temperatures

- If the smaller star is hotter and therefore has the larger surface flux, and the smaller star is entirely eclipsed, the amount of light detected during the primary minimum may be expressed as

$$B_p = k\pi r_l^2 F_{rl} \tag{10}$$

- while the brightness of the secondary minimum is

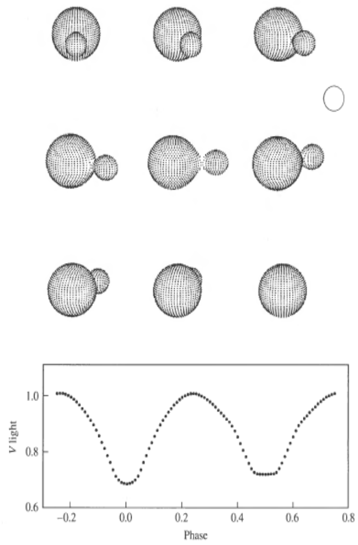
$$B_{sk} = k(\pi r_l^2 - \pi r_s^2)F_{rl} + k\pi r_s^2 F_{rs} \tag{11}$$

Using Eclipses to Determine Radii and Ratios of Temperatures

- Since it is generally not possible to determine k exactly, ratios are employed
- Consider the ratio of the depth of the primary to the depth of the secondary
- Using the expressions for B_o, B_p, and B_s, we find immediately that

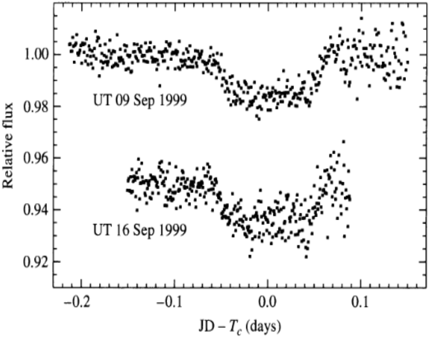
$$\frac{B_o - B_p}{B_o - B_s} = \frac{F_{rs}}{F_{rl}} = \left(\frac{T_s}{T_l}\right)^4 \tag{12}$$

Computer Modelling Approaches



The Search For Exoplanets

The Discovery of Extrasolar Planets



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Thank You