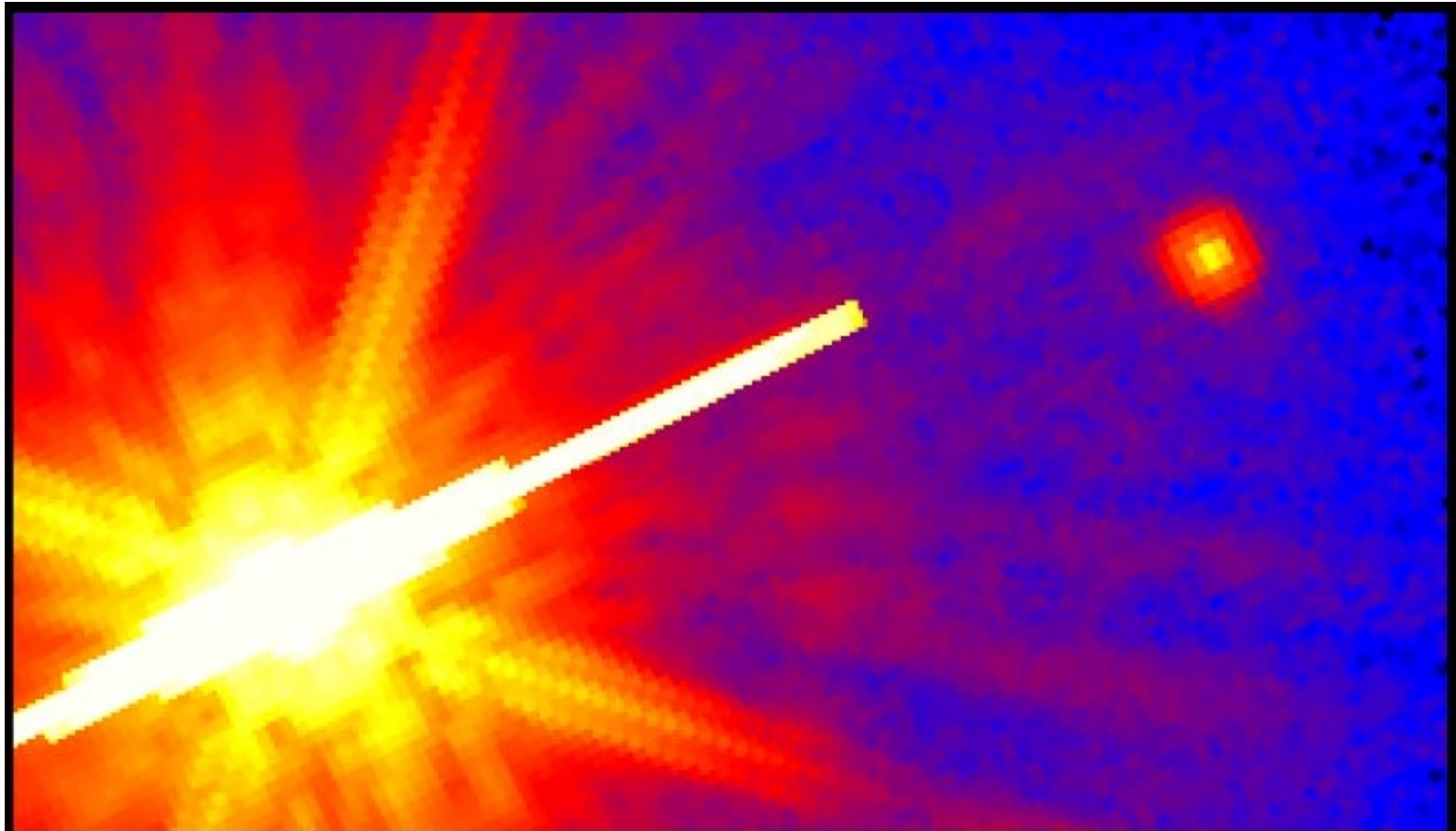


Binary Star Systems

(Chapter 7)



Low Mass Companion to Star Gliese 105A

HST · WFPC2

PRC95-33 · ST ScI OPO · September 14, 1995 · D. Golimowski (JHU), NASA

Binary Star Systems

1) Classification of binary star systems

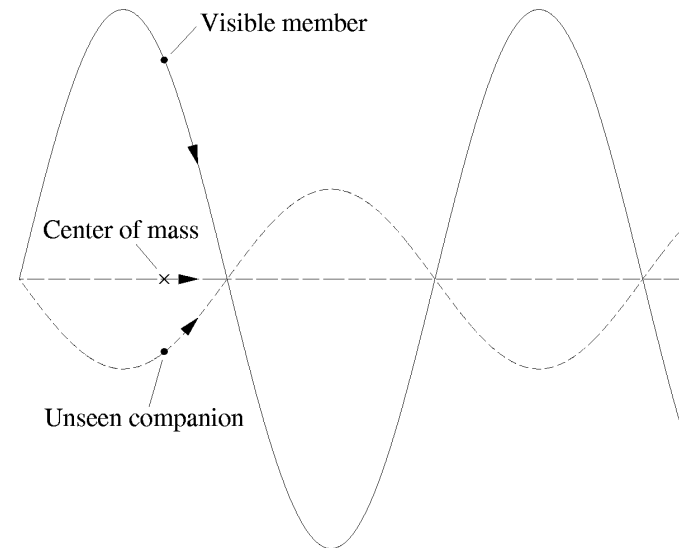
- 1) Optical Doubles
- 2) Visual binary
- 3) Astrometric Binary
- 4) Eclipsing Binary (detached, semi-detached, unattached)
- 5) Spectrum Binary
- 6) Spectroscopic Binary

2) Stellar properties measured with binaries

- 1) Mass
 - 1) From Visual Binaries
 - 2) Complications with Visual Binary method
- 2) Radii, Surface brightness, Surface temperature
- 3) Mass functions from Spectroscopic Binaries

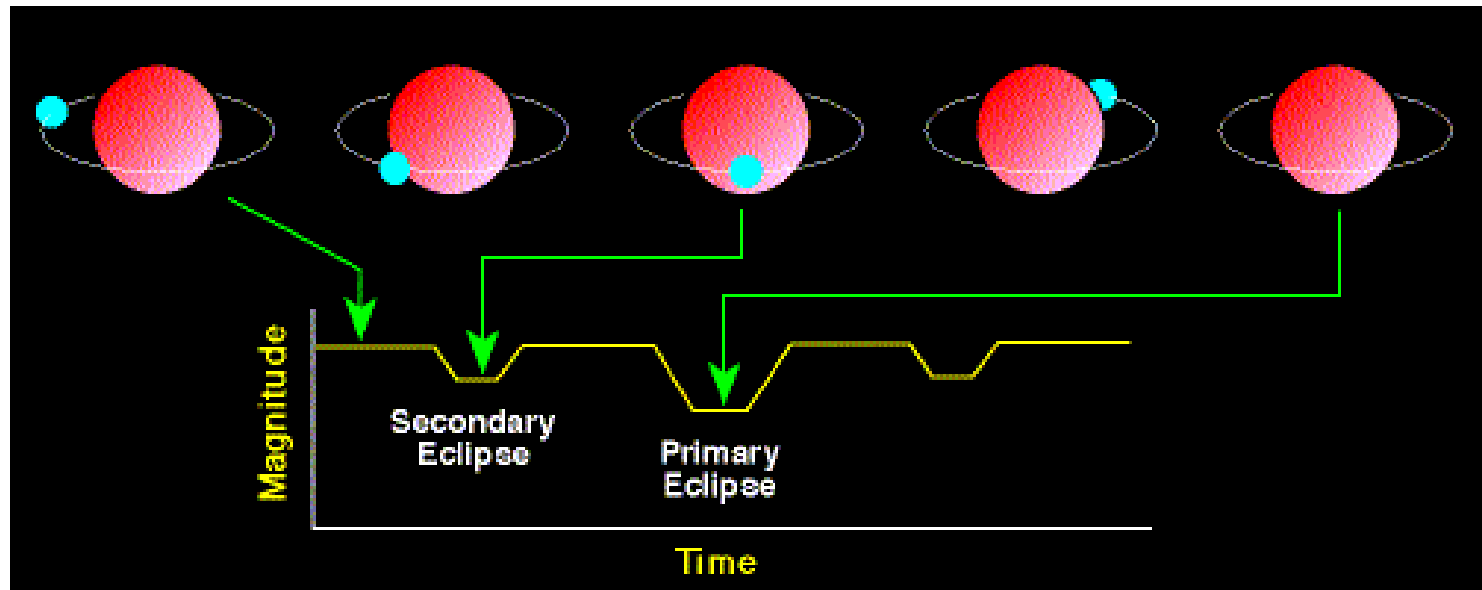
Classification of Binary Star Systems

- Multiple systems are more of a rule than an exception
 - At least half of all stars are multiple systems
- **Optical Double**
 - Lie along the same line of sight and look as though they are companions
 - They have no physical proximity to one another
 - Not gravitationally bound
 - Not a binary star system!
- **Visual binary**
 - Sufficiently close to Earth and the stars are well enough separated that we can see the two stars individually (resolved) in a telescope and track their motion over a period of time
- **Astrometric binary**
 - Detect the presence of an unseen companion (faint, cool star) by its gravitational influence on the primary star
 - Deviation in proper motion



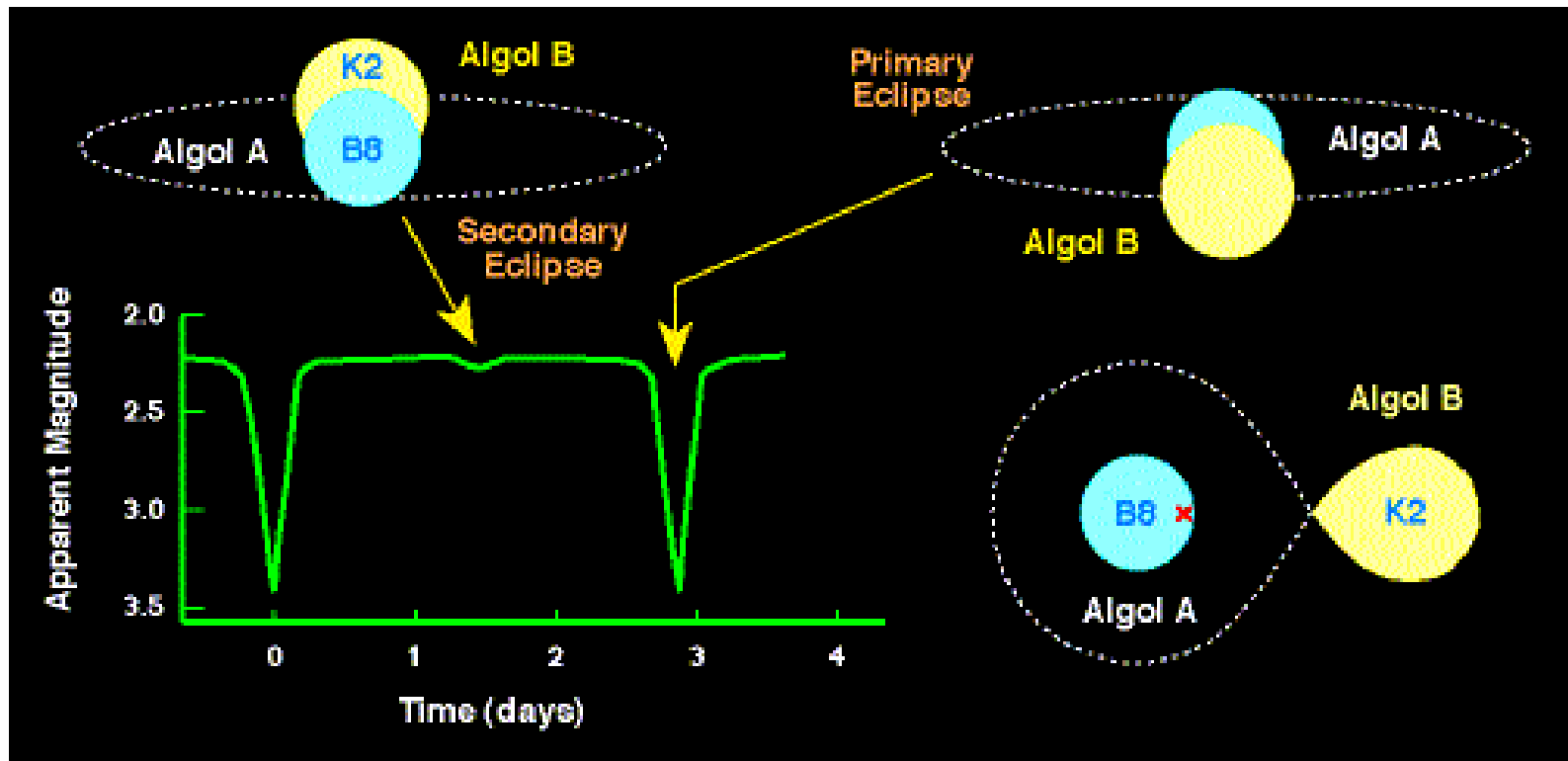
Classification of Binary Star Systems

- **Eclipsing binary**
 - Orbital planes along the line of sight (or nearly so)
 - The system is usually not resolved in the telescope (not vis binary)
 - Photoelectric or CCD photometry over time produces *light curve*
 - Q: What can you tell from the shape of the eclipse dips?
 - Q: How could you tell that the blue star moved left to right?



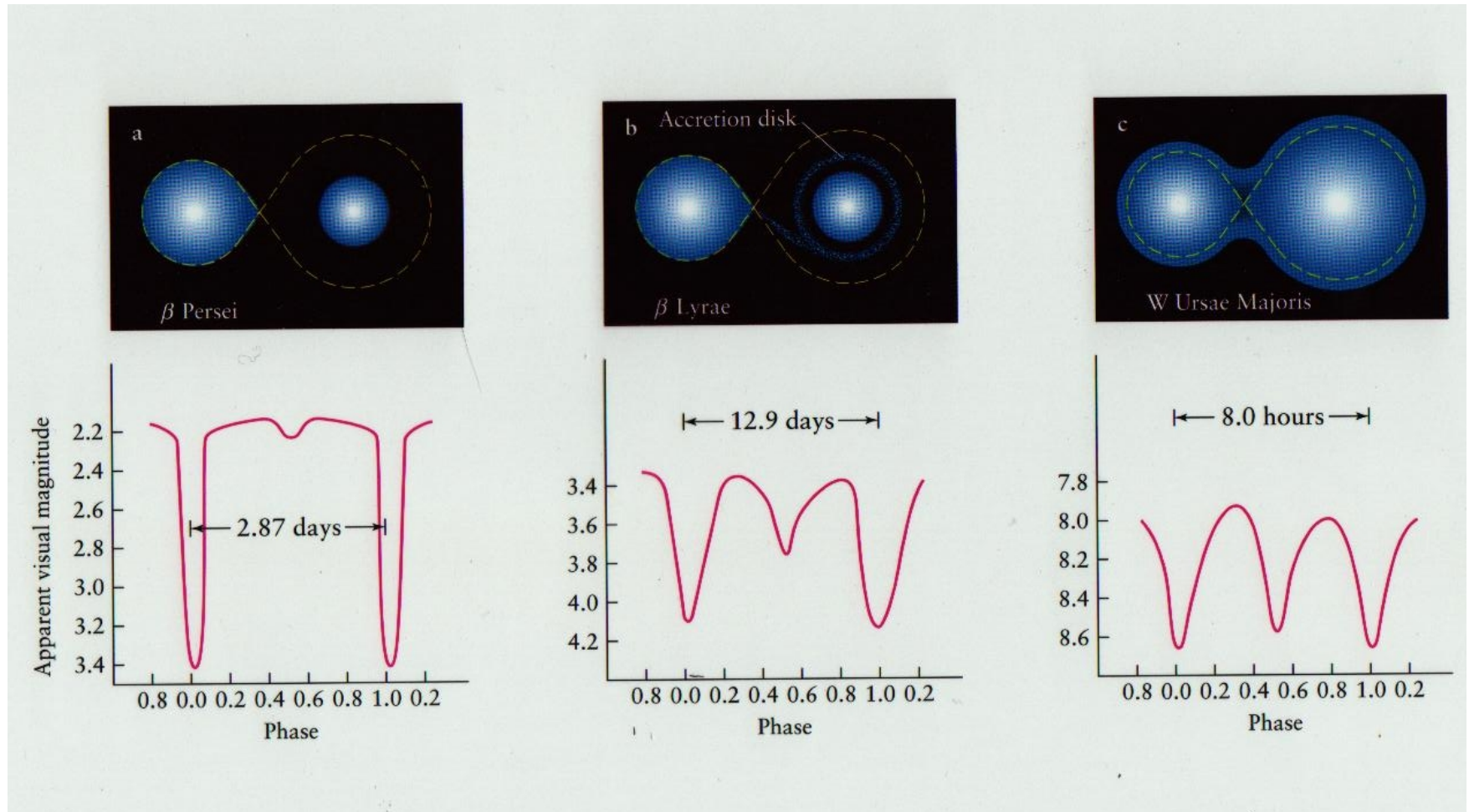
Classification of Binary Star Systems

- **Eclipsing binary Example - Algol**
 - Q: Why is the eclipse of the B8 star deeper than the eclipse of the K2 star?
 - Smaller blue star emits more light per unit surface area than the larger red star
 - Q: Why don't the minima have flat bottoms?
 - During eclipses, neither star gets completely covered up by the other.



Classification of Binary Star Systems

- Eclipsing binary Examples



Classification of Binary Star Systems

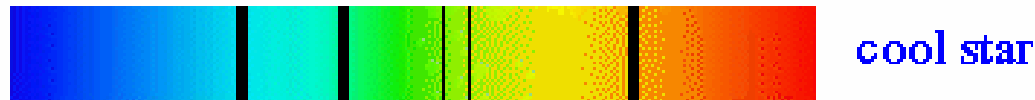
- **Spectrum binary**

- System with two superimposed, independent, discernable spectra

Normally, each star as a unique spectrum (spectral class). For example, a hot star has a spectrum rich in hydrogen lines



A cool star has thicker lines from metals, such as below



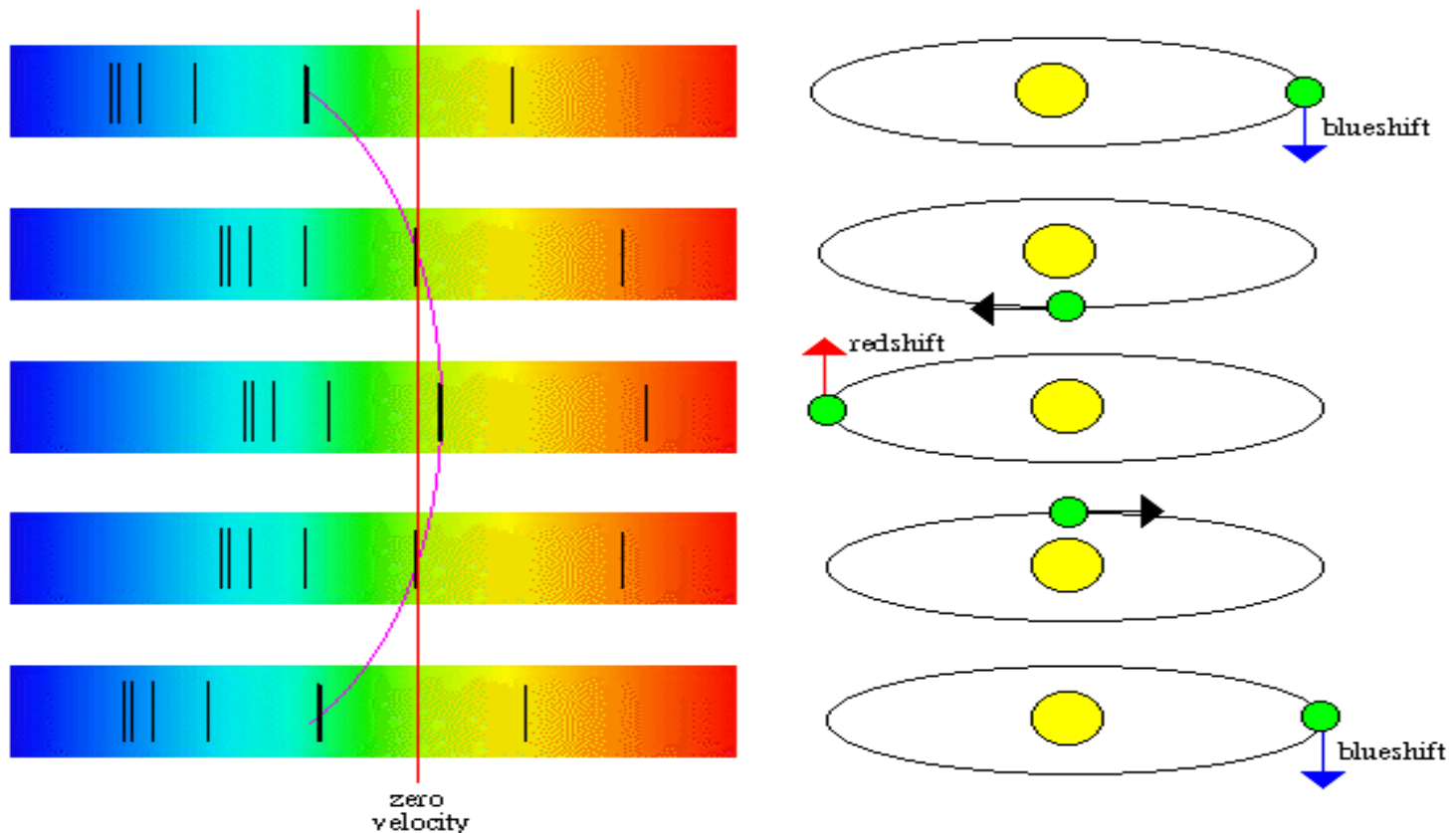
So, a spectrum binary is when you can not see two stars on the sky, but a spectrum of the object show two difference stellar classes, as below.



Classification of Binary Star Systems

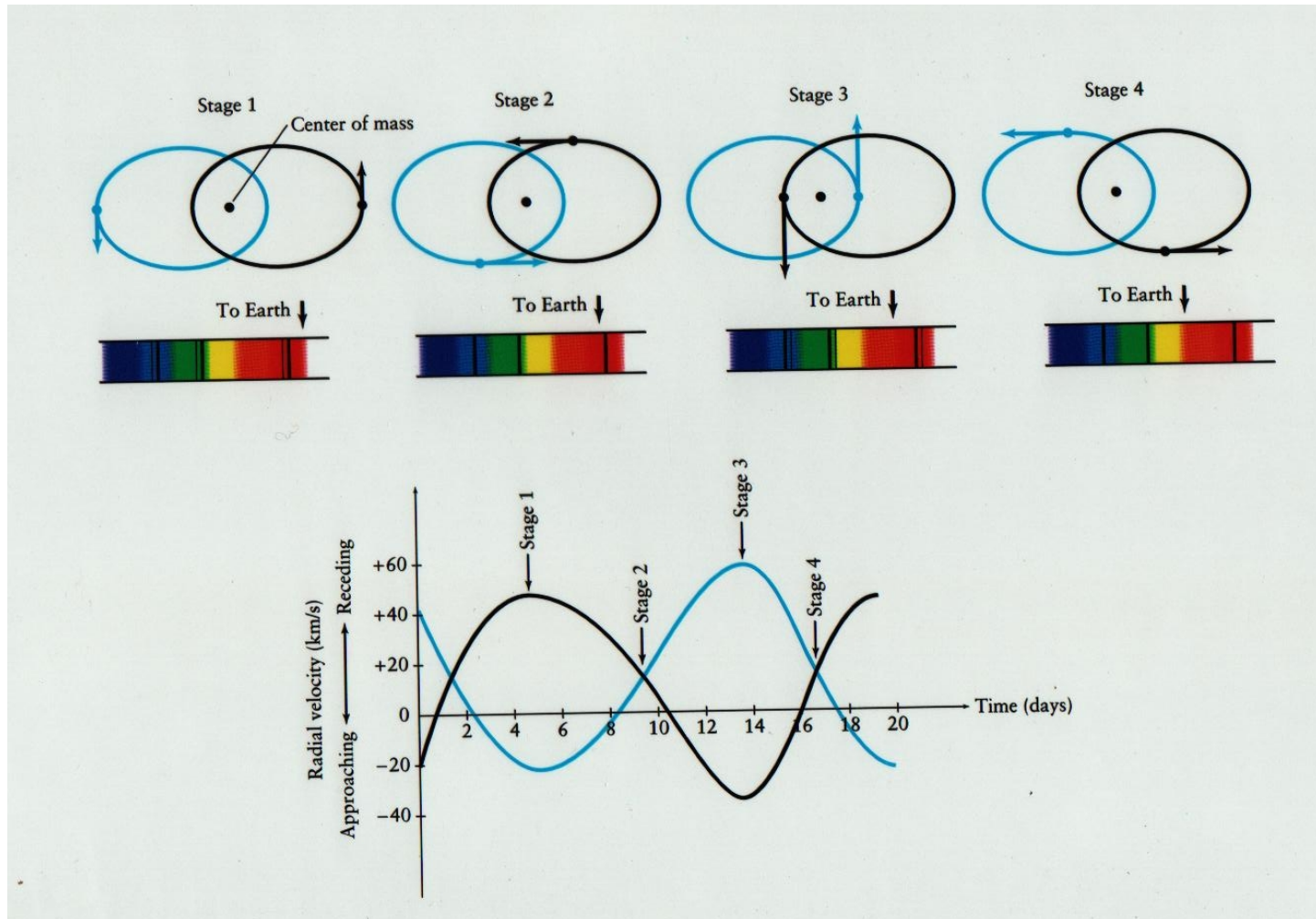
- **Spectroscopic Binary**

- Pair cannot be resolved as a visual binary
- Measure relative velocities via the Doppler shift of their spectral lines
- Motion is usually seen in the lines of one star



Classification of Binary Star Systems

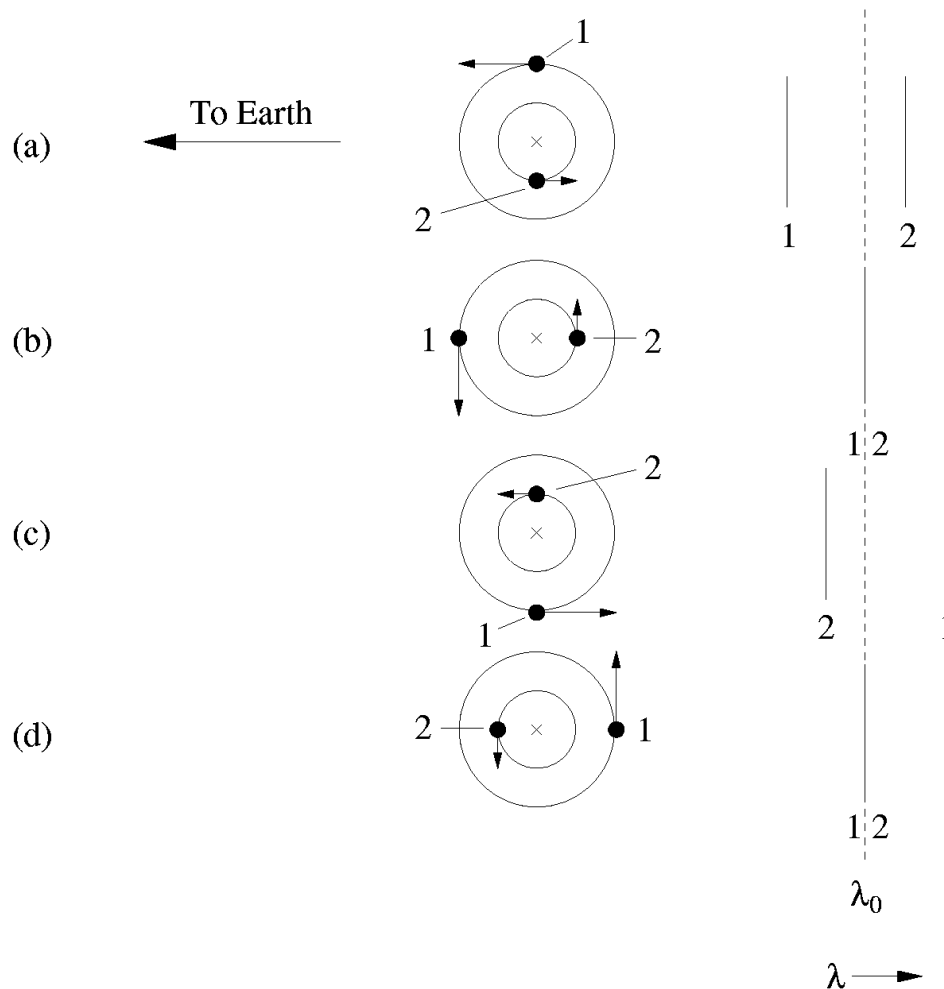
- Spectroscopic binary



Classification of Binary Star Systems

- **Spectroscopic Binary**

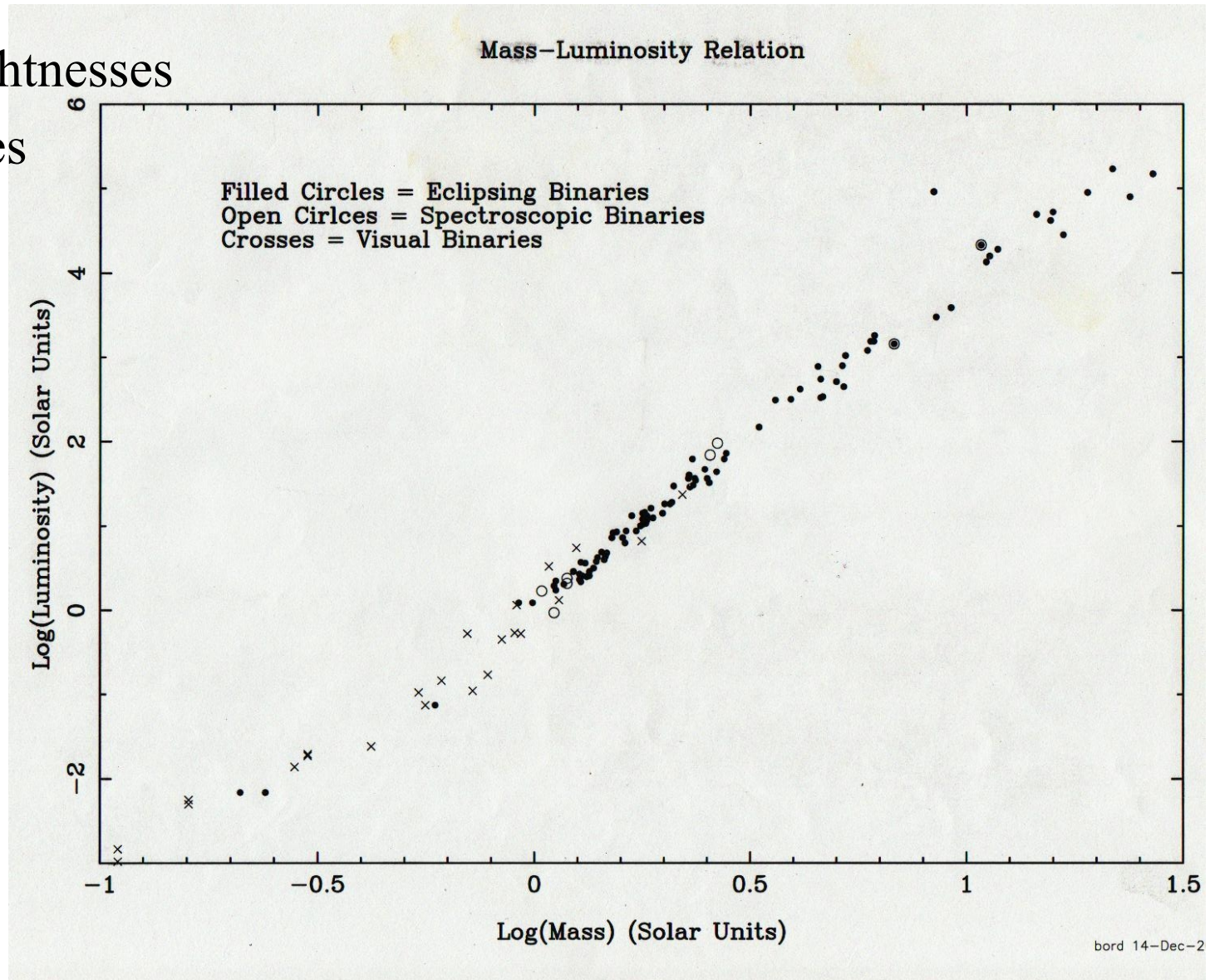
- Double-line spectroscopic binary



$$\frac{\Delta\lambda}{\lambda_0} = \frac{v}{c}$$

Stellar Properties from binaries

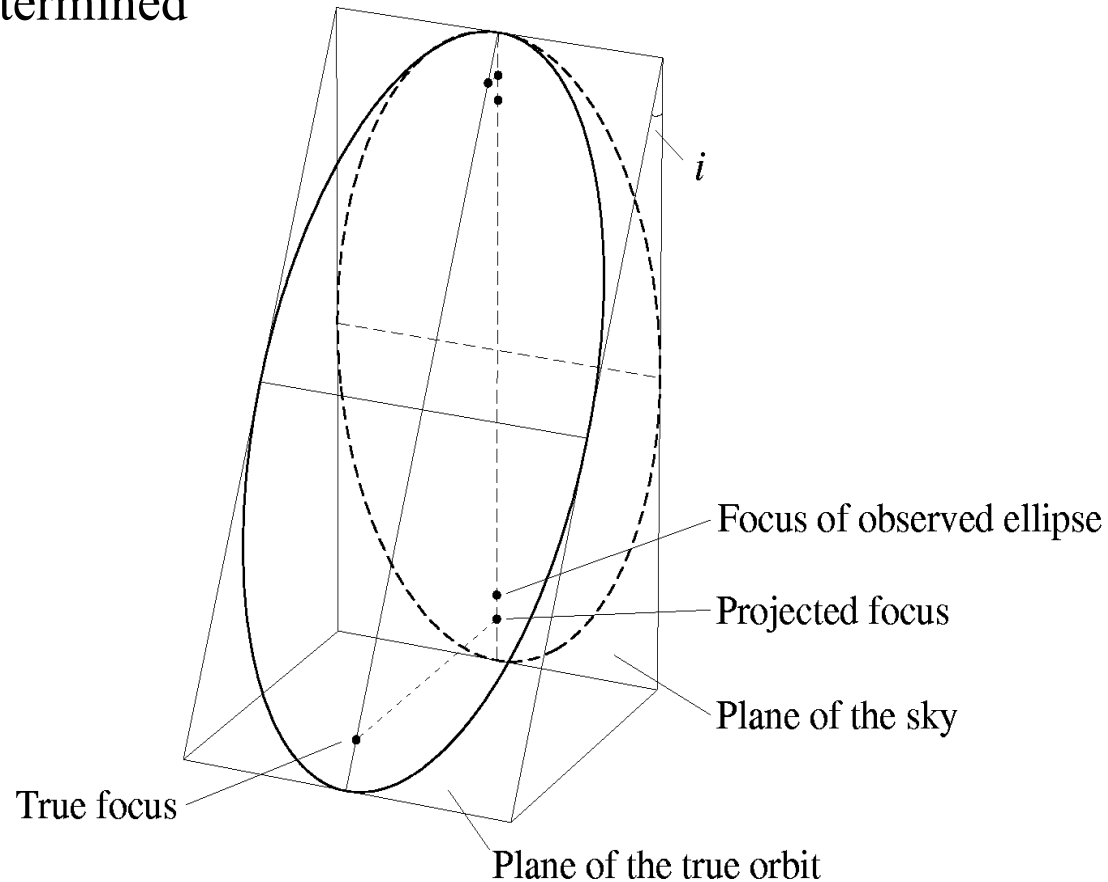
- Radii
- Surface brightnesses
- Temperatures
- MASSES



Mass Determination Using Visual Binaries

- Angular separation greater than telescope resolution
- Observation of orbits yields ratio of stars' masses
- If distance is known
 - Individual masses can be determined

- angle of inclination, i
 - Angle between the plane of the orbit and the plane of the sky



Mass Determination Using Visual Binaries

- Let's assume $i = 0^\circ$
- From the center of mass coordinates
 - Let's put CM at 0 and find ratio of masses

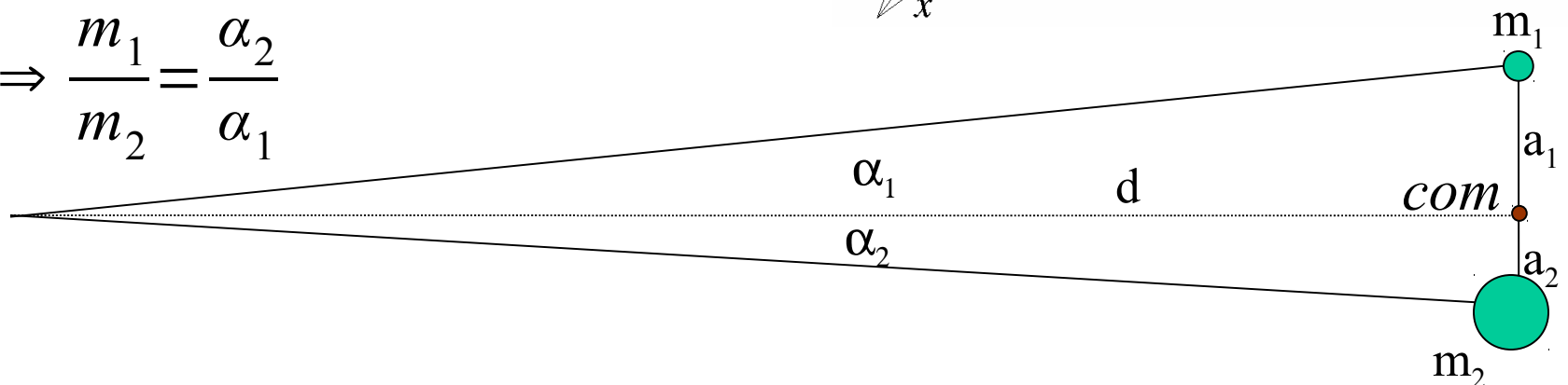
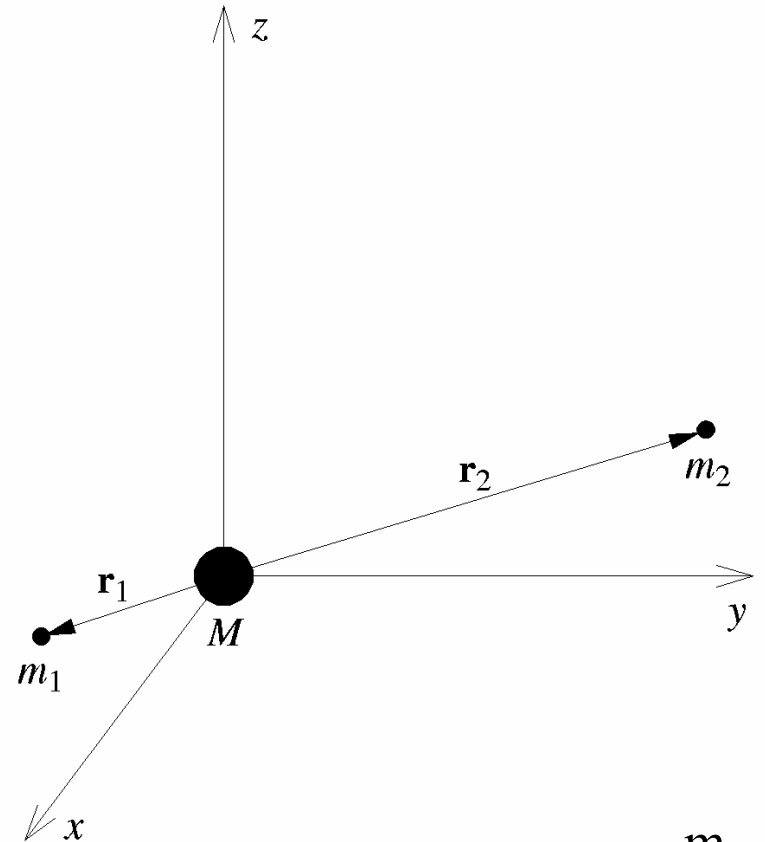
$$R = m_1 r_1 + m_2 r_2 = 0$$

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

- If the distance is known

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

$$\Rightarrow \frac{m_1}{m_2} = \frac{\alpha_2}{\alpha_1}$$



Mass Determination Using Visual Binaries

- General Form of Kepler's third law

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

Where P is the period of orbit and a is the semi-major axis of the reduced mass

$$a = a_1 + a_2$$

- Two equations and two unknowns, game over

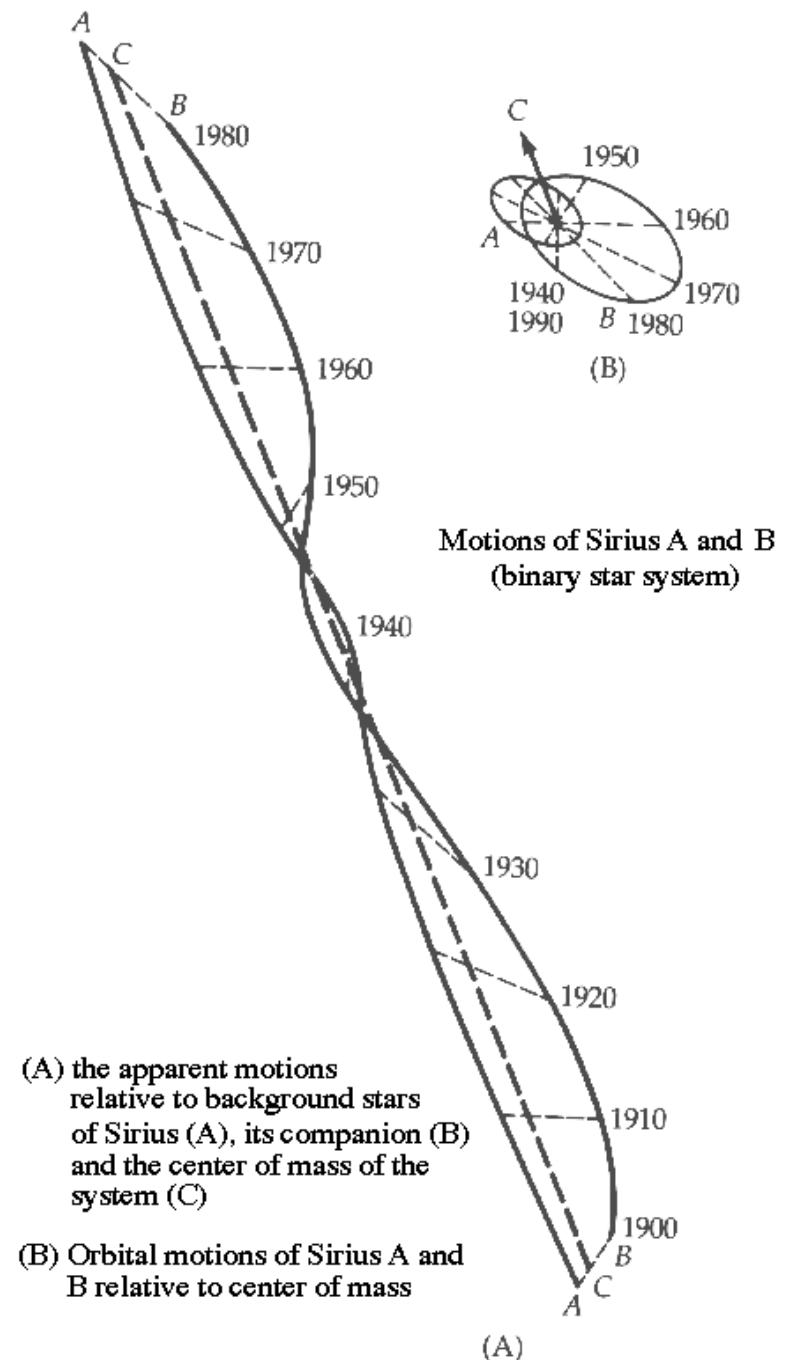
$$\frac{m_1}{m_2} = \frac{\alpha_2}{\alpha_1}$$

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

Mass Determination...

Other complications:

- Parallax
- Proper motion
 - Center of mass is at a constant velocity
 - Can be factored out



Non-zero angle of Inclination

- The angles subtended by the semimajor axes will be reduced

$$\tilde{\alpha}_1 = \alpha_1 \cos i$$

$$\tilde{\alpha}_2 = \alpha_2 \cos i$$

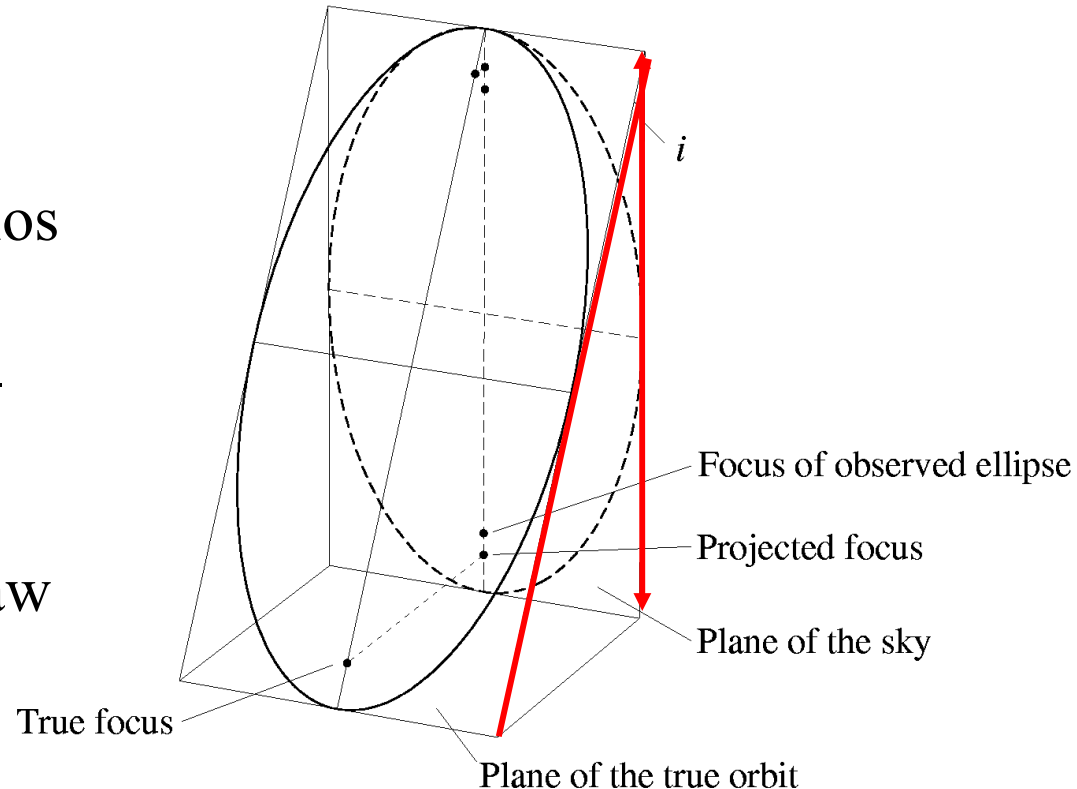
Doesn't matter for mass ratios

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

Does matter for Kepler's Law

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

$$\alpha = \frac{a}{d} \Rightarrow a = \alpha d$$



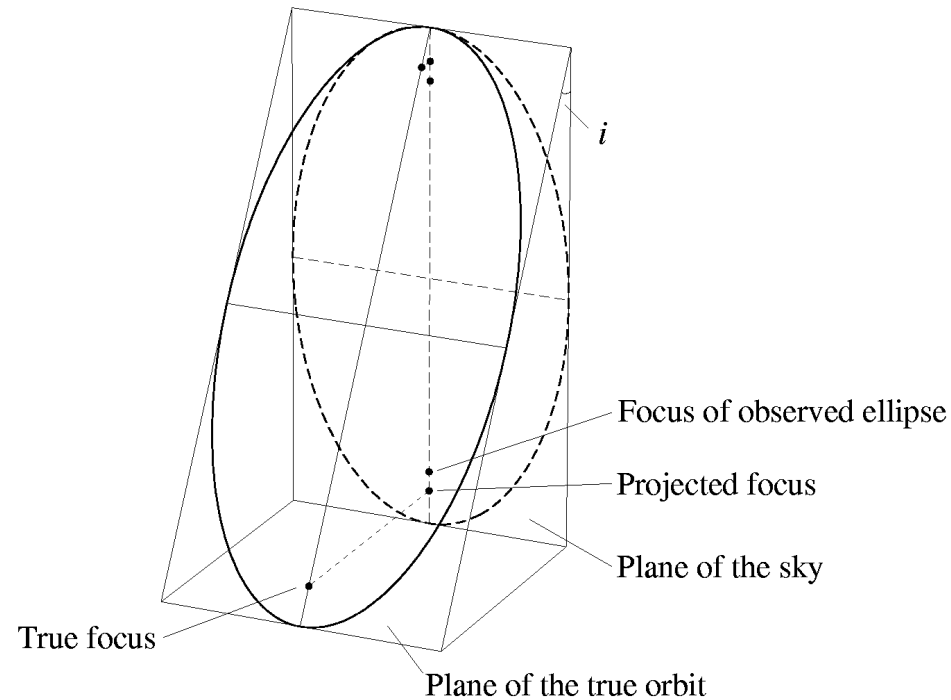
Angle of Inclination

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

$$\alpha = \frac{\tilde{\alpha}}{\cos i}$$

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

$$m_1 + m_2 = \frac{4\pi^2}{GP^2} (\tilde{\alpha} d)^3 \left(\frac{1}{\cos i} \right)^3$$



- Angle of inclination must be determined
- Resolved by noting the *Projected focus* does not coincide with the *observed focus*
 - Center of mass will be off
 - Inconsistencies will result

Spectroscopic Binaries

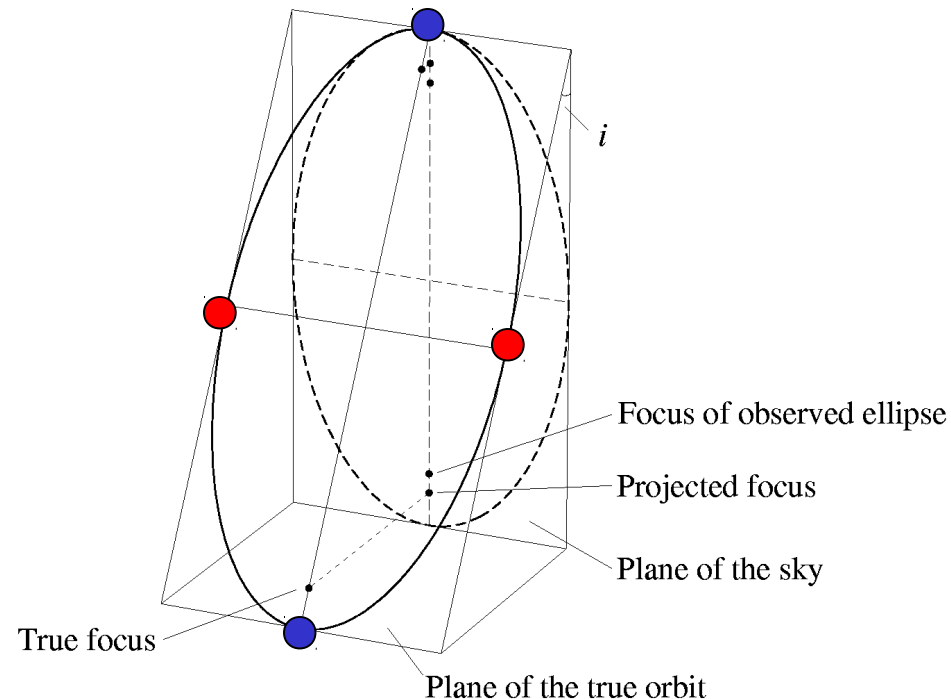
- Usually not a resolvable system
- Double line – each star's spectra is seen
- Can determine:
 - Individual mass, radii, ratio of flux and temperature
- Angle of inclination important
 - Determines the radial velocities

$$v_{1r}^{\max} = v_1 \sin i$$

$$v_{2r}^{\max} = v_2 \sin i$$

● max

● zero



Spectroscopic Binaries for *mass functions*

- v_{1r} and v_{2r} must both be measurable
 - Double-line spectroscopic binary vs. single-line spectroscopic binary
 - Comparable brightness or one star may be overwhelmed

$$\frac{m_1}{m_2} = \frac{v_{2r}}{v_{1r}}$$

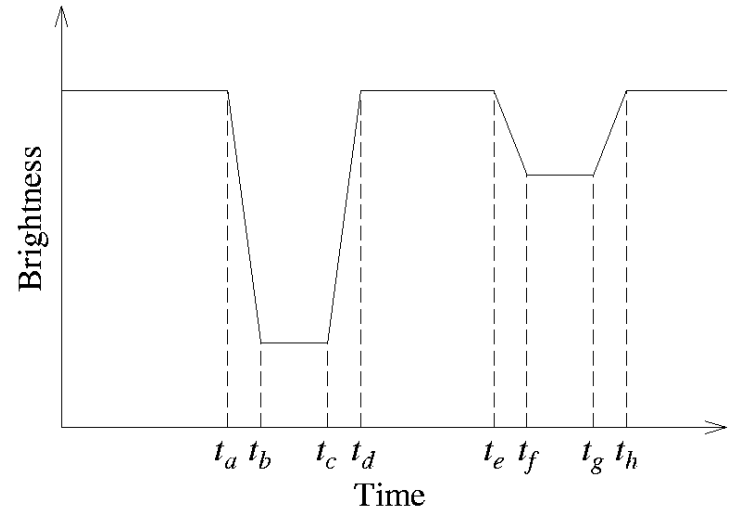
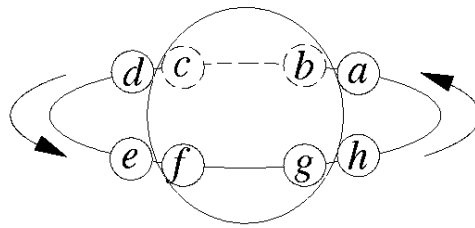
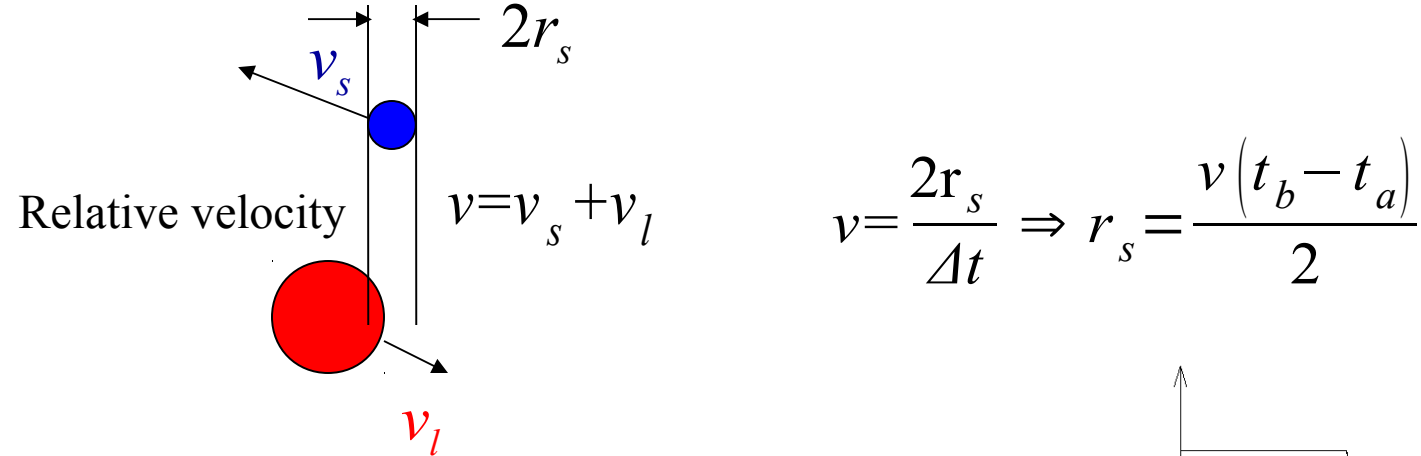
$$m_1 + m_2 = \frac{P}{2\pi G} \frac{(v_{1r} + v_{2r})^3}{\sin^3 i} = \frac{P v_{1r}^3}{2\pi G} \frac{\left(1 + \frac{v_{2r}}{v_{1r}}\right)^3}{\sin^3 i}$$

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

Mass function $\frac{m_2^3}{(m_1 + m_2)^2} \sin^3 i = \frac{P}{2\pi G} v_{1r}^3$ Depends on P and v_{1r}

Eclipsing, Spectroscopic Binaries for radii

- Estimation of radii
- Assume $i \approx 90^\circ$
- Time duration from first contact (t_a) to minimum light (t_b) yields info about the radius of smaller star, $\Delta t = t_b - t_a$



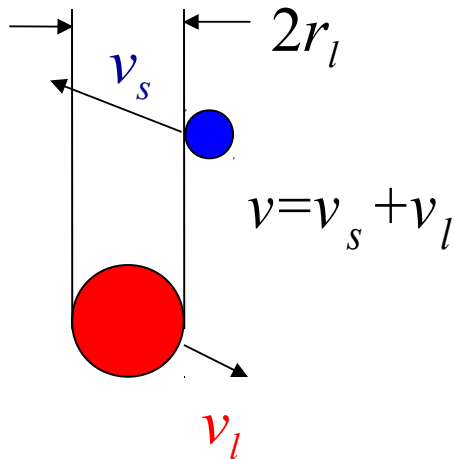
To Earth

Eclipsing, Spectroscopic Binaries

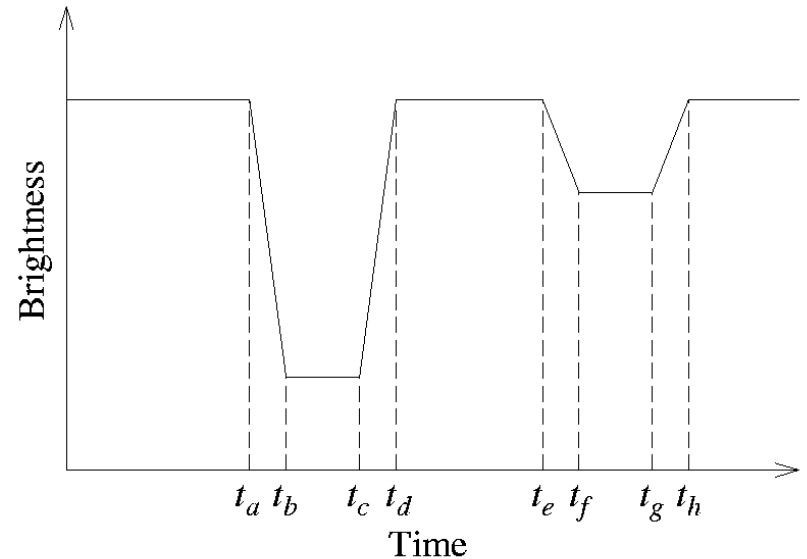
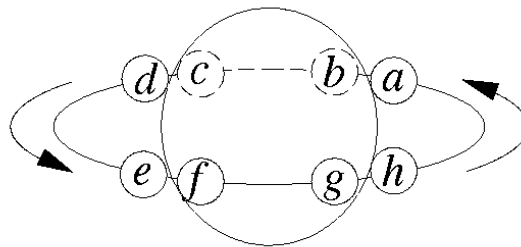
- Time duration from first contact (t_a) to first exposure (t_c) yields info about radius of the larger star,

$$\Delta t = t_c - t_a$$

- This time the distance traveled in-between these events is r_l



$$v = \frac{2r_l}{\Delta t} \Rightarrow r_l = \frac{v(t_c - t_a)}{2}$$



To Earth

Eclipsing Binaries

- Ratio of effective Temperatures

- Obtained from the light curve

- Radiative Surface Flux $F_r = F_{surf} = \sigma T_e^4$

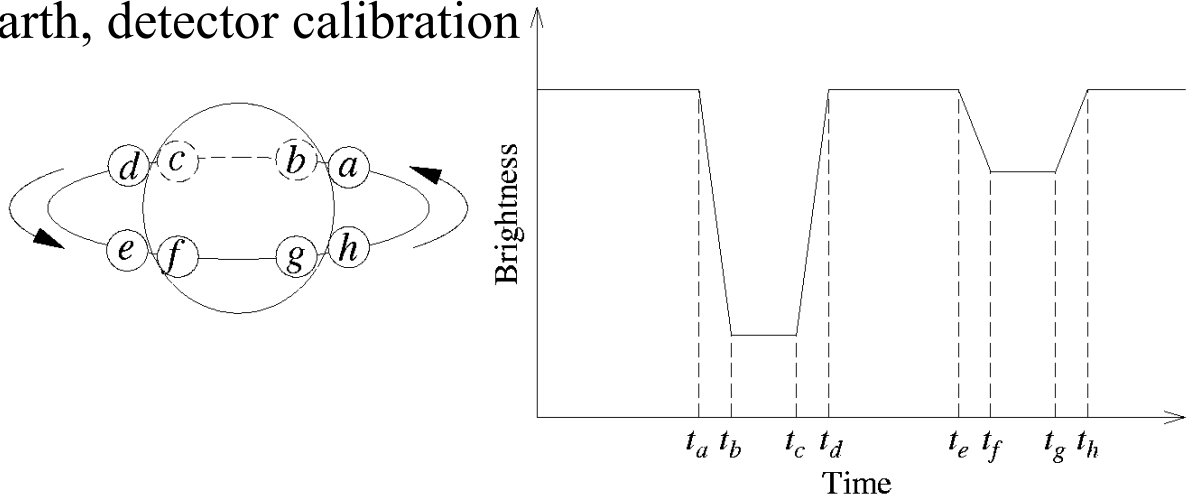
- Both stars visible with no obstructions

- Amount of light detected

$$B_o = B_l + B_s = k \left(A_l F_{rl} + A_s F_s \right) = k \left(\pi r_l^2 F_{rl} + \pi r_s^2 F_s \right)$$

k is a constant that depends on physical constants that will be the same for each star

i.e. distance from Earth, detector calibration



Eclipsing Binaries

- Primary eclipse minima
 - Only the large star is visible

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

- Secondary eclipse minima

- Part of the large star is covered by the smaller, hotter star

$$B_s = B_l - B_l^s + B_s = k \left(\pi r_l^2 F_{rl} - \pi r_s^2 F_{rl} + \pi r_s^2 F_{rs} \right)$$

- Examining ratios which allow unknown factors to cancel

$$\frac{B_o - B_p}{B_o - B_s} = \frac{(B_l + B_s) - (B_l)}{(B_l + B_s) - (B_l - B_l^s + B_s)} = \frac{B_s}{B_l^s}$$

$$\frac{k\pi r_s^2 F_{rs}}{k\pi r_s^2 F_{rl}} = \frac{F_{rs}}{F_{rl}} = \left(\frac{T_s}{T_l} \right)^4 \Rightarrow \frac{B_o - B_p}{B_o - B_s} = \left(\frac{T_s}{T_l} \right)^4$$