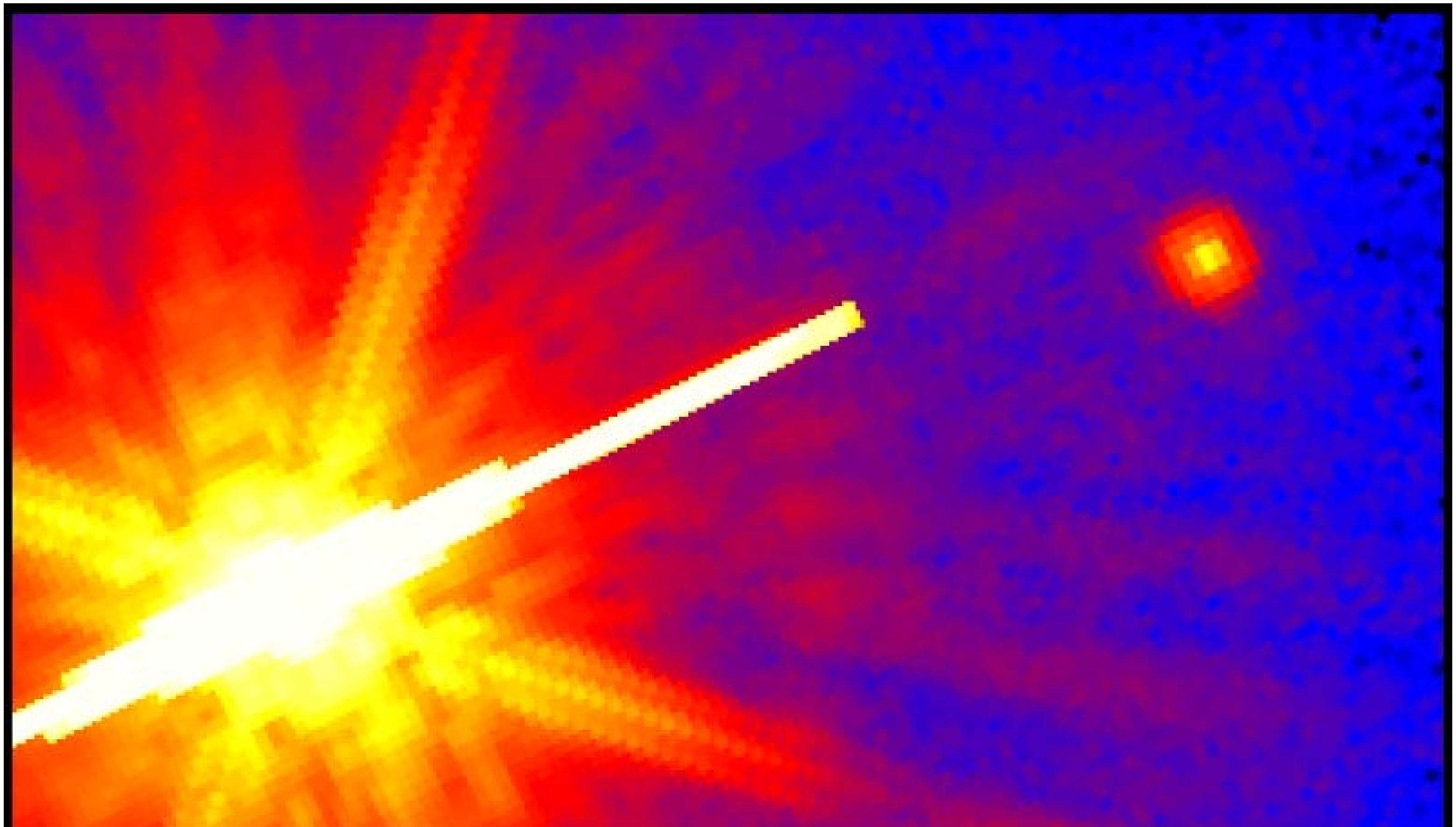
Binary Star Systems

(Chapter 7)



Low Mass Companion to Star Gliese 105A HST • WFPC2

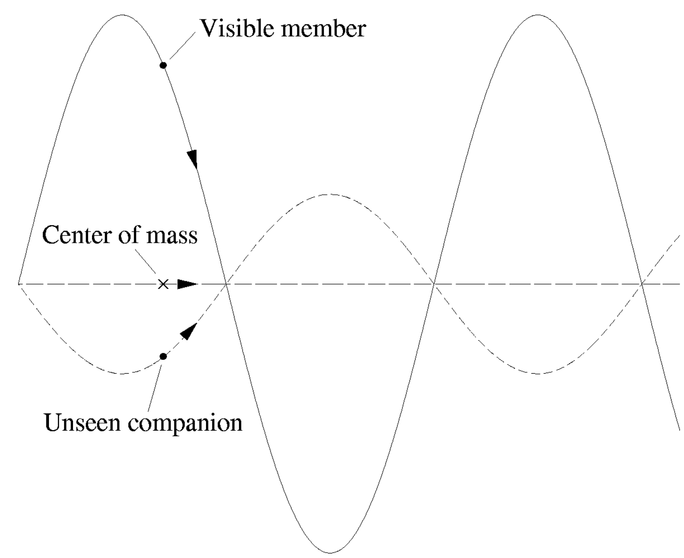
PRC95-33 • ST ScI OPO • September 14, 1995 • D. Golimowski (JHU), NASA

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

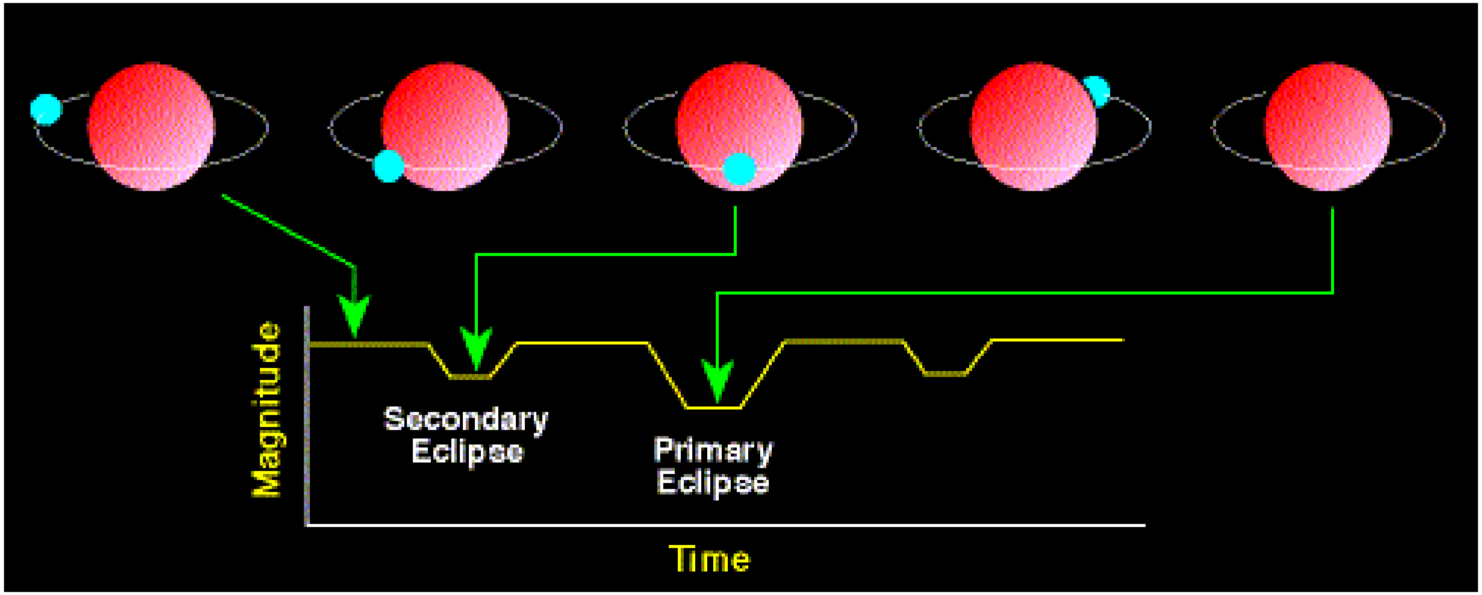
Classification of Binary Star Systems

- 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 influenc on the primary star
  - Deviation in proper motion



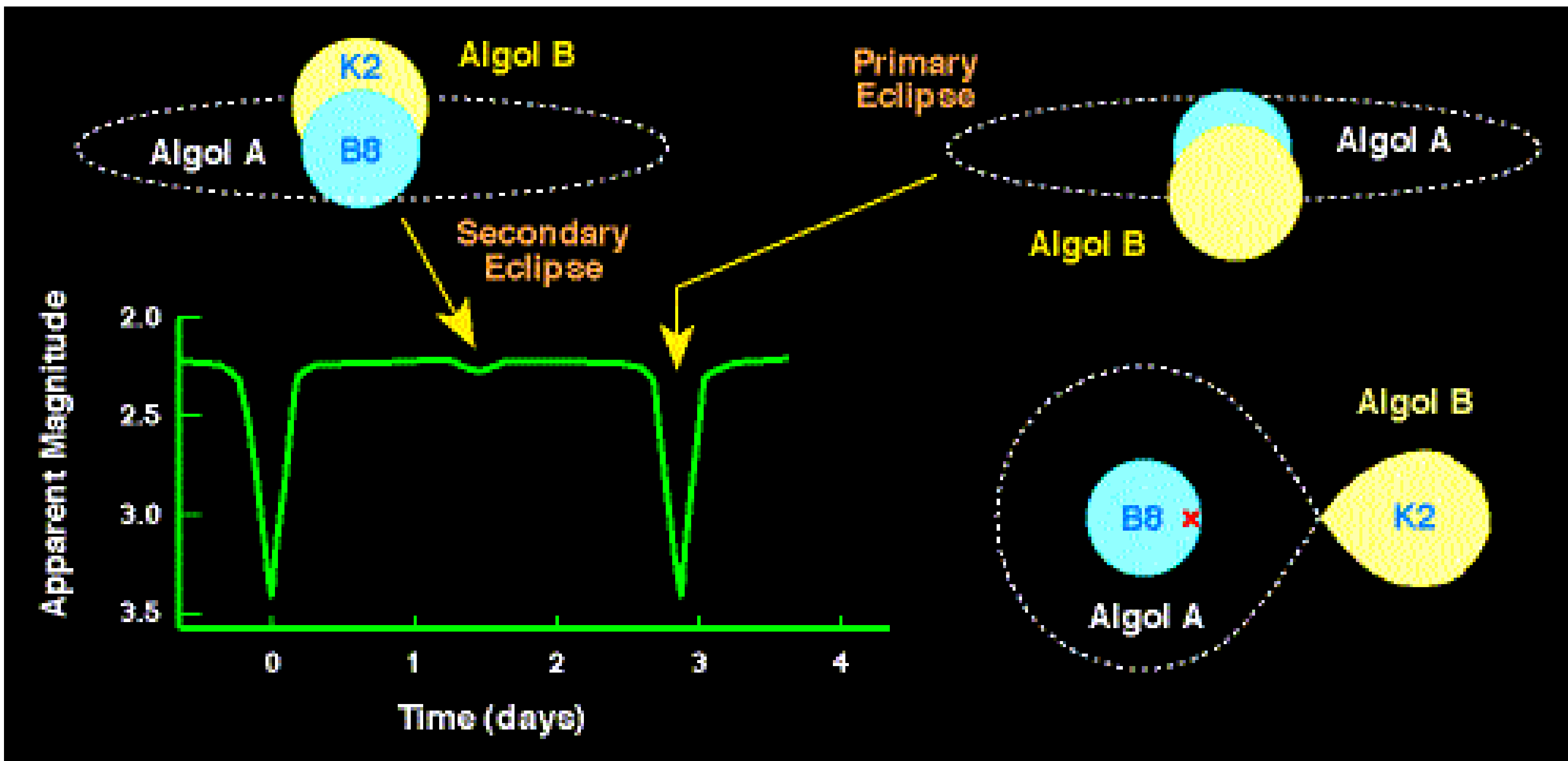
Classification of Binary Star Systems

- 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?



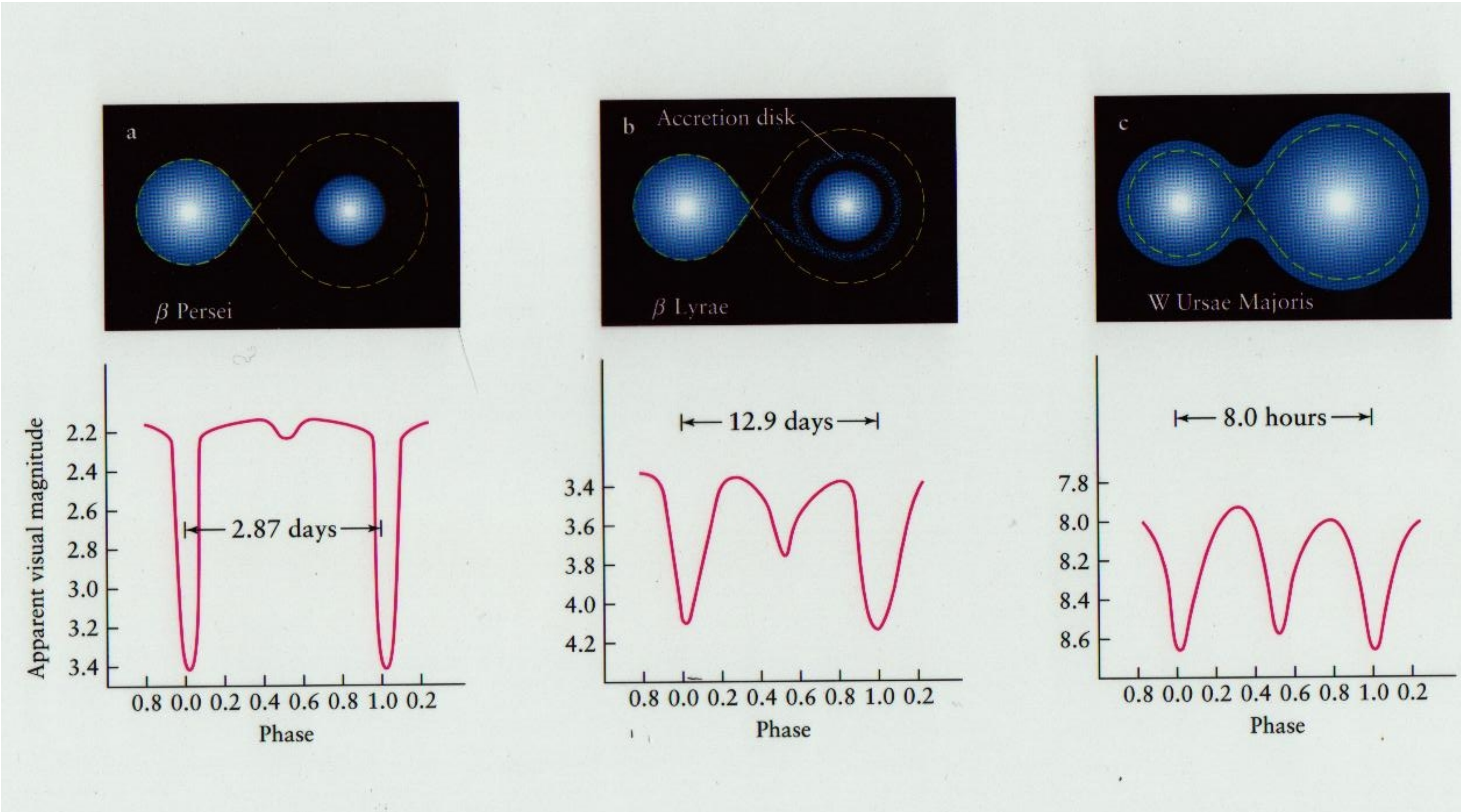
Classification of Binary Star Systems

- 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

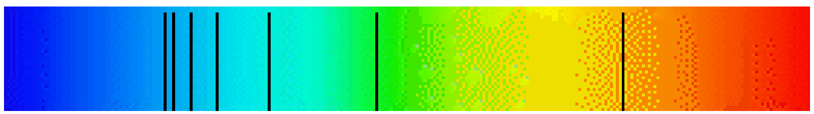
- Eclipsing binary Examples



Classification of Binary Star Systems

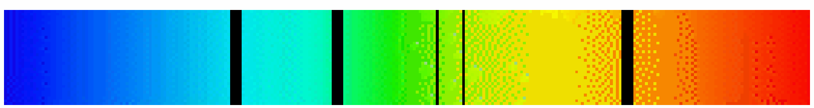
- Spectrum binary
  - System with two superimposed, independent, discernable spectra

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



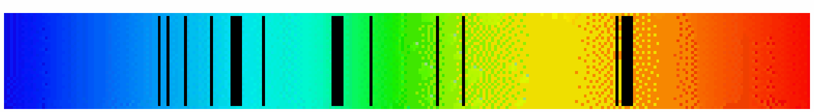
hot star

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



cool star

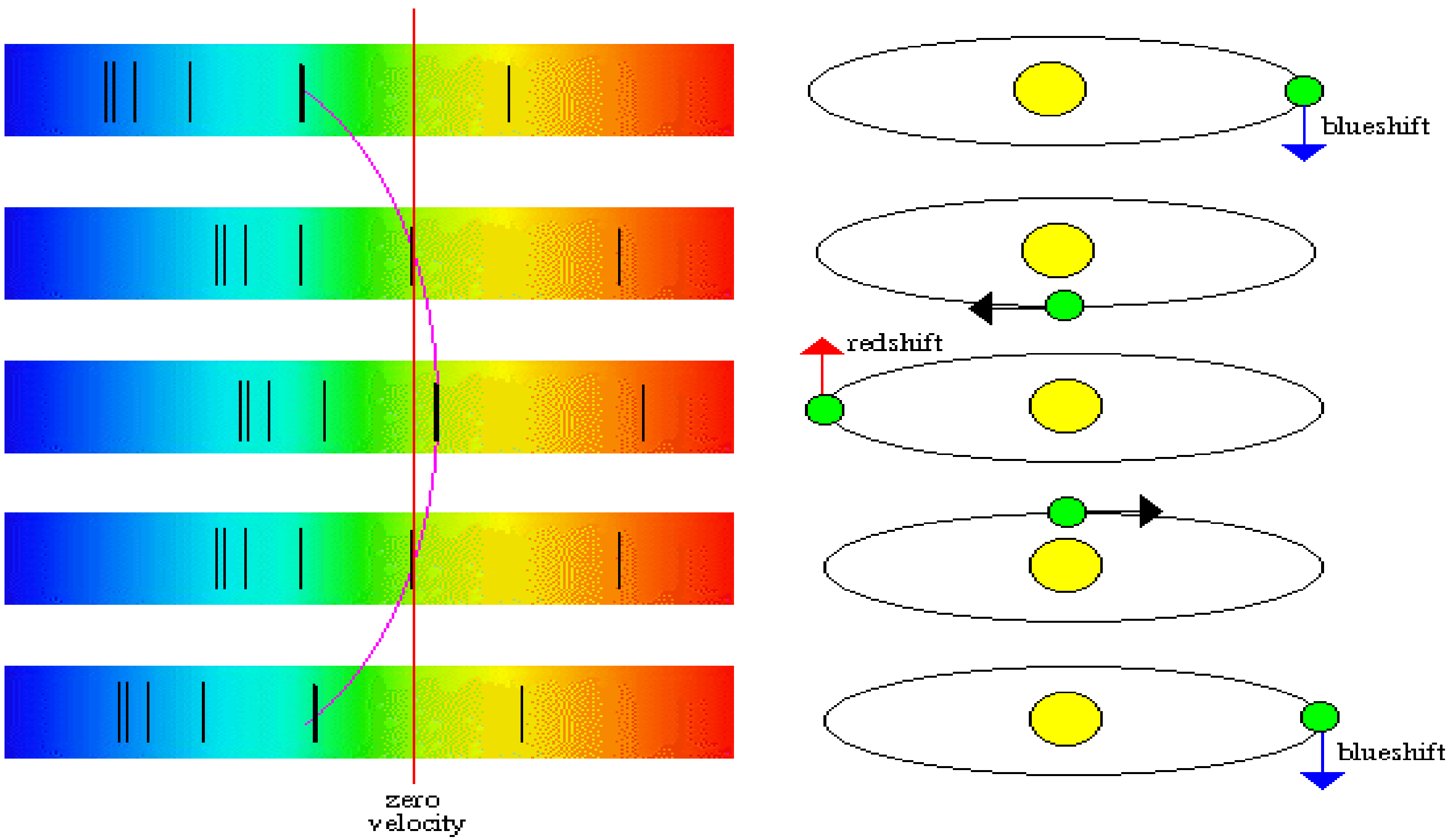
So, a spectrum binary is when you can not see two stars on the sky, but a spectrum of the object show two difference stellar classes, as below.



spectrum binary

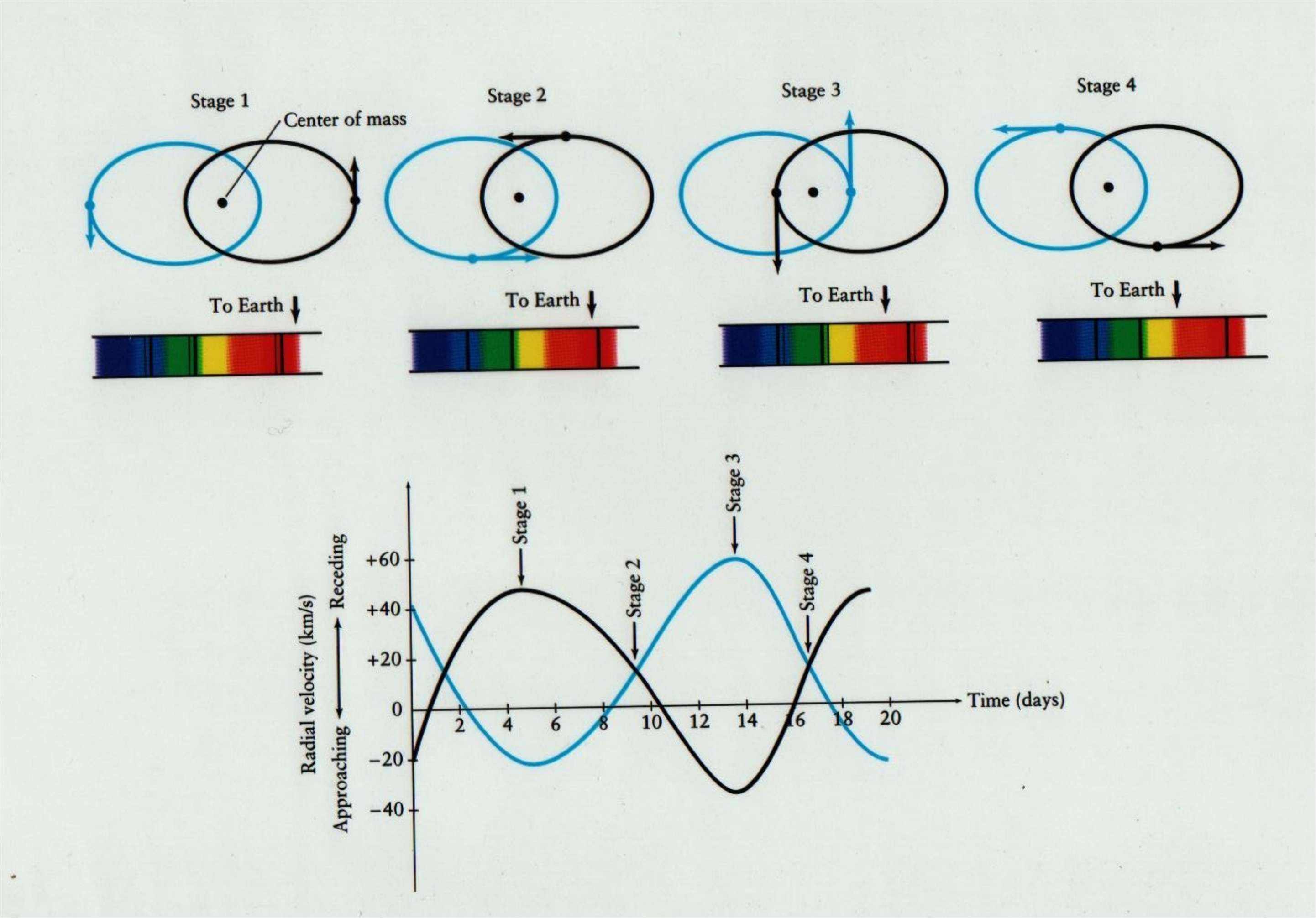
Classification of Binary Star Systems

- 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



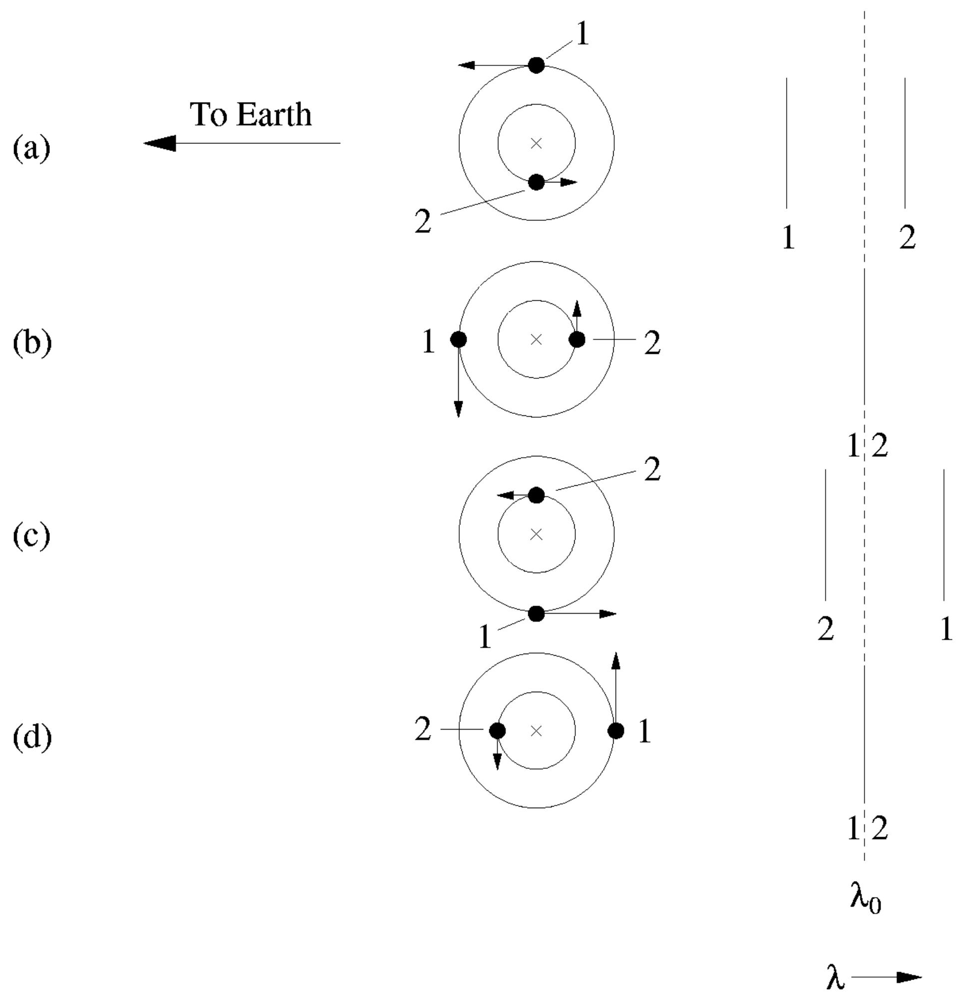
Classification of Binary Star Systems

- Spectroscopic binary



Classification of Binary Star Systems

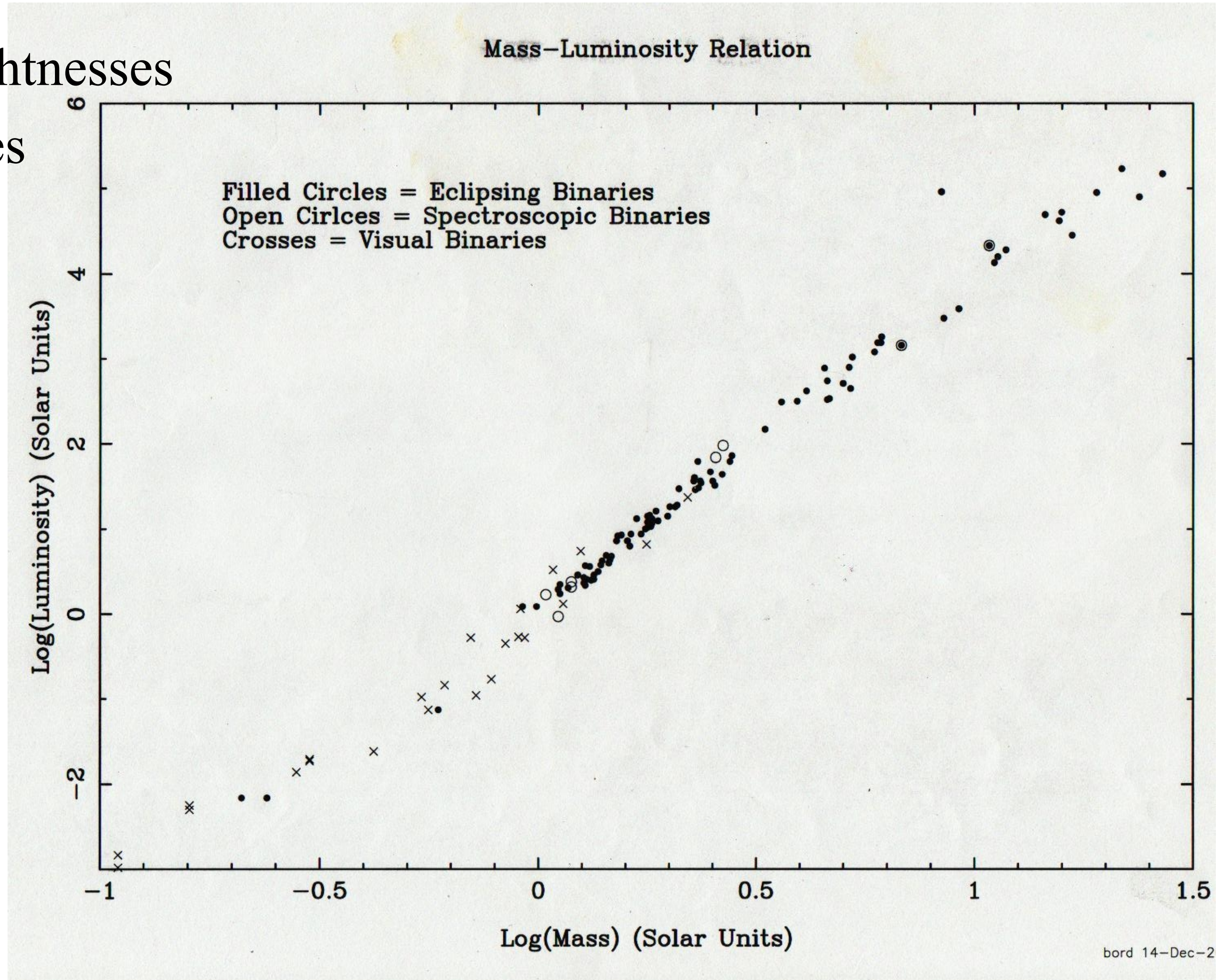
- **Spectroscopic Binary**
  - Double-line spectroscopic binary



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

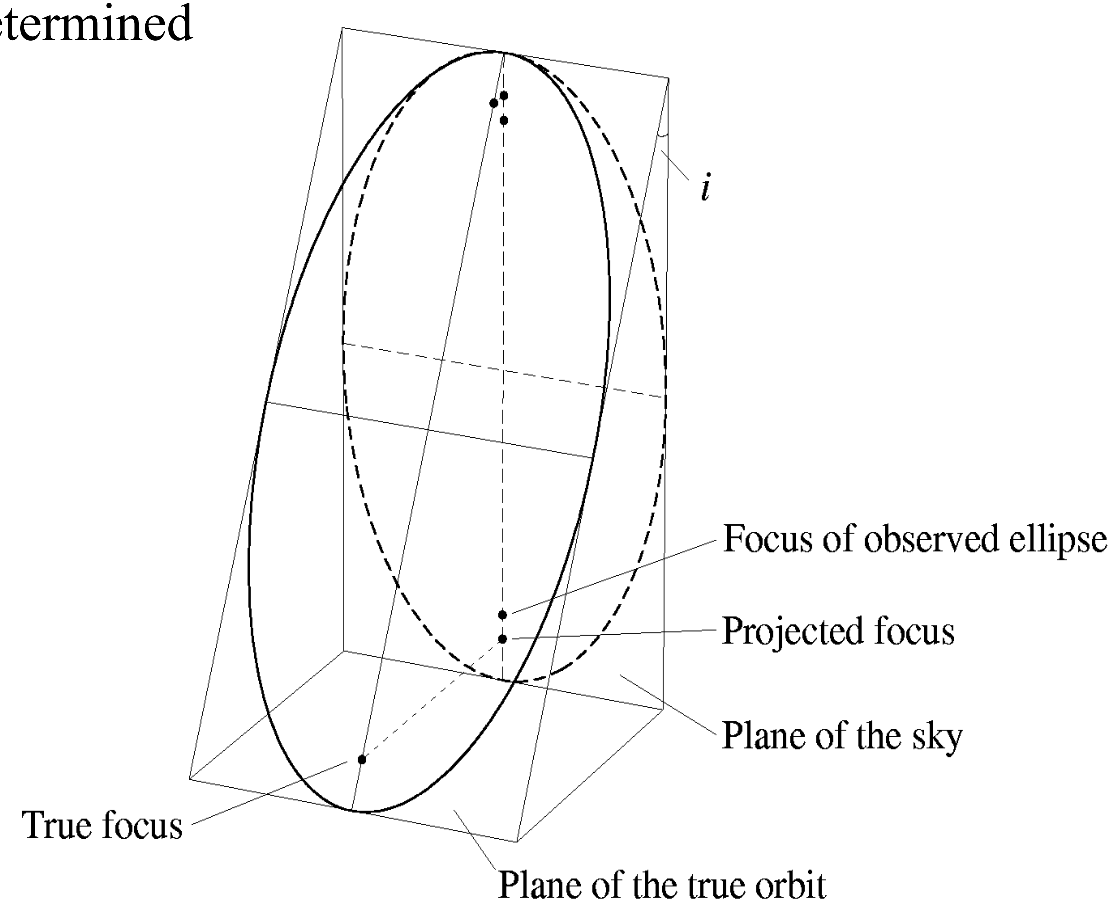
Stellar Properties from binaries

- 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

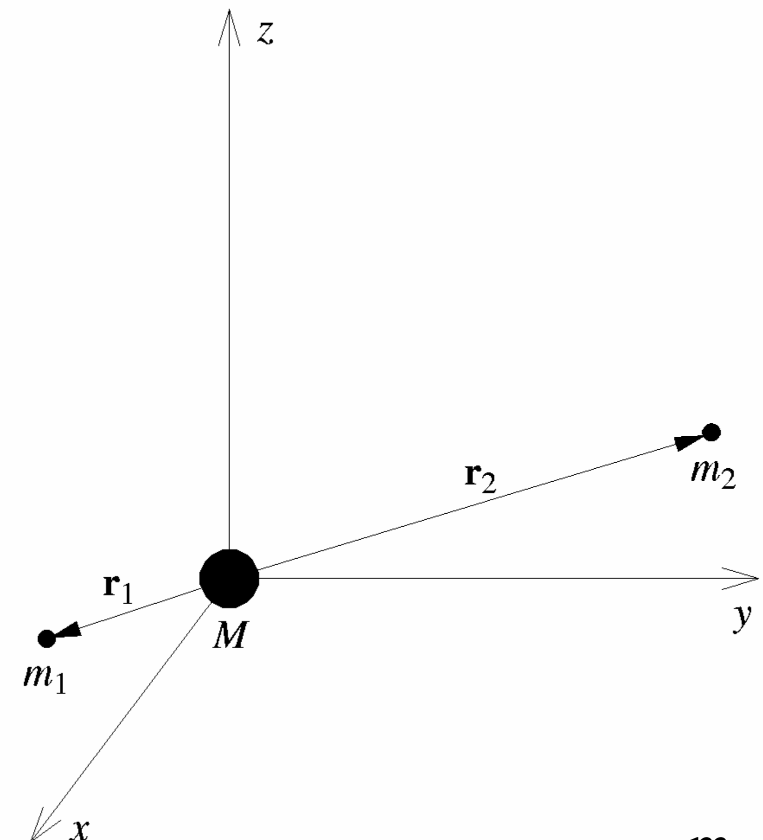


Mass Determination Using Visual Binaries

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

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

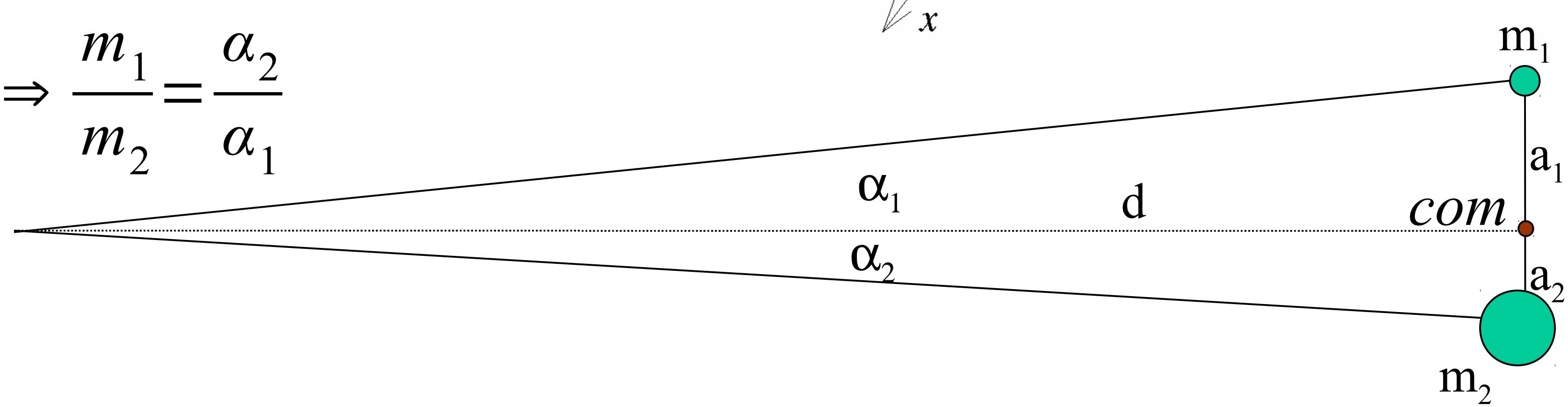
$$\Rightarrow \frac{m_1}{m_2} = \frac{r_2}{r_1} = \frac{a_2}{a_1}$$



- If the distance is known

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

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



Mass Determination Using Visual Binaries

- General Form of Kepler's third law

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

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

$$a = a_1 + a_2$$

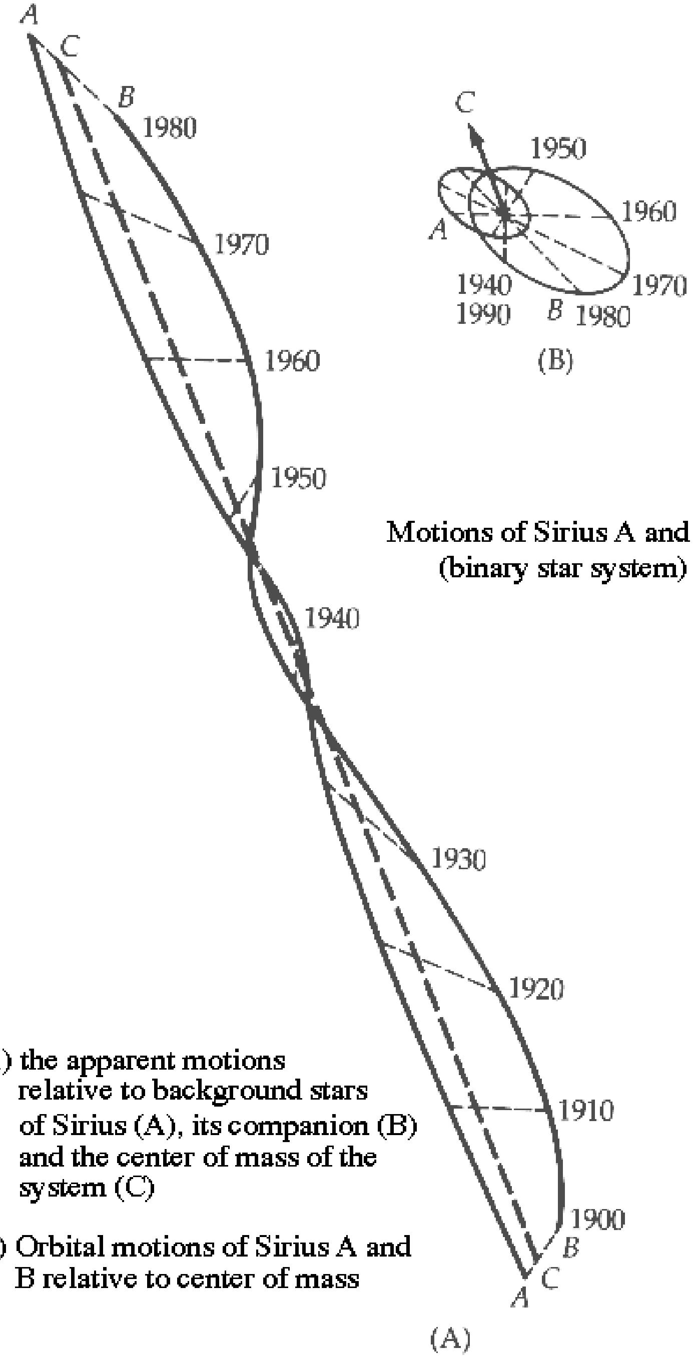
- Two equations and two unknowns, game over

$$\frac{m_1}{m_2} = \frac{\alpha_2}{\alpha_1} \qquad P^2 = \frac{4\pi^2}{G\left(m_1 + m_2\right)} a^3$$

Mass Determination…

Other complications:

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



Motions of Sirius A and B
(binary star system)

(A) the apparent motions relative to background stars of Sirius (A), its companion (B) and the center of mass of the system (C)

(B) Orbital motions of Sirius A and B relative to center of mass

Non-zero angle of Inclination

- The angles subtended by the semimajor axes will be reduced

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

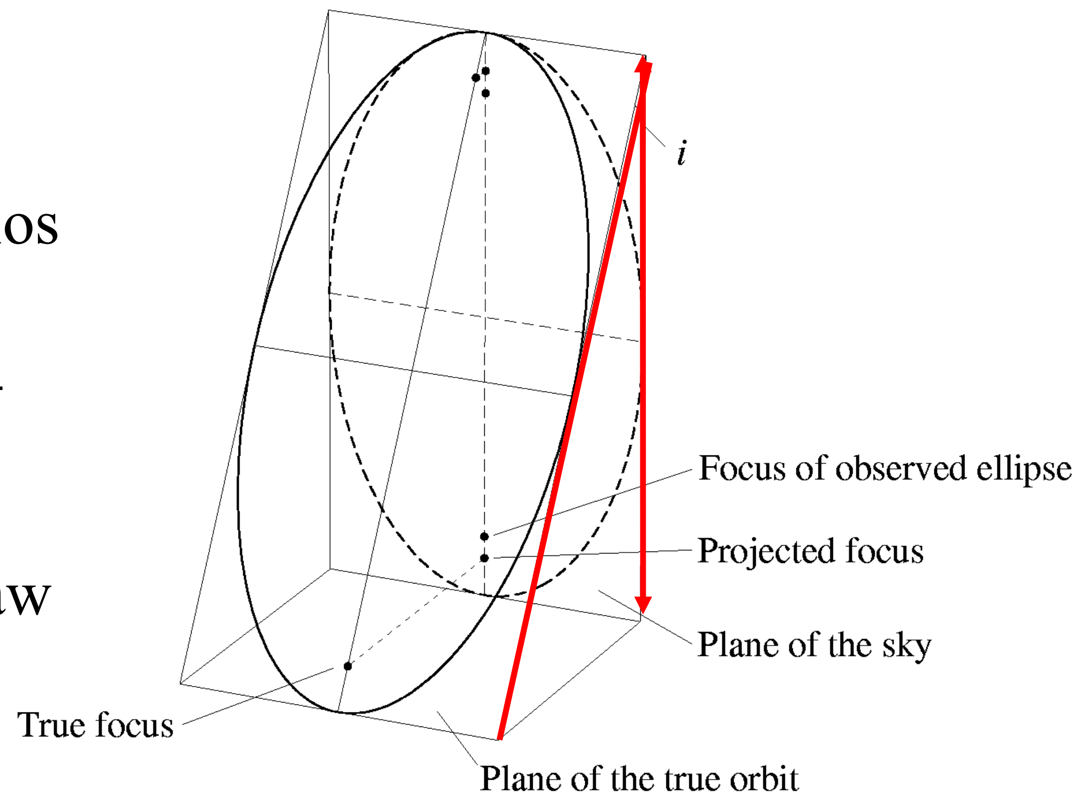
Doesn't matter for mass ratios

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

Does matter for Kepler's Law

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

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



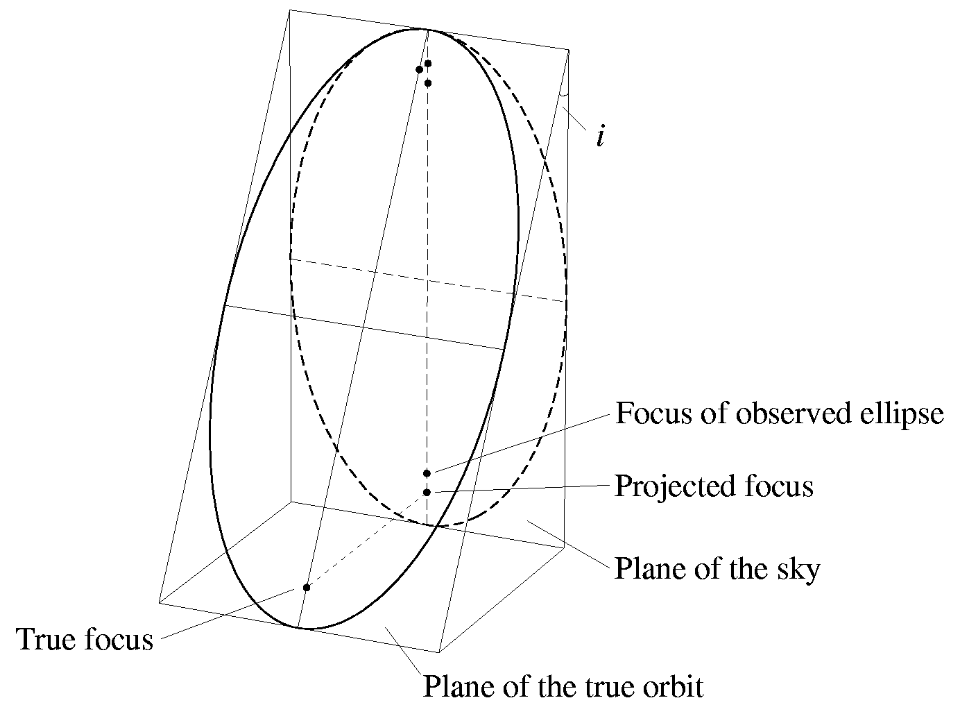
Angle of Inclination

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

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

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

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



- 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

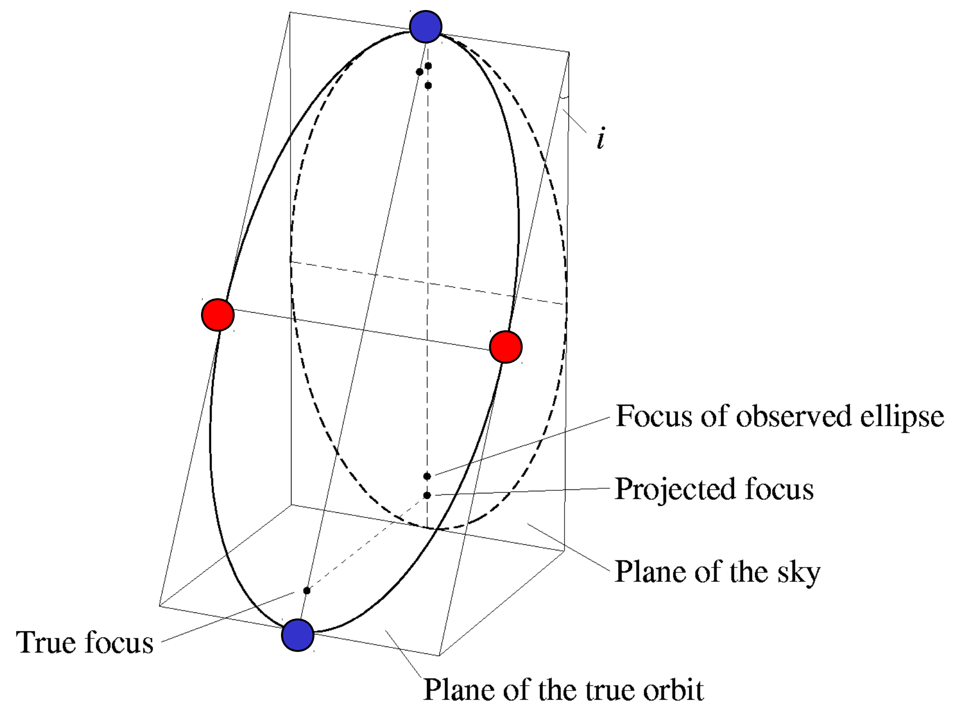
- Usually not a resolvable system
- Double line – each star's spectra is seen
- Can determine:
  - Individual mass, radii, ratio of flux and temperature

- 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

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

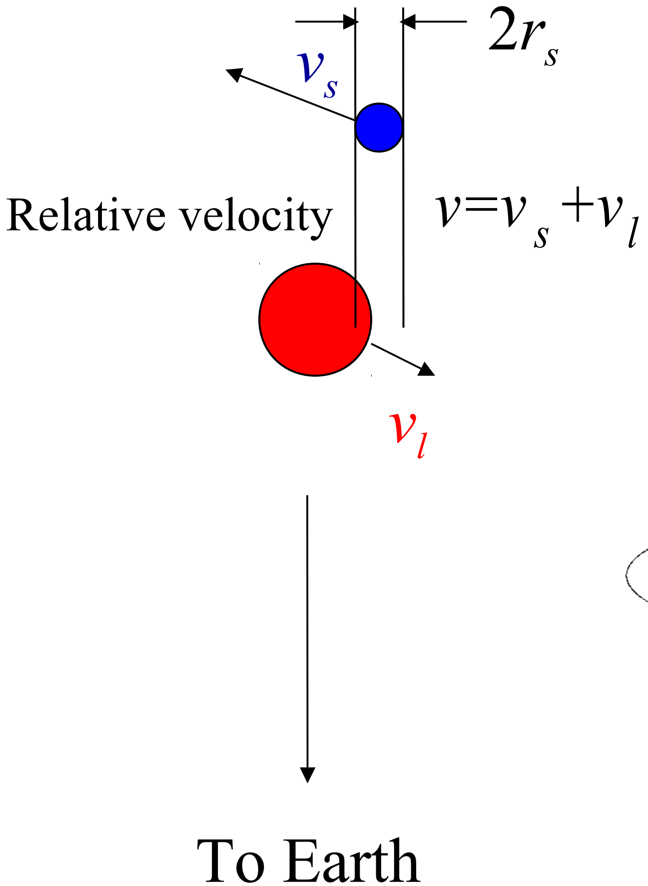
$$m_1 + m_2 = \frac{P}{2\pi G}\frac{(v_{1r} + v_{2r})^3}{\sin^3 i} = \frac{Pv_{1r}^3}{2\pi G}\frac{\left(1 + \frac{v_{2r}}{v_{1r}}\right)^3}{\sin^3 i}$$

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

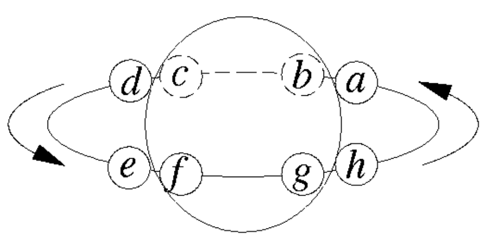
Mass function $$\frac{m_2^3}{(m_1 + m_2)^2}\sin^3 i = \frac{P}{2\pi G}v_{1r}^3$$ Depends on P and v_{1r}

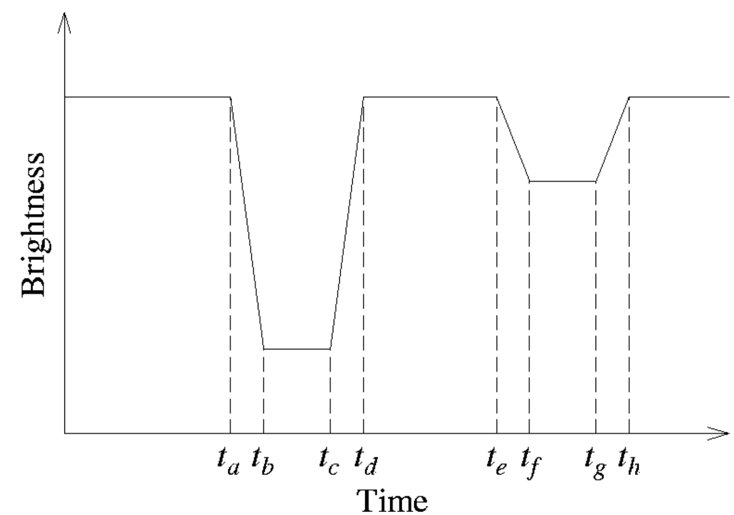
Eclipsing, Spectroscopic Binaries for radii

- Estimation of radii
- Assume $i \approx 90^0$
- Time duration from first contact (t_a) to minimum light (t_b) yields info about the radius of smaller star, $\Delta t = t_b - t_a$



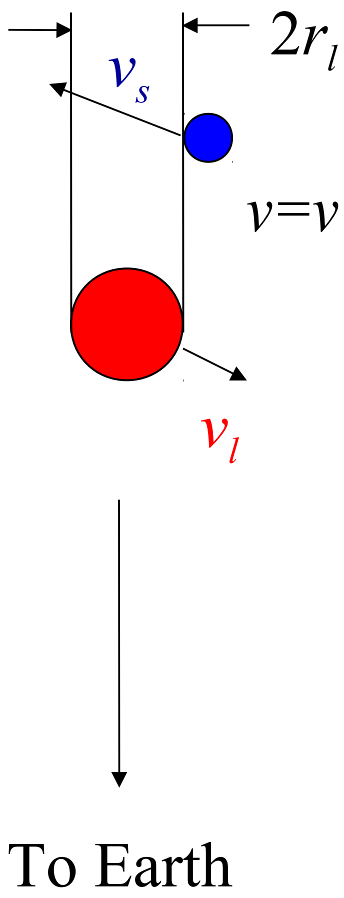
$$v = \frac{2r_s}{\Delta t} \Rightarrow r_s = \frac{v\left(t_b - t_a\right)}{2}$$





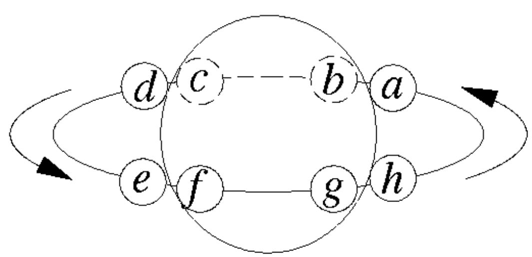
Eclipsing, Spectroscopic Binaries

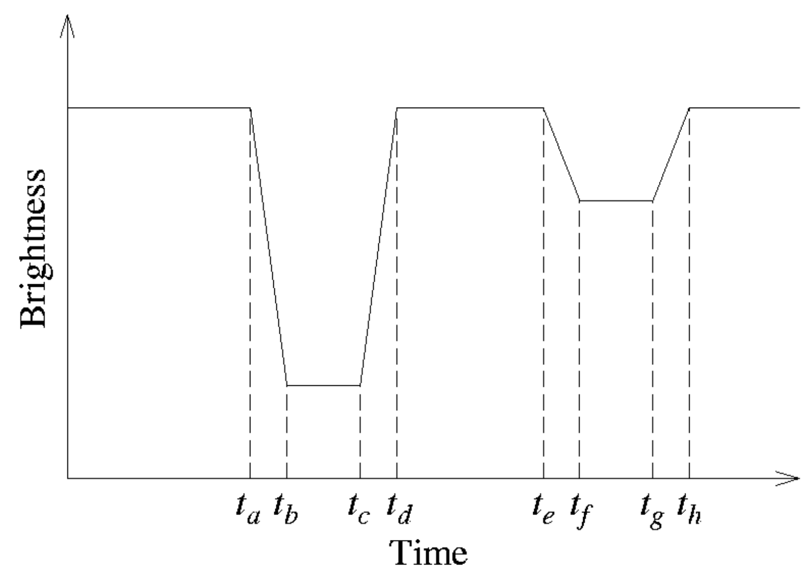
- Time duration from first contact (t_a) to first exposure (t_c) yields info about radius of the larger star, $\Delta t = t_c - t_a$
  - This time the distance traveled in-between these events is r_l



$$v = v_s + v_l$$

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





Eclipsing Binaries

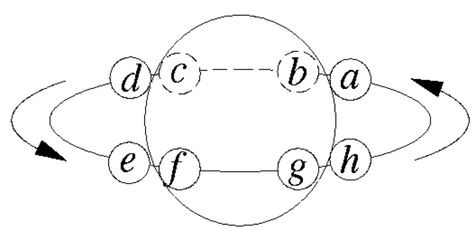
- Ratio of effective Temperatures
  - Obtained from the light curve
  - Radiative Surface Flux $F_r = F_{surf} = \sigma T_e^4$

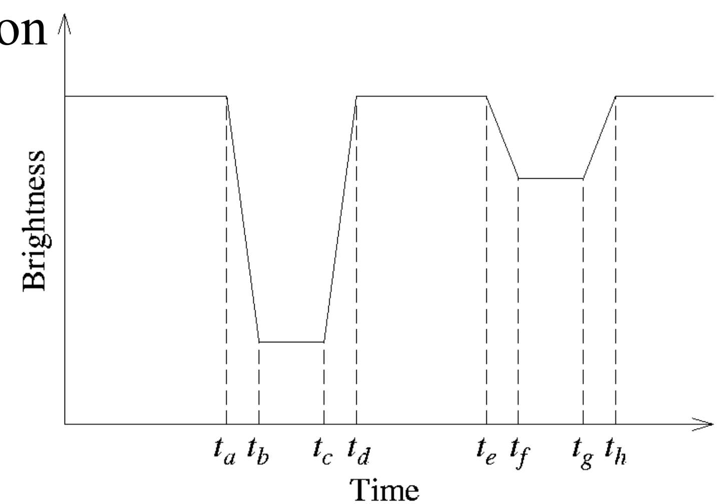
- Both stars visible with no obstructions
  - Amount of light detected

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

  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

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

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