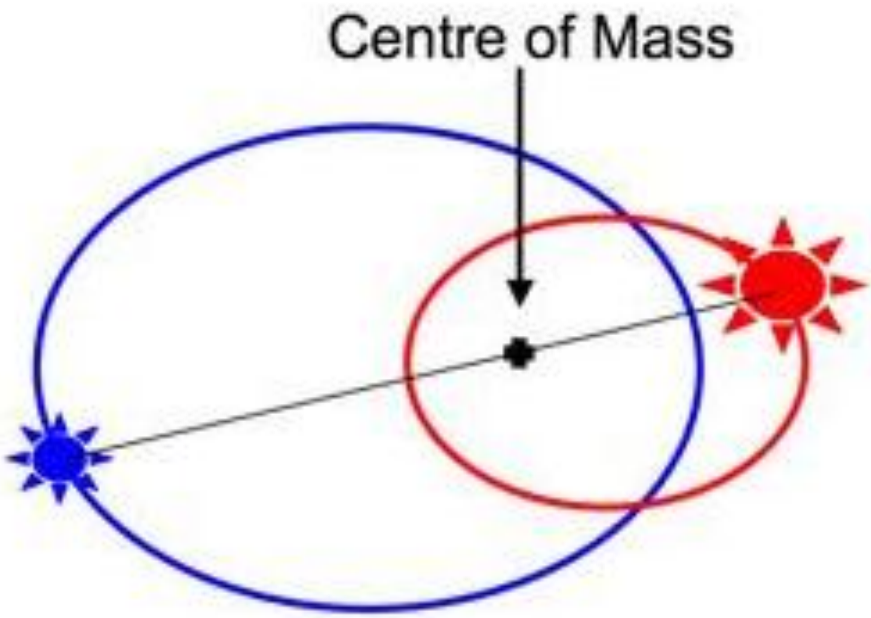
Binary Stars

Lecture 10


Centre of Mass

LIFE ON A PLANET

IN A BINARY STELLAR

SYSTEM

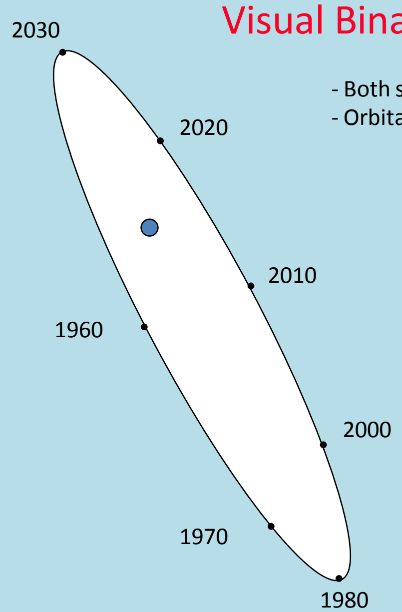
Importance of Binary Stars

- 75 % of all stars are “binary stars”
- Studies give:
  - Stellar Masses (Visual & Spectroscopic)
  - Stellar Radii (Eclipsing)

Types of binaries

- Visual Binary
  - Stars are separated in a telescope.
- Spectroscopic Binary
  - See two sets of spectral lines Doppler shifted due to orbital motion.
- Eclipsing Binary (rare)
  - Stars cross in front of one another.

Visual Binary

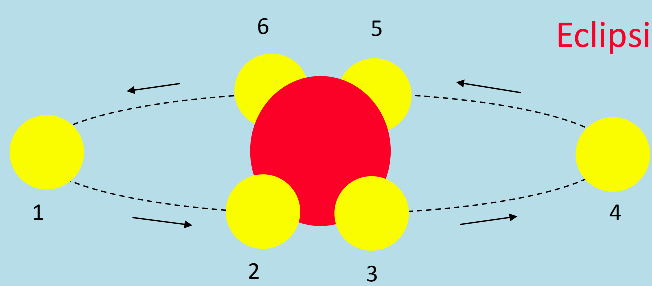


- Both stars seen
- Orbital motion observed

Apparent Orbit - projected path on the sky.

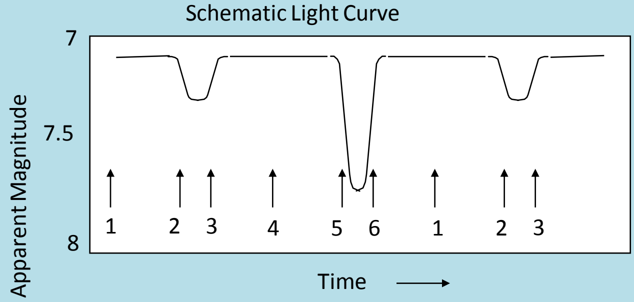
Examples: Cen A & B
Sirius A & B

Eclipsing Binary



- Stars cross in front of one another

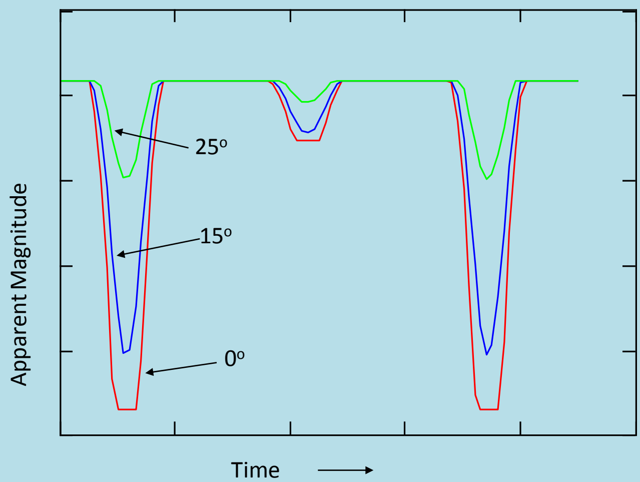
Schematic Light Curve



Examples:
Algol
β Persei
β Lyrae

Simulation

Eclipsing Binary Light Curve



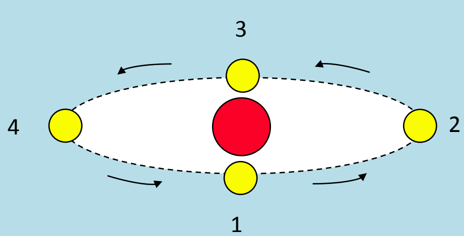
Star 1:
R = 2 R_{sun}
T = 5000 K

Star 2:
R = 4 R_{sun}
T = 3500 K

Separation
10 R_{sun}

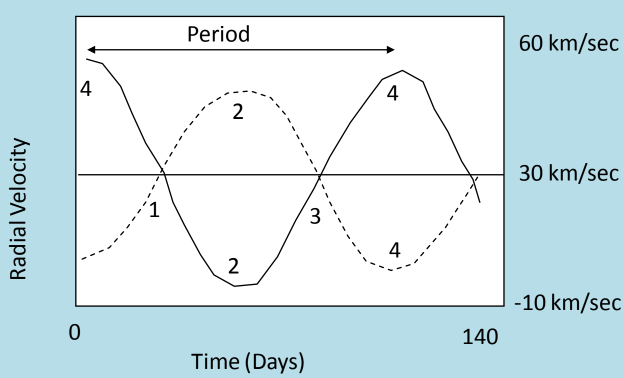
Angles are the orbital inclination. 0° is edge-on.

Spectroscopic Binary



Doppler shift due to orbital motions.

Example: β Aurigae



Masses of Binary Stars

- Newton’s laws allow us to determine the total mass in a binary system.
- For star of mass M_A and M_B, the total mass is related to the period, P, and the average distance between the stars, a.

$$M_A + M_B = \frac{a^3}{P^2}$$

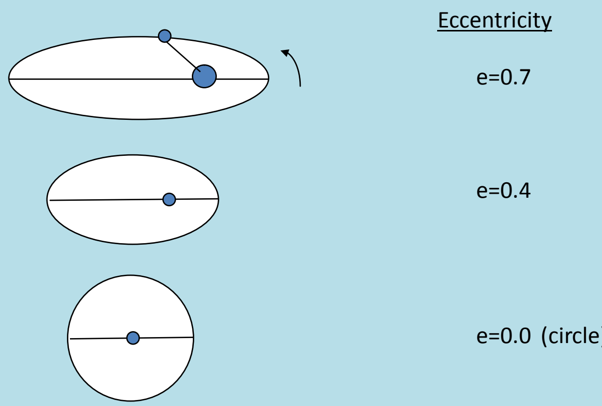
Kepler’s Laws of Planetary Motion

- They apply to binary stars

1. Law of Ellipses
2. Law of Areas
3. Harmonic Law

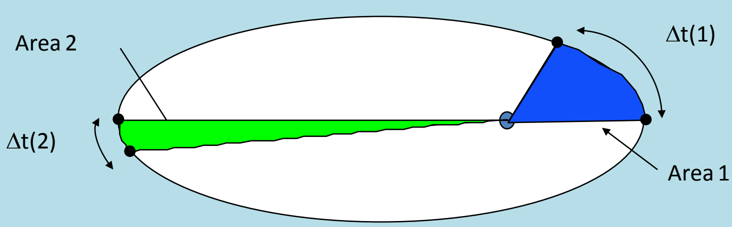
1. Law of Ellipses

- Orbits are ellipses



2. Law of Areas

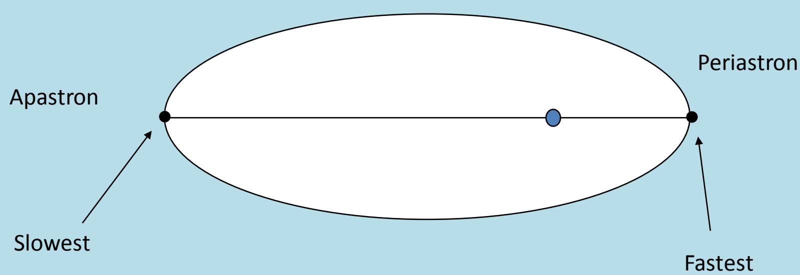
- Equal areas in equal time.



$\Delta t(1) = \Delta t(2)$ => Area 1 = Area 2

2. Law of Areas (continued)

- Orbital speeds



3. Harmonic Law

- (Orbital Period)^2 $\propto$ (Mean Distance)^3

$$P^2 = \frac{a^3}{M_A + M_B}$$

  – P = period of revolution in years
  – a = mean separation in AU
  – M_A and M_B = mass in solar masses

Example:

- If a visual binary has a period of 32 years and an average separation of 16 AU then

$$M_A + M_B = \frac{16^3}{32^2}$$

$$M_A + M_B = 4\ \mathrm{M_{sun}}$$

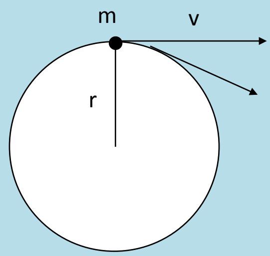
Newton => Kepler !

- Deriving Kepler's third law
- Force = mass x acceleration

$$F = ma$$

- Acceleration is change in velocity with time.
- Force in Newtons.

Circular Motion



$$\text{Acceleration} = \frac{v^2}{r}$$

$$\Rightarrow F = ma = m\frac{v^2}{r}$$

This is the (centripetal) force necessary to keep the mass in a circular orbit.

Newton's Gravity

$$\boxed{F = \frac{GMm}{r^2}}$$

but

$$F = ma = m\frac{v^2}{r}$$

$$\Rightarrow \frac{GMm}{r^2} = \frac{mv^2}{r}$$

So that

$$v^2 = \frac{GM}{r}$$

Putting it together

- The velocity and the orbital period, P, are related. The circumference is $2\pi r$, so

$$\Rightarrow\ P = \frac{2\pi r}{\mathrm{v}} \quad \text{or} \quad \mathrm{v} = \frac{2\pi r}{P}$$

Thus

$$\mathrm{v}^2 = \frac{4\pi^2 r^2}{P^2} = \frac{GM}{r} \quad \Rightarrow \quad P^2 = \frac{4\pi^2}{G}\frac{r^3}{M}$$

$$\text{Or} \quad P^2 \propto r^3$$

Kepler's Third Law!

Orbital Elements

- Apparent Orbit - as seen on the sky
- Real Orbit
- Size of major axis
- Eccentricity of Orbit
- Period of Revolution
- Orbit orientation angle
- Inclination of Orbit

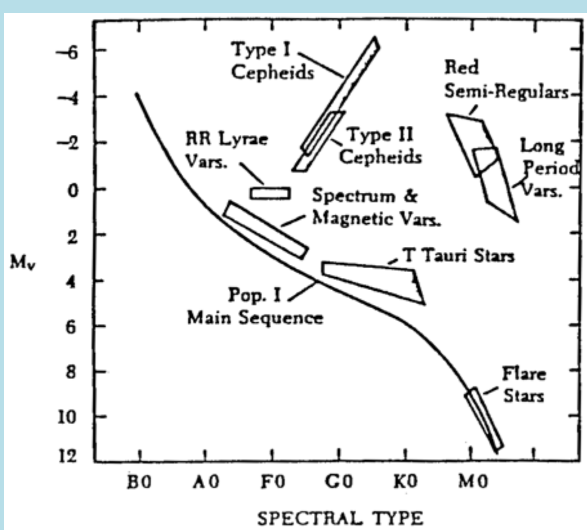
Notes on binary masses

- Don't mistake the mass for magnitude!
- P is measured in years, a in AU and mass in solar masses in this formula.

$$M_A + M_B = \frac{a^3}{P^2}$$

- We can only get the total mass.

Variable Star Classes



Pulsating Variable Stars

Type	Period	Mag. Change	Spectrum
Classical Cepheids (I)	2-80 days	1	F, G Supergiants
Type II Cepheids	1-100 days	1	F, G, K giants
Long Period Variables	90-600 days	3-6	M giants
RR Lyrae	1-24 hr	1	A, F giants
Canis Majoris	3-6 hr	0.1	B
Semiregular	~ 100 days	1	M
Irregular	irregular	1-6	G, K, M

Period Luminosity Relation