Israel Open Astronomy Olympiad 2025

Senior age group problems

Eclipsing binary (50 p)

A binary star consists of two components orbiting around common center of mass. The parameters of the components are:

- Component A (“red”) is a red giant, having mass $M_A = 4M_\odot$, radius $R_A = 30R_\odot$ and temperature $T_A = 3500$ K.
- Component B (“white”) is a main sequence star with mass $M_A = 2M_\odot$, radius $R_A = 3R_\odot$ and temperature $T_A = 9500$ K.

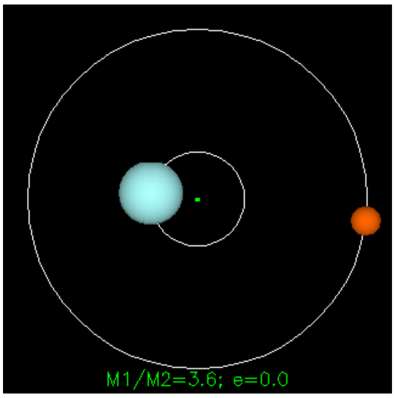


Figure 1. Binary stars orbiting common center of gravity.
Source: https://www.astronomy.ohio-state.edu/pogge.1/Ast162/Movies/vb0anim.gif

Part I. Magnitudes

A Determine the luminosity of each of the stars in the units of solar luminosity. (3 p for each value) Take required Solar values from the data sheet of the Olympiad.

Answer: Luminosity of component A is $L_A = [\qquad]L_\odot$, luminosity of component B is $L_B = [\qquad]L_\odot$.

B Determine the absolute magnitude of each of the stars. Neglect the bolometric correction. (2 p for each value)

Answer: Absolute magnitude of component A is $M_A = [\qquad]^m$, absolute magnitude of component B is $M_B = [\qquad]^m$.

C Determine the total absolute magnitude of the binary star. (1 p.)

Answer: Absolute magnitude of binary star is $M_{AB} = [\qquad]^m$.

D From the Earth, the binary star is measured to have the apparent magnitude $m_{AB} = +9.5^m$. Determine the distance to the binary star in parsec (3 p.). Neglect the interstellar absorption.
Answer: Distance to the binary star is $d =$ [ ] pc.

E The parallax of the binary star is measured to be 0.0009'' with the uncertainty of 0.0001'' (that is, the parallax is measured to be in the range between 0.0008'' and 0.0010''). Determine the range of distances to the star in parsec from this measurement (1 p. for each value).

Answer: Based of the measured parallax value, the distance to the star is in the range from $d_{min} =$ [ ] pc to $d_{max} =$ [ ] pc.

Part II. Eclipse magnitudes

The Solar system is located near the orbital plane of this binary star. This leads to events when (a) the smaller radius star is totally eclipsed ("eclipse") and (b) when the smaller star is transiting in front of the larger star ("transitions").

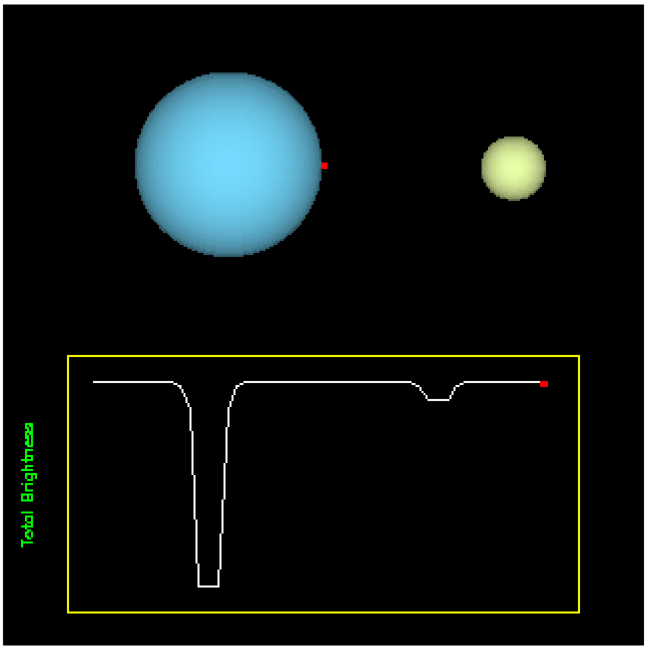


Figure 2. If we observe the binary star "from the side", the smaller component is periodically eclipsed by the larger, and periodically transits across the disk of the larger components. The lower diagram shows how the light curve relates to the star location on the orbit. Source: https://www.astronomy.ohio-state.edu/pogge.1/Ast162/Movies/eclbin.gif

In the next questions please **assume that distance to the binary star is 1490 pc, the absolute magnitude of the component A is -1^m and of component B is 0^m**. *These values may differ from the values obtained in previous questions, so don't use results of your earlier computations. You will have to repeat part of the computations.*

F Determine the apparent magnitude of the binary star during eclipse (2 p.) and during transition (10 p.) events!

Answer: Apparent magnitude of binary star during eclipse is $m_{ecl} =$ [ ]^m and during transition it is $m_{tr} =$ [ ]^m.

G Look at the typical eclipsing binary star light curve. Please identify which phases of the light curve correspond to which reasons. (1 p. for each answer)

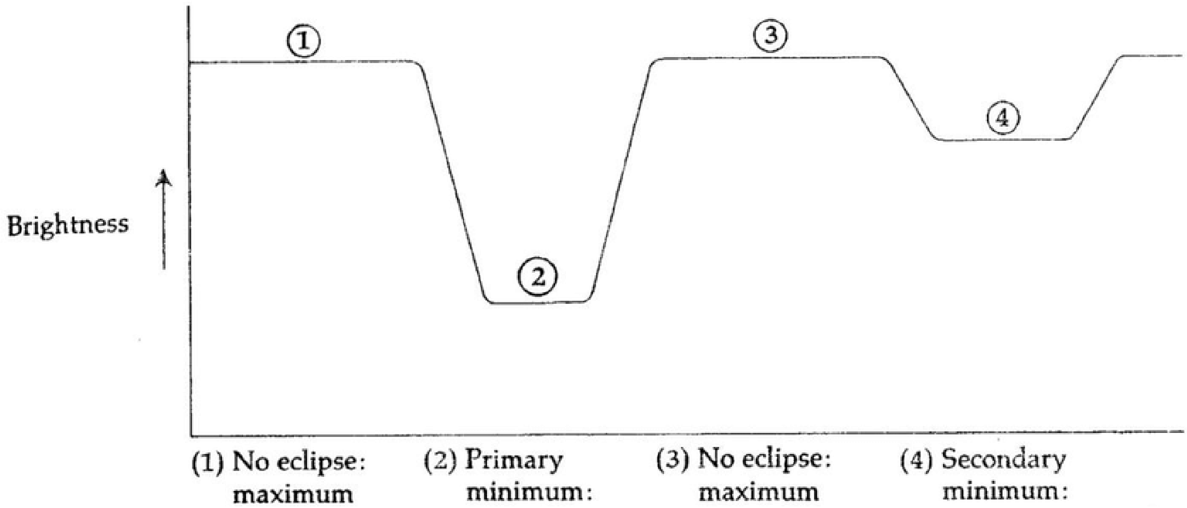
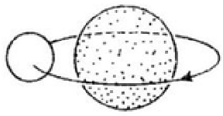
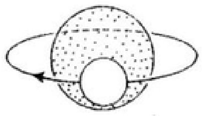
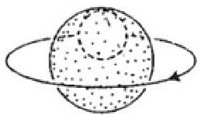


Figure 3. Light curve phases of the eclipsing binary star.

Case A: both stars are visible separately 

Case B: the smaller components is transiting on the disk of the larger one 

Case C: the smaller component is eclipsed by the larger one 

Answer: Phase 1 on the light curve figure corresponds to the case [A]/[B]/[C], Phase 2 to [A]/[B]/[C], Phase 3 to [A]/[B]/[C], and phase 4 to [A]/[B]/[C].

Part III. Eclipse times

In this part we will utilize the concept of **relative orbit**, which is the orbit of one of the components if we assume that the second component is not moving. In the Figure below, the relative orbit is shown.

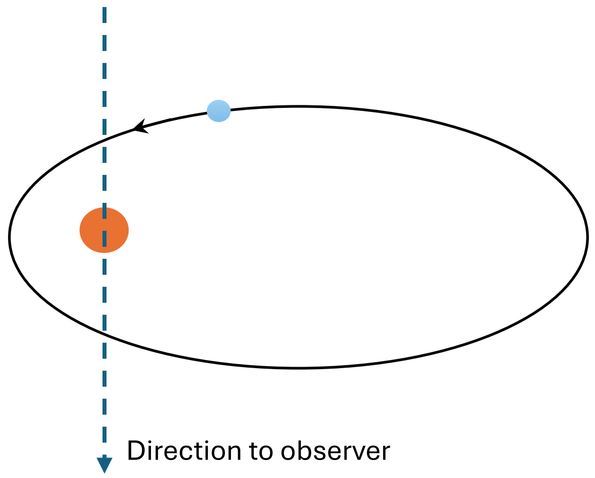


Figure 4. Relative orbit of the binary star and the direction to the observer.

H The period between the eclipses is $T_{\star} = 25$ days. Determine the semimajor axis of the binary star relative orbit in au.

Astronomical unit or au equals to the value of the semimajor axis of the Earth orbit. In this question you may assume that the orbit is circular with the period as given above; then the semimajor axis is the same as the orbit radius. *Hint: compare movement of the component stars to movement of Earth around the Sun.*

Answer: Semimajor axis of the binary star relative orbit is $a_{\star} =$ [ ] au. (5 p)

The orbit of the binary star is nor circular, but elliptic with the major axis perpendicular to the line of sight (see Figure 4 above). Eccentricity of the orbit equals $e = 0.7071$. In the final part of this problem, you should determine the time difference between the primary and secondary minimum events, that is, between the eclipse C and the transition D (see Figure below).

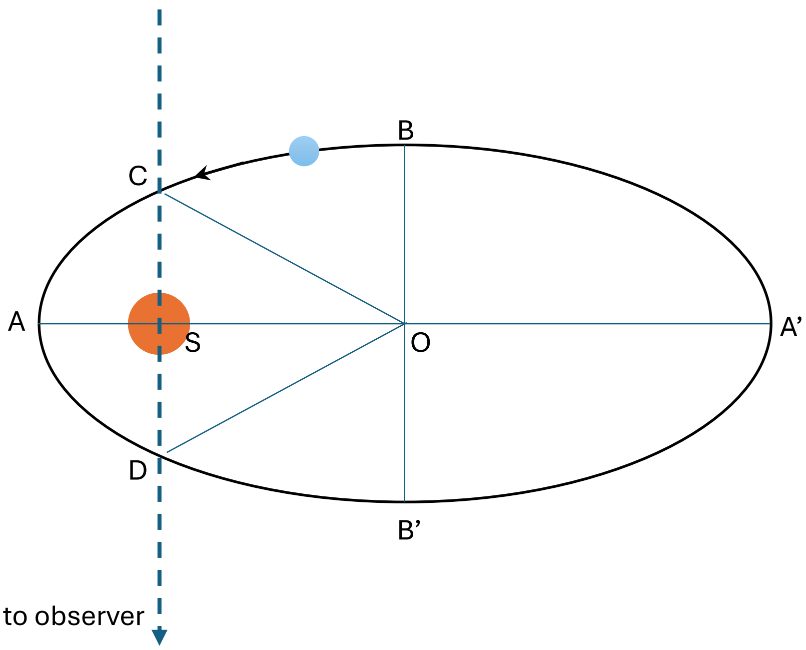


Figure 5. The relative orbit of the binary star.

This is a multistep process which is based on the second Kepler's law and geometrical properties of ellipse. The second Kepler's law states that on a relative orbit "the line connecting the stars sweeps equal areas in equal times", so we will have to compute the areas of parts of the ellipse.

To determine the fraction of the full period that passes between the eclipse and the transition, we will compare the area S_{ecl-tr} that the connecting line sweeps in this time t_{ecl-tr} with the full area of ellipse S_{ell}. That is, $t_{ecl-tr} = T \cdot \frac{S_{ecl-tr}}{S_{ell}}$.

The ellipse may be seen as a circle with radius $a = OA$ which is squeezed in one direction by factor b/a, where $b = OB$ is semiminor axis. The area of the ellipse therefore is $S_{ell} = \pi ab$.

I Which of the following figures encloses the area of the ellipse swept between the eclipse and the transition? (2 p.)

Answer: Select one of the options: [OCAS]/[OCAD]/[OBCADB']/[SCAD]

Properties of the ellipse give the following relations: $OA = a$, $OB = b$, $OS = ae$, $SC = SD = b^2/a$. The eccentricity e is connected with the

J Determine the area enclosed by the points OCAD. (5 p.)

Answer: $S_{OCAD} = \pi ab \cdot [\qquad]$

K Determine the area enclosed by the points OCSD. (2 p.)

Answer: $S_{CADS} = \pi ab \cdot [\qquad]$

L Determine the area enclosed by the points CADS. (2 p.)

Answer: $S_{CADS} = \pi ab \cdot [\qquad]$

M Determine the time from eclipse to transition events. (2 p.)

Answer: The time difference from eclipse event to transition event $t_{ecl-tr} = [\qquad]$ days.