

Monday, April 20, 2026

Example: Determining distance with a Cepheid Variable star

a) Consider a type I Cepheid variable star with period = 4 days.

Q: What is its intrinsic luminosity?

A: From plot, we see that $L_{\text{Cepheid}} \approx 1000 L_{\text{sun}} = 10^3 L_{\text{sun}}$

b) If we measure the Cepheid's apparent brightness to be 10 trillion times less than the sun's, then how far away is it?

$I_{\text{apparent Cepheid}} =$ apparent intensity of Cepheid (as seen on Earth)

$$= \frac{L_{\text{Cepheid}}}{4\pi d_{\text{Cepheid}}^2}; \quad d_{\text{Cepheid}} = \text{distance to Cepheid}$$

$$I_{\text{apparent sun}} = \frac{L_{\text{sun}}}{4\pi d_{\text{sun}}^2}; \quad d_{\text{sun}} = \text{distance to sun} = 1 \text{ AU}$$

$$\Rightarrow \frac{I_{\text{apparent Cepheid}}}{I_{\text{apparent sun}}} = \frac{1}{10 \text{ trillion}} = \frac{1}{10 \times 10^{12}} = \frac{1}{10^{13}} = \frac{\frac{L_{\text{Cepheid}}}{4\pi d_{\text{Cepheid}}^2}}{\frac{L_{\text{sun}}}{4\pi d_{\text{sun}}^2}}$$

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$$\Rightarrow \frac{1}{10^{13}} = \frac{\frac{L_{\text{Cepheid}}}{d_{\text{Cepheid}}^2}}{\frac{L_{\text{Sun}}}{d_{\text{Sun}}^2}} = \frac{L_{\text{Cepheid}}}{L_{\text{Sun}}} \times \frac{d_{\text{Sun}}^2}{d_{\text{Cepheid}}^2}$$

$$= \frac{L_{\text{Cepheid}}/L_{\text{Sun}}}{\left(\frac{d_{\text{Cepheid}}}{d_{\text{Sun}}}\right)^2} \quad \left(\frac{d_{\text{Cepheid}}}{d_{\text{Sun}}}\right)^2 = 10^3$$

 d_{Cepheid} in AU

$$\Rightarrow \frac{1}{10^{13}} = \frac{10^3}{\left(d_{\text{Cepheid, AU}}\right)^2} \Rightarrow d_{\text{Cepheid, AU}} = \frac{10^{13} \times 10^3}{10^{16}}$$

$$\Rightarrow d_{\text{Cepheid, AU}} = \sqrt{10^{16}} = \left(10^{16}\right)^{1/2} = 10^8$$

$$\Rightarrow d_{\text{Cepheid, AU}} = 10^8 \text{ AU}$$

\Rightarrow The distance to the Cepheid is $10^8 \text{ AU} = 100 \text{ million AU}$

$$d = 10^8 \text{ AU} = 10^8 \times (149.6 \times 10^6 \text{ km}) = 149.6 \times 10^{14} \text{ km}$$

$$\div \underbrace{9.4 \times 10^{12} \text{ km}}_{1 \text{ light year}} = 1591 \text{ light years}$$

$$\approx 1.6 \times 10^3 \text{ light years}$$

\Rightarrow The distance to the Cepheid is $10^8 \text{ AU} \approx 1.6 \times 10^3 \text{ light years}$