E.5

Measuring Astronomical Distances

IB PHYSICS | ASTROPHYSICS

Measuring Distances

1 light year (ly) = 9.46×10^{15} m

The distance that light travels in an earth year

1 parsec (pc) = 3.26 ly

distance at which the mean radius of the earth's orbit subtends an angle of one second of arc.

1 astronomical unit (AU) = 1.50×10^{11} m

The average distance between the earth and the sun

IB Physics Data Booklet

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Unit conversions

$$1 \text{ radian (rad)} \equiv \frac{180^\circ}{\pi}$$

$$\text{Temperature}(\text{K}) = \text{temperature}(^\circ\text{C}) + 273$$

$$1 \text{ light year (ly)} = 9.46 \times 10^{15} \text{ m}$$

$$1 \text{ parsec (pc)} = 3.26 \text{ ly}$$

$$1 \text{ astronomical unit (AU)} = 1.50 \times 10^{11} \text{ m}$$

$$1 \text{ kilowatt-hour (kWh)} = 3.60 \times 10^{6} \text{ J}$$

$$hc = 1.99 \times 10^{-25} \text{ Jm} = 1.24 \times 10^{-6} \text{ eV m}$$

Parallax

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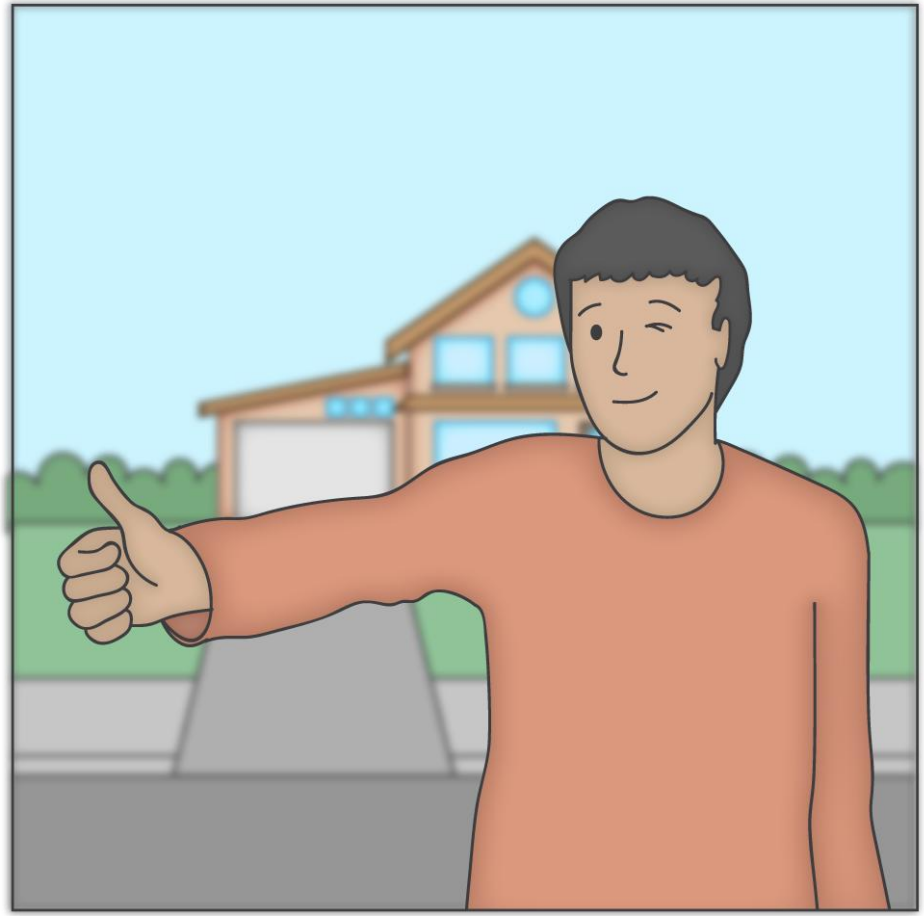
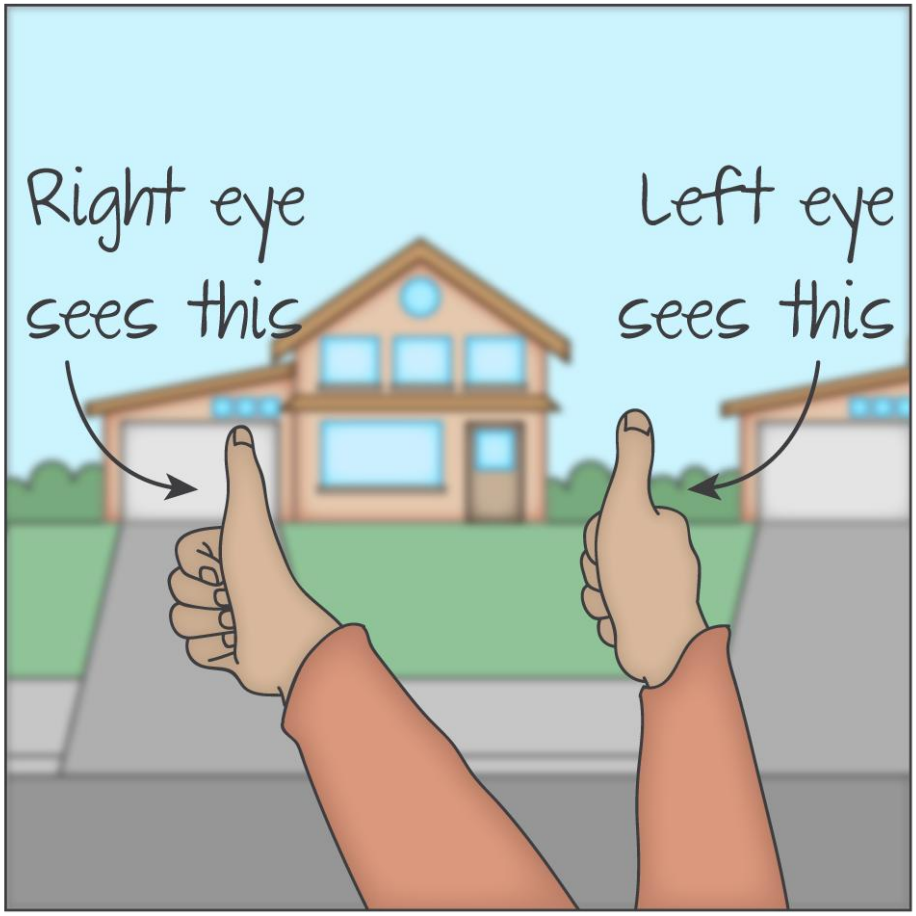
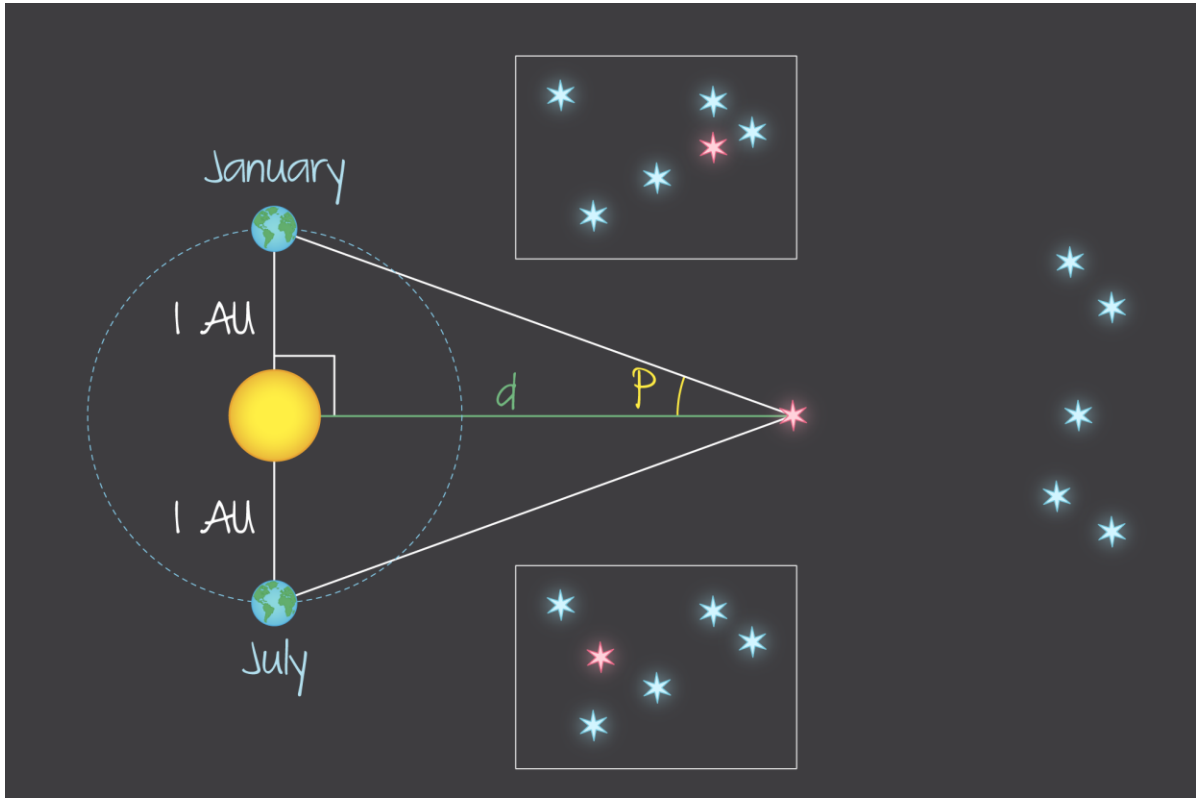




Stellar Parallax

The angle **must** be measured to a very distant field of other stars



**The parallax method only works for stars that are relatively close to earth*

Measuring Angles

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60 seconds in 1 minute

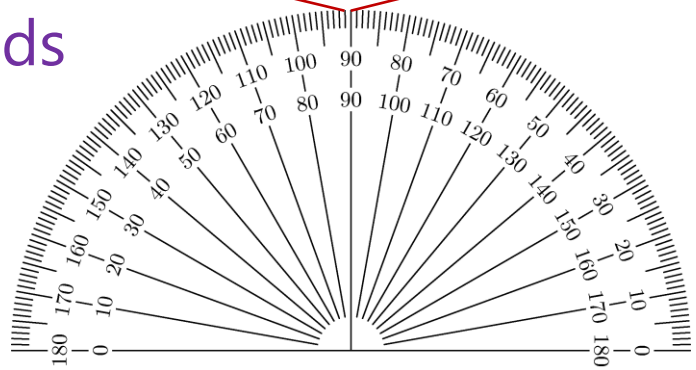
″

60 minutes in 1°

′

1° = 3600 arcseconds

1° = 3600 as



Stellar Parallax

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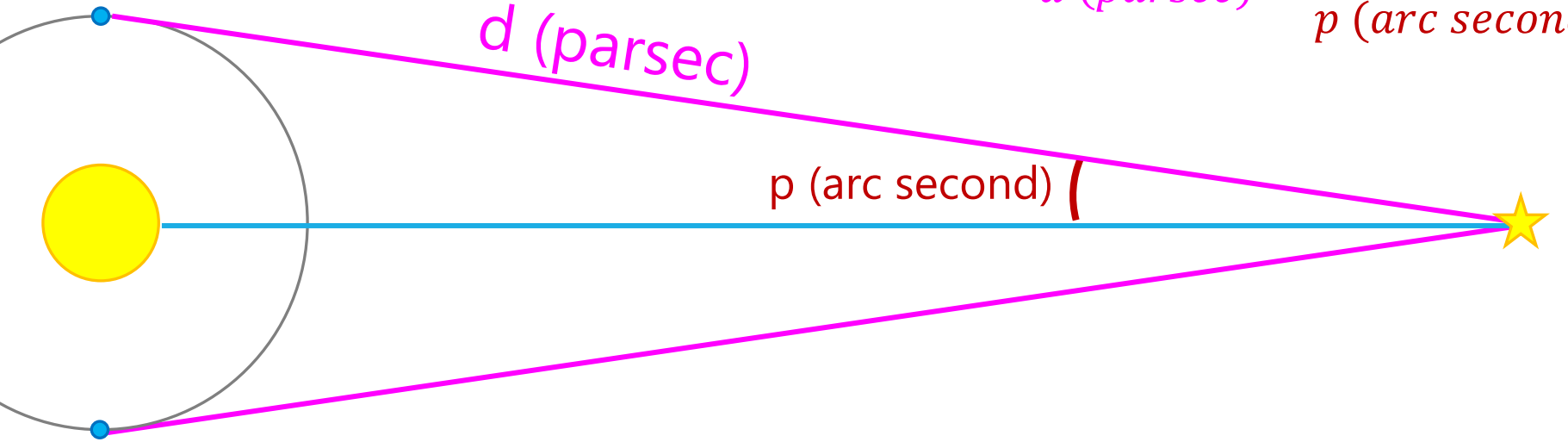
$$d\ (parsec) = \frac{1}{p\ (arc\ second)}$$



E. Nuclear and quantum physics

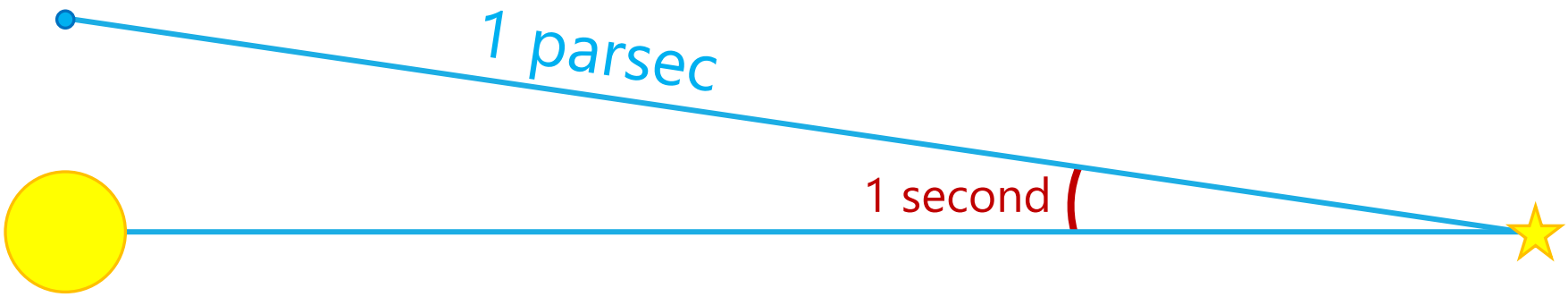
Standard level and higher level	
E.1 Structure of the atom	$E = hf$
E.3 Radioactive decay	$E = mc^2$
E.5 Fusion and stars	$d(\text{parsec}) = \frac{1}{p(\text{arc-second})}$

Parsecs

1 parsec (pc) = 3.26 ly

distance at which the mean radius of the earth's orbit subtends an angle of one second of arc.

parsec stands for **par**allax angle of one **sec**ond



Try This... | #1

$$d\ (parsec) = \frac{1}{p\ (arc\ second)}$$

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The star Betelgeuse has a parallax angle of 7.7×10^{-3} arc seconds. Calculate distance in m.

1 light year (ly) = 9.46×10^{15} m

1 parsec (pc) = 3.26 ly

1 astronomical unit (AU) = 1.50×10^{11} m

arc-seconds → parsecs → light years → meters

$$d = \frac{1}{p} = \frac{1}{7.7 \times 10^{-3}\ arc\ seconds} = 129.9\ parsecs$$

$$129.9\ \text{pc} \times \frac{3.26\ \text{ly}}{1\ \text{pc}} \times \frac{9.46 \times 10^{15}\ \text{m}}{1\ \text{ly}} = \boxed{4.0 \times 10^{18}\ \text{m}}$$

Equation Reminders

B.1

B.1 Thermal energy transfers

$$\rho = \frac{m}{V}$$

$$\overline{E_k} = \frac{3}{2} k_B T$$

$$Q = mc\Delta T$$

$$Q = mL$$

$$\frac{\Delta Q}{\Delta t} = kA\frac{\Delta T}{\Delta x}$$

$L = \sigma A T^4$ ← Luminosity

$b = \frac{L}{4\pi d^2}$ ← Brightness

$\lambda_{max} T = 2.9 \times 10^{-3}\,\text{mK}$ ← Temperature

B.1

All together now!

Brightness (W m^{-2})	**1.2×10^{-7} W m^{-2}**
Max Wavelength (m)	**292×10^{-9} m**
Distance (m)	**8.14×10^{16} m**
Luminosity (W)	**9.98×10^{27} W**
Temperature (K)	**9930 K**
Radius (m)	**1.2×10^{9} m**

The brightest star in the sky is known as Sirius and has a parallax angle of 0.379 arc seconds, apparent brightness of 1.2×10^{-7} W m^{-2}, and a max wavelength of 292 nm. Complete this table of stellar properties.

$$d = \frac{1}{p} = \frac{1}{0.379\ arc\ seconds} = 2.64\ parsecs$$

292×10^{-9} m

$$2.64\ \text{pc} \times \frac{3.26\ \text{ly}}{1\ \text{pc}} \times \frac{9.46 \times 10^{15}\ \text{m}}{1\ \text{ly}} = \mathbf{8.14 \times 10^{16}\ m}$$

$$L = (\text{b})(4\pi d^2) = (1.2 \times 10^{-7})(4\pi(8.14 \times 10^{16})^2) = \mathbf{9.98 \times 10^{27}\ W}$$

$$\text{T} = \frac{2.90 \times 10^{-3}\ \text{mK}}{\lambda_{\text{max}}} = \frac{2.90 \times 10^{-3}\ \text{mK}}{292 \times 10^{-9}} = \mathbf{9930\ K}$$

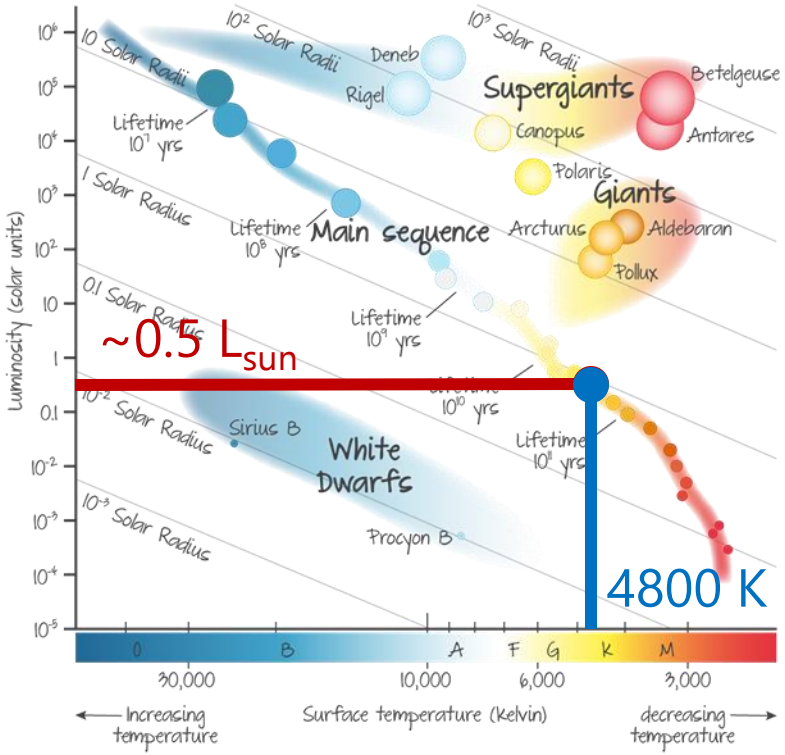
$$L = \sigma A T^4 \qquad 9.98 \times 10^{27} = (5.67 \times 10^{-8})(4\pi r^2)(9930)^4$$

$$\boldsymbol{r = 1.2 \times 10^{9}\ m}$$

H-R Diagram for Calculating Distance

B.1

The maximum wavelength of a main sequence star is measured to be 600 nm, suggesting that it has a temperature of ~4800 K. If this star has a brightness of 2.3×10^{-12} W m^{-2}, what is its distance from Earth?



$$L_{sun} = 3.84 \times 10^{26} \text{ W}$$

$$L_{star} = 0.5 \times (3.84 \times 10^{26})$$

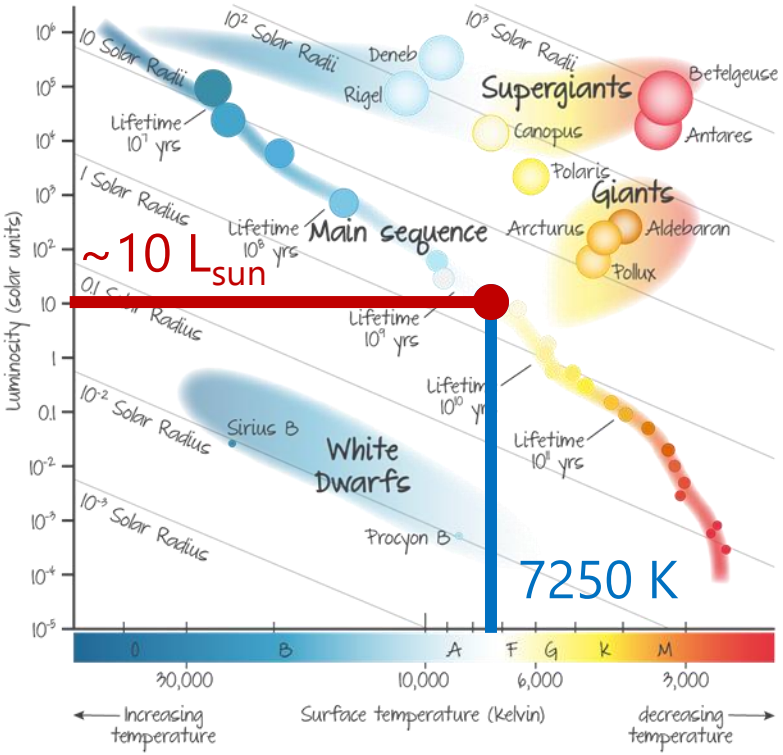
$$= 1.92 \times 10^{26} \text{ W}$$

$$b = \frac{L}{4\pi d^2} \rightarrow d = \sqrt{\frac{L}{4\pi b}}$$

$$d = \sqrt{\frac{1.92 \times 10^{26}}{4\pi(1.0 \times 10^{-12})}} = \boxed{2.58 \times 10^{18} \text{ m}}$$

Try This #2

The maximum wavelength of a main sequence star is measured to be 400 nm. If this star has a brightness of 0.5×10^{-12} W m^{-2}, what is its distance from Earth?



$$L_{sun} = 3.84 \times 10^{26} \text{ W}$$

$$T = \frac{2.9 \times 10^{-3}}{400 \times 10^{-9}}$$

$$T = 7250 \text{ K}$$

$$L_{star} = 10 \times (3.84 \times 10^{26})$$

$$= 3.84 \times 10^{27} \text{ W}$$

$$b = \frac{L}{4\pi d^2} \rightarrow d = \sqrt{\frac{L}{4\pi b}}$$

$$d = \sqrt{\frac{3.84 \times 10^{27}}{4\pi(0.5 \times 10^{-12})}} = \boxed{2.47 \times 10^{19} \text{ m}}$$

Lesson Takeaways

E.5

- ❑ I can convert between lightyears, parsecs, and astronomical units
- ❑ I can determine distance for nearby stars using the parallax method
- ❑ I can determine distance for main sequence stars using temperature and brightness