Stellar Quantities

IB PHYSICS | ASTROPHYSICS

Measuring Distances

1 light year (ly) = 9.46×10^{15} m

The distance that light travels in an earth year

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

The average distance between the earth and the sun

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.

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Unit conversions

1 radian (rad) $\equiv \frac{180°}{\pi}$

Temperature (K) = temperature (°C) + 273

1 light year (ly) = 9.46×10^{15} m

1 parsec (pc) = 3.26 ly

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

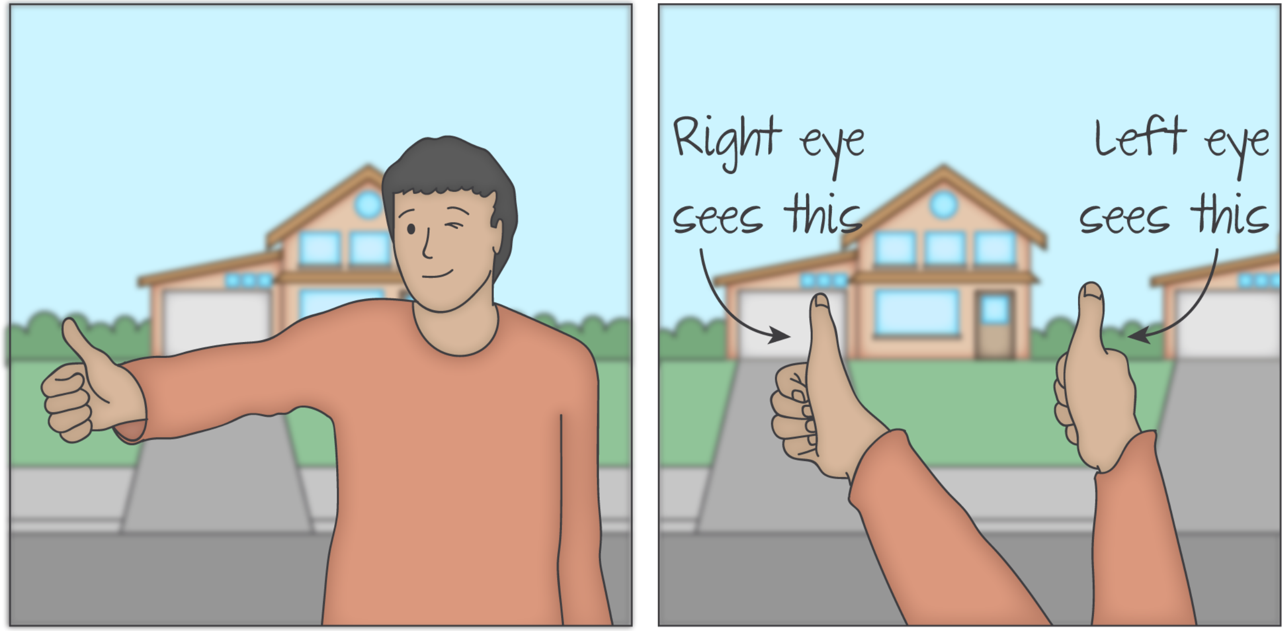
1 kilowatt-hour (kWh) = 3.60×10^{6} J

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

Calculating Stellar Quantities

Distance
Brightness
Luminosity
Temperature
Radius

Stellar Parallax



Measuring Angles

60 seconds in 1 minute

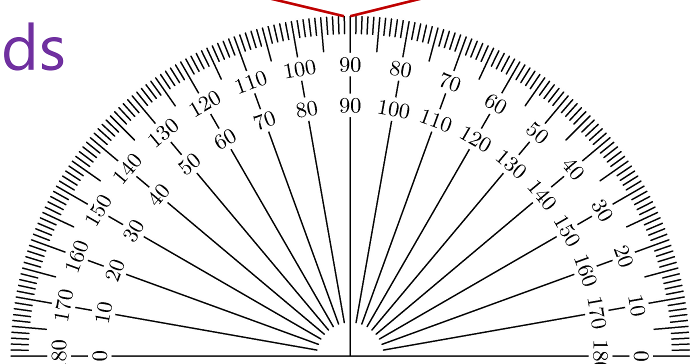
″

60 minutes in 1°

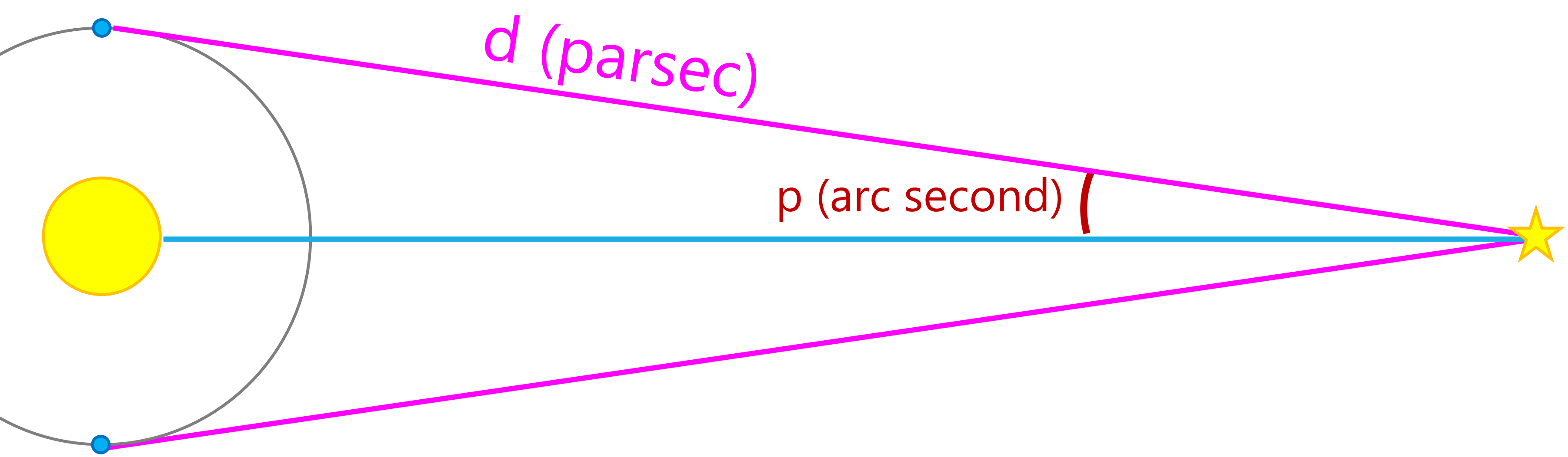
′

1° = 3600 arcseconds

1° = 3600 as



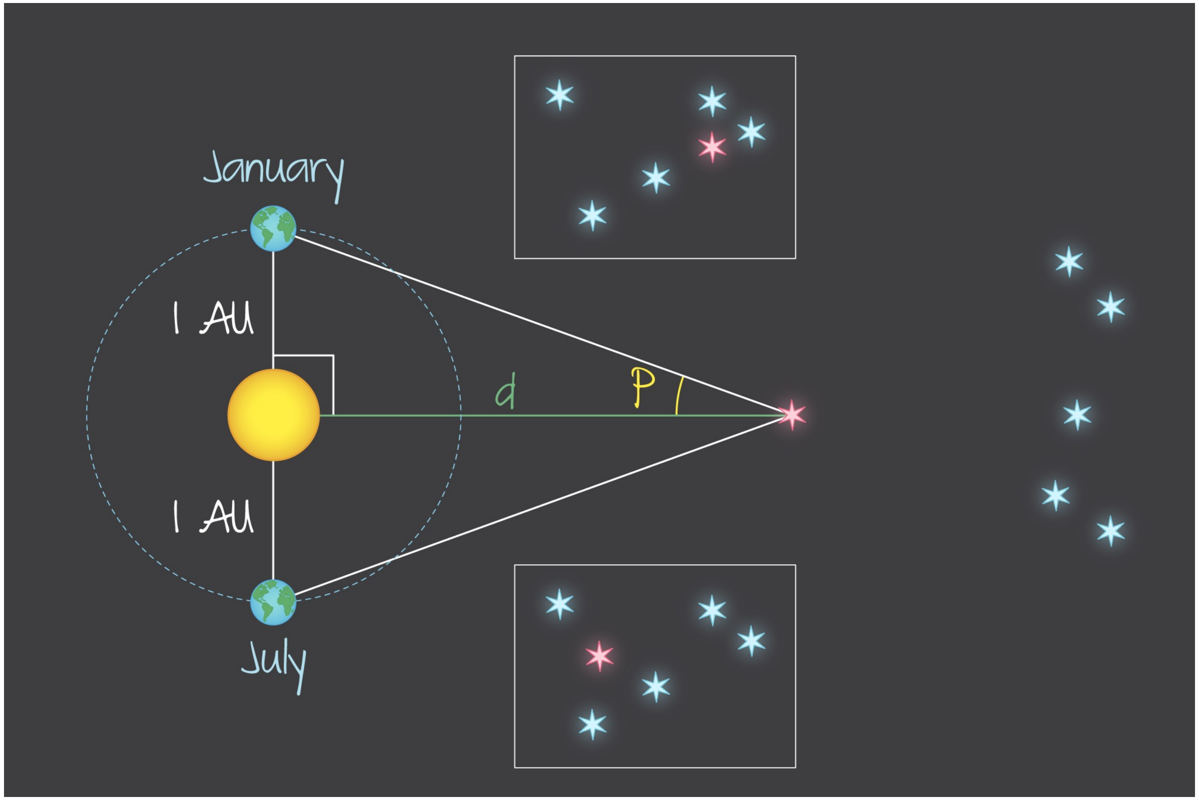
Stellar Parallax



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

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*

Try This... | #1

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

1 light year (ly) = 9.46×10^{15} m

1 parsec (pc) = 3.26 ly

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

arc-seconds → parsecs → light years → meters

$$d = \frac{1}{p} = \frac{1}{7.7\times10^{-3}\ arc\ seconds} = 129.9\ parsecs$$

$$129.9\ \text{pc} \times \frac{3.26\ \text{ly}}{1\ \text{pc}} \times \frac{9.46\times10^{15}\ \text{m}}{1\ \text{ly}} = \boxed{4.0\times10^{18}\ \text{m}}$$

Luminosity vs Brightness

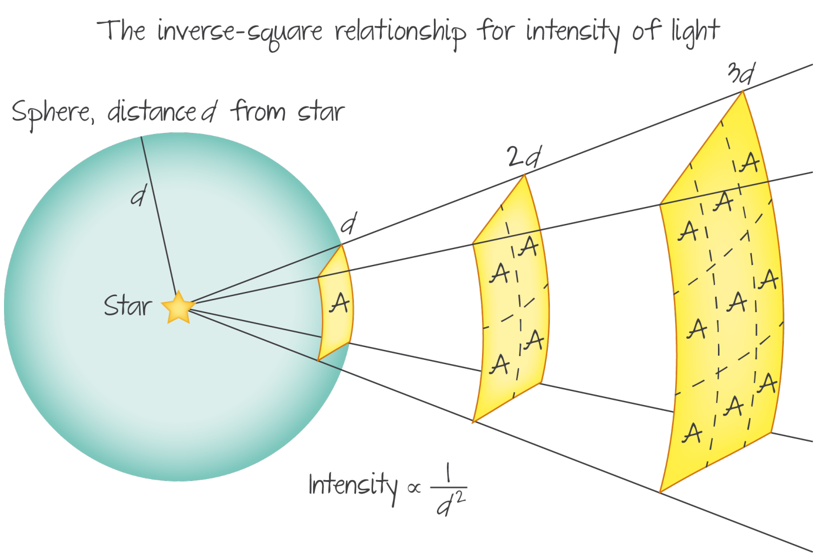
Luminosity	L	Brightness	b
Power Emitted Watts [W]		**Intensity** W/m^2 or $W\ m^{-2}$ **Depends on the observer distance*	

Distance Brightness Luminosity Temperature Radius

Brightness

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

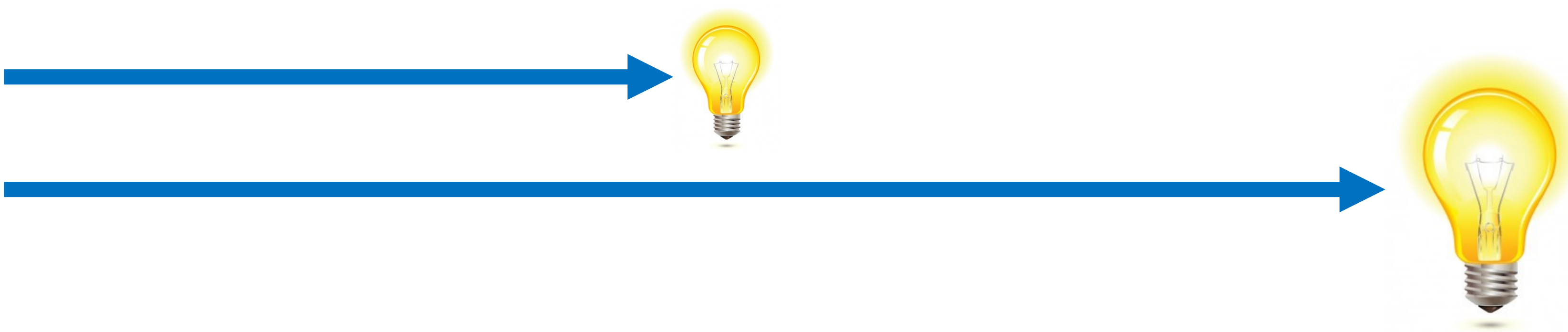
Distance from star



Distance	Brightness
x	b
2x	b/4
3x	b/9
4x	b/16

Same Brightness, Different Stars

It is possible for stars to have the same brightness but have different distances and luminosities



Try This… | #2

The star Betelgeuse has an apparent brightness of 2.0×10^{-7} W m^{-2}. Calculate its luminosity.

$d = 4.0 \times 10^{18}$ m

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

$$L = (\mathrm{b})(4\pi d^2)$$

$$= (2.0\times10^{-7})(4\pi(4.0\times10^{18})^2)$$

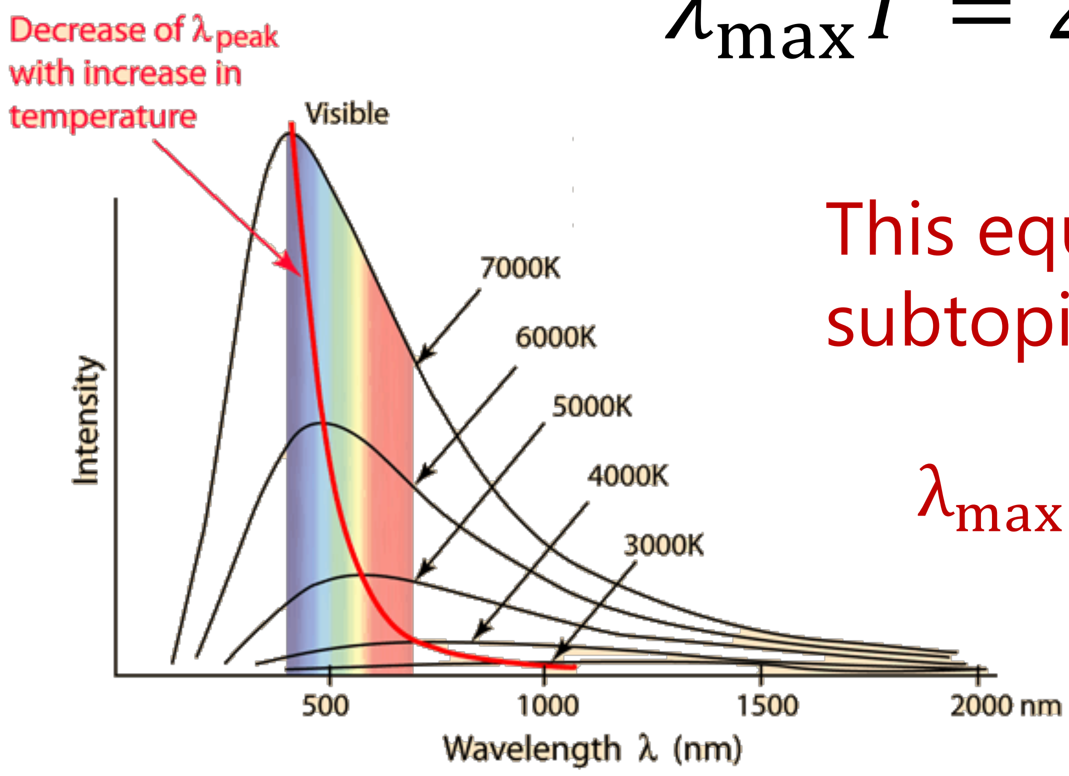
$$= 4.0\times10^{31}\ \mathrm{W}$$

Calculating Stellar Quantities

- [x] Distance
- [x] Brightness
- [x] Luminosity
- [ ] Temperature
- [ ] Radius

Wien's Displacement Law

$$\lambda_{max}T = 2.90\times10^{-3}\ \text{mK}$$



This equation shows up in subtopic 8.2 as

$$\lambda_{max}(\text{metres}) = \frac{2.90\times10^{-3}}{\text{T (kelvin)}}$$

*Note: This assumes perfect blackbody radiation

Try This… | #3

The star Betelgeuse has a max wavelength of 828.6 nm.
What is its surface temperature?

828.6×10^{-9} m

$$\lambda_{\text{max}} T = 2.90 \times 10^{-3}\ \text{mK}$$

Solve for T

$$\text{T} = \frac{2.90 \times 10^{-3}\ \text{mK}}{\lambda_{\text{max}}} = \frac{2.90 \times 10^{-3}\ \text{mK}}{828.6 \times 10^{-9}} = \boxed{3500\ \text{K}}$$

Luminosity

$$L = \sigma A T^4$$

Stefan-Boltzmann Constant	σ	5.67×10^{-8} W m^{-2} K^{-4}

Luminosity
[W]

Temperature
[K]

Surface Area (sphere)
$A=4\pi r^2$

Try This… | #4

Knowing everything else that we know about Betelgeuse, calculate the average radius of the star.

$L = 4.0 \times 10^{31}$ W

T = 3,500 K

$$L = \sigma A T^4$$

Solve for r

$$4.0\times10^{31} = (5.67\times10^{-8})(4\pi r^2)(3500)^4$$

$$r = 6.12\times10^{11}$$

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Sub-topic D.1 – Stellar quantities	Sub-topic D.2 – Stellar characteristics and stellar evolution
$d\text{ (parsec)} = \dfrac{1}{p\text{ (arc–second)}}$ $L = \sigma A T^4$ $b = \dfrac{L}{4\pi d^2}$	$\lambda_{\max} T = 2.9 \times 10^{-3}\text{ m K}$ $L \propto M^{3.5}$
Sub-topic D.3 – Cosmology	**Sub-topic D.5 – Further cosmology (HL only)**
$z = \dfrac{\Delta\lambda}{\lambda_0} \approx \dfrac{v}{c}$ $z = \dfrac{R}{R_0} - 1$ $v = H_0 d$ $T \approx \dfrac{1}{H_0}$	$v = \sqrt{\dfrac{4\pi G\rho}{3}}r$ $\rho_c = \dfrac{3H^2}{8\pi G}$

Distance **Brightness** **Luminosity** **Temperature** **Radius**

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.

292×10^{-9} **m**

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

$$2.64\text{ pc}\times\frac{3.26\text{ ly}}{1\text{ pc}}\times\frac{9.46\times10^{15}\text{ m}}{1\text{ ly}} = \mathbf{8.14\times10^{16}\ m}$$

$$L = (\text{b})(4\pi d^2) = (1.2\times10^{-7})(4\pi(8.14\times10^{16})^2) = \mathbf{9.98\times10^{27}\ W}$$

$$\text{T} = \frac{2.90\times10^{-3}\text{ mK}}{\lambda_{\text{max}}} = \frac{2.90\times10^{-3}\text{ mK}}{292\times10^{-9}} = \mathbf{9930\ K}$$

$$L = \sigma A T^4 \qquad 9.98\times10^{27} = (5.67\times10^{-8})(4\pi r^2)(9930)^4$$

$$\boldsymbol{r = 1.2\times10^{9}\ \mathrm{m}}$$

Distance **Brightness** **Luminosity** **Temperature** **Radius**