Astronomical Measurements:
Brightness-Luminosity-Distance-Radius-Temperature-Mass

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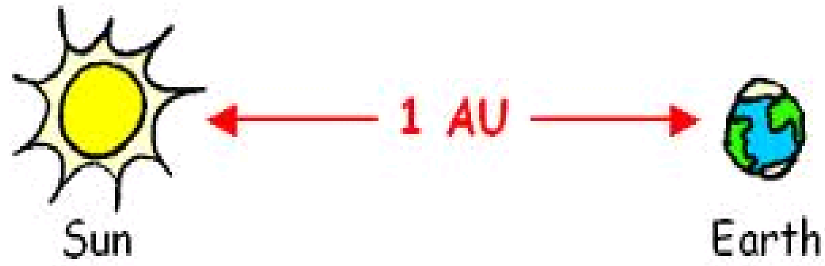
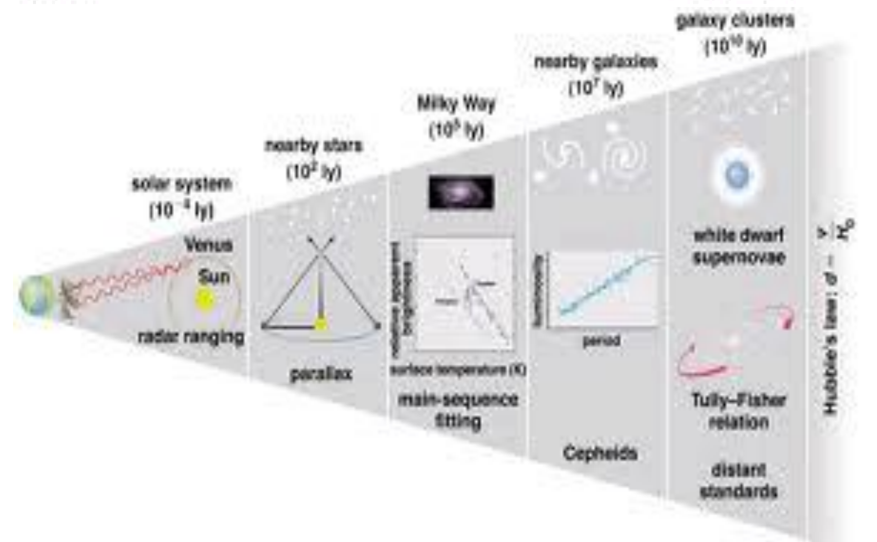
Space Science Distance Definitions

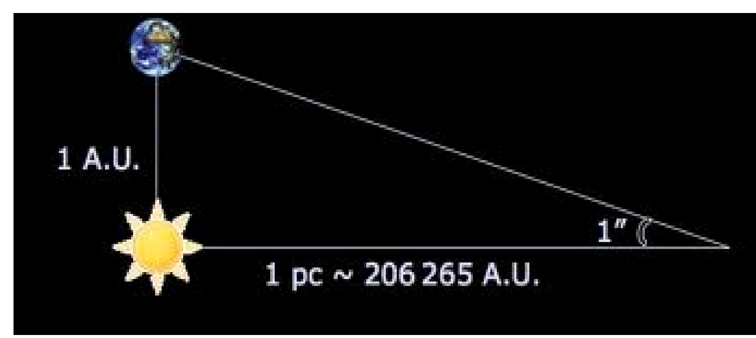
- **One Astronomical Unit** (AU) is the distance from the Sun to the Earth. It is 149,597,870.7 kilometers (92,955,807.3 mi).



- **One Light Year** (ly) is the distance that light travels in vacuum in one year. Equal to 10×10^{15} meters $=63.24\times10^{3}$ AU



- **Parsec** (pc) is equal to 3.26 light years (3.1×10^{13}) km. It is 206,265 AU



Brightness Measurement Units

- The **apparent magnitude** (***m***) of a celestial body is a measure of its brightness as seen by an observer on Earth, adjusted to the value it would have in the absence of the atmosphere. The brighter the object appears, the lower the value of its **magnitude**.
- **Absolute Magnitude** (M) is the apparent magnitude a star would have if it were 32.6 light years (10 parsecs) away from Earth
- **Luminosity** is the amount of electromagnetic energy a body radiates per unit of time

Brightness

- The brightest stars were 'magnitude 1', the next brightest were 'magnitude 2', etc., down to 'magnitude 6', which were the faintest stars that could be seen. Now we also have a negative scale for apparent brightness.

Apparent Visual Magnitudes

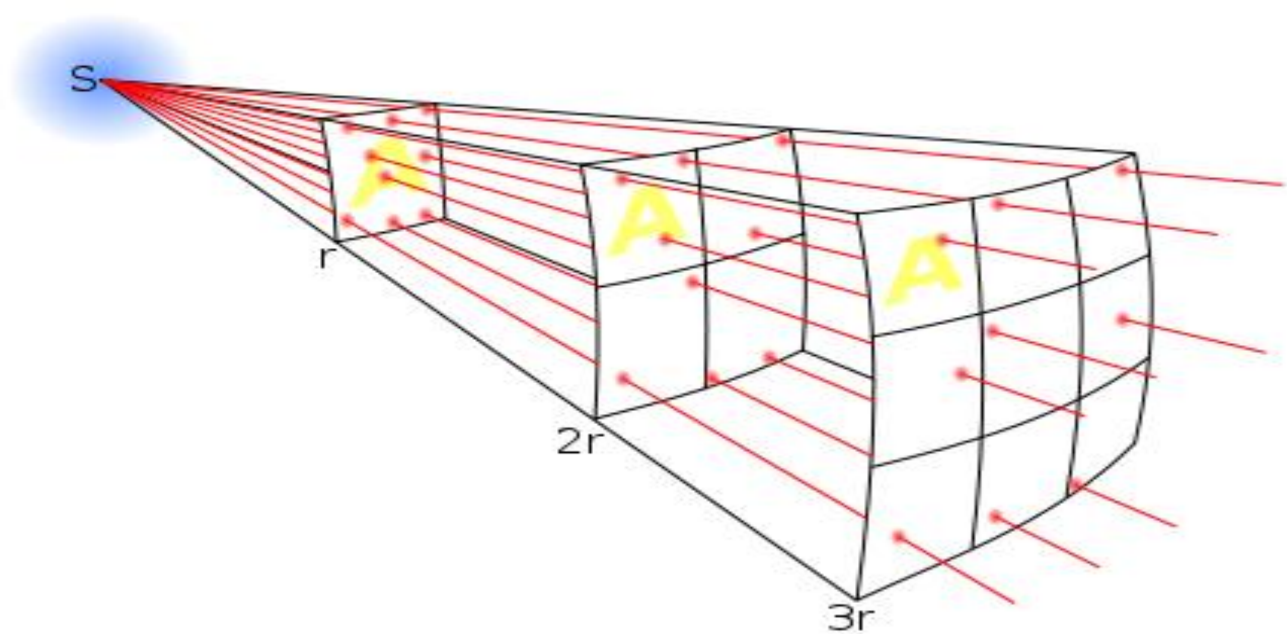
Object	Apparent Visual Magnitude
Sirius (brightest star)	-1.5
Venus (at brightest)	-4.4
Full Moon	-12.6
The Sun	-26.8
Faintest naked eye stars	6-7
Faintest star visible from Earth telescopes	~25
Faintest star visible from Hubble Space Telescope	~?

Luminosity

- The luminosity is how much energy is coming from the per second. The units are watts (W).
- The luminosity of the Sun is $L_{sun} = 3.9 \times 10^{26}$ W
- We will often measure luminosities of stars in units of the luminosity. That is, we might say for a certain star $L_{star} = 5.2 \times L_{sun}$, meaning that the star has 5.2 times the energy output per second of the Sun.
- There are a few stars that are more luminous than the Sun.
  - For instance, Betelgeuse has $L \sim 14000 \times L_{sun}$.
- Most stars are less luminous than the Sun.
  - For instance, $L_{star} \sim 0.001 \times L_{sun}$ is not unusual.
- There are lots more low luminosity stars than high luminosity stars.

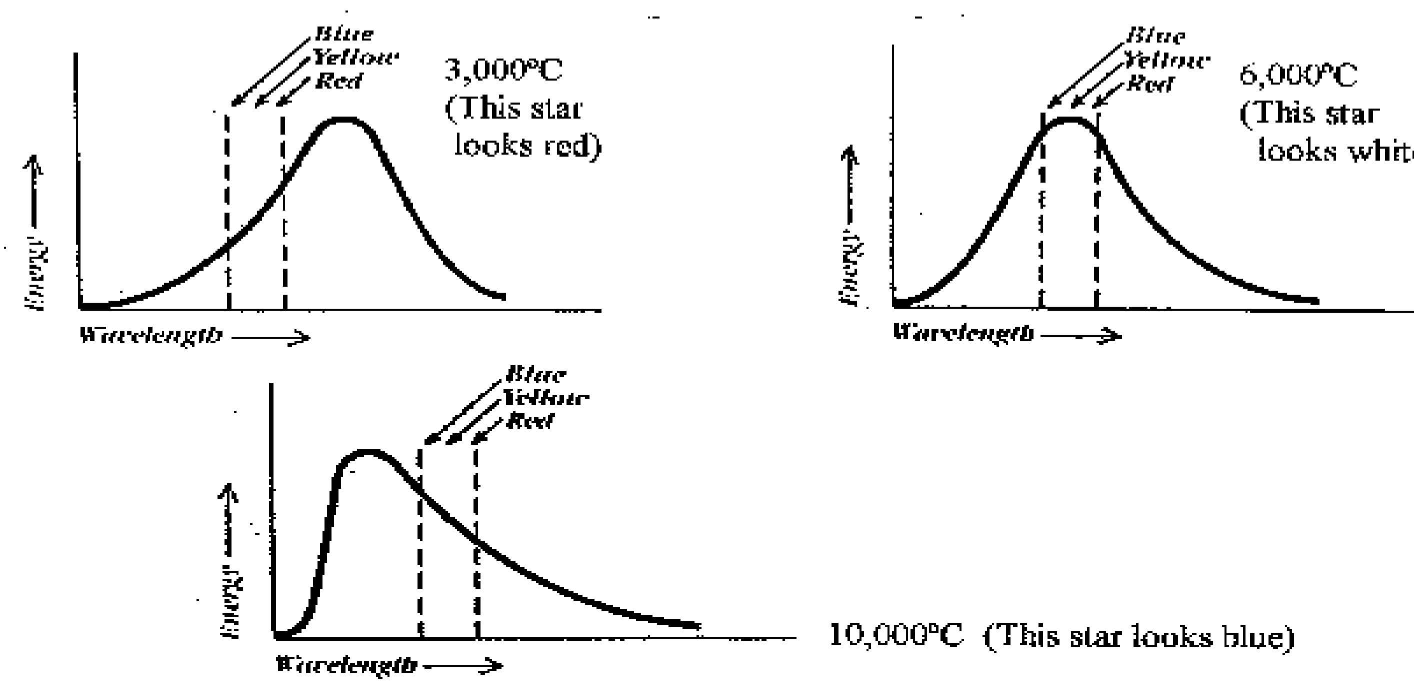
Luminosity and Apparent Brightness

- The difference between luminosity and apparent brightness depends on distance. Another way to look at these quantities is that the luminosity is an intrinsic property of the star, which means that everyone who has some means of measuring the luminosity of a star should find the same value. However, apparent brightness is *not* an intrinsic property of the star; it depends on your location.
- Why do light sources appear fainter as a function of distance? The reason is that as light travels towards you, it is spreading out and covering a larger area. This idea is illustrated in this figure:



Appearance and Temperature of Stars

- Measurements by astronomers tell us that stellar temperatures lie in the range 3,000 to 30,000ºC. Like the Sun with a surface temperature of 5,500ºC, most stars' surface temperatures lie near the cool end of the range, but there are a few very hot stars such as Rigel, Beta Centauri and Spica which shine with a brilliant blue light.

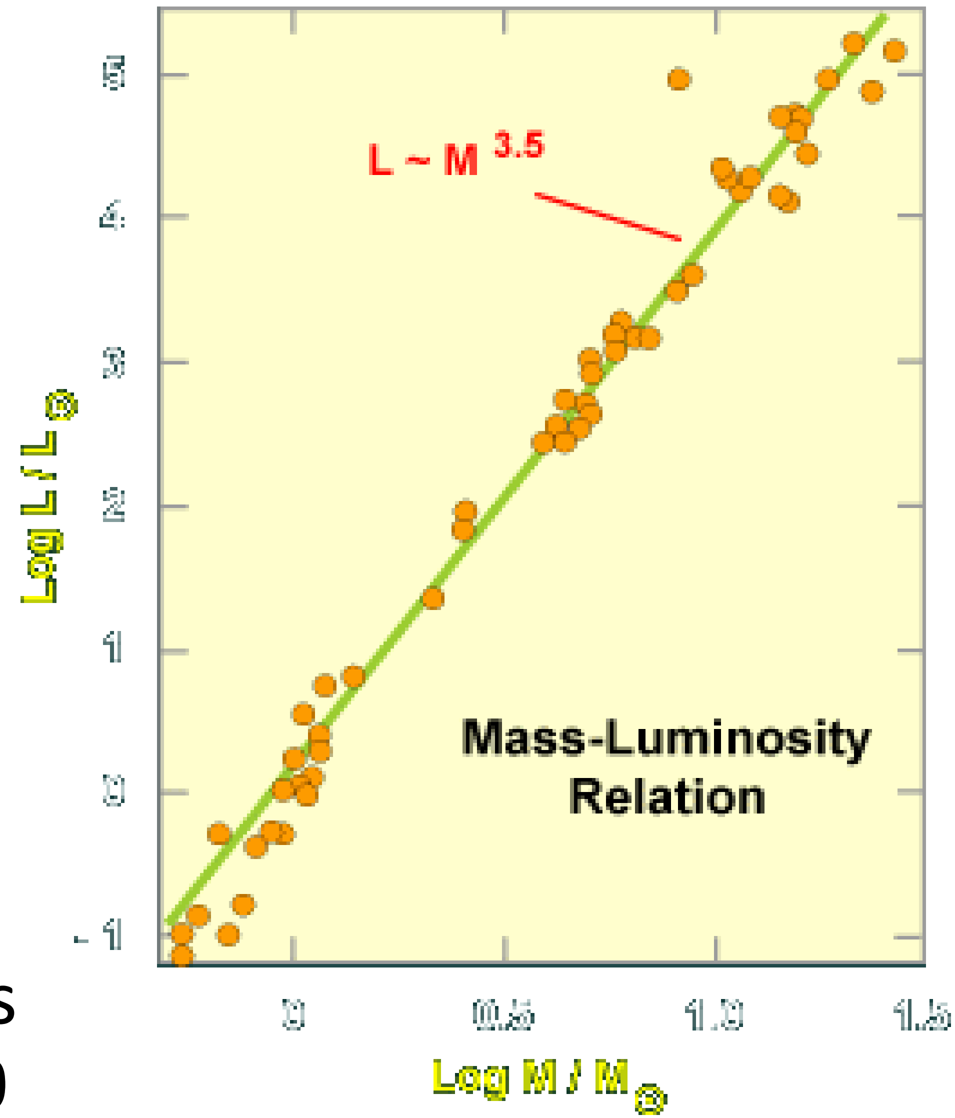


Masses of Stars

- The result of almost two centuries of observing stars is that astronomers have a good idea about the masses of stars. The masses are usually expressed in terms of the mass of the Sun; this is called the solar mass. Obviously, the mass of the Sun is one solar mass (actually 2 x 10^30 kg), and the masses of the other stars lie in the range of one tenth up to about 50 solar masses. High mass stars are extremely rare and most stars contain one solar mass or less

Mass and Luminosity Relationship

- There is a very strong dependence of the luminosity on the mass, since the mass enters raised to the power 3.5. For example, if I double the mass of a main sequence star, the luminosity increases by a factor $2^{3.5} \sim 11.3$. Thus, stars like Sirius that are about twice as massive as the Sun are more than 10 times as luminous.



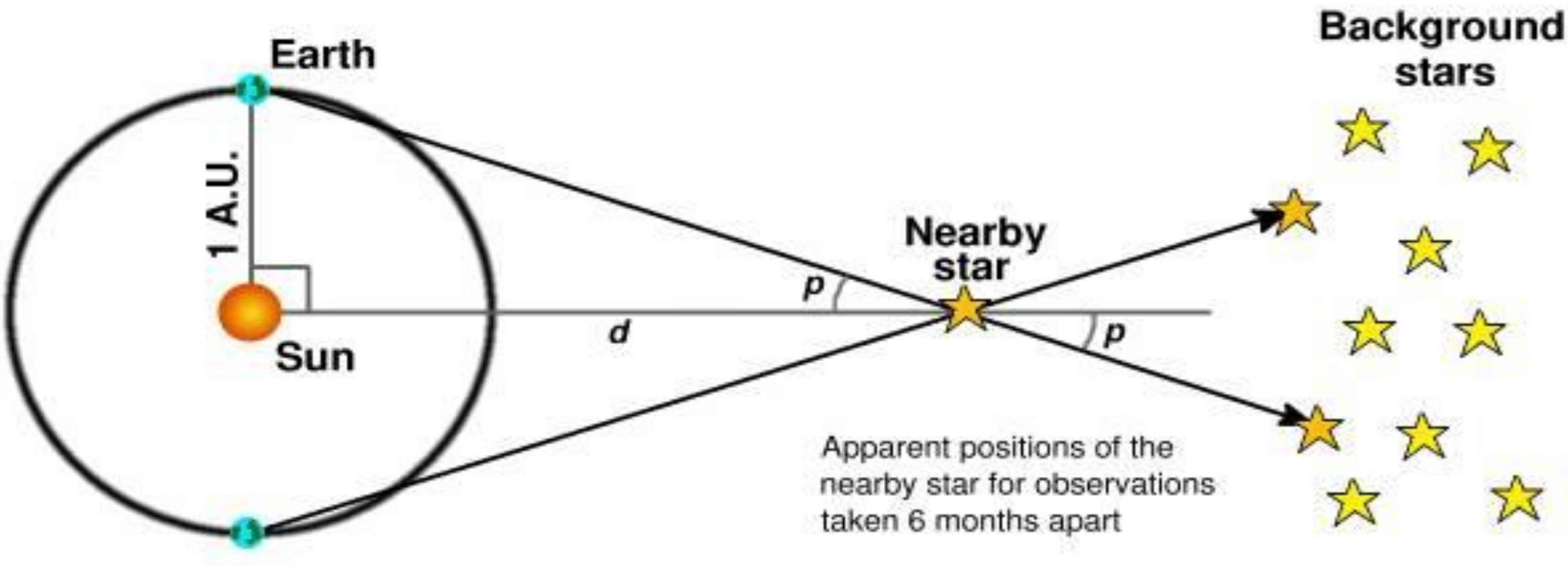
Parallax Effect

- Movement of the observer would create a parallax effect where something may appear closer or in a different location.

Trigonometric Parallax
Notice how the movement of the observer makes the nearby lamppost appear to move relative to the distant tower.

Parallax Effect in Stars

- The stars are so far away that observing a star from opposite sides of the Earth would produce a parallax angle much, much too small to detect. We need to use as large a baseline as possible. The largest one we can easily use is the orbit of the Earth. In this case the baseline is the distance between the Earth and the Sun - an *astronomical unit* (AU) or 149.6 million kilometres. A picture of a nearby star is taken against the background of stars from opposite sides of the Earth's orbit (six months apart).



Interstellar Reddening

- The observed colours of stars are however modified by the effect of the interstellar medium (ISM) through which the light passes on its way to the Earth. In general, the effects of absorption and scattering by dust and gas in the ISM result in the light from the star appearing fainter and redder. The reddening is caused by the fact that particles whose size is similar to that of the electromagnetic radiation that interacts with them preferentially scatter and absorb blue light as opposed to red.
- The observed colour index *B-V* is related to the intrinsic colour index $(B-V)_0$ via:
- $B-V = (B-V)_0 + E(B-V)$
- Where $E(B-V)$ is the **colour excess**. Note that if the star is reddened, then this is a positive number.
- For normal regions of the ISM the colour excess is related to the visual extinction A_V (the number of *V* magnitudes by which the star appears dimmer) via:

$$\frac{A_V}{E(B-V)} = 3.2 \pm 0.2$$

Definitions

m	:	Apparent Magnitude
M	:	Absolute Magnitude
I	:	Light Intensity
P	:	Parallax
R	:	Radius of the star
L	:	Luminosity
T_e	:	Effective Temperature
ρ	:	Density of the star

Formulas

- $m_2 - m_1 = 2.5 \log \frac{I_1}{I_2}$
- We can calculate the distance to a star by the formula
- $m - M = 5 \log d - 5$ distance in Parsec
- For a star with parallax p”
- $d = {}^{1}/_{p''}$ distance in Parsec

- $L = 4\pi R^2 \sigma T_e^4$
- $M_2 - M_1 = 2.5 \log {}^{L_1}/_{L2}$
- $E = \sigma T_e^4$
- $M = {}^4/_3 \pi R^3 \rho$

Space Science Problems

1. If Alpha century has parallax of 0.76” then how far is it?

Solution: $d = {}^{1}/_{p''} = {}^{1}/_{0.76} \approx 1.316$ parsecs

since 1 parsec is 3.26 light years.

d = 1.316(3.26)= 4.26 light years.

2. Which star is nearer?

First star has 0.012" parallax and second star has distance of 271.87 light years.

$d_1 = {}^{1}/_{P1''} = {}^{1}/_{0.012} = 83.33$ parsecs

$d_2 = 271.88$ light years.

First star is nearer.

3. A Star has an absolute magnitude of -2^M and a distance of 1500 parsecs. Find the apparent magnitude and its parallax?

$m - M = 5 \log d - 5$

Here $m = M + 5 \log d - 5$

$m = 8.88$

Also parallax is $p'' = 1/d$

$= 1/1500$

$= 0.00067''$

4.

The sun has an apparent magnitude of -26.7^{m}.
What is the absolute magnitude?

- $m_{\odot} = -26.7$
- $d_{\odot} = 1\ AU = 1/2062.5 = 0.0000048$

  Here $m - M = 5 \log d - 5$
- $M_{\odot} = 4.87$

5. A star has an apparent magnitude of 6 and absolute magnitude is 0. What is the distance in Light years?

$M = 0$, $m = 6$

$m - M = 5 \log d - 5$ is transformed to

$\log d = m - M + 5 / 5 = 2.2$

So $d = 158.5$ parsecs $= 516.71$ light years

6. A star has an apparent magnitude of 4.43 and distance of 190 parsecs. In order for the star to appear 0.1 less , how far it needs to be?

$m_1 = 4.43$ and $m_2 = 4.43 + 0.1$

$M_2 = M_1$

$m_1 - M_1 = 5 \log d_1 - 5$

$m_2 - M_1 = 5 \log d_2 - 5$

$m_1 - m_2 = 5 \log d_1/d_2 = \log d_1/d_2 = -0.02$

$d_1/d_2 = 0.95$

$d_2 = 200$ parsecs

7. A star has an apparent magnitude of 12. Then it undergoes supernova and it has an apparent brightness of -1. How much has the light intensity increased?

$m_1 = 12, \quad m_2 = -1$

$m_2 - m_1 = 2.5 \log {}^{I_2}/_{I_1}$

$\log I_2/I_1 = 8$ and as a result

${}^{I_2}/_{I_1} = 10^{8}$

8. If a white dwarf has an effective temperature of 10^4 *K* and Luminosity of 10^{-2} $L_{\odot}$ then find its radius. $T_{\odot} = 5000K$

$$L_{\odot} = 4\,\pi\, R_{\odot}^{\,2}\, \sigma\, T_{\odot}^{\,4}$$

$$L = 4\,\pi\, R^2\, \sigma\, T_e^{\,4}$$

Divide then to each other

$$\frac{L_{\odot}}{L} = \left(\frac{R_{\odot}}{R}\right)^2 * \left(\frac{T_{\odot}}{T}\right)^4$$

$$\frac{R}{R_{\odot}} = \left(\frac{L}{L_{\odot}}\right)^{0.5} * \left(\frac{T_{\odot}}{T}\right)^{2}$$

$$L = 10^{-2} L_{\odot}$$

$$\frac{R}{R_{\odot}} = \left(\frac{10^{-2} L_{\odot}}{L_{\odot}}\right)^{0.5} * \left(\frac{5000}{10000}\right)^{2}$$

$$R = R_{\odot} / 40$$

9. The sun has an apparent magnitude of -26.7 and temperature of 5780*K*. A star has a temperature of 9000*K* and an absolute magnitude of 0. Find its radius?

$$m_\odot - M_\odot = 5 \log d - 5$$

Here $M_\odot = -26.7 + 5 + 5 \log 206265$

$M_\odot = 4.87$

$$M_\odot - M_s = 2.5 \log L_s / L_\odot$$

$$\log L_s / L_\odot = 0.4 * 4.87 = 1.948$$

$$L_s / L_\odot = 88.7 = \frac{4\pi R_s^{\,2} \sigma T_s^{\,4}}{4\pi R_s^{\,2} \sigma T_\odot^{\,4}}$$

$$\left(\frac{R_y}{R_\odot}\right)^2 = 88.7 * \frac{T_\odot}{T_s}^{2}$$

$$\frac{R_s}{R_\odot} = 3.88$$

$$R_s = 3.88 R_\odot$$

10. A star has an apparent magnitude f 6.0 and 9.0 as minimum and maximum respectively. Its minimum and maximum effective temperature is 2600*K* and 1900*K*. Find the rate of radius?

$$m_{min} - m_{max} = M_{min} - M_{max} = 2.5\log\frac{L_{max}}{L_{min}}$$

$$= 2.5\log\frac{4\pi R_{max}{}^2\,\sigma\,T_{max}{}^4}{4\pi R_{min}{}^2\,\sigma\,Tmin^4}$$

$$\frac{R_{max}{}^2}{R_{min}{}^2} = 4.52$$

$$R_{max} = 2.13\,R_{min}$$