Astro 301/ Fall 2006

(50405)

Introduction to Astronomy

http://www.as.utexas.edu/~sj/a301-fa06

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Lecture 14 Th Oct 19

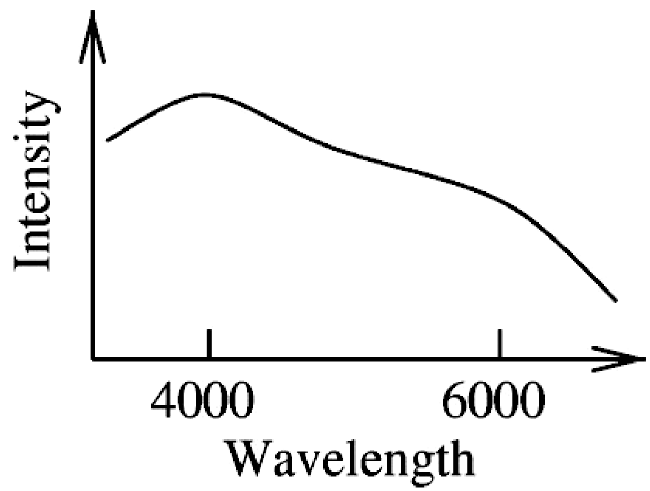
Kirchhoff's First Law

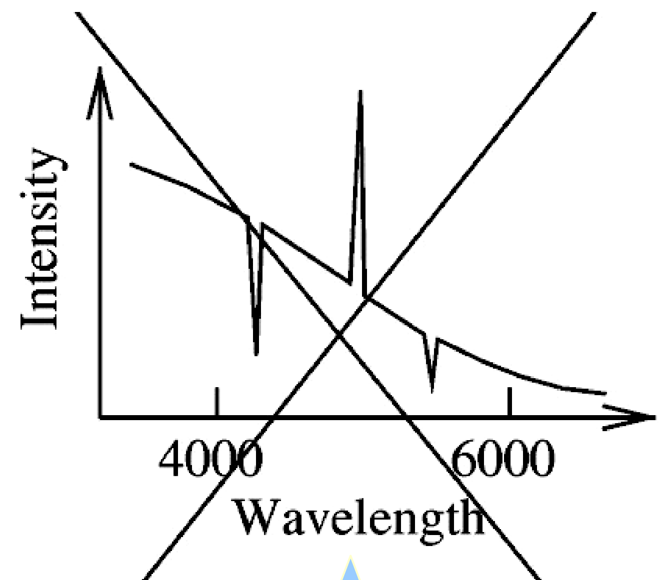
Gustav Kirchhoff
(1824 – 1887)

A hot solid, liquid, or opaque gas emits light at all wavelengths, producing a continuous spectrum (called a continuum spectrum)

A continuum spectrum

A continuum spectrum has continuous emission over a continuous range of wavelengths





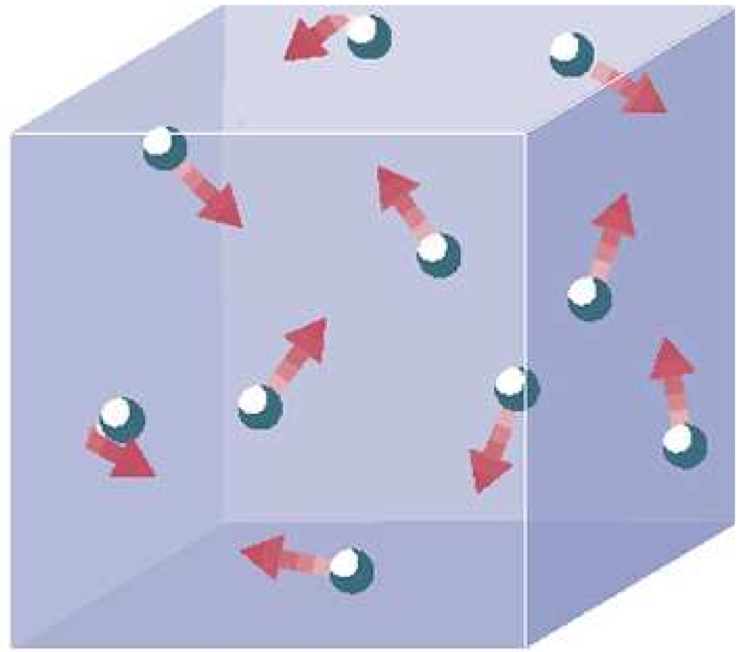
This is a continuum spectrum, …

This is not a continuum spectrum.

Hot solids, liquids, and opaque gases emit a <u>continuum</u> spectrum.

The Meaning of Kirchhoff's First Law

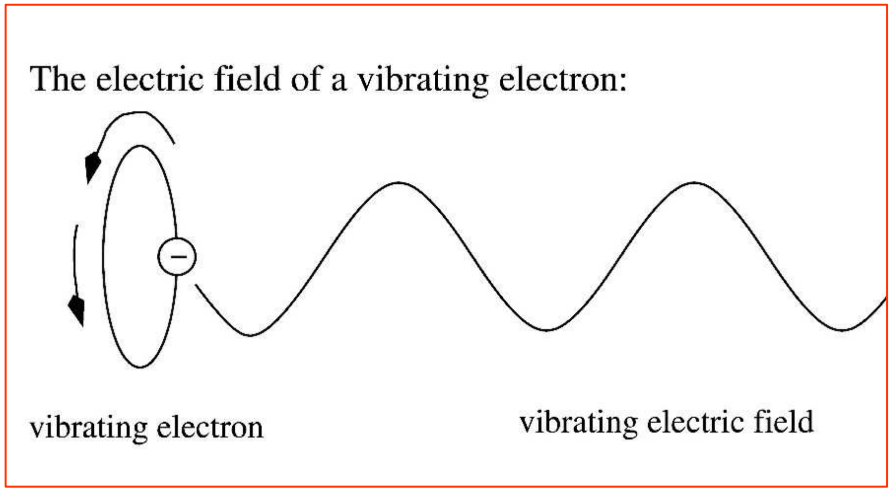
Anything that is hot emits light.



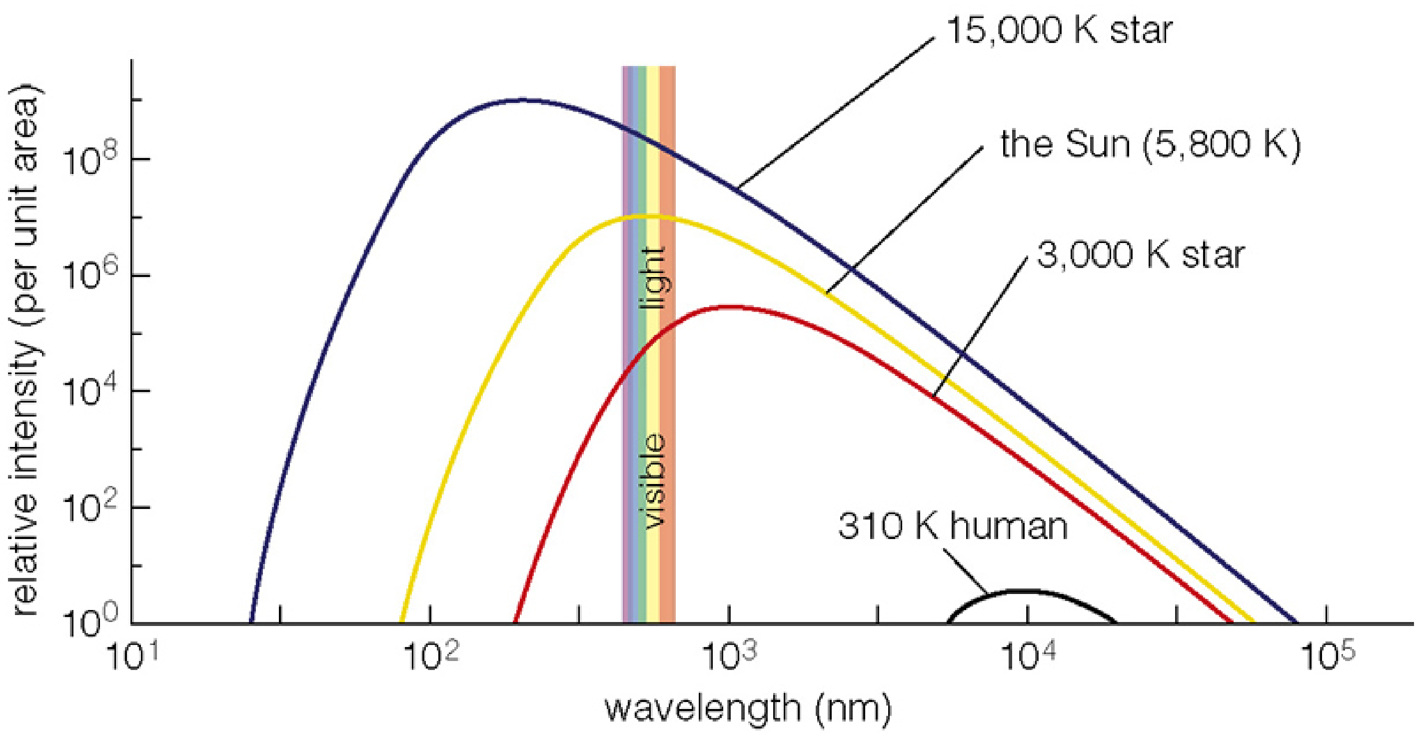
In a hot object, the atoms are moving randomly (vibrating) with an energy set by the temperature of the body. (Recall the concept of thermal energy)

The electrons (and protons) in the atoms and molecules are carried along with the vibration.

The vibrating electrons cause vibrating electric fields. This is light!



Wien's law relates surface temperature and peak wavelength



Wien's law: The continuum emisision of a star or blackbody peaks at a wavelength λ_{peak} that depends inversely on its surface temperature T

λ_{peak}= W/ T , where W = Wien's constant = 2.9 x 10^{-3} m K

Four QEDEx tips applied to Wien's formula

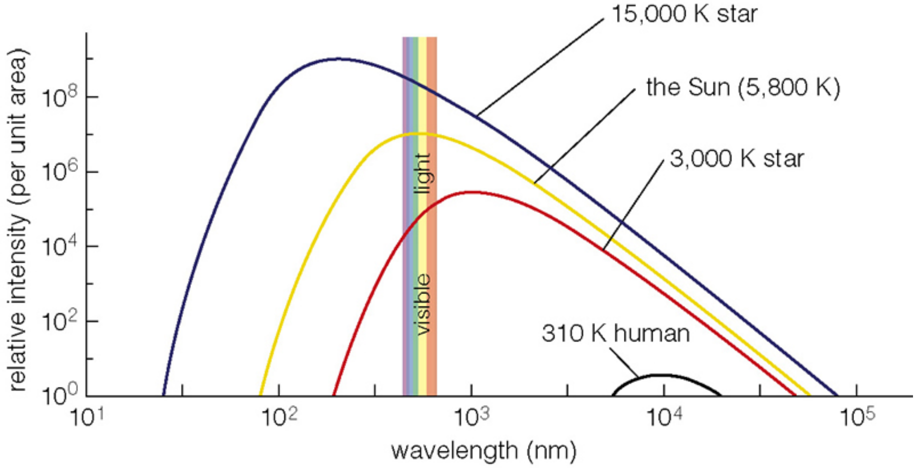
$$\lambda_{peak} = W / T$$

1) **Q:** Quantities: describe quantities fully in words. What is λ_{peak} W, and T?

2) **E** : Express formula in words and understand how quantities relate to each other

à Wien's law implies that the continuum emission of **hotter stars peak at smaller wavelengths** λ_{peak}

3) **D**: Diagram: draw a diagram or graph to illustrate the formula



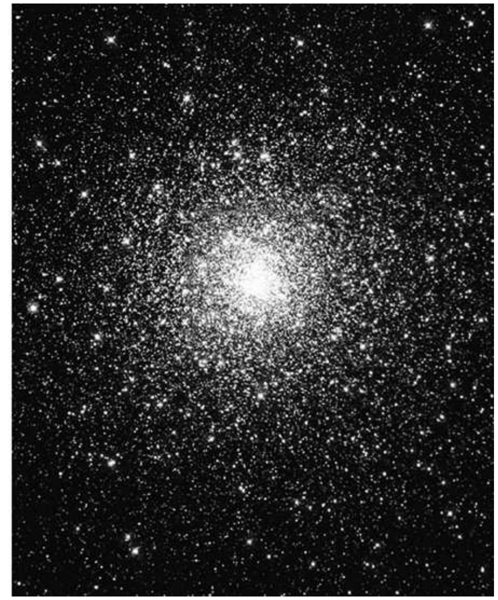
4) **Ex** : Examples: work out an example

For the Sun, λ_{peak} = 5000 A = 5 x 10^{-7} m ,

Sun's surface temperature (T in K) = (2.9 x 10^{-3} m K)/ (λ_{peak} in m) = 5800 K

Temperature and color of stars

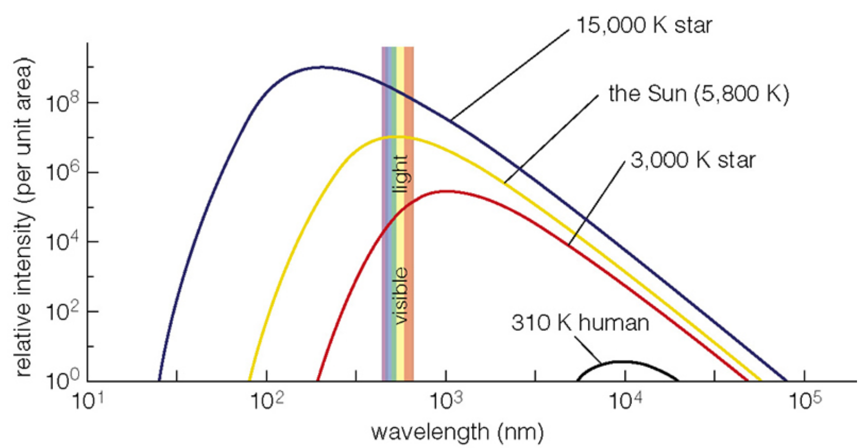
Pleiades stellar cluster



M80 globular cluster (HST image)

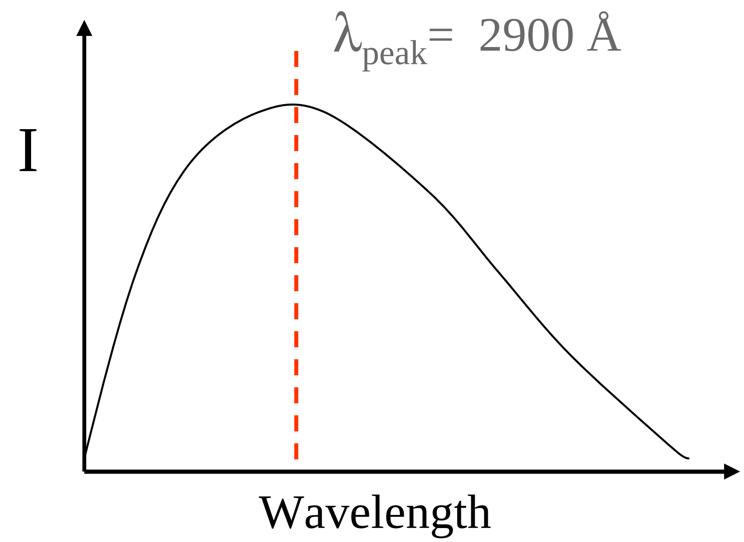
From Wien's law we know that bluer stars are hotter while red stars are cooler.
à Pleaides has hotter stars than M80

The temperature of the star in turn tells us something about the age and mass of stars (see later lecture)



How to measure the surface temperature of a star?

1) Observe the continuum spectrum of the star.



2) Find the peak in the spectrum and measure the wavelength of the peak. This is $\lambda_{\mathbf{peak}}$

3) Calculate the temperature T from Wien's law

(T in K) = (2.9 x 10^{-3} m K)/ (λ_{peak} in m)

For λ_{peak} = 2900 A = 2.9 x 10^{-7} m ,

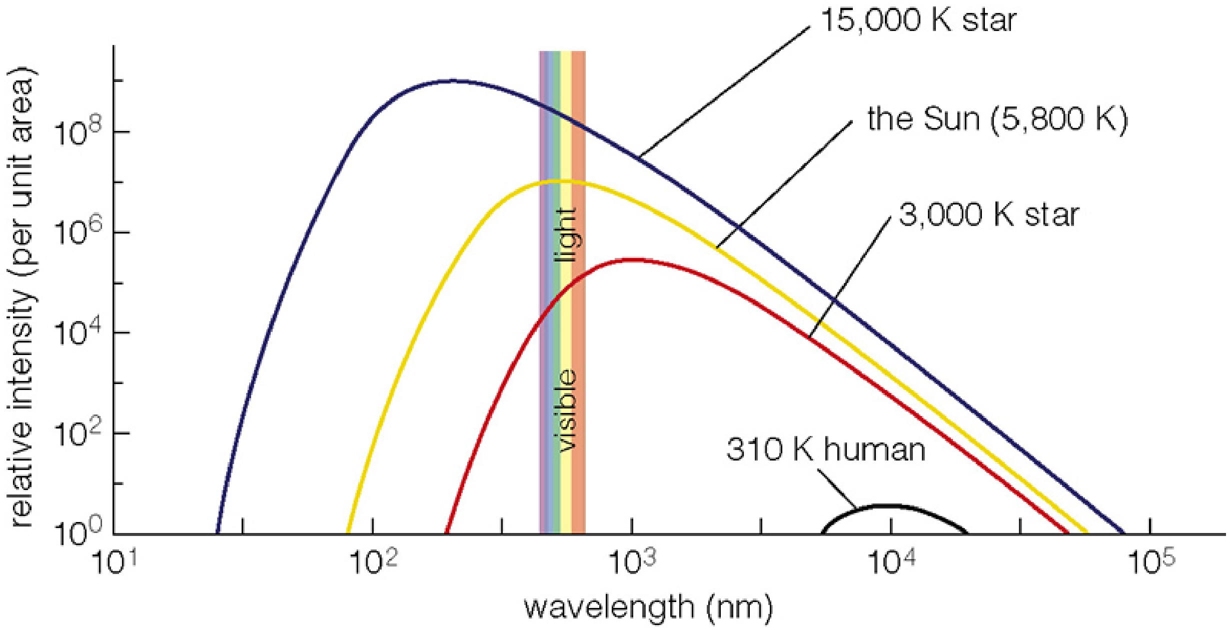
surface temperature (T in K) = (2.9 x 10^{-3} m K)/ (λ_{peak} in m) = 10,000 K

The Temperatures of Stars

Star	Temperature
Hottest normal star	100,000 K
Spica	23,000 K
Sirius	10,000 K
Sun	5,800 K
Betelgeuse	3,200 K
Coolest normal star	2,000 K

Neutron stars can have temperatures greater than 1,000,000 K!

Stefan-Boltzmann law relates surface temperature and flux



Wien's law tells as **at what wavelength** a blackbody emits most of its continuum light.

Stefan-Boltzmann law tells us **how much total light energy** the blackbody emits **over all wavelengths**. It states that the total flux emitted at the surface of a star (or black body) is equal to σT^4, where σ is the Stefan- Boltzmann constant

Flux F at surface of star = σT^4

Luminosity of a star rises rapidly as its surface temperature rises

Start with Stefan-Boltzmann law

Flux F at surface of star = σT^4

But in last lecture we defined

Flux F at surface of star = (Luminosity of star) /(Surface area $4 \pi R^2$ of star)

Equate the 2 expressions for flux at surface of star

Luminosity of star /(Surface area $4 \pi R^2$ of star) = σT^4

Luminosity of star = $(4 \pi R^2) \sigma T^4$

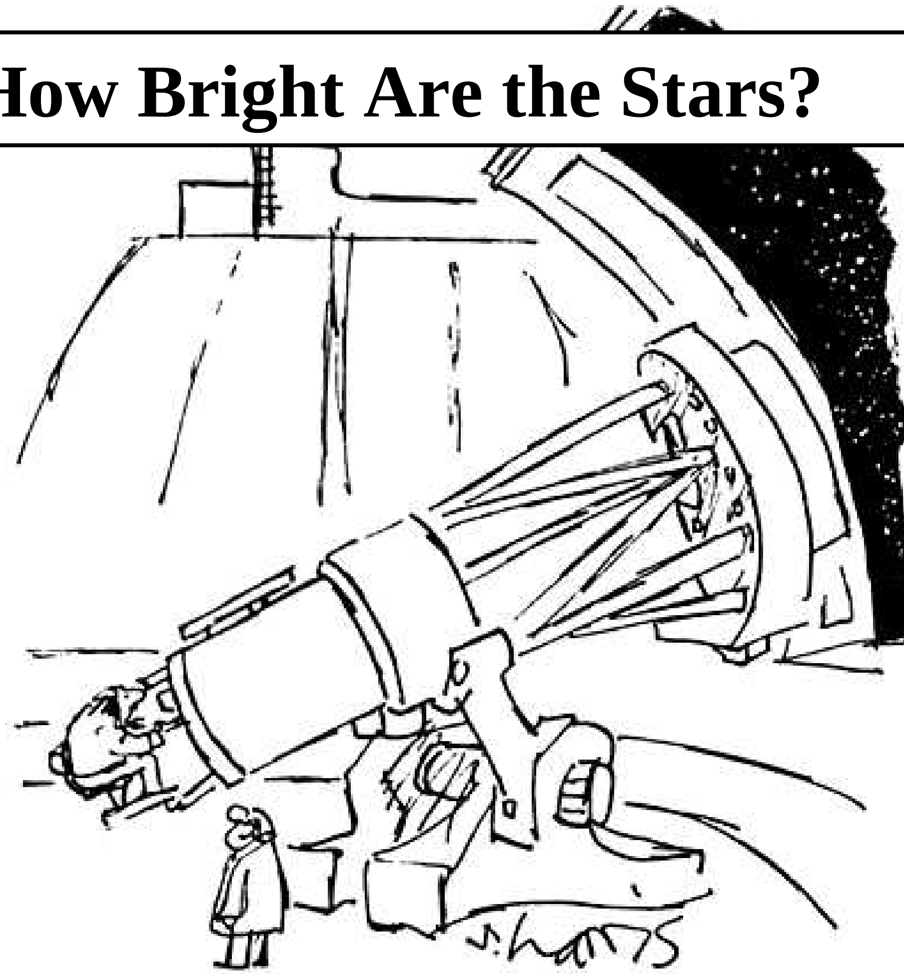
The luminosity of a star is proportional to $(R^2 T^{4)})$ and increases rapidly as its surface temperature and radius rises

If the radius doubles, the luminosity increases by a factor of 2^2 =4.

If the temperature doubles, the luminosity increases by a factor of $2^4 = 16$!

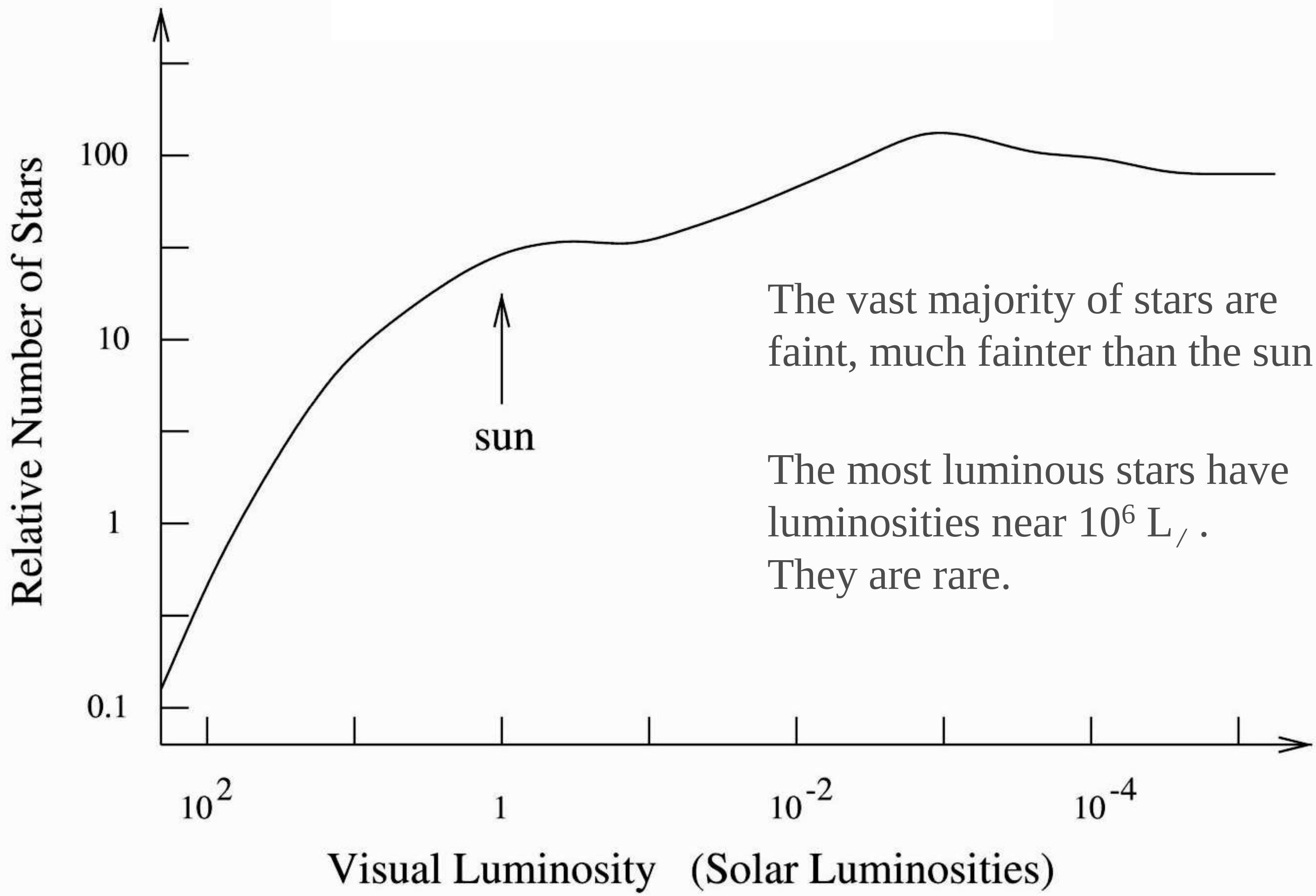
How Many and How Bright Are the Stars?

Count the stars in the neighborhood of the sun!



“ Let’s see, now … picking up where we left off … one billion, sixty-two million, thirty thousand, four hundred and thirteen … one billion, sixty-two million, thirty thousand, four hundred and fourteen … ”

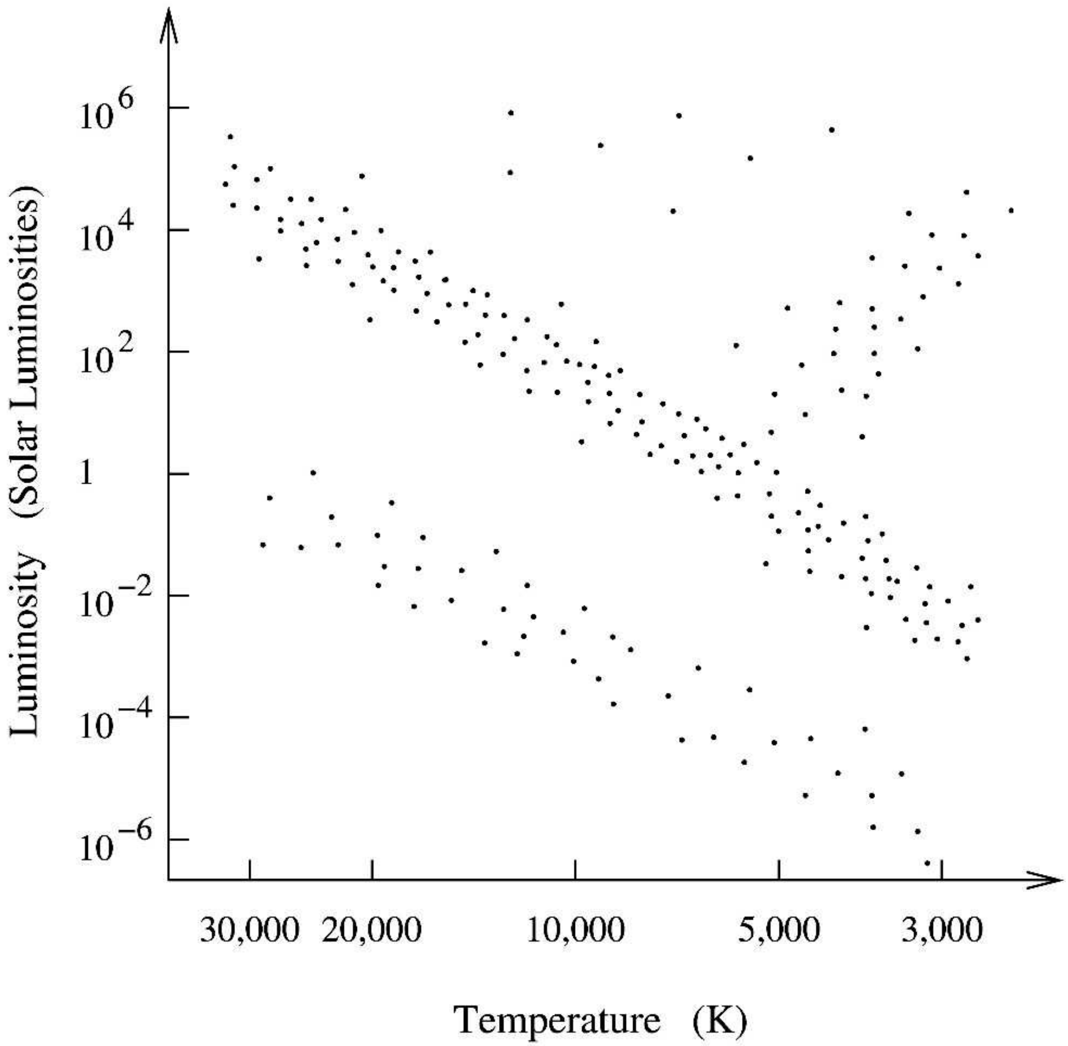
The Luminosity Function



The vast majority of stars are faint, much fainter than the sun.

The most luminous stars have luminosities near 10^6 $L_{/}$.
They are rare.

The Hertzsprung - Russell Diagram

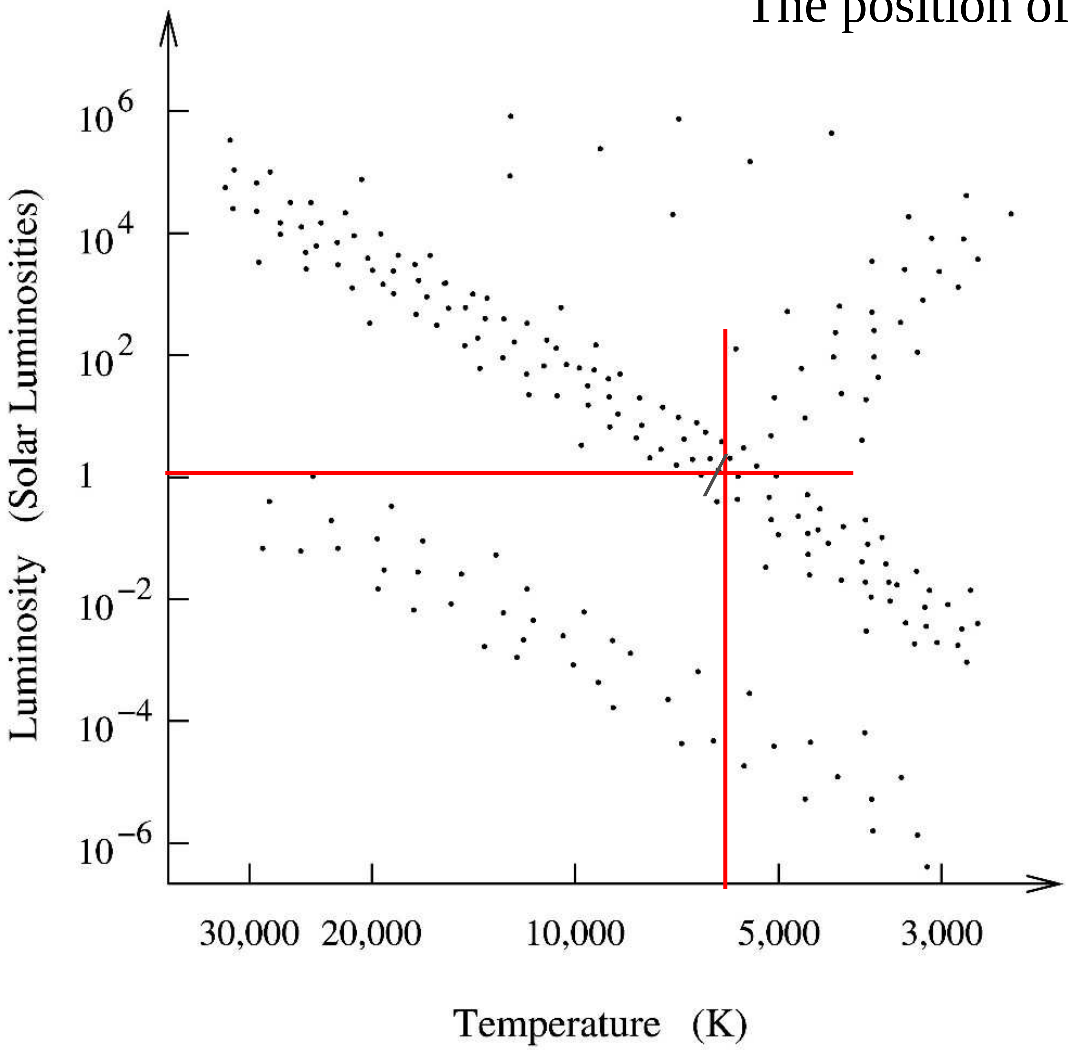


Each dot represents a single star.

The position of the dot gives the star’s temperature and luminosity.

The Hertzsprung - Russell Diagram

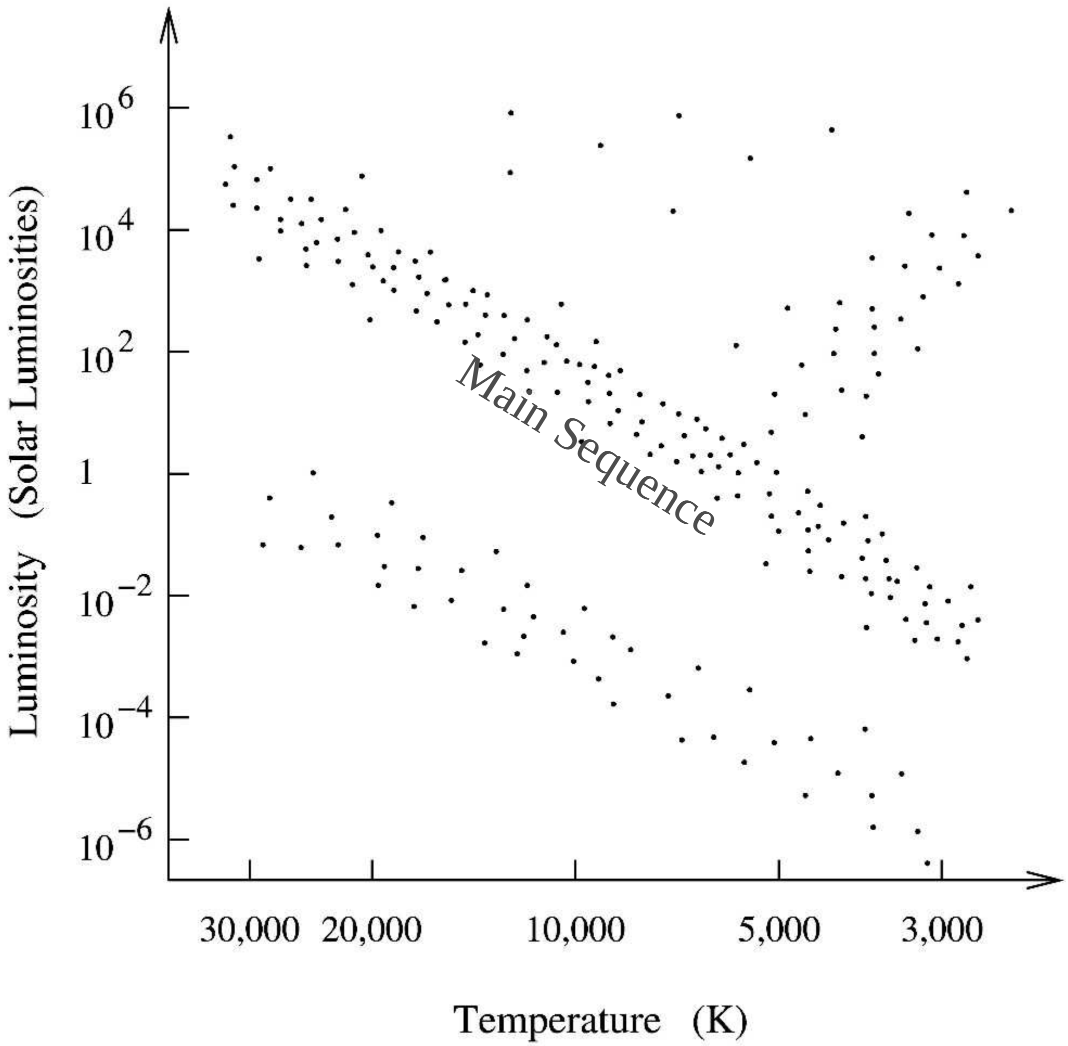
The position of the sun in the H-R Diagram:



T = 5800 K

L = 1 $L_{\odot}$

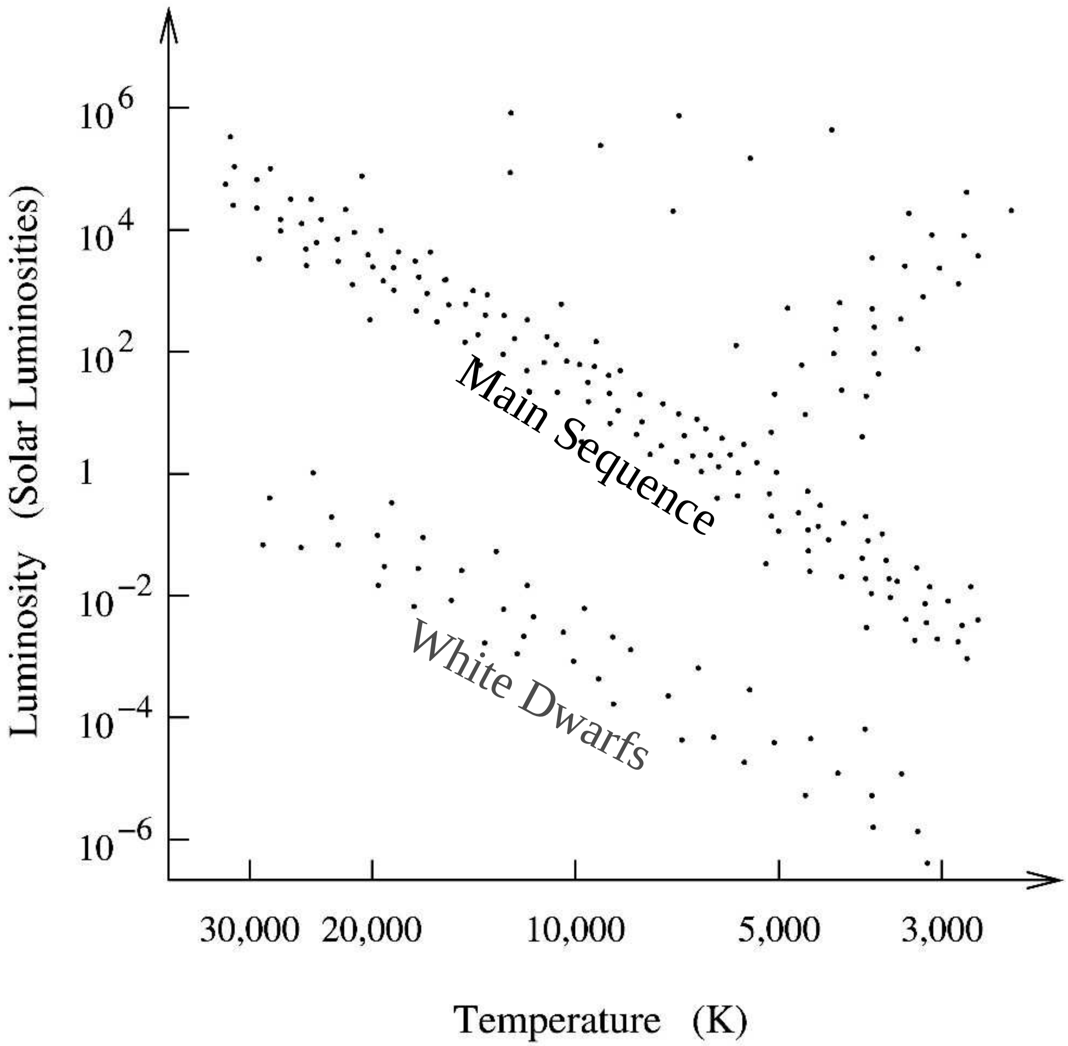
The Hertzsprung - Russell Diagram



The Main Sequence

- Upper left (hot,bright) to lower right (cool, faint)
- 90% of all stars
- Stars like the sun

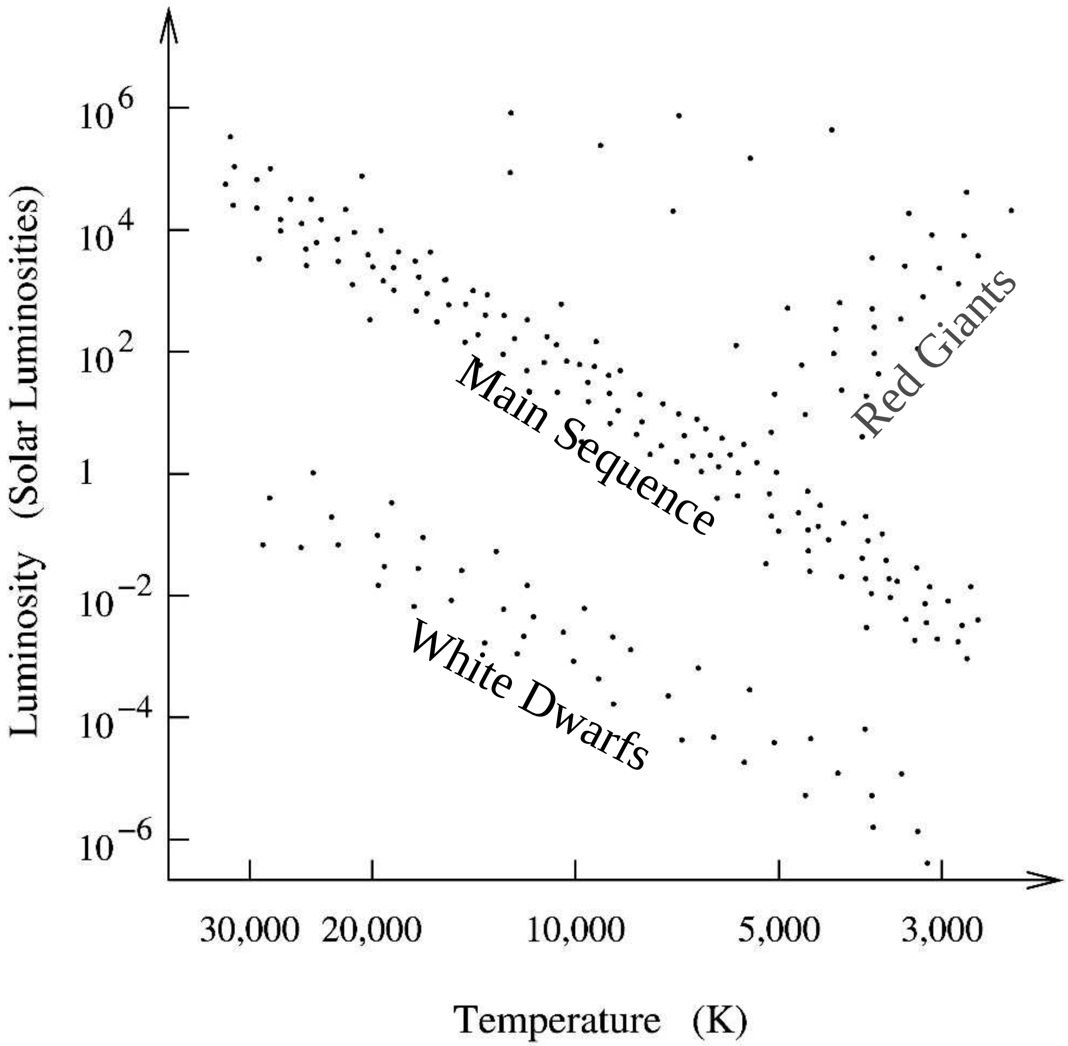
The Hertzsprung - Russell Diagram



White dwarf sequence

- Parallel to the main sequence but 10^{-4} times fainter
- 7% of all star
- Some are hot and blue-white, many are cooler and orange or red.

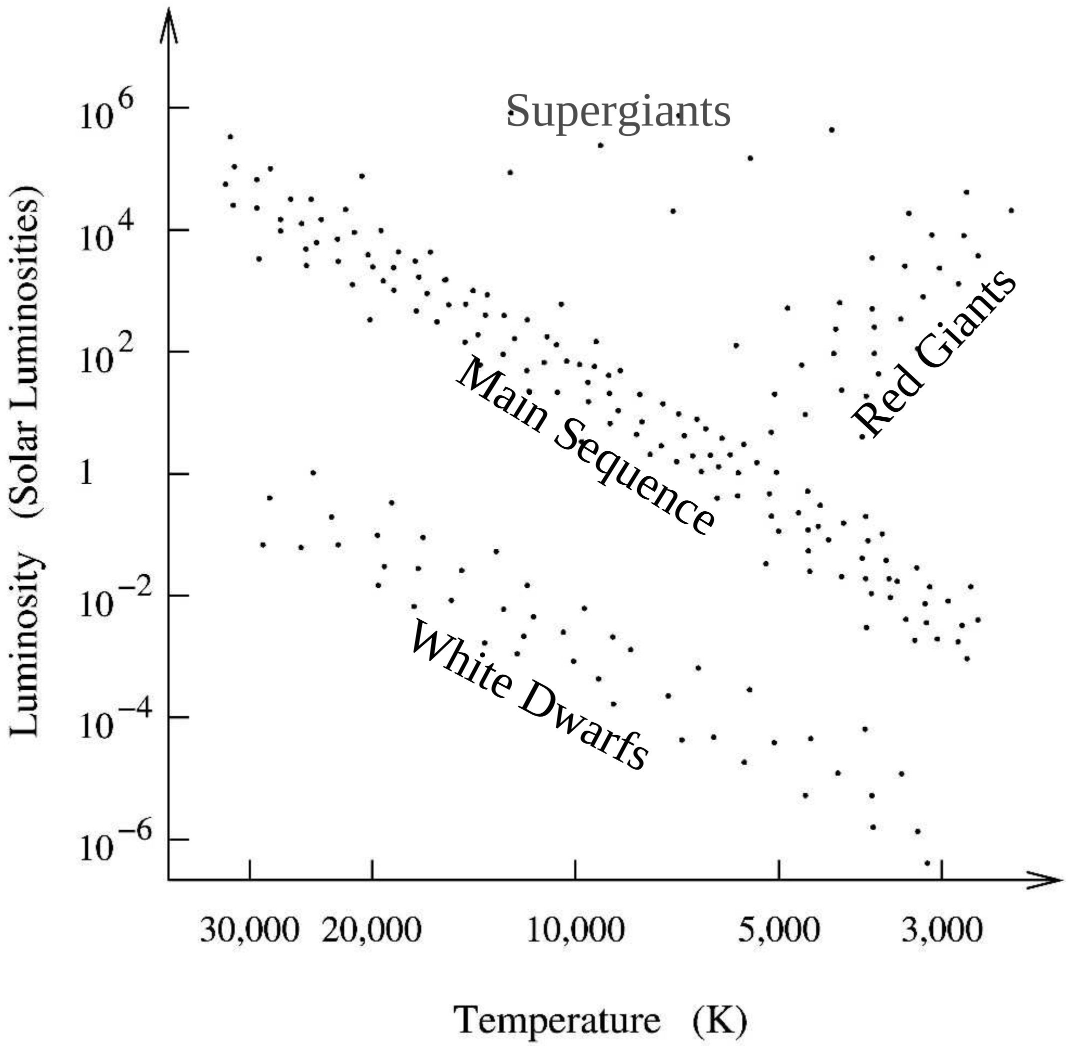
The Hertzsprung - Russell Diagram



Red Giants

- Above and to the right of the main sequence
- 3% of all star
- 5000 K to 3000 K, and so orange and red color.

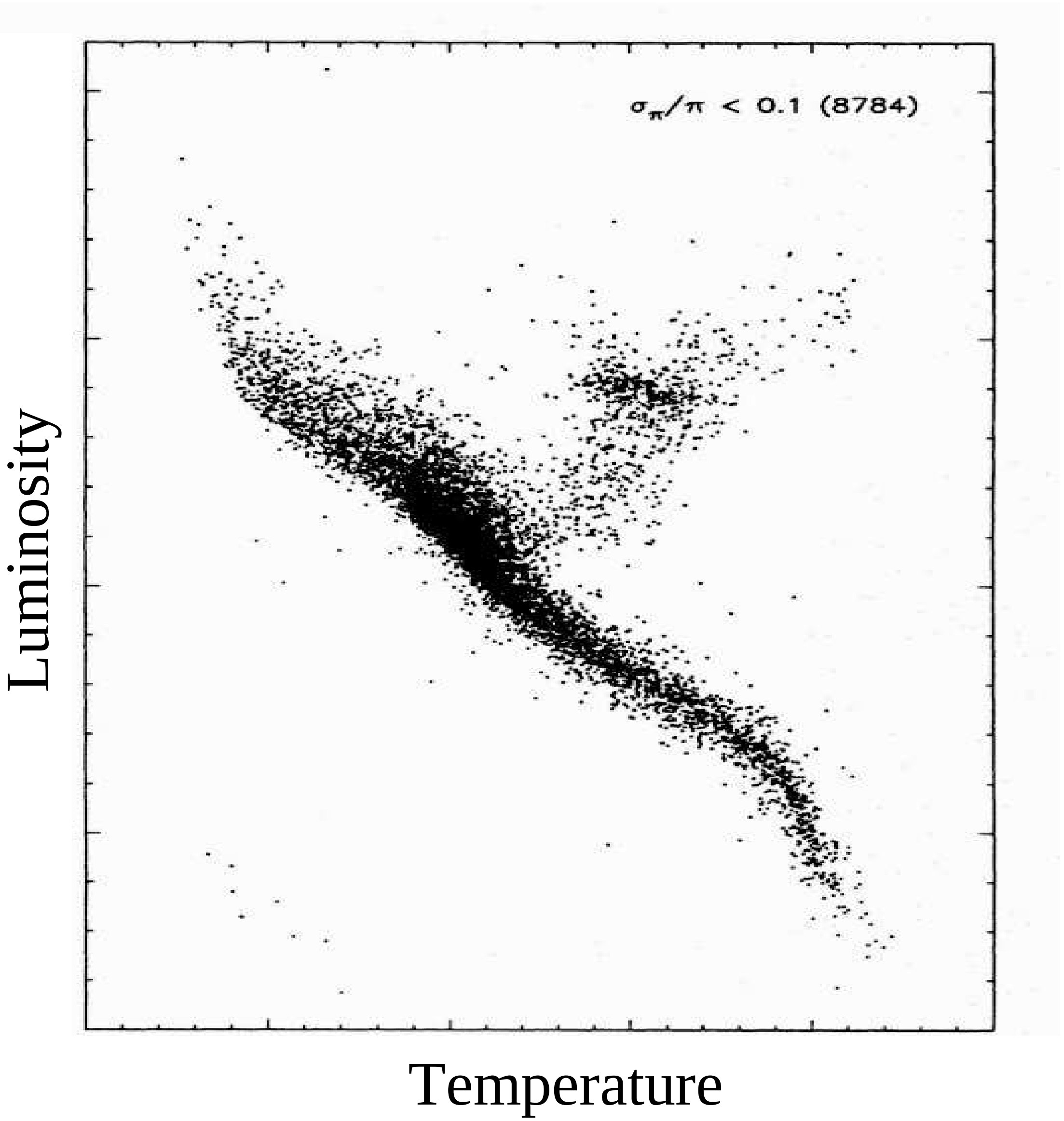
The Hertzsprung - Russell Diagram



Supergiants

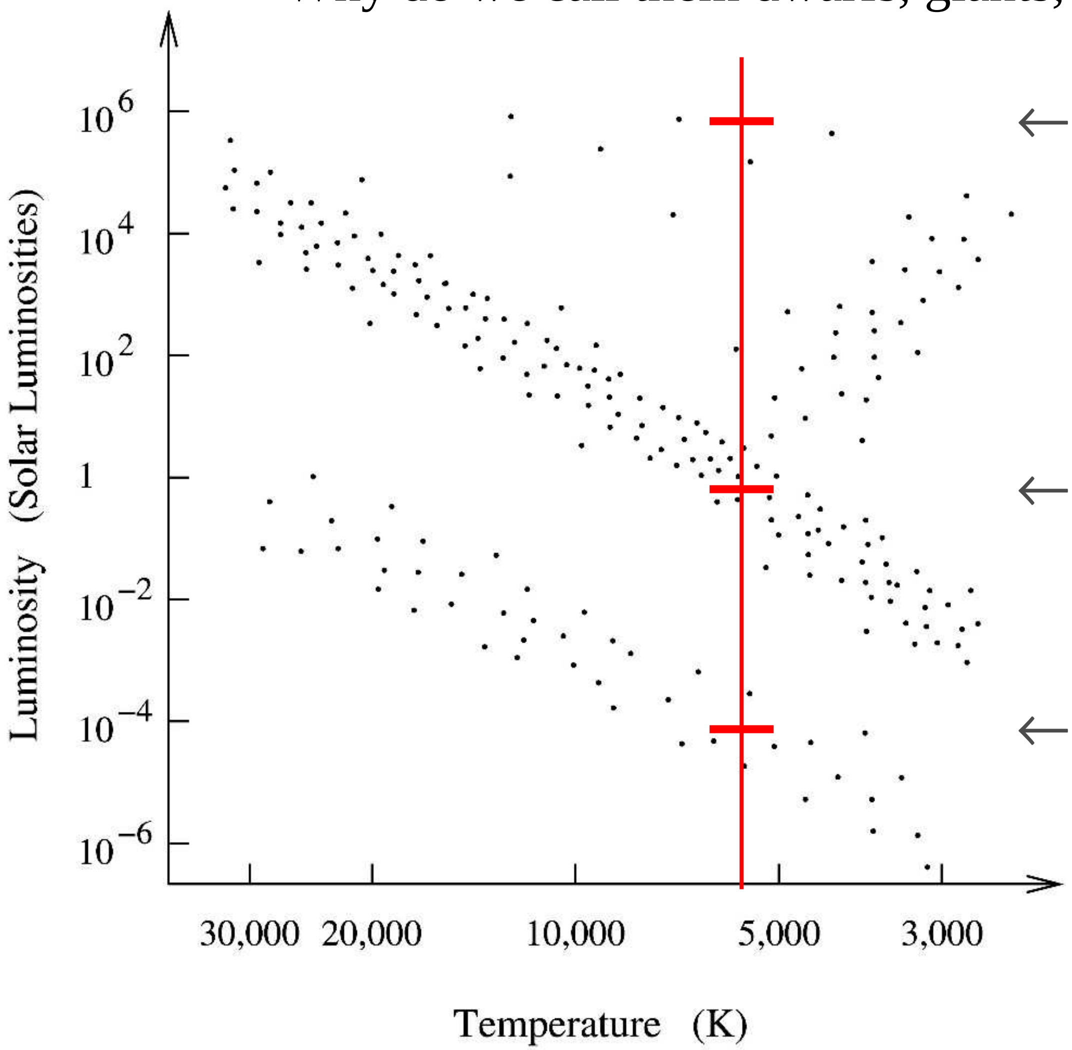
- Rare
- Luminosities up to 10^6 times greater than the sun's.

The Real H-R Diagram for Stars near the Sun



The Hertzsprung - Russell Diagram

Why do we call them dwarfs, giants, and supergiants?



← Supergiant stars: 10^6 $L_{/}$

← Main sequence stars: 1 $L_{/}$

← White dwarfs: 10^{-4} $L_{/}$

Luminosity of a Spherical Black Body (a Star!)

Stars emit roughly like black bodies, so their luminosity is given by:

$$L \propto (Area) \times T^4$$

The surface area of a sphere is $4\pi R^2$.

$$L \propto 4\pi R^2 \times T^4$$

If two stars have the same temperatures but different luminosities, their surface areas must be different.

Example: The Radii of White Dwarfs

A white dwarf has the same temperature as the sun but its luminosity is 10^{-4} smaller than the sun's luminosity.

Taking the ratio of luminosities, we have

$$\frac{L_{wd}}{L_{sun}} = \frac{4\pi R_{wd}^{2} T_{wd}^{4}}{4\pi R_{sun}^{2} T_{sun}^{4}}$$

Simplifying and re-arranging this equation, we find

$$\frac{R_{wd}}{R_{sun}} = \left(\frac{L_{wd}}{L_{sun}}\right)^{1/2} = \sqrt{10^{-4}} = 10^{-2}$$

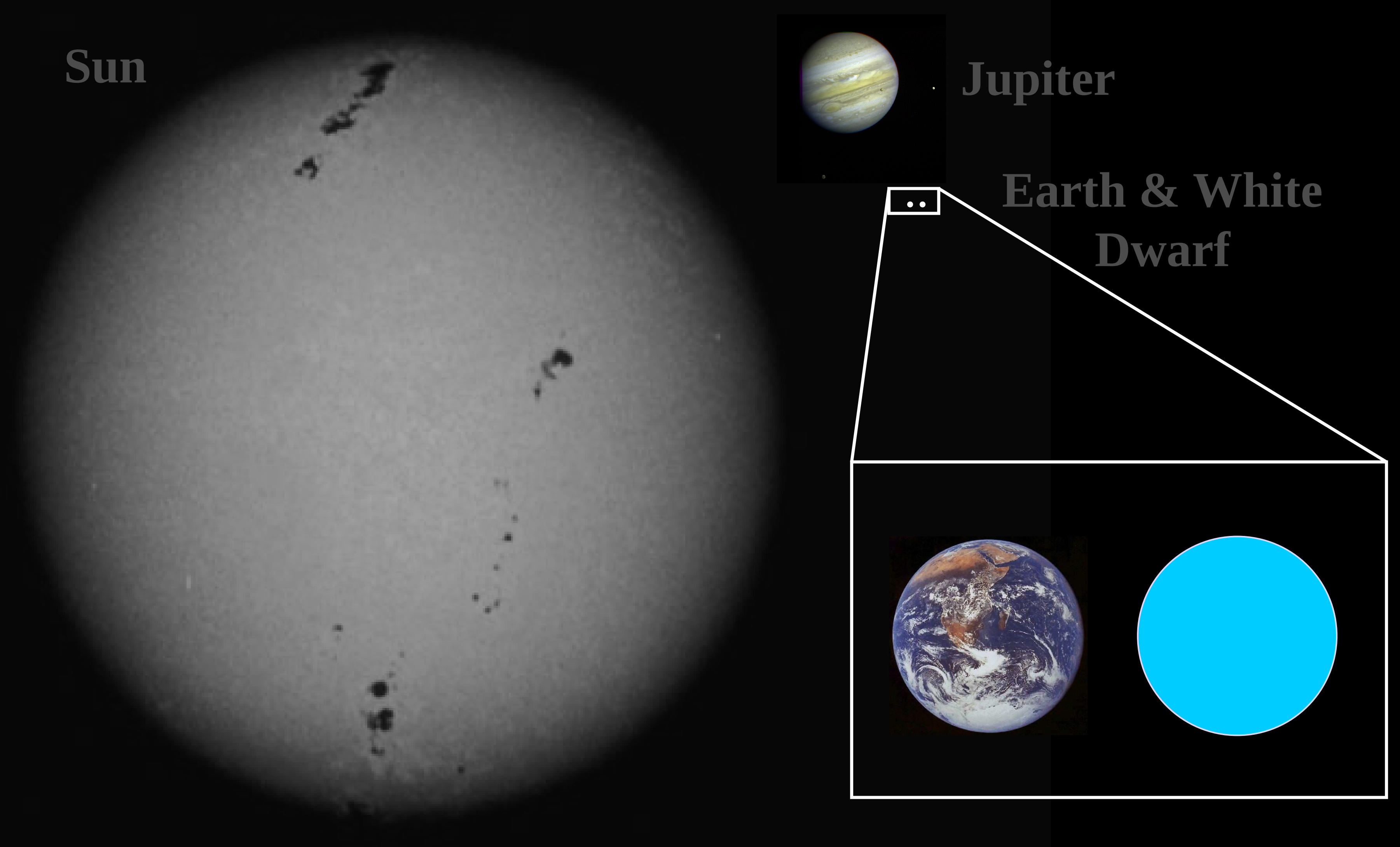
So the radius of the white dwarf is $0.01R_{/}$.

Luminosities and Radii of Stars

(For stars with temperatures near the sun's temperature.)

Type of Star	Luminosity $(L_{/})$	Radius $(R_{/})$	
White dwarf	10^{-4}	0.01	(Earth Radius)
Main Sequence	1	1	
Supergiant	10^{6}	1000	(5 AU)

Comparison of a White Dwarf to the Sun and Earth



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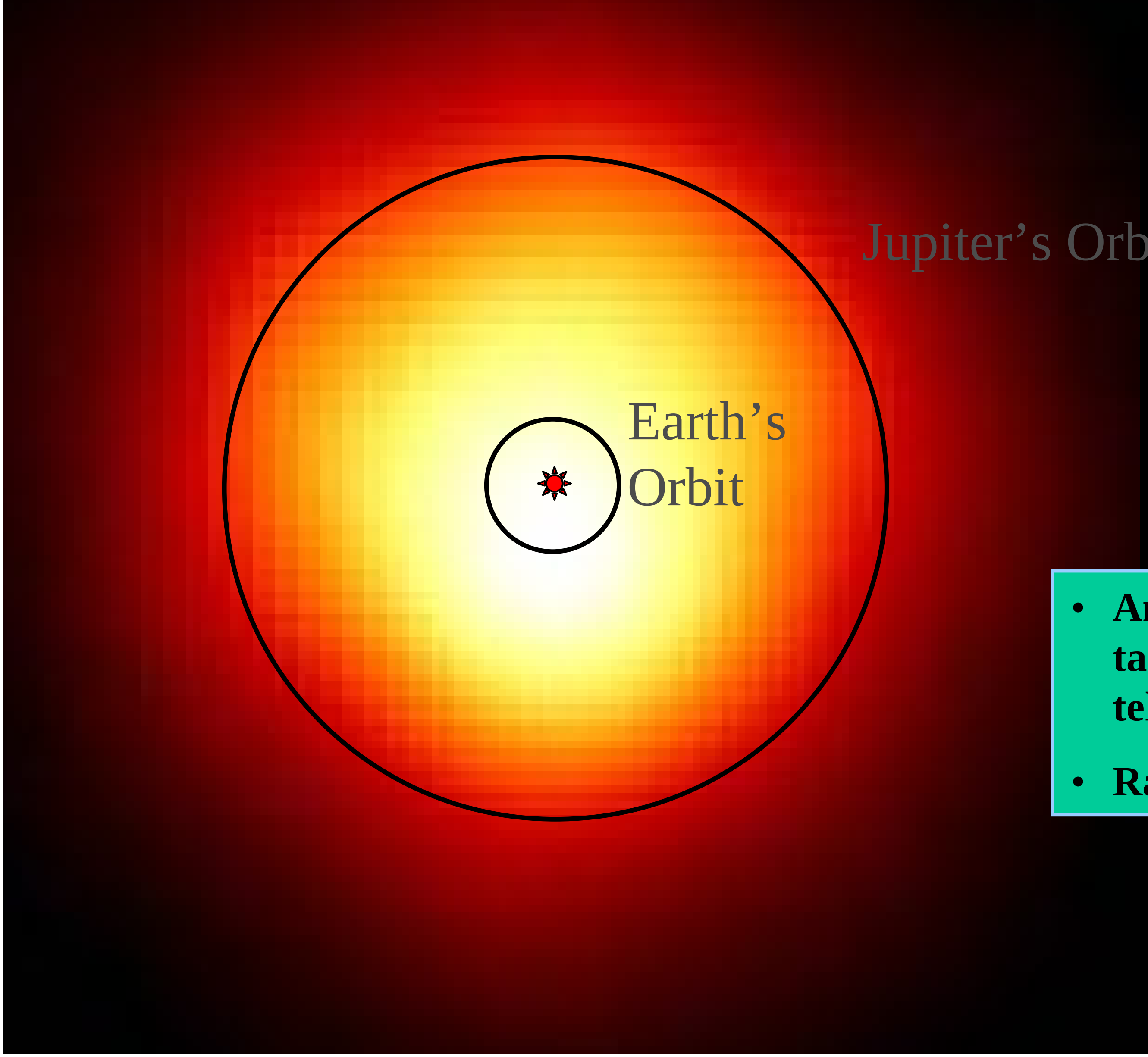
The Supergiant Star Betelgeuse



- **An image of Betelgeuse taken with the space telescope.**
- **Radius = 6 AU**