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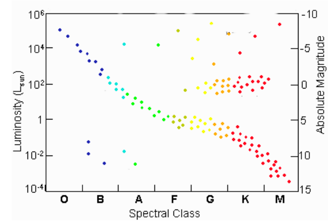


The Hertzprung-Russell (HR) Diagram

Purpose

- Reproduce Hertzsprung's and Russell's simultaneous discovery.
- Investigate the relationships between luminosity, mass, temperature and size of different categories of stars.

Equipment

- Log-log graph paper - supplied
- Ruler
- Pencil crayons

The Distribution of Stars

In 1912, Hertzsprung and Russell, working independently, found that if stars are plotted on a diagram of luminosity versus temperature, most of them lie among a few smooth curves.

Question 1: Using the star catalog in Table 1 and the graph paper provided, place all of the stars on a plot of luminosity versus temperature. **Beware**: the HR diagram uses a decreasing scale for temperatures (blue on the left and red on the right).

a) On your HR diagram, write the words DIM and BRIGHT on the vertical axis and the words COOL/RED and HOT/BLUE on the horizontal axis.
b) Place proper scales on the vertical and horizontal axes with labels and units.
c) Place all the stars (in Table 1) in the catalog on your plot.
d) Compare your diagram to the diagram made by professional astronomers and circle three noticeable sequences of stars. Name them I, II, III.

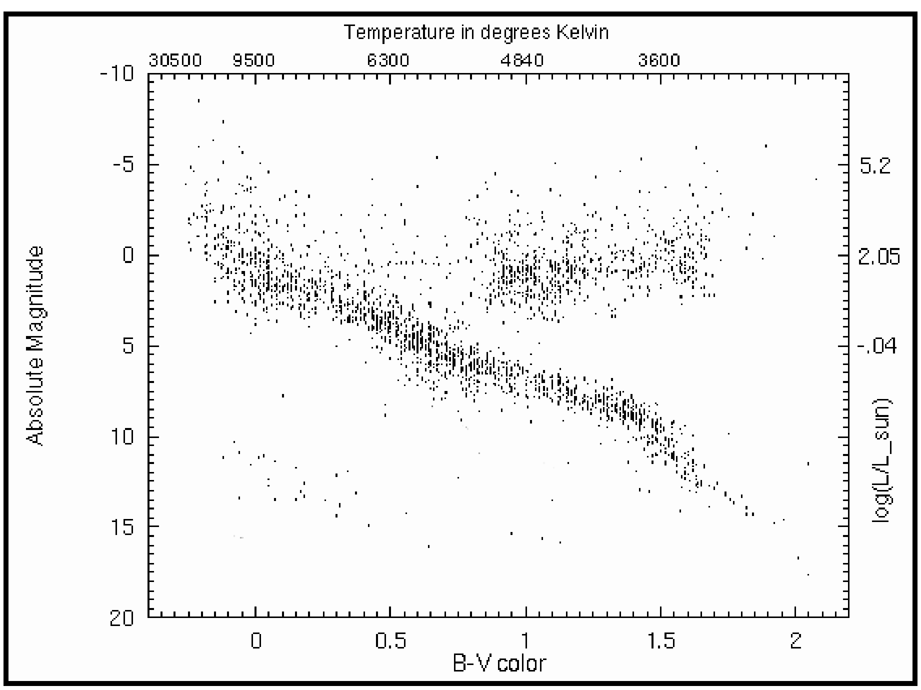


Table 1: Star Catalog

Star	Effective temperature (K)	Luminosity (Sun = 1)	Star	Effective temperature (K)	Luminosity (Sun = 1)
Sun	5,800	1.00	Altair	8,000	11.0
Alpha Centauri A	5,800	1.5	Spica	21,000	2,800.0
Alpha Centauri B	4,200	0.33	Delta Aquarii A	9,400	24.0
Alpha Centauri C	2,800	0.0001	70 Ophiuchi A	5,100	0.6
Wolf 359	2,700	0.00003	Delta Persei	17,000	1,300.0
Lalande 21185	3,200	0.0055	Zeta Persei A	24,000	16,000.0
Sirius A	10,400	23.0	Tau Scorpii	25,000	2,500.0
Luyten 726-8 A	2,700	0.00006	Arcturus	4,500	110.0
Luyten 726-8 B	2,700	0.00002	Betelgeuse	3,200	17,000.0
Ross 154	2,800	0.00041	Aldebaran	4,200	100.0
Ross 248	2,700	0.00011	Antares	3,400	5,000.0
Epsilon Eridani	4,500	0.30	Delta Aquarii B	6,000	4,300.0
Ross 128	2,800	0.00054	Sirius B	10,700	0.0024
61 Cygni A	4,200	0.084	Procyon B	7,400	0.00055
61 Cygni B	3,900	0.039	Grw +70 8247	9,800	0.0013
Procyon A	6,500	7.3	L 879-14	6,300	0.00068
Epsilon Indi	4,200	0.14	Van Maanen's Star	7,500	0.00016
Vega	10,700	55.0	W 219	7,400	0.00021
Achernar	14,000	200.0	Barnard's Star	2,800	0.00045
Beta Centauri	21,000	5,000.0	Luyten 789-6	2,700	0.00009
Fomalhaut	9,500	14.0	Canopus	7,400	1,500.0
Deneb	9,900	60,000.0	Capella	5,900	170.0
Beta Crucis	22,000	6,000.0	Rigel	11,800	40,000.0
Qu Tel	27,000	0.9	Alpha Crucis	21,000	4,000.0

e) Compare the properties of each sequence by completing Table 2. If one of your sequences span all properties, try to generalize (eg. Sequence I – Bright ones are hot and blue)

Table 2: Star properties

Sequence	Bright / dim	Cool / hot	Colour
I			
II			
III			

f) Using the terms in Table 2, how would you characterize our Sun?

g) The name of the diagonal line from the top-left corner to the bottom-right corner is **The Main Sequence**. Label the main sequence on your diagram.

h) What portion of the stars from the catalog falls on the main sequence? Express your answer as a percentage. Show your calculations.

Question 2: Here you will investigate the relationship between the luminosity and radius of stars.

a) Do you expect hotter objects to be brighter than cooler ones? Why?

b) Can you find a cool star that is brighter than a hot one? Name a pair. Find an explanation for this apparent paradox.

c) Betelgeuse (3200 K, 17000 L_{Sun}) is more luminous than Sirius A (10400 K, 23 L_{Sun}). Using the following equation, which of the two stars has the larger radius? Here $4\pi\sigma = 8.73 \times 10^{-16}$ K^{-4}, if R and L are in solar units and T is in Kelvin.

$$L = 4\pi\sigma R^2 T^4$$

d) Fill out Table 3 with the luminosity of stars with a given radius and temperature using the equation above.

Table 3: Luminosity, Radius and Temperature of Stars

Temperature	0.01 R_{Sun}	1 R_{Sun}	100 R_{Sun}
6,000K			
27,000K			

e) Using Table 3, draw a line on your diagram representing the stars of radius 1 R_{Sun}, 0.01 R_{Sun} and 100 R_{Sun}.

f) Estimate and draw the position of the lines of constant radius for stars with radius 0.1 R_{Sun} and 10 R_{Sun}.

Question 3: You will now look at the properties of different groupings of stars on your HR diagram.

a) On your diagram, label the following sequences:
   i. White dwarfs: blue to yellow, dim small
   ii. Giants: red to yellow, bright, large
   iii. Super Giants: very large, very bright

b) Complete Table 4 and find which sequence they belong to.

Table 4: Labeling Stars

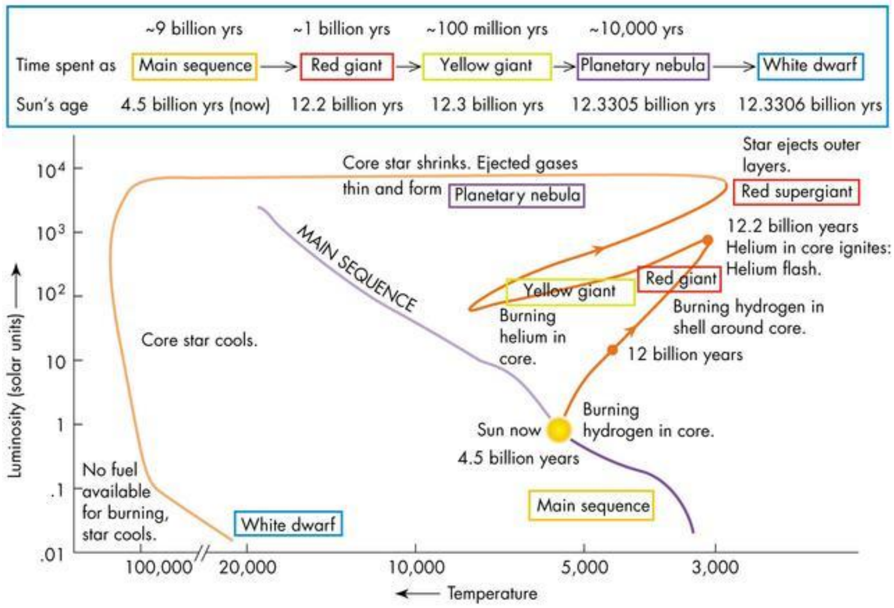
Star	Radius (R_{Sun})	Luminosity (L_{Sun})	Colour	Sequence
Aldebaran		100		
Barnard's		0.00045		
Betelgeuse		17000		
Deneb		60000		
Procyon B		0.00055		
Sirius B		0.0024		
Spica		2800		
Sun		1		

Question 4: Luminosity and mass. In 1924, Sir Eddington discovered that the luminosity of a main sequence star depends on its mass with $L = M^3$, where L and M are in solar units. This relation only holds along the main sequence. For example, it does not hold for white dwarfs: a more massive white dwarf is usually less luminous because its higher gravity contracts the star, reducing its surface area.

a) On your HR diagram, using $L = M^3$, indicate on the main sequence the position of stars with 0.1 M_{Sun}, 1 M_{Sun}, 3 M_{Sun}, 6 M_{Sun}, 10 M_{Sun} and 30 M_{Sun}.

b) Estimate the mass of the following stars in solar units using this mass-luminosity relationship.
- Barnard's
- Betelgeuse
- Procyon B
- Spica
- Sun
- Vega ($L = 55L_{Sun}$)

Question 5: Stellar evolution. We can also infer information related to the evolution of stars through the HR diagram. The following diagram shows the evolutionary track of our Sun on an HR diagram.



a) On your HR diagram, indicate the five main stages of evolution of the Sun and the time spent in each stage.

b) Explain why 90% of the stars observed in the sky are found on the main sequence.

c) For each image at the following link, chose the stellar evolutionary phase that best represented (one of the five stages is not represented):
http://langaraphysics.com/Tyron/EvolutionaryPictures.htm
(There is also a link on Brightspace (Lab 5: HR Diagram) to connect to the pictures: "Evolutionary Pictures".)

Image 1: Image 3:

Image 2: Image 4:

Question 6: The faintest object you can see depends on your equipment. Since brighter stars will be observable at greater distances, it will always seem like the average luminosity of stars in your sample will increase with distance. The actual effect is that you cannot detect the dimmer stars at large distances.

a) The equation below relates the apparent magnitude of a star to its luminosity (in solar units) and distance (in light years).

$$m = -2.72 - 2.5 \log\left(\frac{L}{d^2}\right)$$

Assuming that 14 is the maximum apparent magnitude your photometer can measure, how far is the farthest blue white dwarf you can observe? The farthest Sun-like star? The farthest Betelgeuse-like star? Show your calculations.

b) Can we study distant white dwarfs? Explain.

Instructor's initial: ___________