STELLAR EVOLUTION

INTRODUCTION

Astronomers know that the stars are not permanent in the night sky. As long as humans have been gazing up at the stars, they have occasionally seen what appear as "guest stars" in the night sky. These stars were called "guest stars" since they usually appeared where no star was seen before and shine brilliantly for a few weeks, finally fading from view. Astronomers now know that these "guest stars" are massive stars that are violently ending their existence by a violent explosion. As it turns out, all stars have very predictable life cycles beginning with their formation, life, and death. Tonight's lab will explore how stars end their existence, in particular, how they evolve towards death.

The luminosity of a star, how much energy the entire star is producing each second, is related to the size of the star, and how hot the star is. The following formula relates these basic physical properties of a star:

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

where $4\pi R^2$ is simply the surface area of a sphere, and σT^4 is how much energy is passing through any given incremental part of the surface area. In this equation, σ and π are constants. However, if we change the equation so that the luminosity, radius and temperature are in solar units, we can simplify the equation and the constants drop out:

$$L_\odot = R_\odot^{\,2}\, T_\odot^{\,4} \tag{1}$$

where all units are now in solar luminosities ($L_\odot$), solar radii ($R_\odot$), and solar temperatures ($T_\odot$).

Every physical property of the stars are determined by their mass. The initial mass of each star determines how quickly the star will form, how large it will be, how hot it will be, how luminous it will be, and how long it will live. Because main-sequence stars consume their fuel at an approximately constant rate, we can estimate the amount of time a star spends on the main-sequence (its life expectancy) by estimating the amount of its fuel and its rate of fuel consumption. Since the luminosity of a star is related by its mass by the following equation:

$$L = M^{3.5} \tag{2}$$

we can estimate its life expectancy by the following relations:

$$Time = \frac{fuel}{rate\ of\ consumption} \qquad Time = \frac{M}{L} \qquad Time = \frac{M}{M^{3.5}}$$

or simply:

$$Time = \frac{1}{M^{2.5}}(1.0 \times 10^{10}) \quad years \tag{3}$$

PROCEDURE

You are provided with an H-R diagram from a previous laboratory exercise. By using the relationships listed above, work on tables 1-5 and fill in the missing information about each star. The stars chosen for this lab range from 30 solar masses to 0.2 solar masses.

1. Using the mass and radius for each star listed in Table 1 **ON THE DATA SHEET**, using equation (1), determine the luminosity of each star. Next, using equation (3), determine the lifespan of each star.

2. In Tables 2 - 5 **ON THE DATA SHEET** we will follow a few of the stars from Table 1 as they evolve and grow old. Determine the radii for each star for various times in the future using equation (1) from above. Next, using tables 2-5 **ON THE DATA SHEET** and the H-R diagram, plot the position of each star at each time in the future on the H-R diagram to show how each star evolves toward its eventual death. After each point is plotted for each of the stars, draw a line to connect the points in order to show how the star changes it physical characteristics as it grows old.

3. Finally, using all of the information you have gathered, answer questions 1-10 on the Data Sheet.

ASTRONOMY 105L
LABORATORY EXERCISE

Name________________

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Table 1: MAIN SEQUENCE STARS

STAR #	MASS (M⊙)	TEMP (T⊙)	RADIUS (R⊙)	LUMINOSITY (L⊙)	LIFESPAN (YEARS)
1	30	6.6	7.26		
2	15	5.0	5.33		
3	9	4.0	4.42		
4	5	3.0	1.11		
5	1	1.0	1.00	1.00	1.0 x 10^{10}
6	0.5	0.66	0.41		
7	0.2	0.60	0.28		

Table 2: EVOLUTION

STAR # 1	MASS 30 M⊙		
TIME #	2	3	4
TEMP (T⊙)	2.1	4.0	0.66
RADIUS (R⊙)			
LUMINOSITY(L⊙)	3.16 x 10^5	3.16 x 10^5	3.16 x 10^5

Table 3: EVOLUTION

STAR # 4	MASS 5 M⊙					
TIME #	2	3	4	5	6	7
TEMP (T⊙)	2.35	0.75	0.66	1.32	0.79	0.94
RADIUS (R⊙)						
LUMINOSITY(L⊙)	1250	710	1250	1600	1600	1700

Table 4: EVOLUTION

STAR # 5	MASS 1 $M_\odot$			
TIME #	2	3	4	5
TEMP ($T_\odot$)	0.87	0.81	0.69	0.59
RADIUS ($R_\odot$)				
LUMINOSITY($L_\odot$)	3.16	2.51	12.5	316

Table 5: EVOLUTION

STAR # 6	MASS 0.5 $M_\odot$	
TIME #	2	3
TEMP ($T_\odot$)	0.81	0.73
RADIUS ($R_\odot$)		
LUMINOSITY($L_\odot$)	0.32	3.16

1. Approximately how many years do HIGH MASS stars live?

2. Approximately how many years do LOW MASS stars live?

3. Explain why the HIGH MASS stars live such short lives compared to LOW MASS stars when the HIGH MASS stars have so much more fuel (mass) ?

4. When the stars "move" on the H-R diagram, the stars are changing their:

   A.

   B.

5. The Sun is a 1 $M_\odot$ star. Look on Table 4 and find the maximum size the Sun will get during its evolution.

5a. $R_\odot = 6.9 \times 10^5$ km. Convert your answer above to *km* to determine the radius (in km) that the Sun will be when it is at its largest size.

5b. Convert the radius of the Sun (from 5a) to AU's (recall that 1 AU = 1.58×10^8 km.) The distance from the Sun to Mercury is 0.308 AU. Determine how large will the Sun be compared to the orbit of Mercury at this stage of its evolution.

5c. Using Table 2, find when the 30 $M_\odot$ is at its largest size and calculate its radius in km. (Recall that 1 $R_\odot = 6.9 \times 10^5$ km.) Convert the radius to AU's and determine how much larger this 30$M_\odot$ star would be than the Earth's orbit.

6. Look on your H-R diagram and find the area that has the white dwarfs. **Recall that white dwarfs are very hot but not very luminous**. Using the luminosity of one of the white dwarfs, and equation (1) on the first page, calculate the radius of the white dwarf star (this radius will be in units of $R_\odot$, convert it to kilometers recall 1$R_\odot = 6.9 \times 10^5$ km.) The Earth has a radius of 6350 km. Determine how much larger or smaller this white dwarf star is compared to the size of the Earth.

7. RED GIANT stars are very luminous, very large and very cool. Locate on the H-R diagram where these RED GIANT stars are and label them.

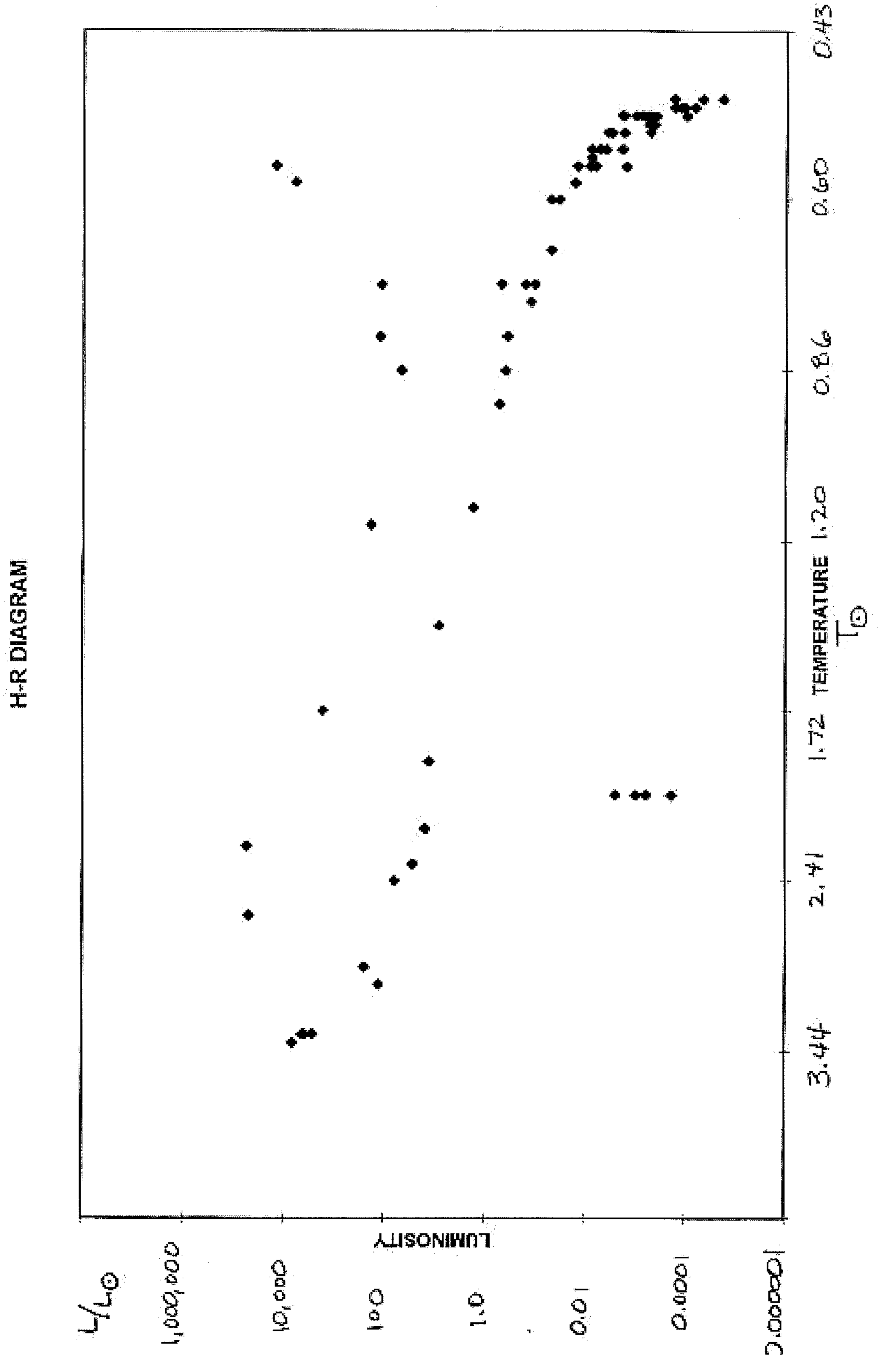
8. Use Table 1 to answer the following question:

   If the Universe is estimated to be 15 billion years old, are there any stars that are as old as the Universe itself?

   What spectral type are these very old stars? (Hint: the cool, low luminosity stars live the longest, look at Table 5)

9. If you were to scoop up a random sample of stars in our galaxy, based upon the information you have gathered, what spectral types would expect MOST of the stars to be?

10. The dinosaurs went extinct 65 million years ago. How many 30 solar mass star have lived and died one after another since the extinction of the dinosaurs?


H-R DIAGRAM
LUMINOSITY
L/L⊙
1,000,000
10,000
100
1.0
0.01
0.0001
0.000001
TEMPERATURE
T⊙
3.44
2.41
1.72
1.20
0.86
0.60
0.43