

# Stellar Structure

## •Materials

Computer program: Microsoft Excel or Equivalent

## •Introduction

When you think of a star, what properties do you associate with it? It's a hot ball of gas, right? What about that hot ball of gas makes it a star? A good answer to this question is that a star is stable. Our Sun, for example, is not exploding or contracting. Scientists refer to the stability of stars by saying that they are in **hydrostatic** and **thermal equilibrium**. Hydrostatic equilibrium is a balance between the forces that act on the star. The forces include downward pressure of the gas layers into the center, upward pressure of the hot gasses, and the downward pull of gravity due to the weight of the gas itself. The upward gas pressure must compensate for both gravity and the pressure of the outer layers. Thermal equilibrium means that even though the temperature in stellar interiors varies with depth, the temperature at each depth remains constant in time.

Another important property of a star is how energy is transported from its center to the surface. The energy source for stars is the nuclear reactions that take place in the core. The energy is transported to the surface by conduction, convection, and/or radiative diffusion. In the sun, energy is transported by radiative diffusion from the core to about 0.7 solar radii. From that depth out, energy is transported by convection. Some stars have very large radiative zones and little or no convective zones, while others have very deep convective zones.

Scientists use equilibrium concepts, along with energy transport mechanisms, to construct models for stellar structure. The models determine the size, temperature, and mass of the star. Some stars are very large and luminous, but cool. Others are small but very hot. The sun is a main sequence, or hydrogen burning, star. In this lab, you will study the relationship between luminosity and three factors: temperature, mass, and radius of main sequence stars.

## •Procedure

In this lab, you will take a close look at how three aspects of stellar structure (temperature, mass, and size) effect luminosity. Scientists often use luminosity to learn about stellar structure because it is easily measured, and many other informative quantities can be deduced from it. You will look specifically at main sequence stars, which generally obey the following equations:

$$1) L/L_{\odot} = (T/T_{\odot})^6$$

$$2) L/L_{\odot} = (M/M_{\odot})^4$$

$$3) R/R_{\odot} = (M/M_{\odot})^{0.7}$$

where  $L$  = luminosity,  $T$  = temperature,  $M$  = mass,  $R$  = radius, and the subscript  $\odot$  refers to the solar value for that variable.

\*How is luminosity related to radius?

$$4) L/L_{\odot} = \underline{\hspace{2cm}}$$

Use equations 1, 2 and 4 to fill out an Excel table. *If you are unfamiliar with doing math in Excel, see the instructions on the next page.* You will **use logarithmic x and y values** to make a plot of the three luminosity relationships in Excel. **The x axis will always have the same values, referring to  $T/T_{\odot}$  for the first relationship,  $M/M_{\odot}$  for the second, and  $R/R_{\odot}$  for the last.** Calculate the y axis values using the appropriate equation:  $(T/T_{\odot})^6$  for the first, etc., then take the logarithm of these values. Once you've made all of your calculations, create a plot in Excel. Excel hint: when plotting this type of data, use the scatter plot that creates a line through the data points. Ask your lab instructor if you have questions on how to create the plot. For credit, turn in your (x,y) values, plot and answers to the questions below.

## •Questions

- 1) What aspect of solar structure increases the luminosity the most as it increases? The least?
- 2) Why is it better to plot the logarithm of the values you calculated rather than the actual values?
- 3) The plot of  $L/L_{\odot}$  vs.  $T/T_{\odot}$  is the usual way you will see a Hertzsprung-Russell diagram displayed. Why is it a straight line instead of a curve? Hint: look at the procedure you followed in the H-R diagram lab compared to this lab.

### Using Excel to do math

1) In Excel, create a column title for each of the columns in the chart below. In column A, enter the x axis values (0.1, 0.25, etc.).

2) Click on the box in column B that has the x value 0.1. Go to Insert -> Function -> Math and Trig -> select LOG10. Click "okay". When the box comes up asking for a number, click on the box in column A with the value 0.1. Click "okay".

3) Now select the box just created in column B (value=-1, log base 10 of 0.1) and Edit -> Copy. Next, highlight the rest of column B and Edit -> Paste. You now have the logarithmic numbers corresponding to the values in column A.

4) Now, we need to find luminosity for the temperature ratio, which goes to the 6<sup>th</sup> power. When the first empty box in column C is highlighted, go to Insert -> Function -> Math and Trig ->

Power. Click "okay". In the box that comes up, put 6 as the power, click the box with the value 0.1 in column A, and click "okay". Copy and paste for the rest of column C as before. Create logarithmic values of column C in column D as you did for the x values.

5) Repeat step 4) for the other luminosity relationships. **Once done, either copy the values from Excel into your notebook, or print off a copy of the Excel workbook to attach with your lab.**

6) Now, plot the three log/log luminosity relationships on the same chart. Highlight columns B, D, F, and H by using ctrl + click to select multiple columns. Go to Insert -> Chart -> XY scatter and choose the chart with the dots and the line through them. Each relationship will be a different color. Name the "series" in the first box that comes up when inserting the chart.

A	B	C	D	E	F	G	H
X Axis values		$L/L_0 = (T/T_0)^6$		$L/L_0 = (M/M_0)^4$		$L/L_0 = (R/R_0)^{(4/0.7)}$	
X/X <sub>0</sub>	Log(X/X <sub>0</sub> )	L/L <sub>0</sub>	Log(L/L <sub>0</sub> )	L/L <sub>0</sub>	Log(L/L <sub>0</sub> )	L/L <sub>0</sub>	Log(L/L <sub>0</sub> )
0.1							
0.25							
0.5							
0.75							
1							
1.5							
2							
2.5							
3							
3.5							
4							
4.5							
5							
10							

For reference:

$$L_0 = 3.86 \times 10^{26} \text{ W}, T_0 = 5776 \text{ K}, M_0 = 2 \times 10^{30} \text{ kg}, R_0 = 7 \times 10^8 \text{ m}$$