PHYSICS 313 - Winter/Spring Semester 2017 - ODU

Astrophysics - Problem Set 5 – Solution

Problem 1

Please mark each of the following statements with "Y" or "T" if it is correct, and with "N" or "F" otherwise:

1a) A protostellar cloud produces its luminosity by nuclear helium burning. **F** [See c)]

1b) Planetary nebulae are the early stages of star evolution **F** [No, they are the ejectiles from late-stage giants]

1c) Initially, a protostar's luminosity is due to gravitational potential energy being converted to heat **T**

1d) A massive protostar takes a longer time to reach the main sequence than a less massive one. **F**

1e) Once on the main sequence, a massive star spends much less time there than a less massive one. **T**

1f) Stars much lighter than sun will become supernovae eventually. **F** [No, they will turn into white dwarfs].

1g) Red giants are what sun-like stars become after hydgrogen burning has stopped in their core. **T**

1h) Without the "convenient" (Hoyle) resonance in Carbon-12 we would not exist. **T**

1i) **All** heavier elements are produced in red giants (with mass comparable to that of the sun). **F** [Stars like the sun cannot produce any nuclei heavier than carbon and oxygen]

Problem 2

Answer the following questions with (brief) derivations and final numerical results:

2a) How much brighter would the sun have to shine (by what factor would its luminosity have to increase) before it would exceed the Eddington luminosity limit, $L_{\max} = \frac{4\pi GMc}{\bar{\kappa}}$? Assume that the average opacity is $\bar{\kappa} = \frac{0.03}{\mathrm{kg/m^2}}$.

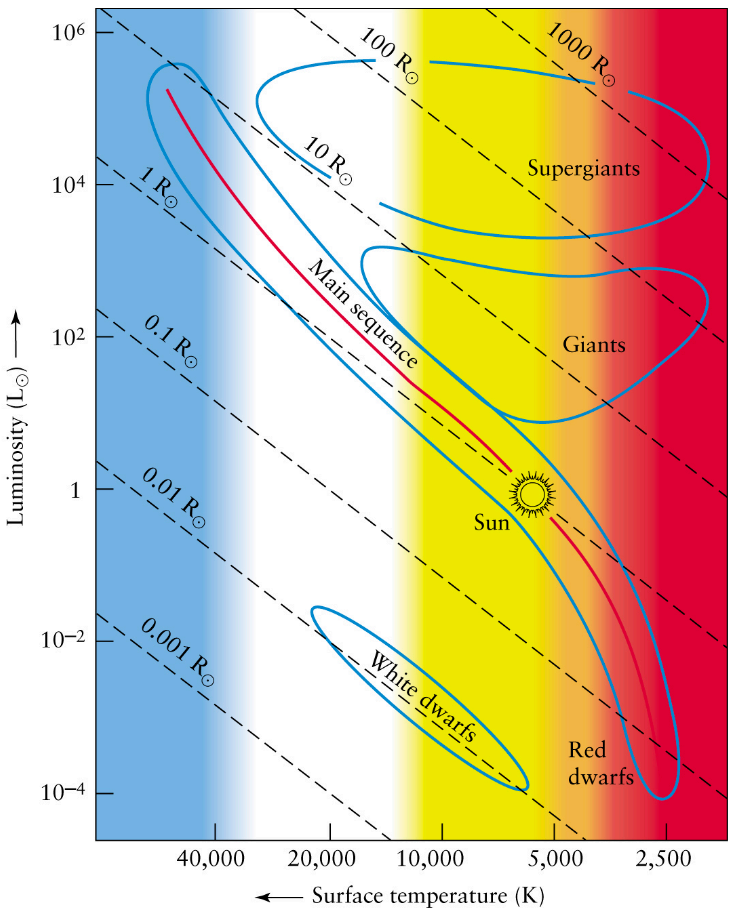
<u>**Answ.:**</u> Plugging in the numbers, the maximum luminosity is $1.67 \cdot 10^{31}$ W. That's **43,411** times sun's actual luminosity.

2b) The nuclear fusion reaction called "hydrogen burning" converts 0.68% of the mass of the intital hydrogen into energy (the rest remains in the form of helium-4 mass). Assuming sun has done this with its present luminosity, $L_{sun} = 3.84 \cdot 10^{26}$ W, for the last 4.5 billion years, how much mass has it lost overall? Compare to the mass of Earth ($6 \cdot 10^{24}$ kg)!

<u>**Answ.:**</u> Using $E = mc^2$, we can easily find that $3.84 \cdot 10^{26}$ W corresponds to $4.27 \cdot 10^{9}$ kg/s. Multiplying with 4.5 billion years yields $\mathbf{6.07 \cdot 10^{26}}$ **kg**, 100 times the mass of Earth (but a tiny fraction of sun's mass).

2c) Continuing with the discussion in 2b), which fraction of its initial hydrogen inventory (assume 73% of its total mass of $M_{sun} = 1.989 \cdot 10^{30}$ kg) has Sun already converted to Helium?

<u>**Answ.:**</u> Since only .68% of the mass of the hydrogen gets converted into energy, the total hydrogen mass that has been burned is $8.92 \cdot 10^{28}$ kg. 73% of sun's total mass is $1.45 \cdot 10^{30}$ kg, so roughly 6.2% of sun's total hydrogen inventory has already been burned.



Problem 3

This figure shows the present location of Sun on the H-R diagram. In your own words (and using the information from lecture), explain where Sun started out, how it moved to its present position, and what it is going to do in the future, including its end stage. Indicate size, temperature, luminosity and predominant mode of energy production at each stage. Provide sufficient detail – at least 5 different stages with at least a sentence or two each!

Answ.: The life of our sun began in the bottom right corner of the H-R diagram, in the form of a large, cool protostellar cloud formed from interstellar medium (gas and dust). The initial cloud is large but very cool (100 K and therefore "shines" only in the infrared. As the cloud contracts due to gravity, it heats up and becomes hotter – with increasing luminosity (albeit hidden inside the dust surrounding it). Eventually it contracts enough to start hydrogen burning and sun appears on the "zero age main sequence line" (coming from the right and slightly above its present position in the H-R diagram). During H burning (the last 4.5 billion years), sun is slowly getting warmer and more luminous, moving across the main sequence. Eventually, H burning stops in the core, and sun will expand but cool off. Through several more stages (H burning in the shell, followed by "Helium flash" and He burning in the core and finally in a shell around the inert C and O core), the sun moves to the upper right in the H-R diagram by becoming a giant star. At the end, it blows off part of its mass as "planetary nebula" and the core shrinks to a degenerate hot white dwarf (bottom left of H-R diagram). As it cools off, the white dwarf will slowly move back to the bottom right (cool and low luminosity), but now it has a completely different structure (and a much smaller radius) than the initial proto-stellar cloud.