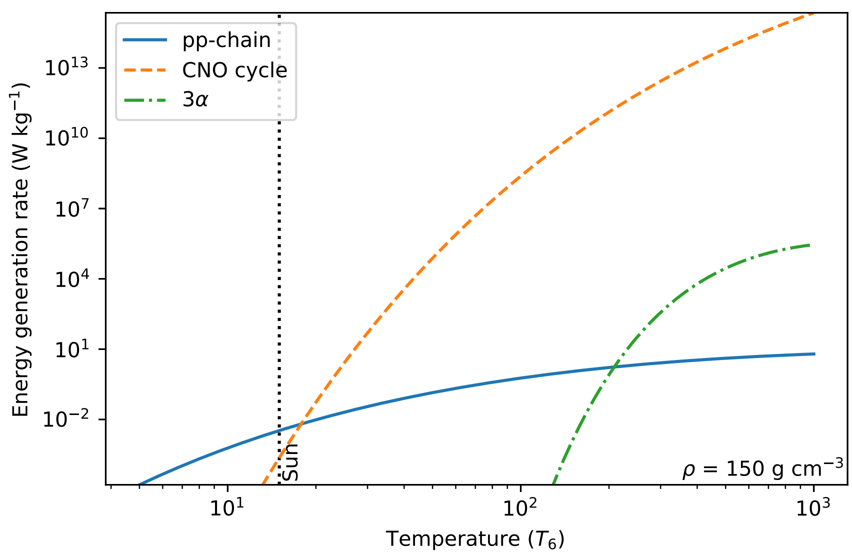
Homework #3 – Solution

The Sun

March 10, 2021

Problem 1 The Salpeter process (20%)

a. Including the 3α process results in the following figure:



b. The temperature in the center of the Sun is roughly 15 MK. This is far too low to turn on the 3α-process, see above Figure.

c. An electric field can, in the presence of free charge carriers, be dampened. This is the so-called screening effect. In the plasma at the center of the Sun, the electrons are free charge carriers. They partially shield the α-nuclei from each other, thus screening the Coulomb barrier that exists between them. This enhances the 3α process. See also Wikipedia.

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Problem 2 Why do we have carbon (20%)

The 3α reaction is highly enhanced thanks to a resonance in the ^{12}C molecule, which effectively boosts this otherwise improbable reaction rate. This resonance was predicted in 1954 by Fred Hoyle and is thus today known as the Hoyle state.

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Problem 3 Fate of the Earth (20%)

During the AGB phase, the Sun will expand so massivly that its radius will reach out to around the orbit of Earth. From the Hertzsprung-Russle Diagram in Figure 4.6 we can see that the approximate surface temperature of the Sun will be around 3000 K. The Earth will thus get at least that hot during the death of the Sun.

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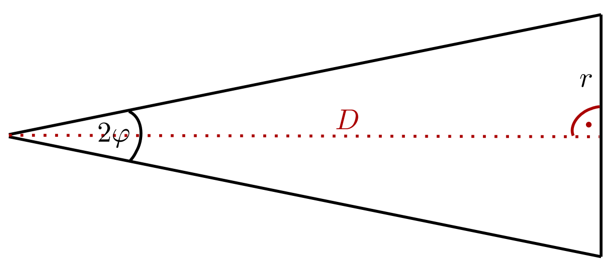
Problem 4 Helix nebula (20%)

a. Below figure shows a sketch of the situation:



Here, $2\phi = 16'$ is the diameter of the nebula, $D = 213$ the distance, and r the radius of the nebula. The diameter of the nebula can then be calculated as:

$$\frac{r}{d} = \tan(\varphi) \tag{1}$$

$$r = d\tan(\varphi) = 0.5\,\mathrm{pc} \tag{2}$$

The nebula thus has a diameter of around 1 pc.

b. Assuming the nebla expanded from a point outwards, the distance it has moved up to today at a velocity of $v = 20\,\mathrm{km\,s^{-1}}$ is r. The age of the nebula can thus be calculated as

$$t = \frac{r}{v} = 24\,\mathrm{ka}. \tag{3}$$

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Problem 5 Population II stars (20%)

a. If these stars formed 1 Ga after the Big Bang, they would today be roughly 13 Ga old. Using equation (4.28) we can calculate the minimum mass that such a star would have, assuming it is about to die right now. This mass is then

$$M = M_\odot \left(\frac{10\,\mathrm{Ga}}{14\,\mathrm{Ga}}\right)^{1/2.5} = 0.87\,M_\odot. \tag{4}$$

b. These stars are fairly difficult to observe because they have a mass that is lower than the solar mass. Using equation (4.27) we can estimate their luminosity to be at most $0.6L_\odot$. This makes these stars faint and thus powerful telescopes are required in order to observe them.

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