Ay 190 Assignment 7

pp-Chain Nucleosynthesis

February 6, 2013

1 Modeling hydrogen burning in the Sun

Frank Timme's Fortran 90 pp-chain nuclear reaction network model (`http://cococubed.asu.edu/code_pages/burn.shtml`) was used to model hydrogen burning in the Sun. Initial mass fractions 25% and 75% ^{4}He and ^{1}H, respectively, were seeded in a hydrostatic model of the sun with a constant temperature of $1.5 \times 10^7 K$ and density of 150 g cm^{-3} that was evolved over 10^{11} years.

The Sun is currently thought to be composed of 73.46% ^{1}H by mass. According to the H-burning model calculated using the above stellar properties, the Sun is thus 65 million years old (should be 4.5 billion years) and will burn hydrogen for a total of about 9.8 billion years.

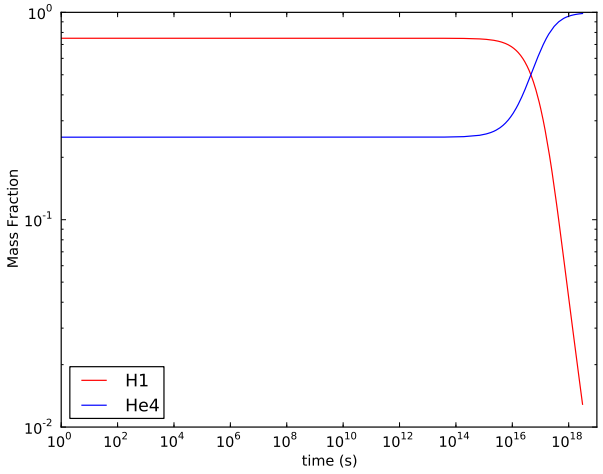

Figure 1: The evolution of the mass fraction of hydrogen and helium in a stellar model with .

2 The proton-proton (pp-)chains

Hydrogen is converted into Helium primarily through 3 proton-proton chains. The net reaction is

$$4\,{}^1_1H \rightarrow {}^4_2\,He + 2e^+ + 2\nu_e + 2\gamma$$

. The first proton-proton chain (PPI) involves three reactions,

$$\begin{array}{rcl} {}^1_1\mathrm{H}+{}^1_1\mathrm{H} & \rightarrow & {}^2_1\mathrm{H}+e^+ + \nu_e \\ {}^2_1\mathrm{H}+{}^1_1\mathrm{H} & \rightarrow & {}^3_2\mathrm{He}+\gamma \\ {}^3_2\mathrm{He}+{}^3_2\mathrm{He} & \rightarrow & {}^4_2\mathrm{He}+2{}^1_1\mathrm{H}. \end{array}$$

The first step is mediated by the weak force, which causes a proton to decay into a neutron, and is the slowest step of the PPI chain. The helium-3 nuclei can alternatively interact with helium-4 nuclei in the second proton-proton chain (PPII),

$$\begin{aligned} {}^3_2\mathrm{He}+{}^4_2\mathrm{He} &\rightarrow {}^7_4\mathrm{Be}+\gamma \\ {}^7_4\mathrm{Be}+e^- &\rightarrow {}^7_3\mathrm{Li}+\nu_e \\ {}^7_3\mathrm{Li}+{}^1_1\mathrm{H} &\rightarrow 2{}^4_2\mathrm{He}. \end{aligned}$$

In the solar core, this occurs with a probability of about 31%. Furthermore, about 0.3% of the time, the beryllium-7 nucleus will capture an proton and instigates the third proton-proton chain (PPIII),

$$\begin{aligned} {}^7_4\mathrm{Be}+{}^1_1\mathrm{H} &\rightarrow {}^8_5\mathrm{B}+\gamma \\ {}^8_5\mathrm{B} &\rightarrow {}^8_4\mathrm{Be}+e^+ + \nu_e \\ {}^8_4\mathrm{Be} &\rightarrow 2{}^4_2\mathrm{He}. \end{aligned}$$

The entire pp-chain sequence is diagramed below.

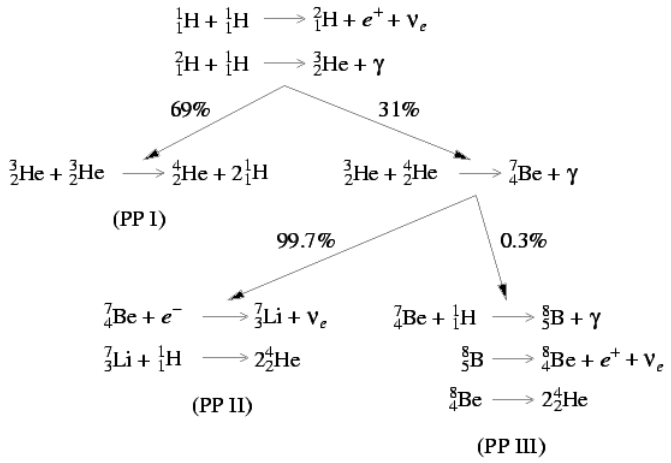

Figure 2: The three branches of the proton-proton chain. Figure from http://burro.astr.cwru.edu/Academics/Astr221/StarPhys/ppchain.gif.