20 Stars notes 2019/10/16 - Wed - pp vs. CNO burning of H, Mass ranges

20.1 pp vs CNO cycle

The simplesest *pp* chain for review is

$$p + p \rightarrow d + \nu + e^+$$

$$p + d \rightarrow^3 He + \gamma$$

$$^3He +^3 He \rightarrow^4 He + 2p$$

pp effectively does $4p \rightarrow^4 He$ with $E_{nuc} = 26.7$ MeV. Here *pp* is the rate limiting step. the *pp* reaction has $E_G = 494$ keV and $S = 3.78 \times 10^{-22}$ keV barn. and so

$$\langle \sigma v \rangle = 1.35 \times 10^{-37} \frac{1}{T_7^{2/3}} \exp\left(\frac{-15.69}{T_7^{1/3}}\right)$$

We know that $p + Li$ happens at $\sim 3 \times 10^6$ K. Could proton captures onto a heavy element compete with *pp* at 10^7 K? Compare $\langle \sigma v \rangle$

pp	$p + X$
$10^{-25} \exp(-15.7/T_7^{1/3})$	$\exp(3(E_G/4kT)^{1/3})$

The 10^{-25} is the weak suppression factor. now ask for which Z are thise rates equal? that is when

$$-57.6 - \frac{15.7}{T_7^{1/3}} = -3\left(\frac{E_G}{4kT}\right)^{1/3}$$

also

$$\frac{E_G}{4kT} = \frac{286}{T_7}(Z_1 Z_2)^2 \left(\frac{m_r}{m_p}\right)$$

for $p + X$ $Z_1 = 1$, plugging in and solving for the other Z,

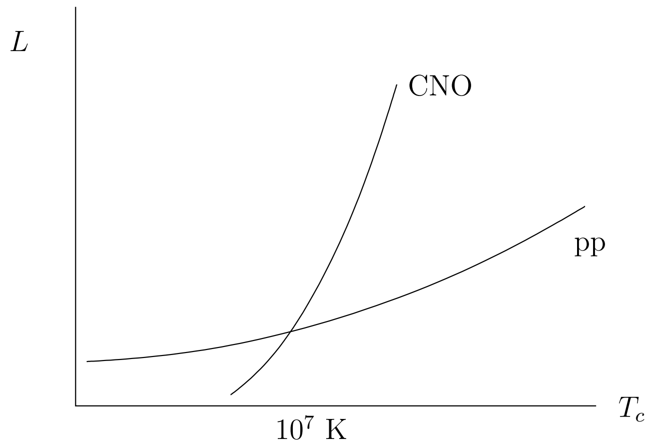
$$Z_2 = 5\left(\frac{m_p}{m_r}\right)^{1/2} (T_7^{1/3} + 0.27)^{3/2}$$

you get:

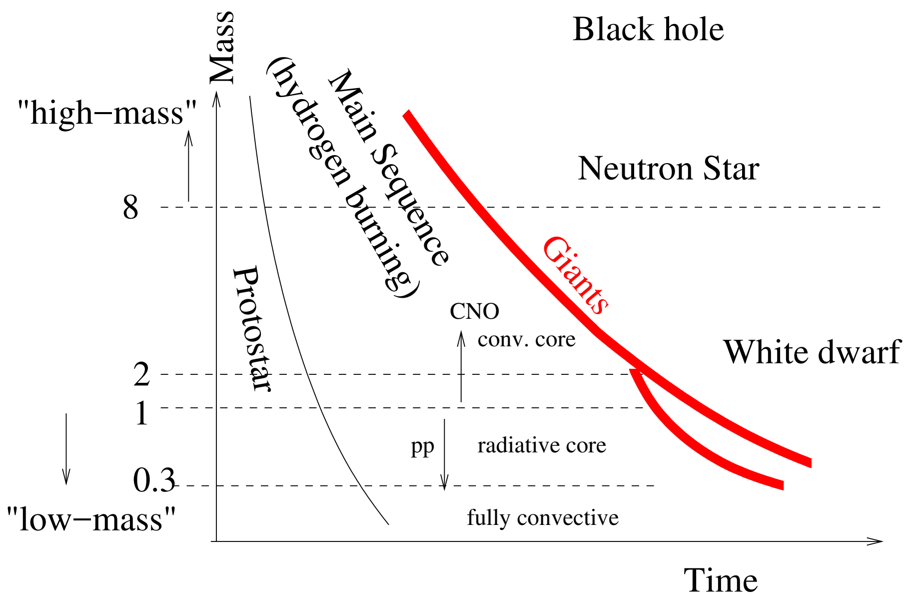
T_7	Z
1	7.2
0.5	5.5

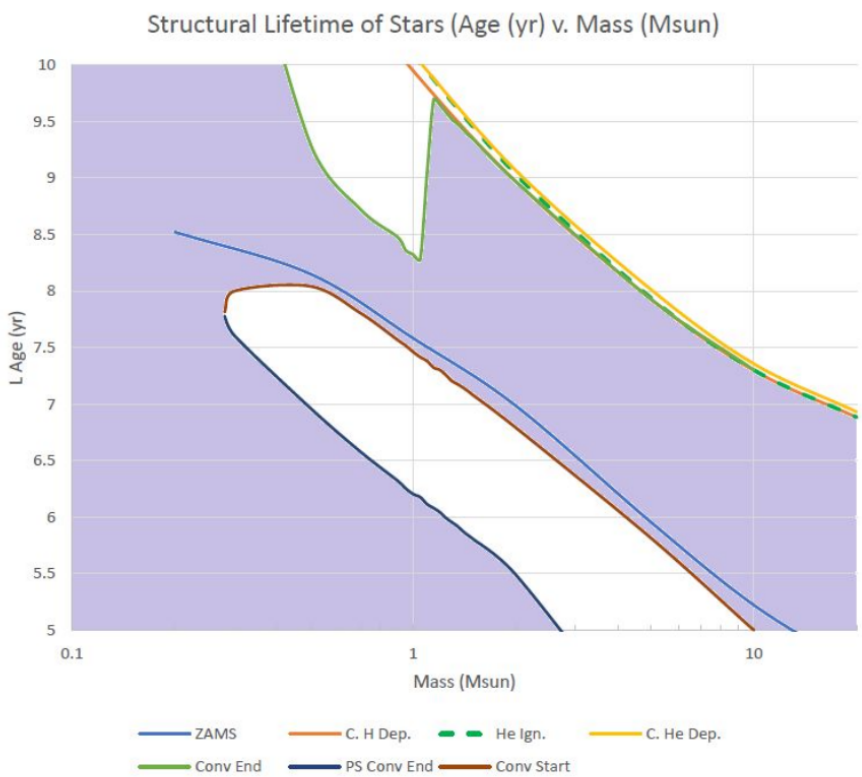
we should look at proton captures onto C, N, and O.

The supression of the pp rate by the weak interactions means that we can pay the price of the Coulomb barrier. On the Lower main sequence $T \leq 10^7$ K you can get pp. for upper main sequence $T \geq 10^7$ K CNO is important. where $M_\odot$ is the approximate divider.



20.2 Overview of stellar life





(Josh Johnson research project Spring 2019)

The sequence of stages and timescales are determined by a star's initial mass (and composition). It's appearance (e.g. whether it is a giant or not) is determined by its age, generally as compared to its fusion lifetime.

All stars expand to become giants toward end of fusion lifetime, but take slightly different paths there.

Main sequence = core H fusion phase : H fusion at center

Upper Main sequence = when CNO wins over pp.

High mass stars = stars that make neutron stars or black holes at end of life (during supernova)

Low mass stars = stars that make white dwarf stars at end of life

Giant = star with large radius, generally with shell burning of H or H and He

Neutron star = compact (10km) stellar remnant composed mostly of neutrons (one big star-sized atomic nucleus)

White dwarf = less compact (few 1000 km) stellar remnant made of carbon and oxygen (or O and Ne)

Black Hole = object compact enough to be inside its own event horizon (internal events disconnected from the universe)

20.3 pp vs CNO continued

Showed mesa simulations from 3 and 1 solar mass stars, showing consumption of C12 in both and the production of He3 is solar mass case. Next time will look at lower mass (no CNO).