NUCLEAR BURNING IN STARS

I) HYDROGEN BURNING

$$4\,{}^1H \rightarrow {}^4He + 2\nu_e + 2e^+ \qquad | \text{ Check!}$$

$$Q = \Delta M = \Delta m c^2 = 26.731 \text{ MeV}$$

1) PP CHAIN $[M_{STAR} \lesssim 1 M_\odot]$

$$2\,{}^1H \rightarrow {}^2H + \nu_e + e^+$$

$$ {}^2H + {}^1H \rightarrow {}^3He + \gamma$$

$$ {}^3He + {}^3He \rightarrow {}^4He + 2\,{}^1H$$

pp1

$$ {}^3He + {}^4He \rightarrow {}^7Be + \gamma$$

$$ {}^7Be + e^- \rightarrow {}^7Li + \nu$$

$$ {}^7Li + {}^1H \rightarrow {}^4He + {}^4He$$

pp2

$$ {}^7Be + {}^1H \rightarrow {}^8B + \gamma$$

$$ {}^8B \rightarrow {}^8Be + e^+ + \nu_e$$

$$ {}^8Be \rightarrow {}^4He + {}^4He$$

pp3

${}^8Be$: very short-lived

Q:		↓ T
26.20	pp1	
25.67	pp2	
19.20	pp3	

$\epsilon_{nuc} \sim T^n$, $n \sim 6$ FOR $T \simeq 5 \times 10^6 K$

3.5 FOR $T \simeq 20 \times 10^6 K$

CNO CYCLE (BI-CYCLE)

CNO-1

$$^{12}C + {}^{1}H \longrightarrow {}^{13}N + \gamma$$

$$^{13}N \xrightarrow{10\ min} {}^{13}C + e^{+} + \nu_e$$

$$^{13}C + {}^{1}H \longrightarrow {}^{14}N$$

$$^{14}N + {}^{1}H \longrightarrow {}^{15}O + \gamma$$

$$^{15}O \xrightarrow{122\ s} {}^{15}N + \nu_e + e^{+}$$

$$^{15}N + {}^{1}H \longrightarrow {}^{16}O^{*}$$ ← EXCITED STATE (ABOVE α-SEPARATION ENERGY LEVEL)

$$^{16}O^{*} \xrightarrow{99.99\%} {}^{12}C + {}^{4}He$$

$$^{16}O^{*} \xrightarrow{0.01\%} {}^{16}O + \gamma$$

$$^{16}O + {}^{1}H \longrightarrow {}^{17}F + \gamma$$

$$^{17}F \longrightarrow {}^{17}O + \nu_e + e^{+}$$

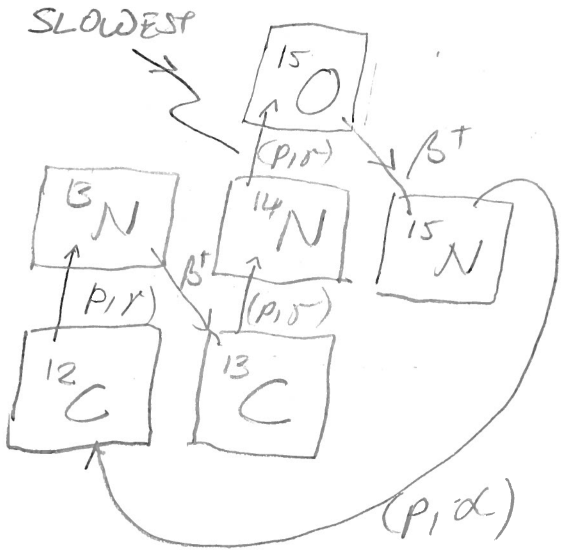
$$^{17}O + {}^{1}H \longrightarrow {}^{14}N + {}^{4}He$$

CNO-2

$$Q_{CNO\text{-}1} = 24.97\ MeV$$

$\varepsilon_{nuc} \sim T^{n}$, $n = 23 \ldots 13$ FOR $T = (10 \ldots 50) \times 10^{6}K$

CNO CYCLE



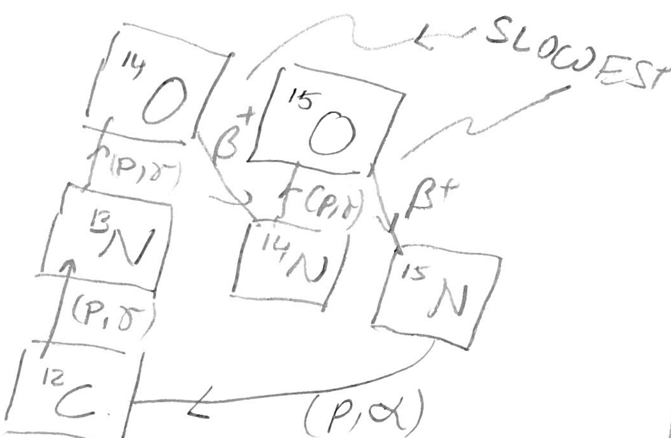
BECAUSE $^{14}N(p,\gamma)$ IS BY FAR SLOWEST (BOTTLENECK)

→ ALL INITIAL CNO WILL BECOME ^{14}N AT ENT OF CNO CYCLE!

HOT CNO CYCLE

$T_7 \gtrsim 8$

X-RAY BURST
NOVAE



$\tau_{1/2}(^{14}O) \sim 70\,s$

$\tau_{1/2}(^{15}O) \sim 123\,s$

$\tau_{p,\gamma}(^{12}C, ^{13}N, ^{14}N)$
$\tau_{p,\alpha}(^{15}N)$ $\ll \tau_{\beta^+}$

AT HIGHT

"NITROGEN BURNING"

BETWEEN H BURN & He BURN

CAN BE SIGNIFICANT FOR STARS WITH SUFFICIENT INITIAL METALLICITY

TYPICALLY "AT BEGINNING" OF He BURNING

$$^{14}N(\alpha,\gamma)^{18}F(\beta^+)^{18}O(\alpha,\gamma)^{22}Ne$$

THIS ^{22}Ne IS LATER SOURCE FOR n THAT ARE RESPONSIBLE TO MAKE MOST HEAVY ELEMENT!

$$^{22}Ne(\alpha,n)^{25}Mg$$

→ "n SOURCE"

HELIUM BURNING

STEP 1: $^{4}He + ^{4}He \rightleftharpoons ^{8}Be^{*}$ ← MOSTLY DECAY BACK

$\tau_{1/2} \sim 2.6 \times 10^{-16} s$

STEP 2: $^{8}Be + ^{4}He \longrightarrow ^{12}C + \gamma$

$Q_{3\alpha} = 7.275 \; MeV$

$\langle \sigma v \rangle \sim \rho^2 T^{40} \;\Big|\; \frac{\partial}{\partial t} Y_{^{12}C} \sim \rho^2 Y_\alpha^3$

O PRODUCTION

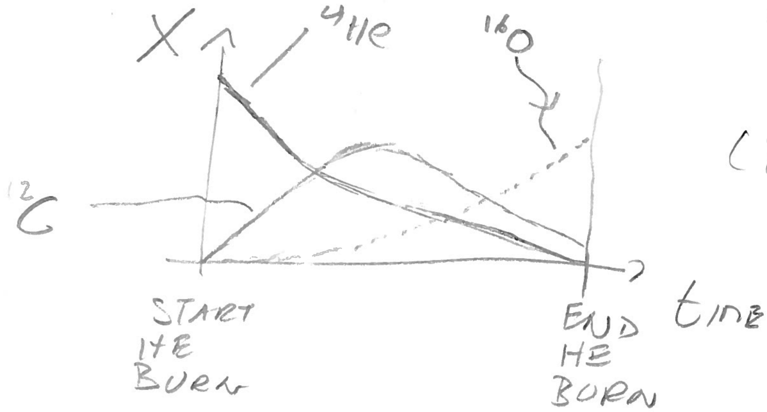
$^{4}He + ^{12}C \longrightarrow ^{16}O + \gamma \qquad Q = 7.162 \; MeV$

$\langle \sigma v \rangle \sim \rho \cdot T^{40} \qquad \frac{\partial}{\partial t} Y_{^{16}O} \sim \rho \, Y_\alpha \cdot Y_{^{12}C}$

REQUIRES ^{12}C HAS BEEN MADE BY 3α

→ COMPETITION FOR ^{4}He

BUT FIRST PROC HAS $(Y_{4H})^3$ DEP, SECOND HAS $(Y_{4H})^1$ DEP



(ROUGHLY)