r-process

$\tau_{n\gamma} \sim 10^{-4}\,s \rightarrow N_n \sim 10^{21}\,cm^{-3}$

HOW TO FIND?

$$N_r(A,Z) = N_\odot(A,Z) - N_s(A,Z)$$

FORM IN $(\gamma,n)-(n,\gamma)$ equil.

WAIT FOR β^- decay

$$\frac{dN(Z,A)}{dt} = -N_n \cdot N(Z,A)\langle\sigma v\rangle_{Z,A} + N(Z,A-1)\,\lambda_\gamma(Z,A-1)$$

IN EQ.

$$\frac{N(Z,A+1)}{N(Z,A)} = N_n \left(\frac{h^2}{2\pi m_{A,n} kT}\right)^{3/2} \frac{(2j_{Z,A+}+1)}{(2j_{Z,A+1}+1)(2\cdot j_n+1)} \cdot \frac{G^{NORM}_{Z,A+1}}{G^{NORM}_{Z,A}}\, e^{-Q_{n\gamma}/kT}$$

$$G^{NORM}_i = \frac{G_i}{g_i} = \frac{\sum_\mu g_{i\mu} e^{-E_{i\mu}/}}{g_i}$$

$\rightarrow$ typical very narrow Peak!

BOTTLENECK environment

to make seeds

$2\alpha + n \rightarrow {}^{9}Be(\alpha, n)\,{}^{12}C$

$3\alpha \rightarrow {}^{12}C$

s-process Branching Points

Cosmic Ray "Nucleosynthesis"

SPALLATION OF HEAVY NUCLEI

COSMIC RAY ACCELERATION IN SN SHOCK

→ FERMI - MECHANISM

"COLLISION-LESS SHOCK"

in MAGNETIZED PLASMA

E.g. $^{12}C(p,p')^{12}C^*(\gamma,p)^{11}B$

$(\gamma,n)^{11}C(\beta^+)^{11}B$

$(\gamma,np)^{10}B$

$(\gamma,2n)^{10}C(\beta^+)^{10}B$

CR: $^{11}B/^{10}B \sim 2.2-2.4$

Solar: $^{11}B/^{10}B \sim 4$

→ CONTRIBUTION BY ν-process in SNe!

Exercise: find T-exponent $\underline{n}$ for

$$\lambda \sim N_A \langle \sigma v \rangle = N_A \left(\frac{4}{3}\right)^{3/2} \frac{\hbar}{u} \frac{N_A}{m_{01} Z_0 Z_1 e^2} S_0 \tau^2 e^{-\tau}$$

such that $\lambda \sim T^n$

$$\tau = \frac{3E_0}{KT}$$

$$E_0 = \left[\left(\frac{u}{\hbar}\right)^2 (Z_0 Z_1 e^2)^2 \left(\frac{m_{01}}{2}\right)(KT)^2\right]^{1/3}$$

FIND

$$\rightarrow \quad n = \frac{\tau - 2}{3}$$

GENERATIONS OF NUCLEOSYNTHESIS PROCESSES

BBN
"PRIMARY" — JUST FROM INITIAL BBN COMPOSITION $\sim [Z]$

r, α

"SECONDARY" — REQUIRES INITIAL "PRIMARY" ELEMENTS

$\sim [Z]^2$

s

"TERTIARY" — REQUIRES INITIAL "SECONDARY" ELEMENTS

$\sim [Z]^3$

$s \longrightarrow p$