ENERGY LOSS FROM NEUTRINOS

$$\sigma_\nu \sim (E_\nu / m_e c^2)^2 \times 10^{-44}\ \mathrm{cm}^2$$

(ABOUT $10^{-18}\times$ SMALLER THAN PHOTON CROSS SECTION...!)

MEAN FREE PATH:

$$\ell_\nu \sim \frac{1}{n\sigma_\nu} \sim \frac{\mu m_H}{\rho \sigma_\nu} \sim \frac{2\times 10^{20}\ \mathrm{cm}}{\rho}$$

$\rho \sim 1\ \mathrm{g/cm^3} \longrightarrow \ell_\nu\ 100\ \mathrm{pc}$

$10^6\ \mathrm{g/cm^3}$ $\quad \ell_\nu \sim 3000\ R_\odot$

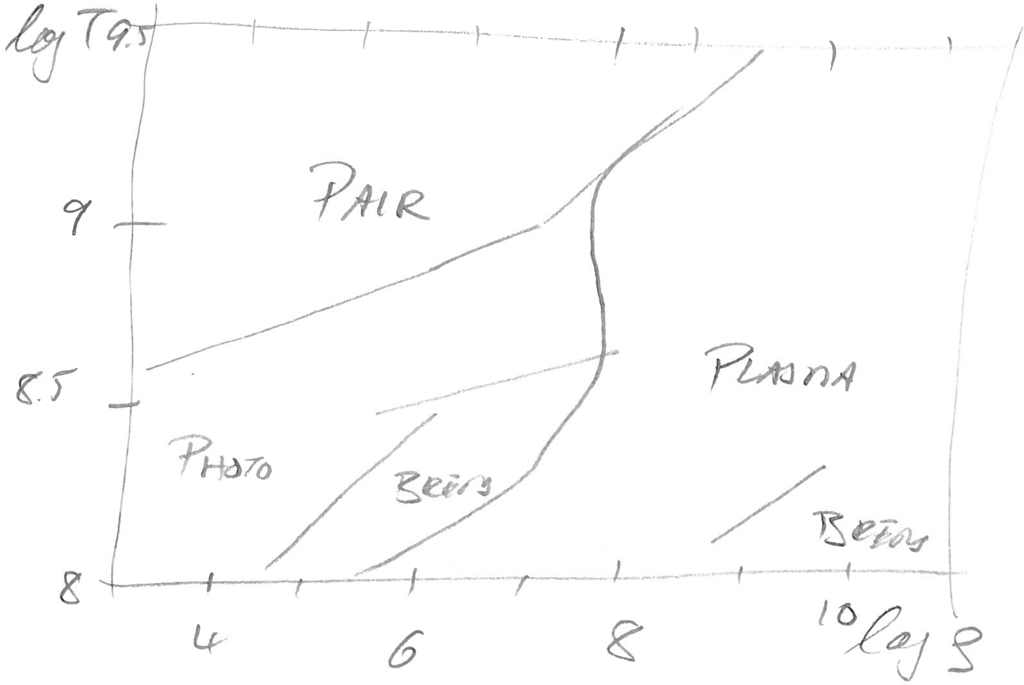
NS: $\rho \sim 10^{14}\ \mathrm{g/cm^3}$ $\quad \ell_\nu \sim 20\ \mathrm{km}$

+ higher E!

$^1H + {}^1H \rightarrow {}^2H + e^+ + \nu$	(pp 1,2,3)	$Q_\nu = 0.263$ MeV
$^7Be + e^- \rightarrow {}^7Li + \nu$	(pp2)	0.80
$^8B \rightarrow {}^8Be + e^+ + \nu$	(pp3)	7.2
$^{13}N \rightarrow {}^{13}C + e^+ + \nu$	(CNO)	0.71
$^{15}O \rightarrow {}^{15}N + e^+ + \nu$	(CNO)	1.0

$\odot$ AVERAGE 25 MeV / ^4He made, $L_\odot \sim 4\times 10^{33}$ erg/s

$\rightarrow 2\cdot \times 10^{38}\ \nu$ /SEC!



PAIR ANNIHILATION Neutrinos:

$$e^- + e^+ \rightarrow \nu\bar{\nu} \qquad T_9 > 1$$

$$\varepsilon_\nu^{PAIR} = \begin{cases} \frac{4.9\times 10^{8}}{\rho} T_9^{3} e^{-1186/T_9} & T_9 < 1 \\ \frac{4.45\times 10^{15}}{\rho} T_9^{9} & T_9 > 3 \end{cases}$$

$1{:}10^{19}$

$\sim \rho^{-1}$ not so dense

Photo Neutrinos

$$\gamma + e^- \rightarrow e^- + \nu\bar{\nu}$$

← IN SOME (few) CASES...
ANALOGUE COMPTON SCATTERING
(DEP. DEGENERACY REL. EFFECTS)

$$\varepsilon_\nu^{(phot)} = \varepsilon_1 + \varepsilon_2 (\mu_e + \bar{\rho})^{-1}$$

$$\varepsilon_1 = 1.103\times 10^{13} \rho^{-1} T_9^{9} e^{-5.93/T_9}$$

$$\varepsilon_2 = 0.976\times 10^{8} T_9^{8} (1 + 4.2\, T_9)^{-1}$$

$$\bar{\rho} = 6.446\times 10^{-6} \rho T_9^{-1} (1 + 4.2\, T_9)^{-1}$$

Plasma Neutrinos

Plasmon Decay $\rightarrow \nu\bar{\nu}$

$\gamma_{plasm} \rightarrow \nu\bar{\nu}$

Plasma Frequency:

$$\omega_0^2 = \frac{m_e}{4\pi e^2 n_e} \begin{cases} 1 & \text{non-deg} \\ \left[1+\left(\frac{\hbar}{m_e c}\right)^2 (3\pi^2 n_e)^{2/3}\right]^{-1/2} & \text{degenerate} \end{cases}$$

dispersion relation

$$\omega^2 = K^2 c^2 + \omega_0^2$$

for EM wave moving thru plasma

K → wave #

propagation $\omega > \omega_0$

$\times \hbar \rightarrow E$

→ REL PARTICLE with rest mass $\omega_0 \hbar$

→ PLASMON "particle"

$$\mathcal{E}_\nu^{plasm} = \mathcal{E}_\nu^{(t)} + \mathcal{E}_\nu^{(e)}$$

(t → transvers, e → longitudinal)

with $\gamma = \hbar\omega_0 / KT$, $\lambda = KT/m_e c^2$

$$\mathcal{E}_\nu^{plasm} = \begin{cases} 3.356\times 10^{19}\, \rho^{-1} \lambda^6 (1+0.0158\gamma^2)\, T_9^{3} & \gamma \ll 1 \\ 5.252\times 10^{20}\, \rho^{-1} \lambda^{7.5}\, T_9^{1.5}\, e^{-\gamma} & \gamma \gg 1 \end{cases}$$

↑ few plasmons can be excited for $K_B T < \hbar\omega_0$

BREMSSTRAHLUNG Neutrinos

inelastic SCATTERING OF e^- in COULOMB FIELD OF NUCLEOUS : usually: photon emission (BREMSSTRAHLUNG)

BUT MAY emit $\nu\bar{\nu}$ instead

$$\varepsilon_\nu^{(\text{brems})} \sim 0.76 \frac{Z^2}{A} T_8^{\,6} \quad \text{at large } \rho$$

smaller at lower ρ by ~ 10 @ $\rho \sim 10^4\ \text{g cm}^{-3}$

→ dominate at low T and high ρ

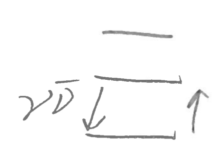
not suppressed by degeneracy!

Synchrotron Neutrinos

in strong magnetic fields

→ synchrotron radiation replaced by $\nu\bar{\nu}$ pair

Nuclear de-excitation

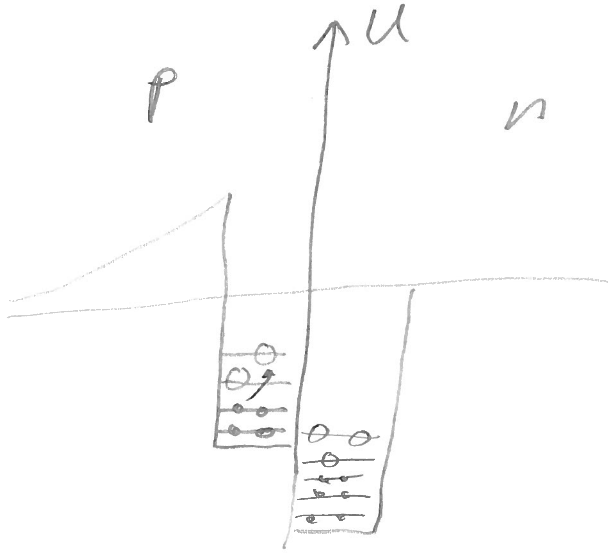


$$\sim e^{-E/k_BT} \cdot (2J+1)$$

phase space $\sim E^5$

may become important @ high enough T and (Si-Burn.; SN collapse

NUCLEI EXCITED STATES



SIMILAR TO EXCITED STATES IN ATOMS
BUT IN THIS CASE <u>NUCLEONS</u>
ARE HIGHER E LEVELS, NOT ELECTRONS

(IN STARS : ATOMS MOSTLY FULLY IONIZED
IN THE INNER PARTS)