Diffusive Nuclear Burning in Neutron Star Envelopes

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A bit of motivation

Make up of NS envelopes

- Evidence of H on the Surface
  - accreting systems
  - Spectral fitting + deduction
    (Rutledge et. al 1999)
    (Pavlov, Zavlin, & Sanwal astro-ph/0206024)
- Evidence for proton capturing (^{12}C) materials underneath.
  - Carbon superbursts
    (strohmayar & Brown 2002)

Temperatures in the deep (10 m) envelope is in excess of 5×10^7 K

$H + {}^{12}C + (T \gtrsim 5 \times 10^7 K) \Rightarrow$ Burning

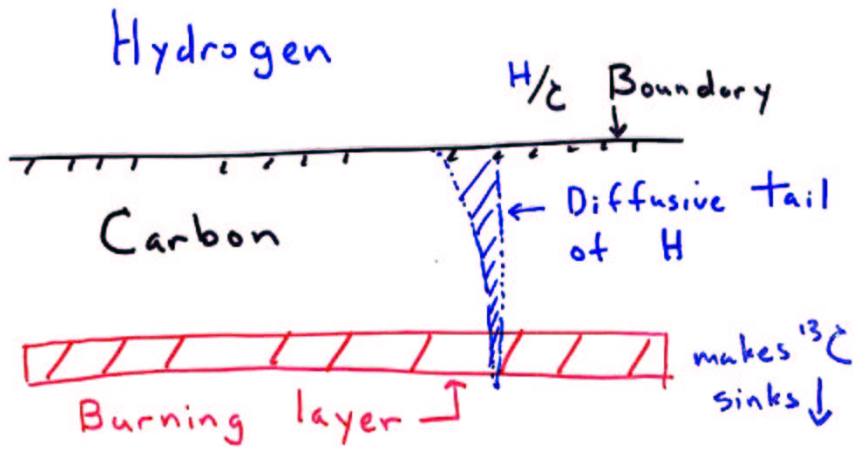
Reaction: $p({}^{12}C, \gamma)\,{}^{13}N$ $\quad {}^{13}N(B^+, \nu_e)\,{}^{13}C$

Endpoint is ^{13}C NOT ^4He

- But $T_c \sim 6-7 \times 10^7$ K for $T_{eff} \simeq 10^6$ K and is only at a depth of 10m!

⇒ Burning in the diffusive tail is important (Rosen 1968)

Simple model



Two limits of this process

1) $t_{Diff} << t_{nuc}$ (DNB in diffusive equilibrium)

2) $t_{Diff} \cancel{<<} t_{nuc}$ (Diffusion limited DNB)

Equations of structure for Diffusive equilibrium

- constant flux $\frac{dT}{dr} = -\frac{3K\rho}{4ac}\frac{\sigma T_{eff}^4}{T^3}$
- H.B. for electrons $\frac{dP_e}{dr} = -eEn_e$
- H.B. for carbon $\frac{dP_c}{dr} = -(12m_pg - 6eE)n_c$
- H.B. for Hydrogen $\frac{dP_H}{dr} = -(m_pg - eE)n_H$

number density

When we are not in diffusive equilibrium, presuming H is a trace element.

- H.B. for H

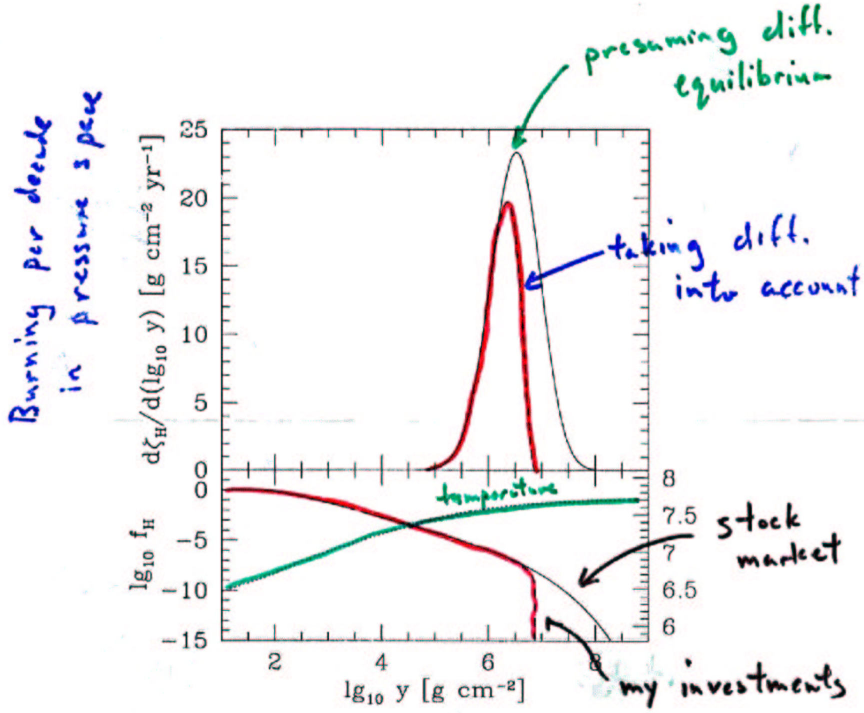
$$\frac{dP_H}{dr} = -(m_pg - eE - \underbrace{\tau_{ip} v_H n_e}_{\text{drag force}})n_H$$

- Drag force is small (usually) but when it gets large ($\tau_{ip} v_H n_e \sim m_pg$) it cuts off n_H rapidly

Local rate of nuc. burning $= \frac{n_H}{\tau_H}$

lifetime of proton for capture

Total rate $\equiv \frac{Y_H}{\tau_{col}} = m_p \int \frac{n_H}{\tau_H} \, dz$



Burning per decade in pressure space

presuming diff. equilibrium

taking diff. into account

stock market

my investments

Timescales for DNB & Conclusions

- vary from 10^{2-4} yrs. (astro-ph/0210218) for DNB in diff. equilibrium
- vary from 10^{0-2} yrs for diffusion limited DNB

- physics of DNB is fairly generic
  - But other systems i.e. WD have very long timescales.

- DNB can change the envelope of NS on fast timescales

- uncertainties include
  - effects of accretion
  - effects of large B-fields (pulsar & magnetars)
  - what is the real makeup of the envelope below the surface.