X-RAY BURSTS OF NUCLEAR ORIGIN?

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The fate of nuclear energy carried by matter accreted onto a neutron star was considered e.g. by Rosenbluth et al.(1973). They examined pycnonuclear reactions on an originally cold star, and found that the whole star is thereby heated up to 10^6-10^7°K. The thermonuclear reactions that can be ignited then, have been studied by Hansen and Van Horn (1975), who computed stationary burning shells, finding, however, that in most cases the shells are thermally unstable.

We consider here the possibility that X-ray bursts are due to instabilities of this type. The observational constraints fix the parameters uniquely.
If ε_g is the gravitational and ε_n the nuclear energy yield ($\varepsilon_g \simeq 140(M/M_\odot)(R/10^6\mathrm{cm})^{-1}$Mev/proton, $\varepsilon_n \simeq 7$ Mev/proton), the mean luminosity in bursts is $\langle L_n\rangle \simeq (\varepsilon_n/\varepsilon_g)L_X$, where L_X is the X-ray luminosity due to accretion, and the recurrence time of bursts is

$$t_{rec} \gtrsim \varepsilon_g E_b/(\varepsilon_n L_X)$$

where E_b is the energy in one burst. For $E_b=10^{39}$ erg, $L_X=10^{37}$ erg/s, $t_{rec} \gtrsim 2000$ s. This condition is satisfied by several bursters (Cf. Clark, these Proceedings) with the exception of MXB 1730-335, the rapid burster, which therefore cannot be explained by the model in its present form.
The total energy $E_b=10^{39}$erg corresponds to the burning of 2×10^{20} g of H, which on the surface of a neutron star with $R=10^6$cm requires for the envelope a minimum thickness of $\rho h \gtrsim 10^7 \mathrm{g\ cm}^{-2}$.
The rise time, $t_{rise} \simeq 1$ s, is limited by the diffusion time t_d

$$t_{rise} \gtrsim t_d \simeq h\tau/c$$

where τ is the optical depth. Assuming Thomson scattering as the dominant

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source of opacity, $\tau = 0.4\ h\rho$. The upper limit on t_d then implies an upper limit to the depth $h \lesssim 5\times10^3$ and a lower limit to the density $\rho \gtrsim 2\times10^3 \mathrm{gcm}^{-3}$. The peak burning rate must be $\approx 5\times10^{17}$ erg $g^{-1}s^{-1}$ which requires that energy is produced through the Carbon cycle* and sets a lower limit to the shell temperature, $T \gtrsim 10^8$ °K, consistent with the observed exterior temperature and required opacity.
The parameters derived in this way closely agree with those calculated independently by Hansen and Van Horn (1975). An important ad hoc requirement (but see Hoyle and Clayton 1974) is that the ratio CON/H before the burst be ≈ 1, in view of the limits to the rate of regeneration of CON imposed by β-decay.

While computations of the evolution of the burning shells are obviously needed, we stress that the model can potentially account for the energetics, time scale, recurrence, energy range of most X-ray bursts. Also their distribution in the Galaxy and association with Globular Clusters could be understood since the process requires neutron stars previously heated by pycnonuclear reactions, which implies a phase of intense accretion lasting longer than seems possible in massive X-ray binaries belonging to Pop I. (Lamers et al. 1976).

References
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*) The "prompt" energy release is then $\sim$ 2Mev/proton, $< \varepsilon_n$.