SHELL-FLASHES ON ACCRETING NEUTRON STARS AND MODE PROFILES OF TYPE-I X-RAY BURSTS

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Thermal stabilities of hydrogen and helium shell-burnings on accreting neutron stars are studied semi-analytically, the progress of nuclear reactions during the flash is followed numerically, and the mechanism which makes different modes of Type-I X-ray bursts is discussed.

The hydrogen shell-burning leads to the ignition of helium shell-flash through three different ways depending on the mass accretion rate dM/dt for the case of realistic core temperature; the stable hydrogen burning growing to the combined hydrogen and helium shell-flash with high dM/dt, the steady state hydrogen shell-burning and the pure helium shell-flash with intermediate dM/dt, and the hydrogen shell-flash developing into the combined hydrogen and helium shell-flash with low dM/dt.

The characteristics of pure helium flash is already described in the review of Joss in this symposium. These of combined hydrogen and helium flash is summarized to show the large variety of its burst profiles; the rise time is determined by the competition between the diffusion timescale and the nuclear timescale of 3α, (α,p), and (p,γ) reactions and the hardness ratio during the decay phase is governed by the β^+-decays of seed nuclei after the exhaustion of helium. Total released nuclear energy per unit mass during the flash also depends on the composition ratio.

These characteristics are consistent with observations of 1608-522 by HAKUCHO satellite both in 1979 and in 1980; short and long rise time ($\lesssim$ several seconds), fast and slow softening (e-folding time is upto ten seconds), and large variety of the ratio α (persistent X-ray luminosity / time averaged burst energy) from $\sim$500 to $\sim$30.

The possibility of partial (regional) shell-flash which grows independently at any part of accreting region is also pointed out.

D. Sugimoto, D. Q. Lamb, and D. N. Schramm (eds.), Fundamental Problems in the Theory of Stellar Evolution, 229–230.

DISCUSSION

Joss: In your case 3, where the hydrogen- and helium-burning shells are separated and the hydrogen undergoes a flash, the temperature probably must rise to a few times 10^8 K in order to ignite a helium flash. This requires that ~1% of the hydrogen must be consumed. However, each CNO nucleus can only capture a few protons, since the beta-decay timescales of the resultant proton-rich nuclei are longer than the local thermal diffusion timescale. Hence, it seems that one needs an enhanced CNO abundance, perhaps as high as 10% by mass, in order to ignite the helium. This is problematic, and especially so if the accreting matter has population II abundances. Can you see a way around this difficulty?

Miyaji: As you saw in my figure showing the stability curves, the burning is unstable to the right of the ignition line. Even when we take account of the saturation effect of the CNO cycle due to beta-decay, there we have $\varepsilon_n > \partial L_r/\partial M_r$, i.e. the nuclear timescale is shorter than the diffusion timescale so that the CNO-cycle can proceed many times.