SHELL FLASHES*

I.-Juliana Sackmann
W. K. Kellogg Radiation Laboratory,
California Institute of Technology,
Pasadena, California 91125, USA

Shell flashes will be discussed here with regard to three different stages of evolution: 1. normal stars, 2. white dwarfs accreting H-rich matter and 3. neutron stars accreting matter.

A shell flash is a thermal instability, a nuclear run-away process, occurring in any nuclear burning shell, as long as it is sufficiently thin in geometrical extent and sufficiently thick for a high enough heat capacity. (In contrast to the off-center helium shell flash, another kind of shell flash which occurs for degenerate matter, the shell flash discussed here does take place for an ideal gas including radiation pressure and does not require degeneracy.) The first shell flash discovered was the helium shell flash, about 15 years ago, by Schwarzschild and Härm (1965); Hayashi, Hoshi, and Sugimoto (1965); and Weigert (1965, 1966).

1. NORMAL STARS

Helium shell flashes first beset a star when it evolves for the second time upward on the red giant branch. The helium shell flash instability, unlike the helium core flash instability, occurs repeatedly. It starts as a small disturbance, growing in strength. After one to two dozen flashes, a peak flash intensity occurs, L^{peak}. (This levelling-off physically corresponds to an achievement of stationary shell burning for the H- and He-burning shell, when averaged over the total flash cycle, Sackmann 1979b.) The peak flash intensity of the He-burning shell, L^{peak}_{He}, reached on the red giant branch is of the order of 10^7 $L_\odot$. This is 10^3 to 10^4 above the energy output of the normal He-burning shell, of 10^2 to 10^3 above the surface luminosity L_{surf}. Little is known where on the red giant branch the most violent shell flashes occur. But the following consequences of the helium shell flash phenomenon, many of them of key observational impact, have been established.

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An intershell convective tongue, extending from the center of the He-burning shell nearly up to the H-burning shell, is produced by the flash. A possible breakthrough of this intershell convective tongue into the H-burning shell is still one of the challenges. Some promising conditions exist for the lower mass red giant stars of core mass $M_c <$ 0.8 $M_\odot$. (For white dwarfs accreting matter for most violent helium shell flash, such a breakthrough has recently been reported by Sugimoto, Fujimoto, Nariai, Nomoto 1978.)

A carbon pocket, with X_c, the proportion by mass of carbon, up to 0.5, has been produced in the intershell region between the H- and He-burning region (Christy-Sackmann and Paczynski 1975; Iben 1975, 1976; Sackmann 1976). This pocket is also greatly enriched in s-process elements (Iben 1975; Fujimoto, Nomoto, and Sugimoto 1976; Truran and Iben 1977; Fujimoto 1977).

A penetration of the deep convective envelope into the above pocket below the H-burning shell region has been found (Thomas 1974; Iben 1975; Fujimoto, Nomoto, and Sugimoto 1976; Sackmann 1976). However, this has been found only for higher core mass stars with massive envelopes; that is for $M_c \geq 0.8$ $M_\odot$ and total mass $M \geq 5$ $M_\odot$. Paczynski (1977) has shown that the exact amount of this penetration is not well known. This penetration into the carbon pocket described above, accounts for the existence of carbon stars and other chemical composition surface enrichments observed on the red giant branch.

An interflash period-core mass relationship, τ - M_c, has been discovered by Paczynski (1975) in the sense that as M_c increases by 0.1 $M_\odot$, τ decreases by a factor of 3. This τ - M_c relationship has been found to be a powerful tool in providing both the distance and the mass of FG Sagittae (Christy-Sackmann and Despain 1974) and certain nuclei of planetary nebulae (Trimble and Sackmann 1978).

Mass loss, driven by pulsational instability and aided by an increase in L_{surf} following a He-shell flash, has been found to lead to ejection of most of the red giant envelope (Härm and Schwarzschild 1975; Tuchman, Sack, and Barkat 1979; Tuchman and Barkat 1979).

A new deeply reaching convective envelope even for blue supergiants, flash-driven, repetitive and carbon-rich, has been found by Sackmann (1978, 1979a) and Schönberner (1979).

Extensive horizontal loops, driven by He-shell flashes, have been found in the HR-diagram. In the red part of the HR-diagram, they have been identified with Population II Cepheids (Schwarzschild and Härm 1970; Mengel 1972, 1973). In the blue part of the HR-diagram, these loops have been identified with the FG-Sagittae type phenomenon and they have been found to occur for timescales as short as 10^3, 10^2 and 10 yrs for M_c = 0.6, 0.8, and 1.2 $M_\odot$, respectively (Paczynski 1970).

H-shell flashes also begin to afflict the star when only a tiny envelope is left (Mengel 1973, Härm and Schwarzschild 1975). However, these H-flashes are not too intense, with peak values, $L_H^{peak} = 10^3$ to 10^4 $L_\odot$.

The He- and H-shell flashes continue in the star until one of its final states. Let us now consider a possible later evolutionary stage.

2. WHITE DWARFS ACCRETING H-MATTER

The results can be considerably different whether one discusses white dwarfs accreting H-matter or white dwarfs accreting He-matter. For the latter see, for example, Nomoto and Sugimoto (1977). The former will be discussed here.

White dwarfs accreting H-rich matter explain nova outbursts. They will be discussed by Dr. Sparks this afternoon. Therefore, I will say only a little here, stressing only the flash phenomenon.

Both H- and He-shell flashes have been found here (first by Giannone and Weigert 1967).

The intensity of the shell flashes here is considerably higher than on the red giant branch. Values of $L_H^{peak} = 10^9$ $L_\odot$ have been found by Paczynski and Żytkow (1978) and L_{He}^{peak} H = 10^{14} $L_\odot$ by Sugimoto, Fujimoto, Nariai, and Nomoto (1978). Yet all of the nova work has been dealing only with the first, the weakest H-shell flashes of $L_H^{peak} = 10^5$ $L_\odot$.

L_H^{peak} seems to depend critically on the accretion rate, $\dot{M}$, decreasing from 10^9 to 10^6 $L_\odot$ as $\dot{M}$ increases from 10^{-11} to 10^{-7} $M_\odot$/yrs (Paczynski and Żytkow 1978).

During the H-shell flash cycle, large loops can be produced in the HR-diagram with the white dwarf moving to blue and even to red supergiant locations again (Paczynski and Żytkow 1978; Kippenhahn, Thomas, and Weigert 1968). Light curves much like U Geminorum and Z Camelopardalis stars have been found.

3. NEUTRON STARS ACCRETING H- OR He-MATTER

Hansen and Van Horn (1975) and later Taam and Picklum (1978) showed that H-rich matter accreted unto a neutron star produced both H- and He-shell flashes at very high temperatures and densities, the H- and He-burning shell even overlapping. It was also shown that the newly produced carbon could lead to a violent degenerate C-flash. Woosley and Taam (1976) showed that the latter could explain γ-ray bursts. Joss (1978) showed that He-pure matter accreted unto a neutron star could explain the X-ray bursts. But only the first, the weakest H- and He-shell flashes have been studied here. Most of the far-reaching consequences have not been investigated. Only the tip of the iceberg has been touched.

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