NOVA MODELING

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1. INTRODUCTION

The mass and energy of nova ejecta are 10^{-5} - $10^{-4} M_\odot$ and 10^{44} - 10^{45} ergs, respectively (Payne-Gaposchkin 1957). Comparison of these quantities with the mass ($1\ M_\odot$) and binding energy (10^{51} erg) of the erupting white dwarf implies that the nova outburst is a surface event. From an average of two or three novae detected each year, it is estimated that the rate of novae is 40-50 per year in our galaxy (Payne-Gaposchkin 1954). Comparing this rate with a white dwarf birth rate of 2 per year in our galaxy (Weidemann 1968), we conclude that the nova outburst is a recurrent phenomenon (cf. Ford 1978). The recurrent nature also implies that the white dwarf cannot be drastically altered from event to event, thus giving further evidence for a surface event. The argument of recurrency become even stronger when it is realized that observations strongly indicate a close binary structure for the nova candidates--the white dwarf and a red companion (Kraft 1964).

Kraft (1963) proposed the following hypothesis. The red companion overflows its Roche lobe and supplies hydrogen-rich material to an accretion disk around the white dwarf. This material eventually accretes onto the white dwarf, forming an hydrogen-rich envelope whose base is electron-degenerate. As the accretion proceeds, the temperature at the base of this envelope increases. This has little effect on the pressure, but greatly increases the thermonuclear energy generation. The thermonuclear energy generation, in turn, increases the temperature. This positive feedback loop leads to a thermonuclear runaway, which Kraft proposed as the cause of the nova outburst. A large number of theoretical studies based on this model have been carried out. These studies are presented in order of increasing realism and complexity in the following sections.

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Patrick A. Wayman (ed.), Highlights of Astronomy, Vol. 5, 505–508.

2. HYDROSTATIC STUDIES

There has been a large number of hydrostatic calculations (Giannone and Weigert 1967; Rose 1968; Hayakawa and Sugimoto 1968; Starrfield 1971a, b; Redkoborodyi 1972; Taam and Faulkner 1975; Colvin, Van Horn, Starrfield and Truran 1976; Paczyński and Żytkow 1978) in which hydrogen-rich material was accreted onto a white dwarf until a thermonuclear runaway occured. The accretion rates varied from 10^{-12} to 10^{-5} $M_\odot$/yr and the white dwarf masses from .12 to 1.0 $M_\odot$. The main conclusion of these studies is that a strong thermonuclear runaway occurs when the hydrogen-rich envelope reaches 10^{-4} to 10^{-3} $M_\odot$. Because of their hydrostatic nature, these studies could not follow the ejection process.

3. HYDRODYNAMIC STUDIES WITH HYDROGEN ENVELOPE IN PLACE

In a long series of papers starting in 1972 by the authors (see Sparks, Starrfield, and Truran 1977 and references therein) and more recently by Prialnik, Shara and Shaviv (1978) the evolution of hydrogen-rich envelopes, originally in hydrostatic and thermal equilibrium, was followed. This approach has the disadvantage that it requires choosing the mass of the envelope but the advantage that it allows the computation of the ejection process. The energy generation rate of a typical thermonuclear runaway model starts at very low values ($\sim 10^{-2}$ erg/gm-sec) some thousands of years before its maximum. In Figure 1 we show the exponential increase of the energy generation rate for the last 10^6 sec before the peak. The upper limit to the energy generation rate is due to the fact that, at the high temperature involved (>100 million °K), the proton capture rate falls below the decay rates of the β^+-unstable nuclei created in the CNO bi-cycle (Starrfield <u>et al.</u> 1972). Also, at these high temperatures the electron degeneracy is lifted and the pressure increases. The resultant expansion leads to a cooling and the decrease in the energy generation rate in Figure 1. In the course of time, the energy generation rate approaches a value given by Paczyński's (1970) core mass-luminosity relationship.

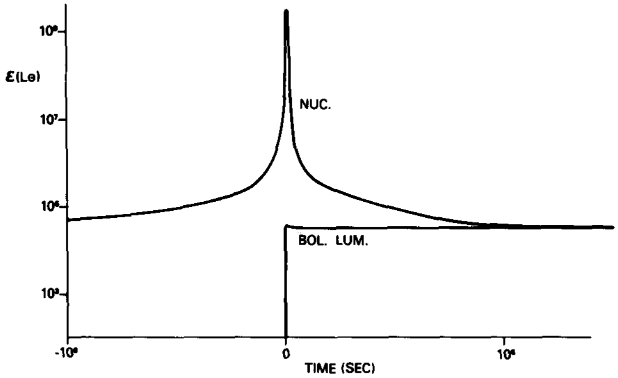

Fig. 1 - Energy rates vs. time for a typical nova outburst. The zero point of the time is at maximum energy generation.

Let us next examine some of the parameters that affect the runaway. Either a lower white dwarf mass, a lower envelope mass or a lower intrinsic luminosity will give a lower temperature at the base of the hydrogen-rich envelope, which in turn results in a longer runaway time. A higher degeneracy or a higher CNO abundance will give a stronger outburst. Also, the only way to produce a fast nova (i.e. for the bolometric luminosity to significantly exceed the Eddington luminosity) is by increasing the CNO abundance above the solar value. A higher white dwarf mass will give a larger post-outburst luminosity. The evolution time scale of this luminosity is determined by the envelope mass and the post-outburst mass loss rate.

4. HYDRODYNAMIC STUDIES WITH ACCRETION, NO ROTATION

The effect of the accretion process on the outburst has been studied by Nariai, Nomoto and Sugimoto (1979) and Kutter and Sparks (1979). If the accretion rate is approximately 10^{-10} $M_\odot$/yr or less, the energy due to the accretion process is radiated away, and the evolution is similar to that with the hydrogen-rich envelope in place. If the accretion rate is larger than 10^{-10} $M_\odot$/yr, then not all of this energy can be radiated away, and the envelope becomes hotter. This causes the thermonuclear runaway to occur sooner and less mass is accreted. A lower mass envelope causes a less violent outburst.

5. HYDRODYNAMIC STUDIES WITH ACCRETION AND ROTATION

Kippenhahn and Thomas (1978) developed a method which describes how material accreted with angular momentum is distributed on a white dwarf. They found that shear mixing occurs between the accreted and the stellar material, which gives a composition distribution differing drastically from the sharp H-He boundary used in all earlier nova models.

In their present work, Sparks and Kutter (1979) are including this process of shear mixing in an accreting nova model. They find that turbulence, driven by the shear, transports energy from the outer envelope layers to the inner ones. This is just the opposite from ordinary convection. In the P-V plane turbulent mixing corresponds to a refrigeration cycle (Figure 2). This inward energy transport alters the temperature structure of the envelope and affects the timing and the location within the envelope of the nuclear runaway.

In summary, let us view the progress made in the nova problem during the past two decades. By 1963 observers had firmly established the binary nature of novae and suggested the thermonuclear runaway mechanism as being responsible for the outburst. Within a decade the theorists confirmed the viability of this mechanism using hydrostatic calculations. Today we have a host of computations that reproduce the gross features of the dynamics of the ejection process. During the next decade we should see a continuation of these efforts with particular attention payed to the details of the accretion process, to deviations from spherical symmetry and to the post-outburst mass loss.

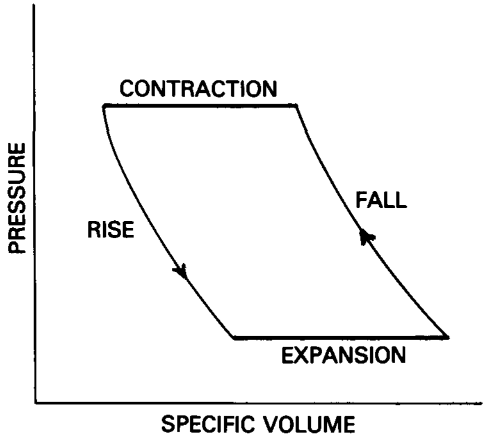

Fig. 2 - Schematic P-V diagram of shear mixing.

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