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TITLE: NEON NOVAE, RECURRENT NOVAE, AND TYPE I SUPERNOVAE

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NEON NOVAE, RECURRENT NOVAE, AND TYPE I SUPERNOVAE

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I. INTRODUCTION

Over the past few years, we have been investigating the effects of accretion onto massive white dwarfs and its implications for their growth in mass toward the Chandrasekhar limit, in attempts to identify a possible relationship between SN I and novae. In our studies we have considered accretion at various mass accretion rates onto a variety of different white dwarf masses. We have found that there is a critical white dwarf mass above which a significant fraction of the accreted mass can remain on the white dwarf after the outburst. Below this value of the white dwarf mass, all of the accreted mass, plus core material dredged up into the envelope, is ejected as a result of the explosion. Our latest results include accretion and boundary layer heating produced by the infalling material. From these studies, we have identified some members of the class of recurrent novae, those involving a thermonuclear runaway, as the novae that are occurring on very massive white dwarfs and evolving toward a SN I explosion. One of the outgrowths of our UV studies of novae in outburst has been the identification of a class of novae which eject material that is very rich in the elements from oxygen to aluminum. We have shown that these outbursts occur on ONeMg white dwarfs, which are necessarily very massive white dwarfs.

The assumption commonly made is that a classical nova system is a close binary with one member a white dwarf and the other member a cooler star that fills its Roche lobe. Because it fills its lobe, there is a flow of gas through the inner Lagrangian point into the lobe of the white dwarf. The high angular momentum of the transferred material causes it to spiral into an accretion disk surrounding the white dwarf. Some (unknown) viscous process transfers mass inward and angular momentum outward through the disk, so that a fraction (also unknown) of the material lost by the secondary ultimately ends up on the white dwarf. The accreted layer grows in thickness and is heated by compression until it reaches a temperature that is high enough for thermonuclear burning of hydrogen to begin at the bottom. The simulations show that, if the material is degenerate, a thermonuclear runaway (hereafter: TNR) occurs and the temperature in the accreted envelope can grow to values exceeding 10^8 K.

The further evolution of nuclear burning on the white dwarf now depends upon the mass and luminosity of the white dwarf, the rate of mass accretion, and the chemical composition of the reacting layer (Truran 1982; Starrfield 1989; Starrfield, Sparks, and Shaviv 1988; and references therein). Observations of novae ejecta also imply that there is mixing of core material into the accreted layer, so that the chemical composition of the material that is ultimately ejected by the outburst reflects a combination of core plus accreted material (Sparks *et al.* 1988).

It was proposed some years ago that accretion onto white dwarfs in close binary systems could lead to SN I (Truran and Cameron 1971; Whelan and Iben 1973). There have always been difficulties with including novae in this scenario, however, since they have been thought to eject most of their accreted mass. Unfortunately, although there have been other proposals for close binary progenitors of SN I, none of these proposals has yet received observational confirmation. It is the purpose of this paper to show that there is a class of nova-like events in which the white dwarf component is probably increasing in mass and is already close to the Chandrasekhar limit. We also note that the core composition of this class of novae has been identified.

II. RECURRENT NOVAE AND "NEON" NOVAE

Over the past few years, there has been intensive study of a class of novae that is referred to as "recurrent" because they have been *observed* to go through more than one outburst. They experience low amplitude outbursts which repeat on time scales of 20 to 50 years although the shortest known recurrence time is that of U Sco, which underwent outbursts in 1979 and 1987. Recurrent novae eject very small amounts of material, $\leq 10^{-7} M_{\odot}$, which represents only a *small* fraction of the amount of envelope mass necessary to initiate a TNR on a massive white dwarf. Presumably, the rest of the accreted material remains on the white dwarf.

The short recurrence times for this kind of outburst demands that the mass of the white dwarf exceed $1.3M_{\odot}$ and the closer to $1.4M_{\odot}$ the better (Starrfield, Sparks, and Truran 1985; Starrfield, Sparks, and Shaviv 1988; Truran *et al.* 1988). The simulations also show that the accreted envelope is burned to helium very rapidly, ensuring that the entire accreted envelope does not have to be ejected in order for the system to return to quiescence. In addition, abundance analyses of the ejecta of recurrent novae indicate that the heavy element abundances are not enhanced relative to a solar mixture (c.f., Williams *et al.* 1981; Starrfield 1988). We interpret these results as implying that this class of novae is neither mixing core material into the accreted envelope nor ejecting all of the accreted material. Therefore, it seems likely that the mass of the white dwarf, in *recurrent novae systems*, is growing as a result of the nova outburst. We have identified U Sco and V394 CrA as two recurrent novae which contain white dwarfs already close to the Chandrasekhar limit (Starrfield, Sparks, and Shaviv 1988). Finally, because the observed recurrence time scales require high $\dot{M}$ and because most of the material remains on the white dwarf, we predict that their mass must be growing at a very high rate ($\dot{M} > 10^{-7} M_{\odot} \text{yr}^{-1}$).

It is also possible to speculate on the internal composition of the white dwarfs in these systems. The basis of this speculation is the UV studies of novae done with the IUE satellite (Starrfield 1988) which show that many novae are ejecting significant amounts of core material into space as a consequence of the outburst. These are the

classical novae that show large enhancements of helium and heavier nuclei over a solar mixture (Truran and Livio 1986). In this context, we have been able to identify a subclass of novae that must be occurring on ONeMg white dwarfs based upon abundance analyses of the ejected material. Currently, we have positive identifications for four such novae (V1370 Aql, V693 CrA, QU Vul, and Nova Vul 1987) and in all cases the intermediate elements are a major fraction of the ejecta.

Observations allow us to estimate what fraction of the ejected material is core material and they show that, in some cases, the fraction is large (Truran and Livio 1986; Sparks *et al.* 1988). In the most extreme case, that of V1370 Aql, the efficiency of this process is very high and it appears that most of the ejecta is core material. The straightforward interpretation is that the white dwarfs in these nova systems are being eroded in mass as a result of the nova outburst. Therefore, *novae that show large enrichments of intermediate mass nuclei in their ejecta cannot be the progenitors of SN-like events.* We note that they must have been formed as high mass white dwarfs in order for the pre-white dwarf to survive carbon burning.

III. CONCLUSIONS

We draw the following conclusions:

1) Those recurrent novae that are powered by thermonuclear runaways, such as U Sco and V394 CrA, must involve a very massive white dwarf, close to the Chandrasekhar limit. This is demanded by the short recurrence times characteristic of these systems and the fact that only massive degenerate dwarfs can accrete sufficient matter on the observed recurrence time-scales to initiate a runaway.

(2) The white dwarfs in these recurrent nova systems appear to be growing in mass since the observed masses of the ejecta are less than the envelope masses necessary to trigger a TNR. This result is consistent with the findings that the ejecta of recurrent novae show no evidence for high concentrations of heavy nuclei, so that dredge-up and ejection of white dwarf core matter cannot have occurred.

(3) The massive white dwarfs in these systems are most likely to be ONeMg white dwarfs. This prediction is consistent with stellar evolution calculations (Iben, private communication) which suggest that it is difficult to form CO white dwarfs in the mass range, $M > 1.3M_{\odot}$, necessary to understand the recurrent novae and is also consistent with observational evidence for the presence of ONeMg systems among the classical novae.

(4) Typical classical novae are very unlikely to be progenitors of supernovae, since it appears that the compact component in these systems is systematically being reduced in mass as a consequence of successive outbursts.

It thus seems reasonable that the recurrent nova systems, which experience TNR's, may indeed see their white dwarf components evolve to the Chandrasekhar limit, setting the stage for the occurrence of a more violent event. The explosion of an ONeMg white dwarf in a close binary system should be investigated to determine whether the formation of a neutron star in a close binary can be achieved in this manner. Williams (private communication) has suggested a possible relation between recurrent novae and low mass x-ray binaries, since both classes show evidence for helium enrichments in the material being transferred from the secondary. Studies of the long term evolution of recurrent nova systems and hydrodynamic studies of

the evolution of the resulting ONeMg white dwarf at the Chandrasekhar limit can hopefully provide a clear statement regarding this matter.

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