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The recurrent nova T Pyx: a progenitor of a type Ia supernova ? ⋆

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Abstract. We discuss the possibility that the recurrent nova T Pyx could be a progenitor of a supernova Type Ia. The mass accretion rate during "quiescence" is compatible with "nova" outbursts at the observed average recurrence time of about 20 years only if the white dwarf component is very massive ($M_1 \sim 1.38 M_\odot$). This requirement, together with the observational evidence that the ejecta have solar-like abundances, would appear to indicate that the white dwarf in T Pyx is increasing in mass after each cycle of accretion and ejection and will eventually explode as SNIa. On the other hand, the high mass of the nebula and the presence of dark lines in the early nova spectrum, as reported from previous outbursts, suggest instead the ejection of a rather massive envelope and would indicate a decrease (erosion) in the white dwarf mass and a less catastrophic ultimate fate.

Key words. stars: novae, cataclysmic variables – stars: supernovae – ultraviolet

1. The recurrent novae as progenitors of Type Ia supernovae

It is generally accepted that Type Ia supernovae represent the complete thermonuclear disruption of mass accreting white dwarfs, although the exact nature of the progenitors is still unknown (Livio 1999). In the "single-degenerate" scenario the progenitors could be systems like symbiotic stars, super-soft x-ray sources, and recurrent novae (RNe) (Hachisu & Kato 2001). Very recently, Hachisu & Kato (2002) have proposed a new unified picture of binary evolution to SNeIa in which the channel of the recurrent novae to SNeIa can be understood as a part of the evolutionary stages in the super-soft x-ray sources and symbiotic channels.

We recall that the "nova" phenomenon occurs in semi-detached binary systems in which the accreting object is a white dwarf. The donor star can be either a low-mass main sequence star or an M giant star similar to the ones that are observed in symbiotic stars. The nova outburst is a thermonuclear runaway that is produced when the pressure at the base of the H-rich ac-

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⋆ Based on observations made with the International Ultraviolet Explorer.

creted layer on the surface of the white dwarf becomes sufficiently high for nuclear reactions to begin. The critical ignition mass M_{ign} which has to be accreted prior to thermonuclear runaway depends primarily on the mass of the white dwarf and is $\sim 3.6\ 10^{-5}\ M_{\odot}$ for M_1=1.0 $M_{\odot}$, while for M_1=1.4 $M_{\odot}$ it is $\sim 6\ 10^{-7}\ M_{\odot}$.

Recurrent novae are characterized by nova-like outbursts with recurrence time of decades. Solid theoretical considerations indicate that this behavior necessarily requires a high accretion rate onto a **very massive white dwarf** with M_1 close to the Chandrasekhar mass limit. On the observational side, the fact that the ejecta of RNe (unlike in "classical" novae) are not enriched in "heavy" elements, such as carbon, oxygen and neon, has been taken as an indication that the massive white dwarf in RNe is **gaining** mass after each cycle of accretion and ejection. The apparently unescapable conclusion is that the WD will eventually explode as a Type Ia supernova.

Recurrent novae can provide a direct observational test of these arguments since spectroscopic and photometric observations of recurrent novae in quiescence and during the outburst and post outburst stages can be used to set definite constrains on the secular balance between the total mass accreted during the quiescent inter-outburst phase and the mass ejected in the explosive phase.

2. The disk luminosity and the mass accretion rate of T Pyx

The recurrent nova T Pyx has undergone five historical records outbursts in 1890, 1902, 1920, 1944, and 1966. Its UV spectrum has been observed with IUE from 1980 to 1996 and has shown a remarkable constancy in the continuum energy distribution. (The next outburst is now at least 15 years overdue.)

An accurate knowledge of the distance is crucial for the determination of L, $\dot{M}$, M_{shell} and other basic parameters of the system T Pyx. We have obtained a new estimate of the distance ($d \sim 4100$ pc) using a new value for the absolute magnitude at maximum M_v^{max}=-6.85 (as an average from recent MMRD relations of Della Valle & Livio (1995), and Downes & Duerbeck (2000)) and a new and accurate value for the reddening ($E_{B-V} = 0.25$), as estimated by applying the common method of removing the wide interstellar absorption band at ~ 2175 Å. A very similar value for M_v^{max} can be obtained assuming that L=L_{Edd} in the outburst phase corresponding to the extended plateau in the nova light-curve at $m_v = 7.0$.

The de-reddened mean UV flux (1.94 10^{-10} erg cm^{-2} s^{-1}) together with the new value for the distance has yield a UV luminosity $L_{UV} \sim 3.93\ 10^{35}$ erg s^{-1} = 102 $L_{\odot}$. The de-reddened continuum is very well approximated by a single black body (BB) with T=34100 K or by a power-law $F_{\lambda} \sim \lambda^{-2.25}$, see Fig. 1. If we assume that the observed UV and optical luminosity comes from an accretion disk heated by viscous dissipation of gravitational energy, then the mass accretion rate $\dot{M}$ can be obtained from the relation $\dot{M} = (2R_1 L_{disk})/(\mathrm{G}M_1)$ where L_{disk} is the bolometric disk luminosity.

L_{disk} can be estimated from the observed L_{UV}, after correction for the inclination and after allowance for the unseen luminosity at $\lambda \leq 1200$ Å. From the models of Wade & Hubeny (1998) and from the flux distribution of a BB with T=34100 K, we obtain $L_{bol} = L_{disk} \sim 165\ L_{\odot}$ for the bolometric disk luminosity. This value is confirmed by an independent estimate of L_{bol} obtained from the value of the absolute optical magnitude at minimum light ($M_v = +2.3$) after the temperature specific bolometric correction.

If we constrain M_1 in the range 1.25 - 1.4 $M_{\odot}$ and adopt for R_1 the corresponding average values (5.1 10^{-3} $R_{\odot}$ - 2.5 10^{-3} $R_{\odot}$) from various M_1 - R_1 relations in the literature, we obtain a mass accretion rate $\dot{M}$ in the range from 2.2 10^{-8} $M_{\odot}$yr^{-1} (for M_1=1.4 $M_{\odot}$) to 4.6 10^{-8} $M_{\odot}$yr^{-1} (for M_1 = 1.25 $M_{\odot}$).

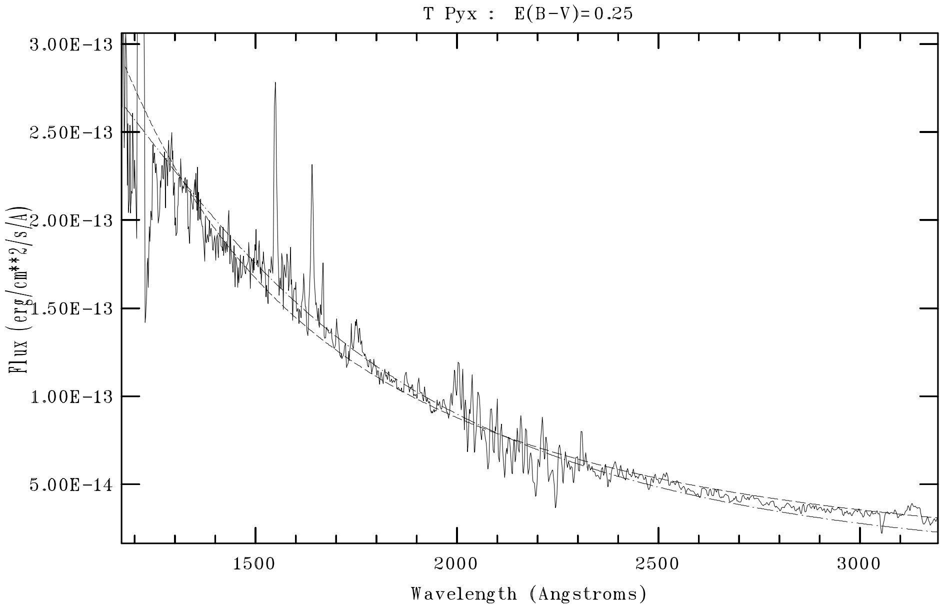

Fig. 1. The average UV spectrum of the recurrent nova T Pyx, corrected for E_{B-V}=0.25. A 34100 K black-body curve (dot-dashed line) and a power-law curve with index α=-2.23 (dashed line) are superposed.

3. The mass of the shell and the critical mass for ignition

The total amount of mass deposited on the surface of the white dwarf during the inter-outburst interval is necessarily associated with the critical mass for ignition M_{ign}, and can provide an observational test of the theoretical predictions on M_{ign}. Various estimates for M_{ign}, primarily a strong function of M_1, have been calculated by various authors and they differ from each other mostly in the choice of the critical pressure at the base of the accreted envelope (about 4 10^{19} dynes cm^{-2}). The minimum M_{ign} (for M_1=1.4 $M_\odot$) is close to 6 10^{-7} $M_\odot$ and increases very rapidly with the decrease of M_1 (it is about 2.2 10^{-6} $M_\odot$ for a white dwarf with M_1=1.35 $M_\odot$).

Therefore, ignition on the recurrent nova T Pyx requires a **very massive** white dwarf with M_1 = 1.4 $M_\odot$. In this case, the corresponding $\dot{M}$ is less than 3 10^{-8} $M_\odot yr^{-1}$ and the total mass accreted during an average interoutburst of 20 years is of about 5 10^{-7} $M_\odot$, compatible with the theoretical requirements of $\sim$ 6 $10^{-7} M_\odot$.

We point out that if we assume a less massive white dwarf (say, M_1 $\sim$ 1 $M_\odot$) we obtain an higher $\dot{M}$ ($\sim$ 1 10^{-7} $M_\odot yr^{-1}$) but we would need to introduce a dramatic unbalance between the accreted mass M_{accr} $\sim$ 2 10^{-6} $M_\odot$ and the theoretical requirements for ignition on a white dwarf with M_1 $\sim$ 1$M_\odot$ (M_{ign} $\sim$ 3.6 10^{-5} $M_\odot$).

If M_{accr} is about 5 10^{-7} $M_\odot$, this quite low value is an upper limit to the amount of mass ejected in a **single** outburst. This is in apparent contrast with the observational fact that in T Pyx the nebula is still visible, despite the time elapsed from outburst and the quite large distance. In most of the best studied CNe the shell is barely evident just a few years after outburst although these objects are on average at a shorter distance than T Pyx and are supposed to eject much more massive shells (10^{-4} - 10^{-5} $M_\odot$).

The anomalous strength of the observed shell of T Pyx can be explained if the shell is the result of the accumulation of the material ejected in successive outbursts (Shara et al. (1997)), but in any case the presence of absorption lines in spectra taken during outburst ((Catchpole 1969) and (Chincarini & Rosino 1968)) indicates a behavior that is similar to that reported in classical novae and suggests the **ejection of a rather massive shell in a single outburst**. The reported presence of these lines during the "principal maximum" phase of the outburst is difficult to explain if the mass of the newly ejected shell is less than $\sim 1.3\ 10^{-6}$ $M_\odot$.

Note that assuming a lower distance would reduce L_{UV}, and in turn $\dot{M}$ and M_{accr}, thus exacerbating the discrepancy. Instead, the adoption of a larger d would produce an uncomfortably high $\dot{M}$ value, close to the one needed for the onset of steady burning. In either case $\dot{M}$ would fall outside the limited range where a "theoretical RN" can be produced.

4. Conclusions

The mass accretion rate is compatible with the theoretical requirements for the onset of ignition (after quiescent accretion during an average inter-outburst interval of about 20 years) **only** if the white dwarf in T Pyx has $M_1 \sim 1.4 M_\odot$.

This requirement, together with the observational evidence that the ejecta have solar-like abundances (Williams (1982)) and that it is therefore unlikely that the white dwarf expels more material than it has accreted, seems to indicate that the white dwarf in T Pyx is increasing in mass after each cycle of accretion and ejection and will eventually explode as SNIa.

On the other hand, the persistence of the nebular shell and the presence of absorption lines in the early nova spectrum suggest the ejection of a rather massive envelope and would indicate a decrease in the white dwarf mass and a less catastrophic ultimate fate. However, these observational evidences are in puzzling contrast with the allegedly small amount of material ($\sim$5.0 10^{-7} $M_\odot$) accumulated on the surface of a massive white dwarf during the inter-outburst interval.

It is not clear to us if these contradictory conclusions come from faults in the theoretical assumptions or in the interpretation of the observations. In any case, this highlights the crucial need for accurate values of the most critical parameters of this recurrent nova i.e. the mass M_1 of the white dwarf and the mass and chemical composition of the ejecta.

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