The secrets of T Pyxidis

II. A recurrent nova that will not become a SN Ia

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Novae in theory and in practice:
a (not so) short introduction
Observational properties of a “classical” nova

Rise in optical brightness by 8-12 magnitudes
$M_v(\text{max}) \sim -6 \text{ to } -9$

Luminosity $\sim L_{\text{Edd}} \sim 10^5 \ L_\odot$

Significant decline ($t_3$) in $\sim 30\text{-}100$ days

Ejected masses $\sim 10^{-5} - 10^{-4} \ M_\odot$

Evidence of mass outflow from 300 to 3000 km s$^{-1}$

Ejecta enhanced in C, N, O, Ne

Nova rate in the Milky Way: $\sim 35$/yr, but $\sim 5$/yr discovered optically
Novae and their relatives

Novae are members of the class of cataclysmic variables (CVs): short-period binaries consisting of an accreting white dwarf primary star and (typically) a low-mass main-sequence (K-M red dwarf) secondary star.

The orbital periods of CVs typically range from approximately 0.6 day (14 hr) to 0.06 day (90 min).

The system is “semi-detached”, with the secondary star filling its Roche lobe (“donor” star).
The WD mass distribution
Mass transfer through Roche lobe overflow

The white dwarf captures matter lost through the inner Lagrange point $L_1$ of the secondary.

Material transferred has high angular momentum and cannot accrete directly onto the white dwarf, but forms a disk around the compact star.

As it loses angular momentum, because of viscous stresses, the material in the disk slowly drifts inward and accretes onto the surface of the white dwarf. Kinetic energy converted into heat and radiated.
Binary star configurations and mass transfer

Detached: mass transfer via wind

Semidetached: mass transfer via Roche lobe overflow

Contact
Figure 1.1: Equipotential surfaces in the orbital plane for a cataclysmic variable with a mass ratio $M_2/M_1 = 0.5$. The saddle points of the potential are the inner and outer Lagrange points L1–L3. The bold line passing through L1 shows the critical Roche surface (Roche lobe).
Roche Lobes
Lagrange points are gravitational balance points where the attraction of one star equals the attraction of the other. The balance points in general map out the star’s Roche lobes. If a star’s surface extends further than its Roche lobe, it will lose mass.

L1 – Inner Lagrange Point
- in between two stars
- matter can flow freely from one star to other
- mass exchange

Earth-Sun
L1: SOHO
L2: Gaia, WMAP, JWT
The accretion disk (AD)

AD heated by viscous dissipation of gravitational energy

\[ L_{\text{acc}} = \frac{dE_{\text{acc}}}{dt} = \frac{GM}{R} \frac{dm}{dt} = \frac{GMm}{R} \]

\[ L_{\text{disk}} = G \frac{M_1 m}{2R_1} = \frac{1}{2} L_{\text{acc}} \]

The accretion disk is responsible for most of the UV + visible + IR radiation emitted by the system during the “quiescent” phases.
Disk structure

One half of the accretion luminosity is released in the AD, the other half in the boundary layer, very close to the star.

- **X-ray**: Hot, optically-thin inner region; emits bremsstrahlung.
- **UV**: Outer regions are cool, optically-thick and emit blackbody radiation.
- **optical**: Bulge

Optically-thin inner region; emits bremsstrahlung.

Outer regions are cool, optically-thick and emit blackbody radiation.
The “boundary layer”

**DISK ACCRETION**

For slowly rotating WD:

$L_{\text{disk}} = L_{\text{BL}} = 1/2 G M M_{\text{wd}} / R_{\text{wd}}$

**MAGNETIC ACCRETION**

- Hard X-rays
- Soft X-rays
- Cyclotron
The “nova” phenomenon

Build-up of hydrogen-rich material on the top of the WD: accreted hydrogen is compressed up to degenerate conditions.

Compressional heating until ignition, when the “critical” pressure is reached, but degeneracy prevents envelope expansion.

As T increases degeneracy is lifted $\rightarrow$ explosive thermonuclear runaway (TNR) $\rightarrow$ nova “outburst”: envelope ejection.
Early models of a “stella nova”

Kepler (1606) in “De stella nova in pede Serpentarii”:
- novae are stars, not “flames” but “bodies”
- changes in the “celestial matter” in the most dense part of the aether contained in the Milky Way” (As Tycho suggested for Nova 1572)
- Likely that a “stella nova” is produced by “spontaneous generation” (similar to the alleged origin of frogs from mud, or that of louses from sweat in the hair).
Kepler

7. The New Star of 1604

The excitement reached its highest pitch in the fall of 1604 when an extremely bright new star appeared in the immediate proximity of the two planets which were forming a great conjunction, and which Mars, in the meanwhile, had also approached. At dawn on October 11, an imperial official, earnestly concerned with weather observations, came to Kepler in acute agitation with the announcement that on the previous day he had seen a brilliant new star in a gap in the clouds in the evening sky. Kepler hesitated to believe the report. In the days following, the sky was overcast and the mathematician had almost forgotten the tidings when, on October 17, the weather was clear and he saw the wonderful spectacle. In Ophiuchus near the three outer planets, Saturn, Jupiter and Mars, which were all close together, a fourth star had appeared; it competed with Jupiter in brilliance and sparkled in all the colors of the rainbow, like a well-cut diamond turned in the sunlight. How curious that exactly at that time when those planets had a rendezvous and exactly at the place of this rendezvous a new star should appear next to the old trusted wandering ones. No wonder that
as a matter of course. In contrast to the opinion that the planets had ignited the new star, he supported the stand that he was here dealing with an agglomeration of heavenly material, which also manifests itself in other phenomena. The causes of such an agglomeration he seeks in an architectonic natural ability inherent in that material. He refers to the analogous creative ability of the earth, which according to the law of spontaneous generation is able to bring forth all kinds of lower animate creatures. He rejects the possibility of the star appearing by accident at the same place and time as the great conjunction; in it he sees God's way which adapts itself to men and makes use of the rules of astrology which are in themselves objectionable in order to exhort men, who are dependent on him, and to inform them of his opinions. But what was the wonderful phenomenon supposed to signify? There were many interpretations. There was talk of a universal conflagration, of the Day of Judgment, of the overthrow of the Turkish kingdom, of a general revolution in Europe, of the appearance of a great new monarch: *Nova stella, novus rex*. Kepler himself let his thoughts run in the direction of the religious dominion.
Scenario

Mass transfer from the companion star onto the \textcolor{red}{white dwarf} (cataclysmic variable)

\textcolor{red}{\downarrow}

Hydrogen burning in degenerate conditions on top of the \textcolor{red}{white dwarf}

\textcolor{red}{\downarrow}

\textcolor{red}{Thermonuclear runaway}

\textcolor{red}{\downarrow}

\textcolor{red}{Explosive H-burning}

Decay of short-lived radioactive nuclei in the outer envelope (transported by convection)

\textcolor{red}{\downarrow}

\textcolor{red}{Envelope expansion, L increase and mass ejection}
The “Standard Model” for Classical Novae

Thermonuclear explosions in hydrogen-rich envelopes on white dwarfs in close binary systems

Accretion of matter from a companion leads to growth of the envelope until a critical pressure is achieved at its base to trigger a thermonuclear runaway.

A combination of degenerate conditions at the base of the envelope and the “dredge-up” of C, O, and Ne fuels from the white dwarf core yields rapid energy release on a dynamic time scale.
The (static) ignition mass

Ignition occurs at a critical pressure $P_{\text{ign}} \approx 10^{19}$ dyn/cm$^2$ (Truran and Livio, 1986). Basically, this is the condition that $T_{\text{base}} \approx 10^7$ K.

Since $P_{\text{ign}} = \frac{G M_1 M_{\text{ign}}}{(4 \pi R_1^4)}$, this corresponds to a certain critical mass $M_{\text{ign}}$.

For $M_1 < 1.0 \, M_\odot$: $R_1 \sim M_1^{-1/3} \rightarrow$ the critical ignition mass varies as $M_1^{-7/3}$

For more massive WD, $R_1$ decreases more rapidly (Hamada and Salpeter, ...) and $M_{\text{ign}}$ decreases with a steeper slope.

Various studies indicate a lower limit to $M_{\text{ign}}$ (for $M_1$ close to 1.4 $M_\odot$) in the range $2.0 - 4.0 \times 10^{-6} \, M_\odot$. 
The ignition mass (cont.)

However, more recent studies (Prialnik & Kovetz 1995, Yaron et al., 2005, Townsley and Bildsten, 2004), have led to the recognition that three independent parameters control the behavior of a CN eruption: $M_1$, $M_{\text{dot}}$, $T_c$.

The dependence on $M_1$ is less strong than previously assumed, while that on the accretion rate can become significant. This fact was underestimated in the previous "static" models. A system of a given mass can have a factor of 10 range in $M_{\text{ign}}$!

$M_{\text{ign}}$ decreases with increasing $M_1$ and increasing $M_{\text{dot}}$.

“A thousand and one nova outbursts “!
11.2 Nuclear burning

Nuclear burning is ignited in an envelope of H-rich matter accreted onto a WD, in case a critical envelope mass $\Delta M_{\text{crit}}$ has been reached which can sustain the high temperature ($\sim 10^8$ K) and pressure ($\gtrsim (10^{18} - 10^{20})$ g cm$^{-1}$ s$^{-1}$) required for nuclear burning, mainly the CNO cycle (Fujimoto 1982a,b). $\Delta M_{\text{crit}}$ decreases with increasing WD mass $M_{\text{WD}}$ and increasing accretion rate $\dot{M}_{\text{acc}}$ (Prialnik and Kovetz 1995) and is (for a WD temperature $T_{\text{WD}}=10^7$ K and for $\dot{M}_{\text{acc}} \geq 10^{-10}$ $M_\odot$ yr$^{-1}$) approximated by

$$\log\left(\frac{\Delta M_{\text{crit}}}{M_\odot}\right) \approx$$

$$A + B \left(\frac{M_{\text{WD}}}{M_\odot}\right)^{-1.436} \ln(1.429 - \left(\frac{M_{\text{WD}}}{M_\odot}\right)) + C \left(\log\left(\frac{\dot{M}_{\text{acc}}}{M_\odot \text{ yr}^{-1}}\right) + 10\right)^{1.484}, \quad (11.1)$$

with $A = -2.862$, $B = 1.542$, and $C = -0.197$. The accretion rate onto the WD determines the strength of the outburst. Higher accretion rates lead to less violent outbursts. If the accreted envelope remains on the WD,
Hydrogen Accreting Binaries

Townsley & Bildsten 2005

Supersoft Sources: Burn H Stably (van den Heuvel et al 1992)

Cataclysmic Variables all undergo unstable H burning, leading to Classical Novae

The WD mass range is quite uncertain.
> 1M_{\odot} White Dwarfs:

For steady burning on the WD surface, the mass-transfer rate should be $\sim (1-6) \times 10^{-7} M_{\odot}/yr$. At larger rates, burning is also steady, but X-rays don’t come out.

For accretion rates $> 10^{-8} M_{\odot}/yr$, the flashes are weak and burned matter probably retained (e.g. Kato and Hachisu, 2004).

Figure 5  Regimes of steady nuclear burning, weak flashes (cyclic burning), and strong flashes (novae) in the $M_{\odot}$-$M_{\odot}$ plane (cf Fujimoto 1982a, b, Nomoto 1982, Di Stefano & Rappaport 1995). The $\Delta M_H$ values indicate envelope masses (for a given accretion rate) at which burning is ignited. Below the dash-dot line, flashes produce nova explosions.
The mass of the ejecta

The ejected mass in classical novae is of about $10^{-4} - 10^{-5} \, M_\odot$ (from spectroscopic observations in the early optically thick phase and in the nebular stage). But, quite large uncertainties.

**Models** of novae indicate that the (theoretical) mass of the ejected shell $M_{ej}$ is quite close to the (theoretical) $M_{\text{ign}}$ and that a fraction of the accreted mass may be retained and steadily burned after the explosion: increase of the WD mass.

But, in some novae, evidence that the (observed) $M_{\text{shell}} > M_{\text{ign}}$

Very uncertain whether there is a secular increase or decrease of the WD mass, but, in any case, $\sim 0.3-0.6 \, M_\odot$ of matter is put on the WD over its lifetime.
Ejecta of all studied novae are characterized by enrichment (30-40% by mass) in either He, CNO elements, or O, Ne, Mg elements (Truran and Livio 1986).

Such enrichment cannot reflect the composition of the matter transferred from the (typically) low-mass stellar companions.

Nuclear burning alone will not produce significant conversion of helium to carbon or heavier elements.

Requisite enrichment must result from outward mixing (dredge-up) of material from underlying C/O or O/Ne white dwarf.

Mechanism for mixing is the most critical issue.
Recurrent novae (RNe)

Recurrence interval ~ 10-100 years; ~ 10 objects.
Generally “very fast” decay, with $t_3$ on the order of 10 days.

RNe are “extreme” classical novae: a very massive WD and high $M_{\dot{m}}$ are required.

Since the recurrence interval $\Delta t = M_{\text{ign}} / M_{\dot{m}}$, outbursts in massive WDs occur more frequently.

The ejecta should be much less massive than in CNe
Recurrent novae (cont.)
RNe are an ideal laboratory to test the expectations of the TNR theory.

From the observed $M_{\text{dot}}$ and the observed inter-OB interval: total accreted mass, to be compared with both the “theoretical” ignition mass and the “observed” mass of the ejecta.

What is the net balance between accretion and ejection?

Are RNe progenitors of SNe Ia?
“Standard model” for SNe Ia (Hoyle & Fowler, 1960)

SNe Ia are TNR explosions of C+O WD stars

Progenitor: massive WD in a binary system

Growth to the Chandrasekhar limit (~1.4 Mo) by accretion from a companion

Recurrent novae appear as good progenitors candidates.
The secrets of T Pyx II.
A recurrent nova that will not become a SN Ia

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Received....; accepted

ABSTRACT

Aims. We compare the observed and theoretical parameters for the quiescent and outburst phases of the recurring nova T Pyx.

Methods. IUE data were used to derive the disk luminosity and the mass accretion rate, and to exclude the presence of quasi-steady burning at the WD surface. XMM-NEwTON data were used to verify this conclusion.

Results. By various methods, we obtained $L_{\text{disk}} \sim 70 \ L_{\odot}$ and $\dot{M} \sim 1.1 \times 10^{-8} \ M_{\odot} \ yr^{-1}$. These values were about twice as high in the pre-1966-outburst epoch. This allowed the first direct estimate of the total mass accreted before outburst, $M_{\text{accr}}=\dot{M}_{\text{pre-OB}} \cdot \Delta t$, and its comparison with the critical ignition mass $M_{\text{ign}}$. We found $M_{\text{accr}}$ and $M_{\text{ign}}$ to be in perfect agreement (with a value close to $5 \times 10^{-7} \ M_{\odot}$) for $M_1 \sim 1.37 \ M_{\odot}$, which provides a confirmation of the thermonuclear runaway theory. The comparison of the observed parameters of the eruption phase, with the corresponding values in the grid of models by Yaron and collaborators, provides satisfactory agreement for values of $M_1$ close to $1.35 \ M_{\odot}$ and $\log \dot{M}$ between -8.0 and -7.0, but the observed value of the decay time $t_3$ is higher than expected. The long duration of the optically thick phase during the recorded outbursts of T Pyx, a spectroscopic behavior typical of classical novae, and the persistence of P Cyg profiles, constrains the ejected mass $M_{\text{ign}}$ to within $10^{-5} - 10^{-4} \ M_{\odot}$. Therefore, T Pyx ejects far more material than it has accreted, and the mass of the white dwarf will not increase to the Chandrasekhar limit as generally believed in recurrent novae. A detailed study based on the UV data excludes the possibility that T Pyx belongs to the class of the supersoft X-ray sources, as has been postulated. XMM-NEWTON observations have revealed a weak, hard source and confirmed this interpretation.
The recurrent nova T Pyx

Five recorded outbursts in 1892, 1902, 1920, 1944 and 1966, with a mean recurrence time of about 22 years.

Very similar photometric and spectroscopic behavior: $t_3 \sim 90$ days, and outflow velocities $\sim -1500$ km/s in the H-Balmer absorption components (Adams & Joy 1920, Joy 1945, Catchpole 1969, Chincarini & Rosino 1969).

OB amplitude close to 8.5 magnitudes (from $\sim 15.0$ to $\sim 6.5$). The “quiescent” magnitude $m_v$ has shown some decline (by $\sim 0.3$ $m_v$) in the last 50 years.
The continuum energy distribution

UV observations with IUE started in 1980 and lasted 16 years. The rationale was to monitor the nova just before and during the early phases of the allegedly imminent outburst, but the star somehow managed to postpone the outburst by at least 20 years (so far).

UV+vis+IR data show that, after correction for reddening (E(B-V)=0.25), the spectral energy distribution is dominated by an accretion disk that is described by a power-law:
\[ F_\lambda \sim \lambda^{-2.33} \]

\[ F_{(UV)} = 1.94 \times 10^{-10} \text{ erg cm}^{-2} \text{ s}^{-1} \text{ (}\lambda\text{-integrated)} \]
Average IUE spectrum of T Pyx obtained by co-adding and merging 35 SW and 14 LW IUE spectra.
Fig. 9. UV-Opt-IR “spectrum” of T Pyx. The B, V, R, J average fluxes are indicated. The hot source is clearly the main contributor at all wavelengths (the departure from the $-2.33$ power law at long wavelengths probably indicates that these fluxes arise in the outer part of the disk, where it becomes optically thin or reaches a physical edge). The $\alpha=-2.9$ power law is an aid to the eye. The black body that best “fits” the UV continuum (though meaningless for an accretion disk) is also plotted.
The distance, and the binary system parameters

We aim to determine the disk luminosity and the mass accretion rate. This requires prior knowledge of the distance, and of system parameters like the inclination angle $i$ and the mass of the primary star $M_1$.

Adoption of theoretical assumptions and semi-empirical constrains has enabled a quite restricted range for the values of $i$ and $M_1$ in the mass function:

$i \sim 25 \pm 5$ degrees, $M_1 \sim 1.25-1.40 \, M_\odot$

Distance determined by various MMRD relations, and the assumption of $L \sim L_{\text{edd}}$ at maximum: $d \sim 3500 \pm 350$ pc.

\[
\frac{(M_2 \cdot \sin{i})^3}{(M_1 + M_2)^2} = 1.037 \times 10^{-7} \cdot K_1^3 \cdot P
\]
Table 2. The system inclination for $M_1 = 1.25$-$1.40$ $M_\odot$ and $K_1 = 24 \pm 5$ km s$^{-1}$ for the cases (1) $P_{h}=1^h.829$, $M_2=0.12$; and (2) $P_{h}=3^h.439$, $M_2=0.24$

<table>
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<th>$M_1$ (M$_\odot$)</th>
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<th>$i$ (P=3$^h$.44)</th>
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Fig. 1. The $q$ vs $M_1$ plane for $P_{h}=3^h.439$ and $P_{h}=1^h.829$. The lines of constant inclination refer to $K_1 = 19$ km s$^{-1}$ (solid) and $K_1 = 29$ km s$^{-1}$ (dashed), spanning the error range in the value of $K_1$. The values of $i$ are indicated. The error bars represent the ranges in $M_1$ and $M_2$ discussed in the text.
The disk luminosity and the mass-accretion rate

\[ L_{\text{UV}} \sim 2.85 \times 10^{35} \text{ erg s}^{-1} \] (UV, observed)

\[ L_{\text{disk}} \text{ (obs.)} \sim 5.2 \times 10^{35} \text{ erg s}^{-1} \] (bolometric, observed)

\[ L_{\text{disk}} \sim 2.7 \times 10^{35} \text{ erg s}^{-1} \] (bolometric, 4\(\pi\) averaged)

THESE VALUES REFER TO THE POST-1967 OB PHASE;

PRE-1967 VALUES ARE ABOUT TWICE AS HIGH!

\[ M_{\dot{\text{}}}=\frac{(2R_{1}L_{\text{disk}})}{(G M_{1})} \] - Note that \(R_{1}=R_{1}(M_{1})\)

Table 5: \(M_{\dot{\text{}}}\sim 2.1 \times 10^{-8} \, M_{\odot} \, \text{yr}^{-1} \) (for \(M_{1} = 1.37 \, M_{\odot}\))

(PRE-1967)
Table 5. $M_1$, the estimated pre-1967-outburst accretion rate $\dot{M}_{\text{pre-OB}}$ (for $L_{\text{disk}}=140 \, L_\odot$), the theoretical ignition mass $M_{\text{ign}}$, the accreted mass $M_{\text{accr}}=22 \cdot \dot{M}_{\text{pre-OB}}$ and the expected recurrence time $\tau=M_{\text{ign}}/\dot{M}_{\text{pre-OB}}$.

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<th>$M_{\text{ign}}$ (10$^{-7}$M$_\odot$)</th>
<th>$M_{\text{accr}}$ (10$^{-7}$M$_\odot$)</th>
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11.2 Nuclear burning

Nuclear burning is ignited in an envelope of H-rich matter accreted onto a WD, in case a critical envelope mass $\Delta M_{\text{crit}}$ has been reached which can sustain the high temperature ($\sim 10^8$ K) and pressure ($\gtrsim (10^{18} - 10^{20})$ g cm$^{-1}$ s$^{-1}$) required for nuclear burning, mainly the CNO cycle (Fujimoto 1982a,b). $\Delta M_{\text{crit}}$ decreases with increasing WD mass $M_{\text{WD}}$ and increasing accretion rate $\dot{M}_{\text{acc}}$ (Prialnik and Kovetz 1995) and is (for a WD temperature $T_{\text{WD}}=10^7$ K and for $\dot{M}_{\text{acc}} \geq 10^{-10}$ $M_{\odot}$ yr$^{-1}$) approximated by

$$\log\left(\frac{\Delta M_{\text{crit}}}{M_{\odot}}\right) \approx$$

$$A + B \left(\frac{M_{\text{WD}}}{M_{\odot}}\right)^{-1.436} \ln(1.429 - \frac{M_{\text{WD}}}{M_{\odot}}) + C \left(\log\left(\frac{\dot{M}_{\text{acc}}}{M_{\odot} \text{ yr}^{-1}}\right) + 10\right)^{1.484}, \quad (11.1)$$
Summarizing....

The theoretical $M_{\text{ign}}$ and the observed $M_{\text{accr}}$ are in excellent agreement in the case of a massive WD. New support for the TNR theory.

BUT NOTE:

$M_{\text{dot}} \sim 2.1 \times 10^{-8} \, M_\odot \, \text{yr}^{-1}$ during a 22 years interval gives a total accreted mass: $M_{\text{accr}} \sim 4.6 \times 10^{-7} \, M_\odot$
Table 6. A comparison between Yaron et al. (2005) grids and observations.

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<td>$M_1$</td>
<td>1.36</td>
<td>1.33</td>
<td>1.30</td>
<td>1.40</td>
<td>1.35±0.05</td>
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<tr>
<td>$\dot{M}$</td>
<td>$3.0 \times 10^{-8}$</td>
<td>$5.0 \times 10^{-8}$</td>
<td>$7.0 \times 10^{-8}$</td>
<td>$1.0 \times 10^{-8}$</td>
<td>$2.4\pm0.6 \times 10^{-8}$</td>
</tr>
<tr>
<td>$M_{ign}$</td>
<td>$6.6 \times 10^{-7}$</td>
<td>$1.03 \times 10^{-6}$</td>
<td>$1.40 \times 10^{-6}$</td>
<td>$2.0 \times 10^{-7}$</td>
<td>$\sim5.3 \times 10^{-7}$</td>
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<td>$M_{ej}$</td>
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<td>$0.93 \times 10^{-6}$</td>
<td>$1.30 \times 10^{-6}$</td>
<td>$2.0 \times 10^{-7}$</td>
<td>(see Sect. 10.2)</td>
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<td>$\tau$</td>
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<td>19.8</td>
<td>20.2</td>
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<td>6.6</td>
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<td>-720</td>
<td>-572</td>
<td>-1760</td>
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<td>$t_{3,vis}$</td>
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<td>32</td>
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<td>$m_{v}^{max}$</td>
<td>6.7 ± 0.1</td>
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<tr>
<td>$A_{v}$</td>
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<td>Distance</td>
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<tr>
<td>$m_{v}$</td>
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<tr>
<td>$M_{v}$</td>
<td>1.79 ± 0.21</td>
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<tr>
<td>$i$</td>
<td>25 ± 5 degrees</td>
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<td></td>
<td></td>
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<tr>
<td>$\Delta m_{v}(i)$</td>
<td>0.74 ± 0.06</td>
<td></td>
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<tr>
<td>$M_{v}^{corr}$</td>
<td>2.53 ± 0.23</td>
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<tr>
<td>$L_{UV}$</td>
<td>74 ± 15 $L_{\odot}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$L_{disk}$</td>
<td>70 ± 15 $L_{\odot}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$M_{1}$</td>
<td>$\sim$ 1.36 $M_{\odot}$</td>
<td></td>
<td></td>
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<tr>
<td>$\dot{M}$</td>
<td>$1.1 \pm 0.25 \times 10^{-8}$ $M_{\odot}$ yr$^{-1}$</td>
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<tr>
<td>$\dot{M}_{pre-OB}$</td>
<td>$2.2 \pm 0.5 \times 10^{-8}$ $M_{\odot}$ yr$^{-1}$</td>
<td></td>
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</table>
Anamnesis of the outbursts

Far longer optical decline time ($t_3 \sim 90$ days) compared with that of other RNe

Spectrum characterized by P Cyg features in the hydrogen and Fe II lines, that endured for about three months.

Outflow velocities $\sim -1700 \pm 300$ km s$^{-1}$

Behavior similar to that observed in “classical” novae: optically thick shell. Instead, most RNe are “emission line” objects at maximum
Fig. 3. Comparison of microphotometer tracings of spectra No. 1198 and 1222.
Recurring Nova T Pyxidis
PRC97-29 • ST Scl OPO • September 18, 1997
M. Shara and R. Williams (ST Scl), R. Gilmozzi (ESO) and NASA
The mass of the ejected shell

Note that the presence of an optically thick stage requires a column density of the order of $10^{23}$ cm$^{-2}$.

$R_{\text{ej}} \sim 7.7 \times 10^{14}$ cm, $N_e \sim 10^8 \times 10^9$ cm$^{-3}$, $M_H = N_e \, m \, V = 1.5 \times 10^{-4}$ $M_\odot$

$N_h \times R_{\text{ej}} = 3.0 \times 10^{52} \times R^{-2}$ [cm$^{-2}$] for a shell of $1.0 \times 10^{-4}$ $M_\odot$ (Williams, 1994). We have $R_2 = 5.8 \times 10^{29}$ [cm$^2$] and $N_h \times R_{\text{ej}} \sim 5.2 \times 10^{22}$ [cm$^{-2}$]. Therefore, $M_{\text{ej}} > 10^{-4}$ required to produce an optically thick stage for about 60 days.

$log \, M_{\text{ej}} = 0.74 \, log \, t^2$ (Della Valle et al., 2002) gives $M_{\text{ej}} \sim 10^{-4}$

$M_{\text{ej}} = 6.0 \times 10^{-8} \, N_{H,24} \, (V_{\text{exp}} \times t_3)^2 \, M_\odot$ (Shore, 2002, 2008), gives $M_{\text{ej}} \sim 1.5 \times 10^{-4} - 1.5 \times 10^{-3}$.
The mass of the ejected shell (cont.)

The similarity between the spectroscopic and photometric characteristics of the outbursts of T Pyx (with the presence of long-lasting P Cyg profiles) and those of CNe, which allegedly eject about $10^{-4} \ 10^{-5}$ Mo, suggests in itself that during outburst T Pyx expelled a shell of comparable mass.

In conclusion, both quantitative methods and qualitative considerations indicate that $M_{\text{ej}} \sim 10^{-4} \ 10^{-5} \ M_\odot$
WE HAVE A PROBLEM HERE

The ejection of a massive shell \((\text{Mej} \sim 5 \times 10^{-5} \, M_\odot)\) contrasts with the results of the UV and optical observations during \(Q\), and the theoretical requirements for the ignition mass, which imply \(M_{\text{accr}} \sim M_{\text{ign}} \sim 5 \times 10^{-7} \, M_\odot\).

Apparently, T Pyx has ejected more material than it has accreted. Serious mismatch between the shell mass indicated by the optical observations during outburst and that determined by the UV and optical observations during quiescence.

Previous studies of novae containing a massive WD indicated the ejection of more material than theoretically predicted (Starrfield, 1998), but this was attributed to inadequacy in the theory.

OUR RESULTS SHOW THAT THE DISCREPANCY IS REAL.

But, why abundances appear as nearly “standard”? No erosion ??
The SN Ia and the SSS connection

RNe have been considered as likely progenitors of SNe Ia (Starrfield, 1985, Livio and Truran, 1992).

Recently, Hachisu and Kato (2002) have proposed a unified picture of binary evolution to SNe Ia in which RNe are part of the evolutionary stages of supersoft X-ray sources (SSS) to SNe Ia.

Patterson et al. (1998) and Knigge et al. (2000) have proposed that in T Pyx steady nuclear burning takes place during Q phases, and that T Pyx is a wind-driven SSS. This would lead to evaporation of the secondary star and/or to a rapid evolution of the WD to the Chandrasekhar limit, in form of an “assisted stellar suicide.”
The UV spectrum of T Pyx is of much lower strength and excitation as compared to that of V Sge (SSS).

**Fig. 3.** Comparison between the reddening-corrected SWP spectra of the supersoft source V Sge (continuous line) and of T Pyx (dashed line). The continuum of T Pyx has been scaled to that of V Sge (multiplied by a factor 40). Note the prominence of the high ionization lines of NV $\lambda$ 1240, CIV $\lambda$ 1550, HeII $\lambda$ 1640, and NIV $\lambda$ 1719 in V Sge, in contrast with their moderate intensity or absence in T Pyx.
No SN Ia, no SSS, no suicide.

XMM observations (Nov. 10, 2006).

The three EPIC cameras were operated in Full Frame mode with the Medium Filter, for a total of 22.1 ks.

In Fig. 4, the XMM spectrum is compared to the simulation of two SSS sources with $T \sim 2.4 \times 10^5$ k.

Very weak and flat source.

We predict that, fortunately, any form of stellar suicide in the near future is extremely unlikely.
Fig. 4. The XMM-Newton EPIC-pn spectrum of T Pyx (bottom) compared with the simulations of a 20 ksec exposure of a blackbody of $2.4 \times 10^5$ K and a luminosity of $1 \times 10^{37}$ erg s$^{-1}$ computed with two assumptions: a distance of 3500 pc and a reddening $E_{B-V}=0.25$ (values assumed in this paper, dots), and a distance of 3000 pc and a reddening of 0.4 (values assumed by Knigge et al., 2000, continuous line). The three spectra shown here have been re-binned to 20 counts per bin.
The recurrence time and the next outburst

In 1986, monitoring of T Pyx with IUE, prior to the expected next outburst. Unfortunately, the star successfully managed to postpone the long-awaited outburst.

Shaefer (2005): lower $M_{\text{dot}}$ in recent years, OB expected for A.D. 2052.

With the help of Table 3 we can refine this prediction and estimate that the next outburst will occur around A.D. 2025.

With this new date, we (or at least some of us) feel a bit more confident about the chance of personally testing this prediction.
Schaefer (2005)
Table 3. $M_1$, $R_1$, the factor $\phi = (R_1/M_1)/(R_{10}/M_{10})$, the post-1967 mass accretion rate $\dot{M}$ (for $L_{\text{disk}} = 70 \, L_\odot$), the ignition mass, and the recurrence time $\tau = M_{\text{ign}}/\dot{M}$ (see Sect. 8).

<table>
<thead>
<tr>
<th>$M_1$ ($M_\odot$)</th>
<th>$R_1$ ($10^{-3}R_\odot$)</th>
<th>$\phi$</th>
<th>$\dot{M}$ ($10^{-8}M_\odot\text{yr}^{-1}$)</th>
<th>$M_{\text{ign}}$ ($10^{-7}M_\odot$)</th>
<th>$\tau$ (yrs)</th>
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<tr>
<td>1.00</td>
<td>8.10</td>
<td>1.000</td>
<td>3.66</td>
<td>108.78</td>
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<td>1.05</td>
<td>7.63</td>
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<td>1.10</td>
<td>7.10</td>
<td>0.797</td>
<td>2.92</td>
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<td>1.15</td>
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<td>1.20</td>
<td>5.85</td>
<td>0.602</td>
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<td>0.90</td>
<td>3.06</td>
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<td>1.40</td>
<td>2.60</td>
<td>0.229</td>
<td>0.84</td>
<td>1.78</td>
<td>21.2</td>
</tr>
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</table>
Summary and conclusions

From UV and other observations we have inferred that $M_{\text{accr}} \sim 5.2 \times 10^{-7} \, M_\odot$, in excellent agreement with the theoretical $M_{\text{ign}}$. This is the first reliable determination of the mass accreted prior to a nova outburst.

Spectroscopic and photometric data during the outbursts indicate an ejected mass $M_{\text{ej}} \sim 5 \times 10^{-5} \, M_\odot$; therefore, T Pyx ejected far more material than it has accreted.

No way to reconcile this discrepancy; note that current nova models predict that $M_{\text{ej}} \leq M_{\text{accr}}$.

No evolution toward SN Ia, no SSS.
“Ooooooooooooooooooo!”
“It's no good, Dawson! We're being sucked in by the gravitational field and there's nothing we can do! ... And let me add those are my sunglasses you're wearing!”
Tempers flare when Professors Carlson and Lazzell, working independently, ironically set their time machines to identical coordinates.
When worlds collide
“It’s no good, Dawson! We’re being sucked in by the gravitational field and there’s nothing we can do! ... And let me add those are my sunglasses you’re wearing!”
“It’s no good, Dawson! We’re being sucked in by the gravitational field and there’s nothing we can do! ... And let me add those are my sunglasses you’re wearing!”