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Astronomy & Astrophysics

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(max) ~ -6 to -9
Luminosity ~ L_{Edd} ~ 10^5 L_o
Significant decline (t_3) in ~ 30-100 days
Ejected masses ~ 10^{-5} – 10^{-4} M_o
Evidence of mass outflow from 300 to 3000 km s^{-1}
Ejecta enhanced in C, N, O, Ne
Nova rate in the Milky Way: ~ 35/yr, but ~ 5/yr discovered optically

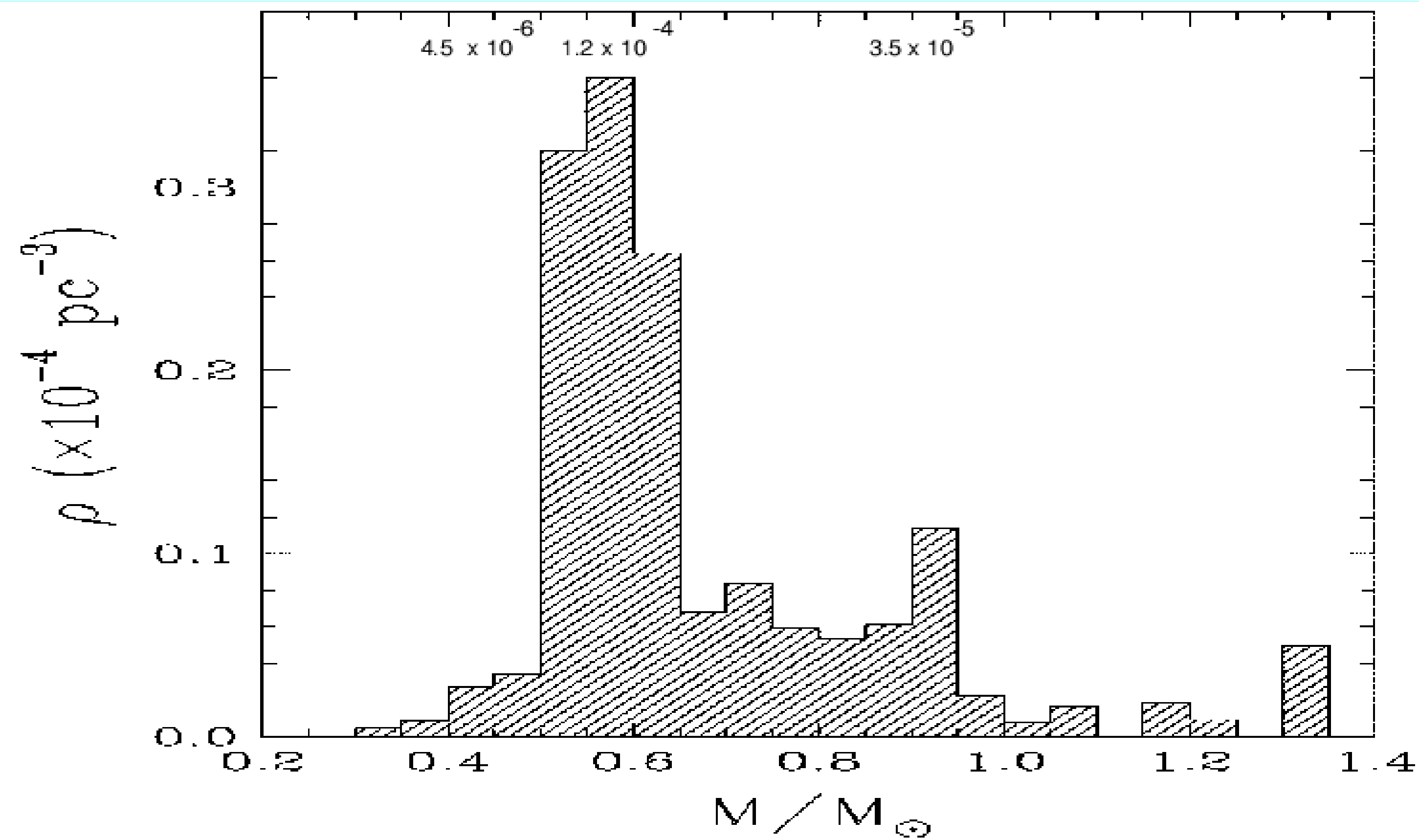
Novae and their relatives

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 Distribution Corrected to Fixed Volume of Space

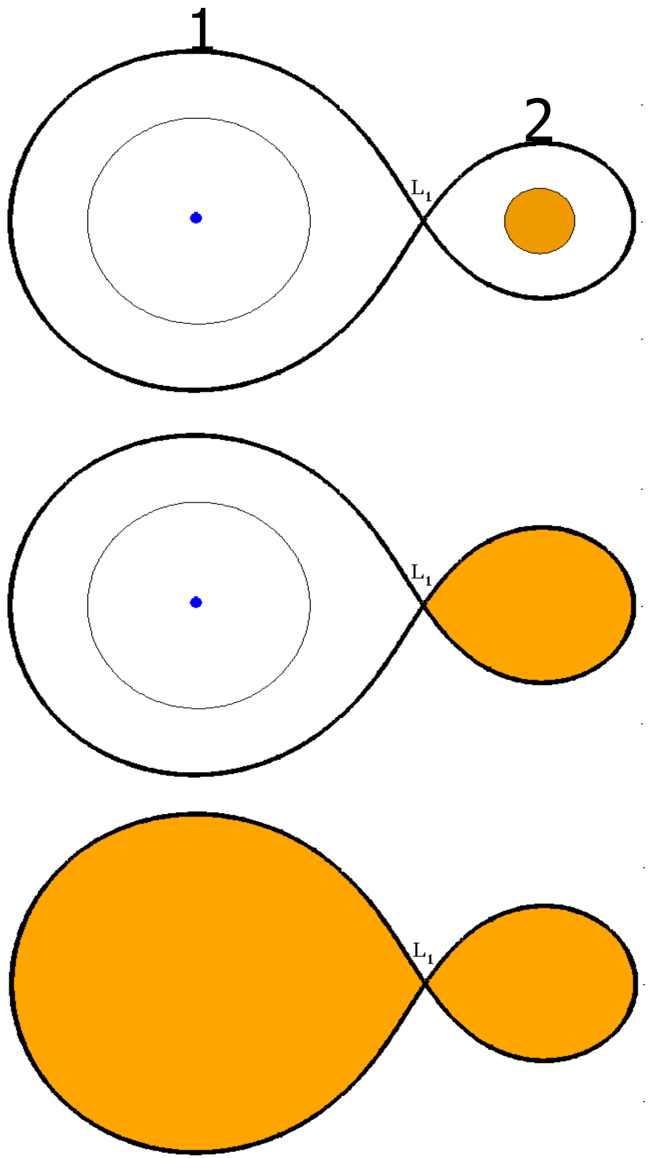
Mass transfer through Roche lobe overflow

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

Roche geometry

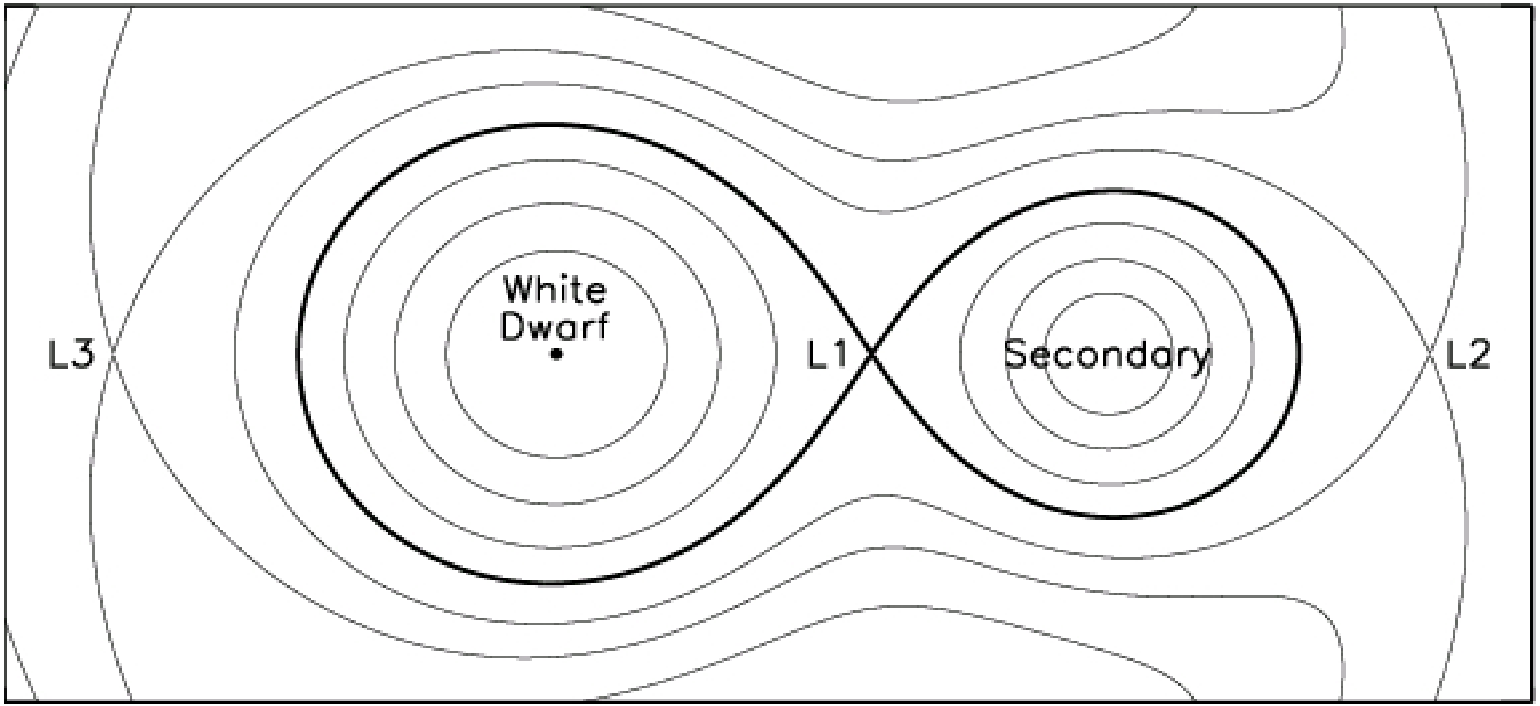
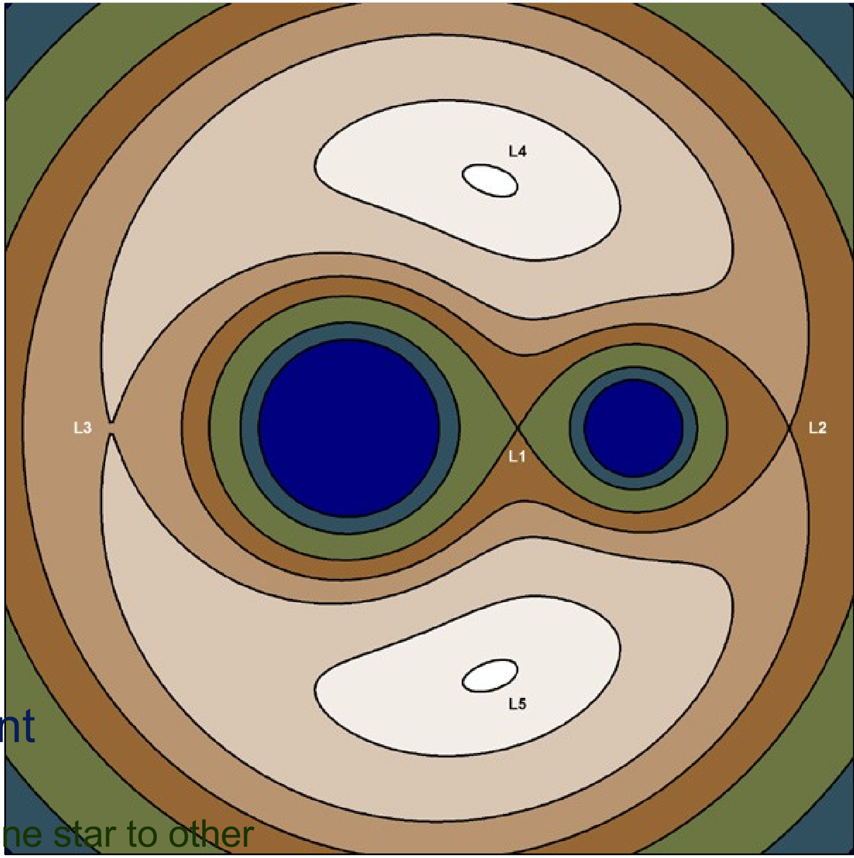


Figure 1.1: Equipotential surfaces in the orbital plane for a cataclysmic variable with a mass ratio $M_2/M_1 = 0.5$. The saddle points of the potential are the inner and outer Lagrange points L1–L3. The bold line passing through L1 shows the critical Roche surface (Roche lobe).

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


Companion
Red Dwarf
Accretion
Disk
Stream of Matter


Accretion
Disk

The accretion disk (AD)

AD heated by viscous dissipation of gravitational energy

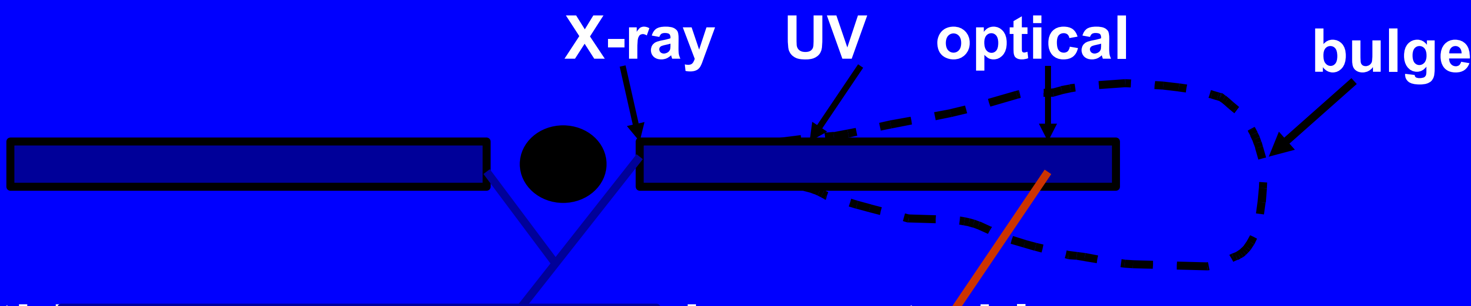
$$L_{acc} = \frac{dE_{acc}}{dt} = \frac{GM}{R}\frac{dm}{dt} = \frac{GMm}{R}$$

$L_{disk} = G\ (M_1 m)/(2R_1) = ½\ L_{acc}$

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

Disk structure

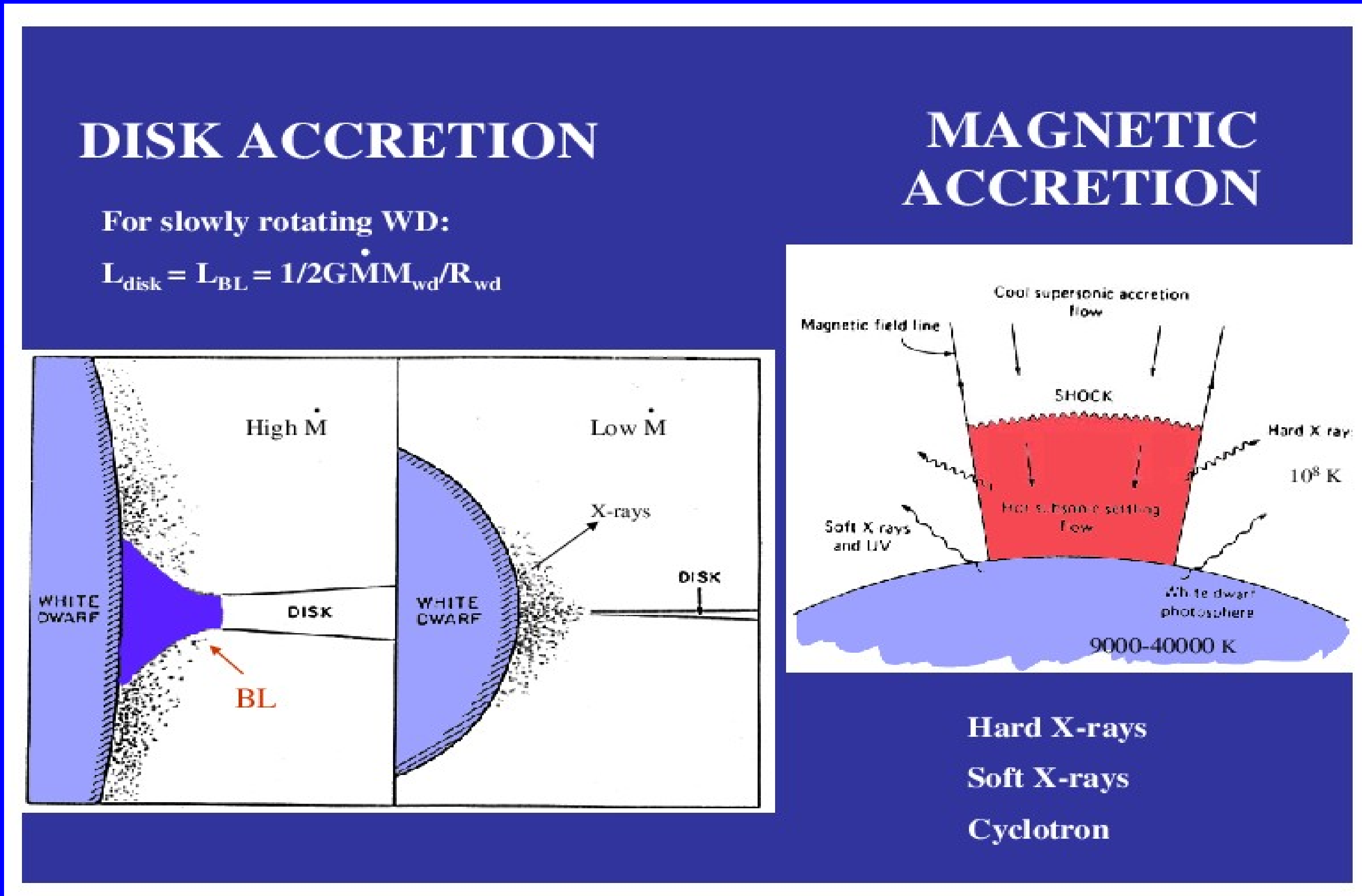
One half of the accretion luminosity is released in the AD, the other half in the boundary layer, very close to the star.



ptically-thin inner region; emits bremsstrahlung

Outer regions are cool, optically-thick and emit blackbo

The “boundary layer”



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 → explosive thermonuclear runaway (TNR) → 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).

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 analagous 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

Scenario

Mass transfer from the companion star onto the white dwarf (cataclysmic variable)

↓

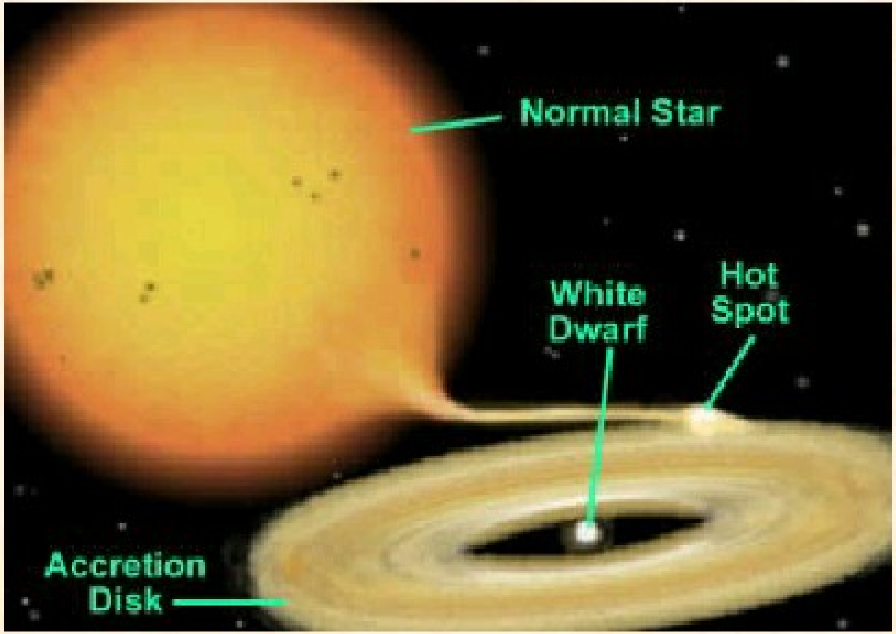
Hydrogen burning in degenerate conditions on top of the white dwarf

↓

Thermonuclear runaway

↓

Explosive H-burning

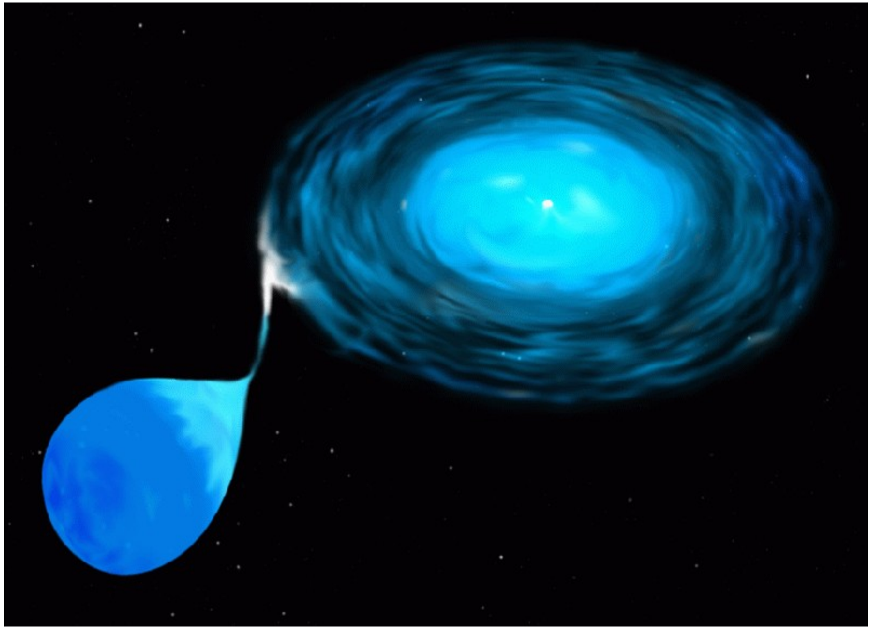


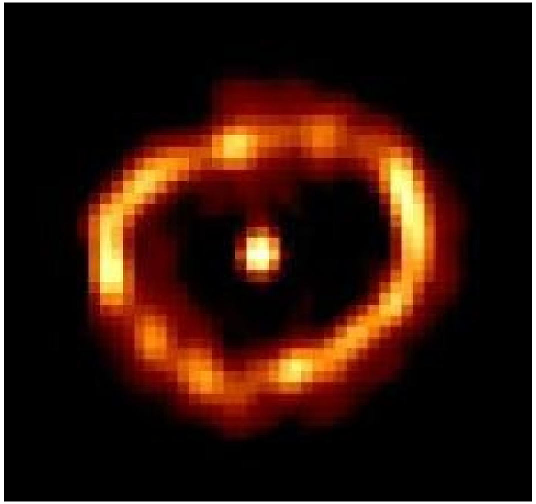
Decay of short-lived radioactive nuclei in the outer envelope (transported by convection)

↓

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_{ign} = ~ 10^{19} dyn/cm^2 (Truran and Livio, 1986). Basically, this is the condition that T_{base} ~ 10^7 K. Since $P_{ign} = (G\, M_1\, M_{ign})/(4\, \pi\, R_1^{\,4})$ this corresponds to a certain critical mass $M_{ign.}$

For $M_1 < 1.0\ M_o$: $R_1 \sim M_1^{-1/3}$ -> the critical ignition mass varies as $M_1^{-7/3}$

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

Various studies indicate a lower limit to M_{ign} (for M_1 close to 1.4 M_o) in the range 2.0 - 4.0 $10^{-6}\ M_{o.}$

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_{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_{ign} !

M_{ign} decreases with increasing M_1 and increasing M_{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 $\Delta M_{\rm crit}$ 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). $\Delta M_{\rm crit}$ decreases with increasing WD mass $M_{\rm WD}$ and increasing accretion rate $\dot{M}_{\rm acc}$ (Prialnik and Kovetz 1995) and is (for a WD temperature $T_{\rm WD}$=10^7 K and for $\dot{M}_{\rm acc} \geq 10^{-10}$ $M_\odot$ yr^{-1}) approximated by

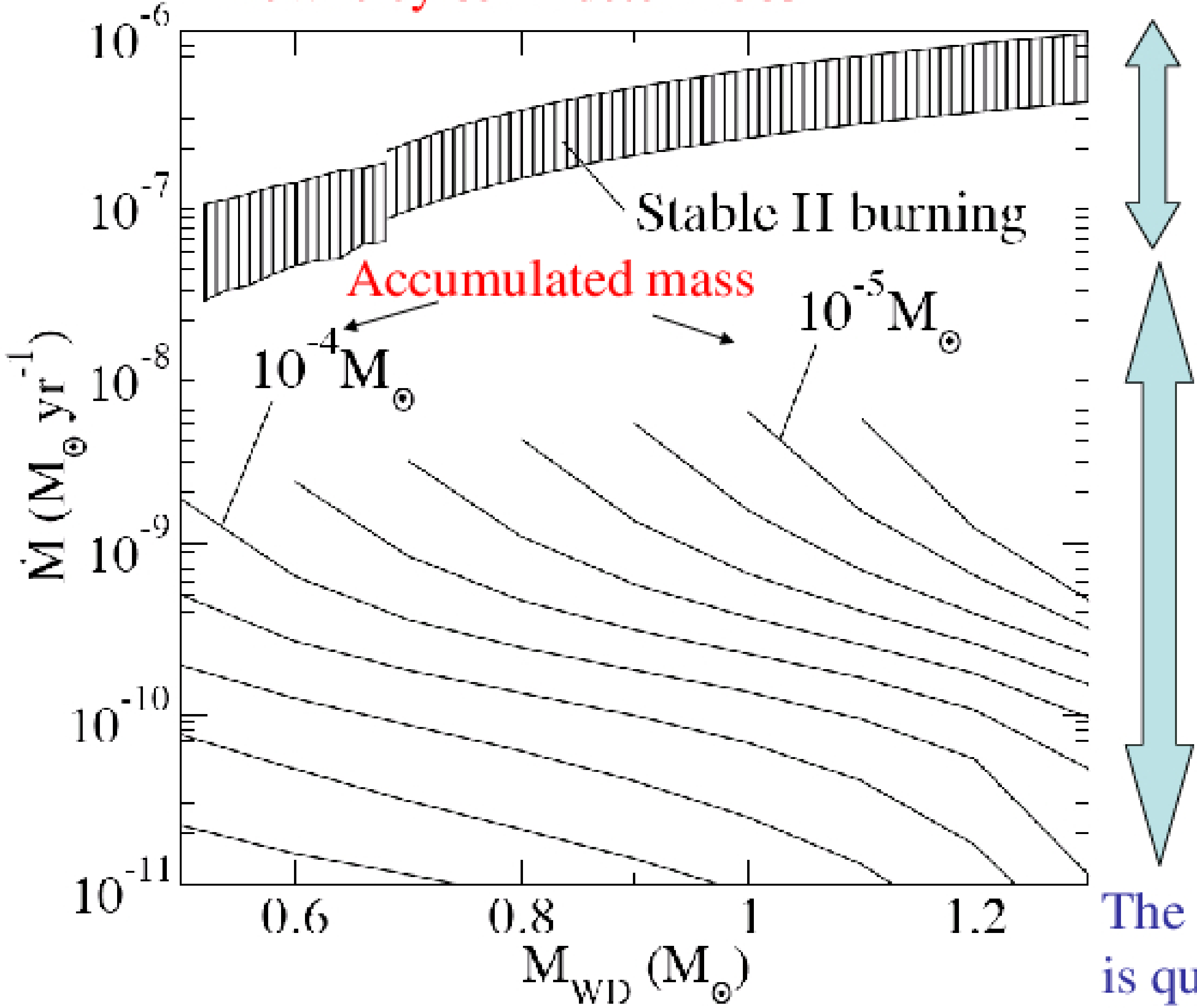
$$\log(\frac{\Delta M_{\rm crit}}{M_\odot}) \approx$$

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

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.

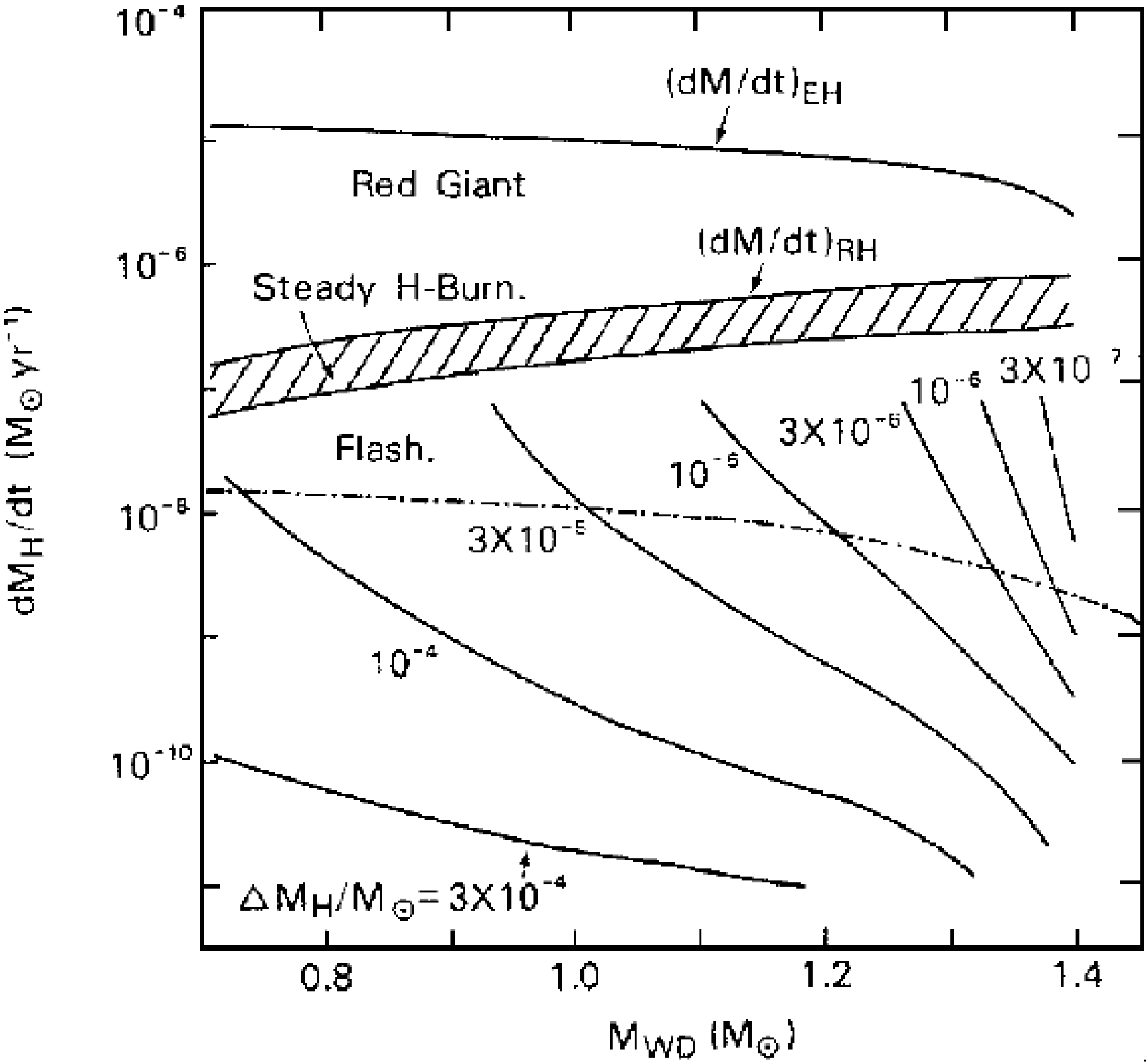


Figure 5 Regimes of steady nuclear burning, weak flashes (cyclic burning), and strong flashes (novae) in the $\dot{M}$–M_{WD} plane (cf Fujimoto 1982a,b, Nomoto 1982, DiStefano & Rappaport 1995). The ΔM_H values indicate envelope masses (for a given accretion rate) at which burning is ignited. Below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

> 1Msun White Dwarfs:

For steady burning on the WD surface, the mass-transfer rate should be ~(1-6).10^{-7}Msun /yr. At larger rates burning is also steady, but X-rays don't come out.

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

The mass of the ejecta

The ejected mass in classical novae is of about 10^{-4} -10^{-5} M_o (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_{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) $M_{shell} > M_{ign}$

Very uncertain whether there is a secular increase or decrease of the WD mass, but, in any case, ~ 0.3-0.6 M_o of matter is put on the WD over its lifetime.

The Ejecta Enrichment Mechanism

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} are required.

Since the recurrence interval Δt is = M_{ign}/M_{dot}, 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_{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 $L_{disk} \sim 70\ L_\odot$ 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, $M_{accr}=\dot{M}_{pre-OB} \cdot \Delta t$, and its comparison with the critical ignition mass M_{ign}. We found M_{accr} and M_{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_{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.

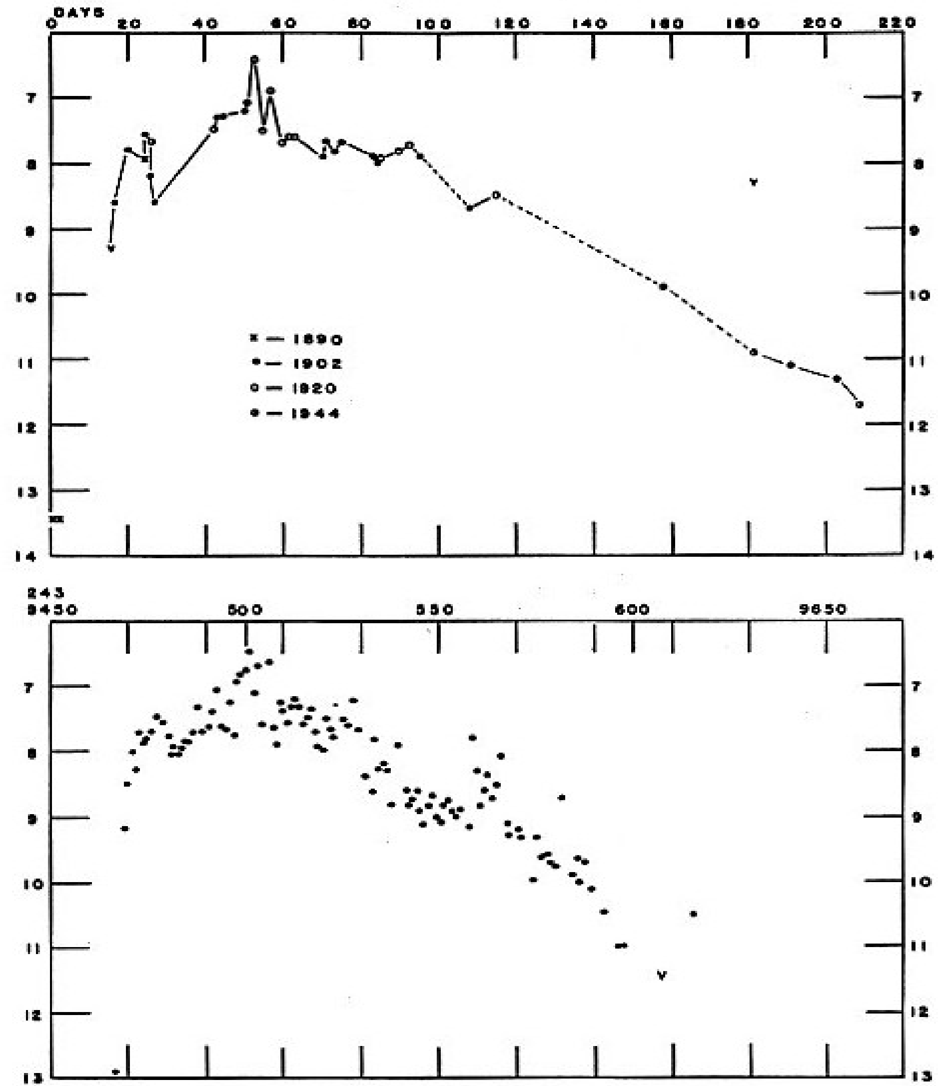
The recurrent nova T Pyx

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 ~ -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 ~ 15.0 to ~ 6.5).

The "quiescent" magnitude m_v has shown some decline (by ~ 0.3 m_v) in the last 50 years.



090031 T PYXIDIS, DAILY MEANS
UPPER — MAX. OF 1890, 1902, 1920 & 1944 COMBINED
LOWER — 1966 MAXIMUM

The continuum energy distribution

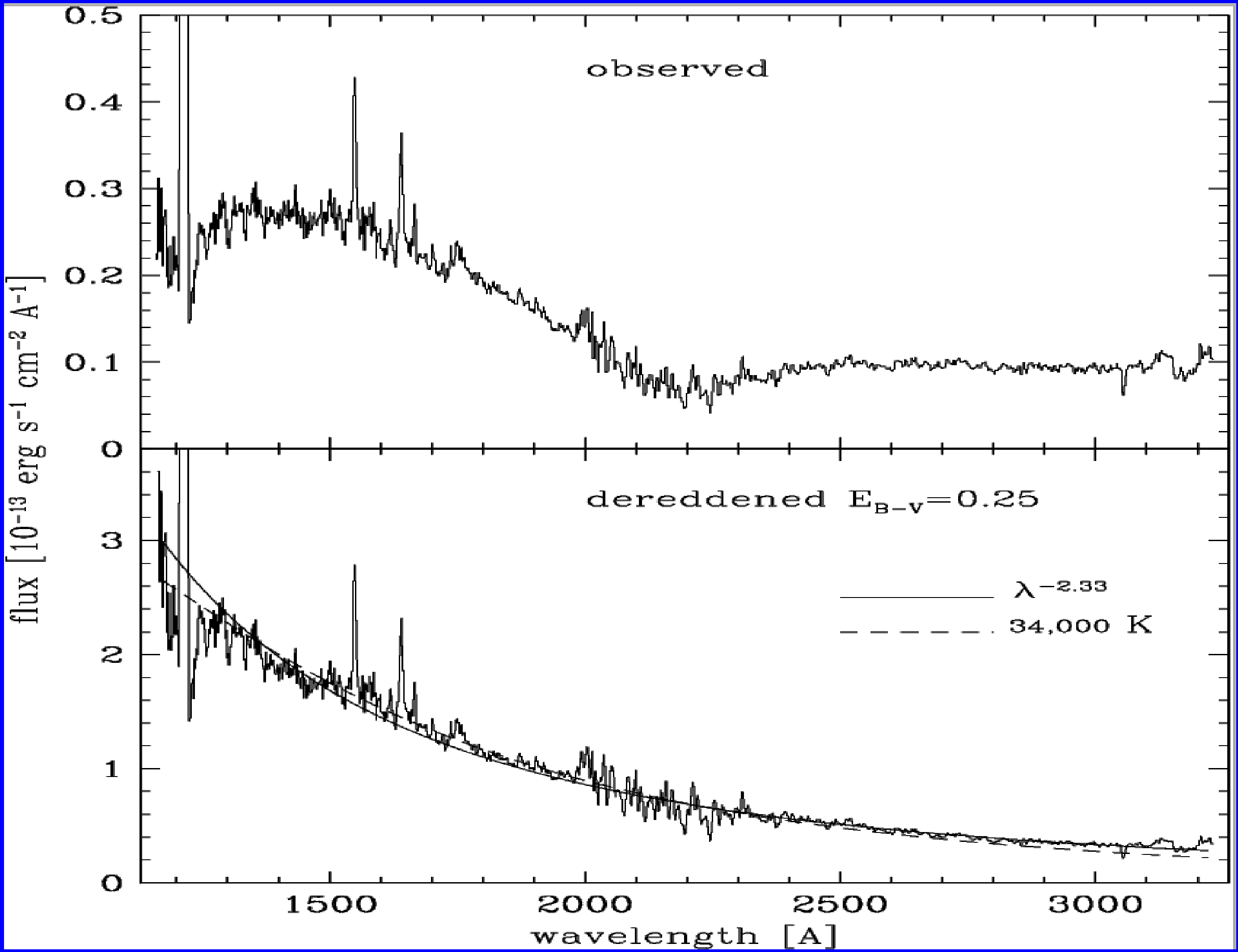
UV observations with IUE started in 1980 and lasted 16 years

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 : $F_\lambda \sim \lambda^{-2.33}$

$F_{(UV)} = 1.94\ 10^{-10}$ erg cm^{-2} s^{-1} (λ-integrated)

T Pyx
in the UV



Average IUE spectrum of T Pyx obtained by co-adding and merging 35 SW and 14 LW IUE spectra

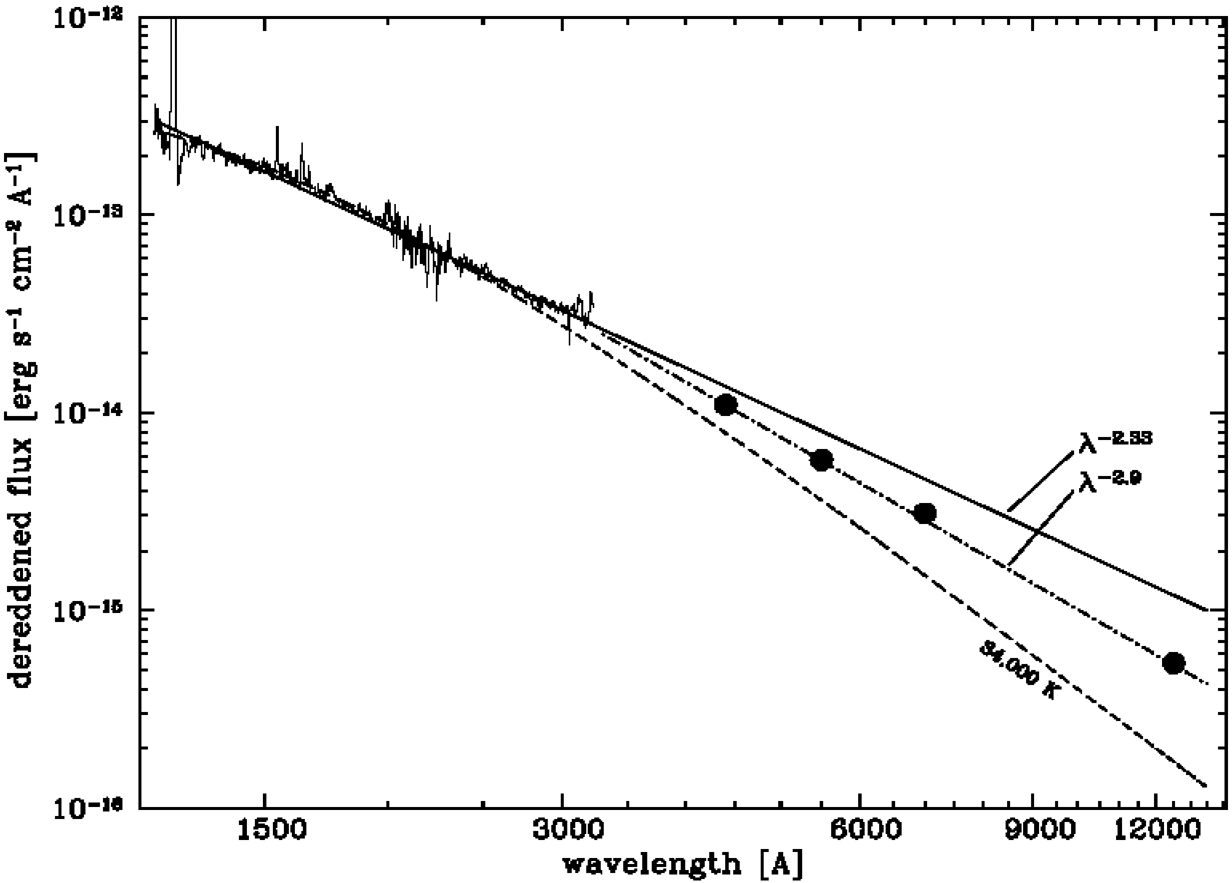


Fig. 9. UV-Opt-IR “spectrum” of T Pyx. The B, V, R, J average fluxes are indicated. The hot source is clearly the main contributor at all wavelengths (the departure from the −2.33 power law at long wavelengths probably indicates that these fluxes arise in the outer part of the disk, where it becomes optically thin or reaches a physical edge). The α=-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~ 25+-5 degrees, M_1~1.25-1.40 M_o

$$\frac{(M_2 \cdot \sin i)^3}{(M_1 + M_2)^2} = 1.037 \times 10^{-7} \cdot K_1^3 \cdot P$$

Distance determined by various MMRD

assumption of L ~ L_{edd} at maximum:

Table 2. The system inclination for M_1 = 1.25-1.40 $M_\odot$ and K_1 =24 ± 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

M_1 ($M_\odot$)	K_1 (km s^{-1})	i (P=$1^h.83$) (degrees)	i (P=$3^h.44$)
1.25	19	22.9	14.7
1.25	24	29.4	18.7
1.25	29	36.4	22.8
1.30	19	23.5	15.0
1.30	24	30.2	19.1
1.30	29	37.4	23.3
1.35	19	24.0	15.4
1.35	24	31.0	19.6
1.35	29	38.4	23.9
1.40	19	24.6	15.7
1.40	24	31.7	20.0
1.40	29	39.5	24.4

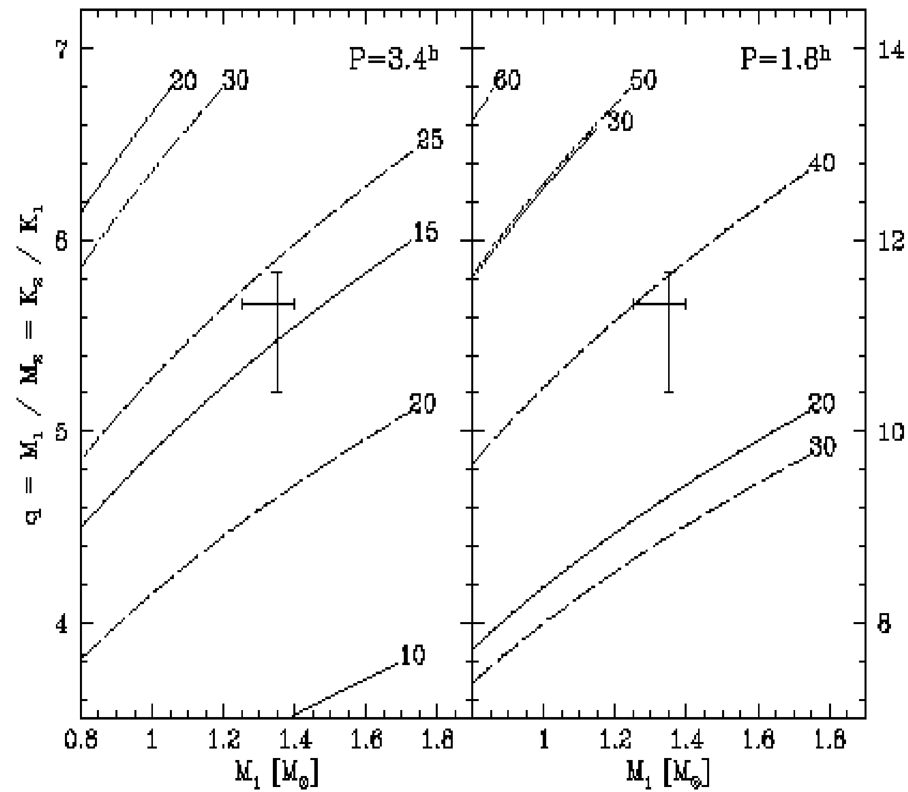


Fig. 1. The q *vs* M_1 plane for $P_h=3^h.439$ and $P_h=1^h.829$. The lines of constant inclination refer to K_1 = 19 km s^{-1} (solid) and K_1 = 29 km s^{-1} (dashed), spanning the error range in the value of K_1. The values of i are indicated. The error bars represent the ranges in M_1 and M_2 discussed in the text.

The disk luminosity and the mass-accretion rate

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

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

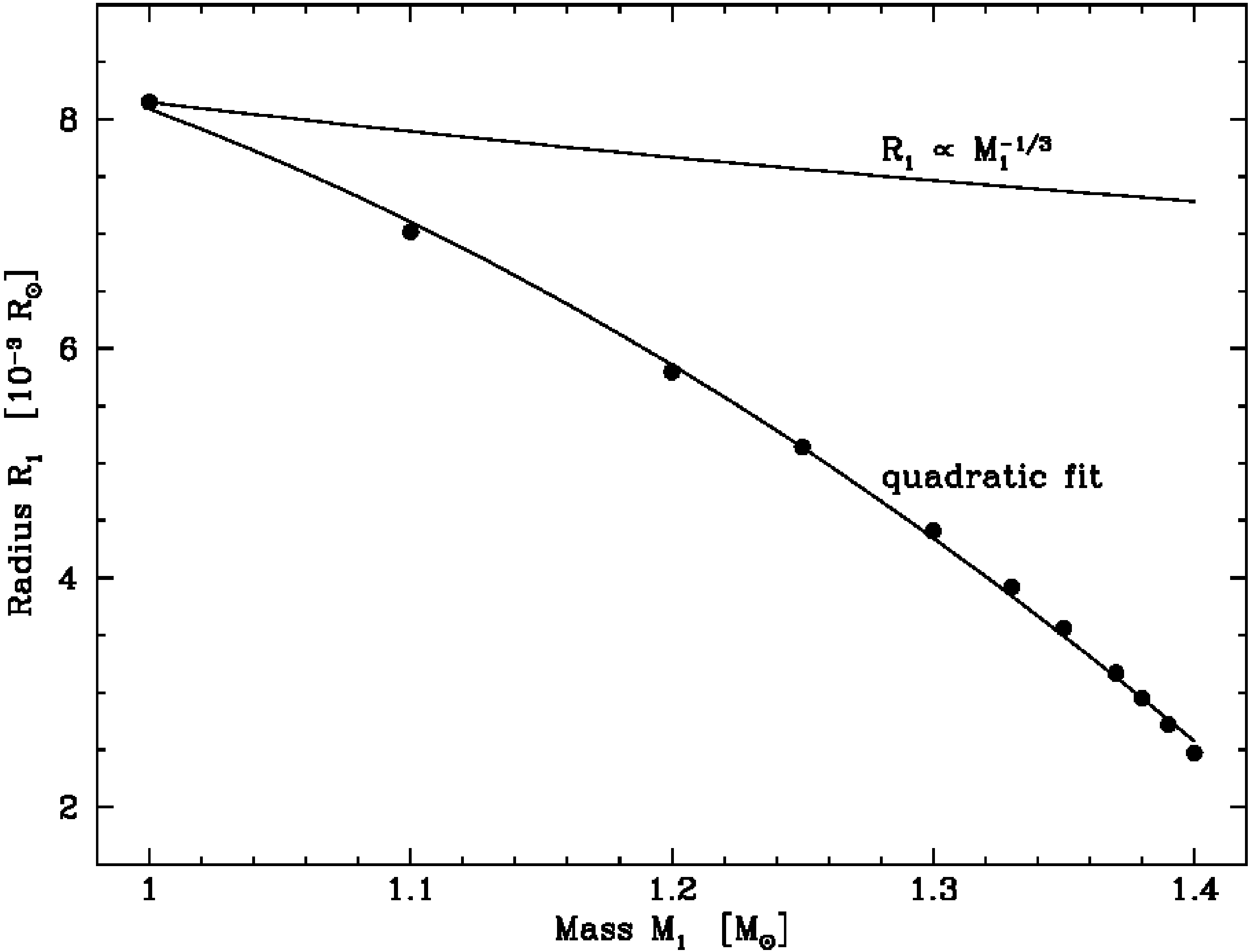
$L_{disk} \sim 2.7 \times 10^{35}$ erg s^{-1} (bolometric, 4π averaged)

THESE VALUES REFER TO THE POST-1967 OB PHASE;

PRE-1967 VALUES ARE ABOUT TWICE AS HIGH !

$M_{dot} = (2R_1 L_{disk})/(G M_1)$ - Note that $R_1 = R_1(M_1)$

Table 5 : $M_{dot} \sim 2.1\ 10^{-8}\ M_o\ yr^{-1}$ (for $M_1 = 1.37\ M_o$)
(PRE-1967)



$R_1 \propto M_1^{-1/3}$
quadratic fit
Radius R_1 [10^{-3} $R_\odot$]
Mass M_1 [$M_\odot$]
2
4
6
8
1
1.1
1.2
1.3
1.4

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

M_1 ($M_{\odot}$)	$\dot{M}_{pre-OB}$ ($10^{-8} M_{\odot} yr^{-1}$)	M_{ign} ($10^{-7} M_{\odot}$)	M_{accr} ($10^{-7} M_{\odot}$)	τ (yrs)
1.00	7.32	77.2	16.10	105.5
1.05	6.56	67.6	14.43	103.0
1.10	5.84	56.2	12.84	96.2
1.15	5.12	45.7	11.26	89.2
1.20	4.40	36.3	9.68	82.5
1.25	3.72	25.7	8.18	69.1
1.30	3.02	16.2	6.64	53.6
1.33	2.62	11.0	5.76	42.0
1.35	2.34	7.69	5.15	32.8
1.36	2.22	6.14	4.88	27.7
1.37	2.08	4.73	4.58	22.7
1.38	1.94	3.44	4.27	17.7
1.39	1.80	2.29	3.96	12.7
1.40	1.68	1.33	3.69	7.9

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 $\Delta M_{\rm crit}$ 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). $\Delta M_{\rm crit}$ decreases with increasing WD mass $M_{\rm WD}$ and increasing accretion rate $\dot{M}_{\rm acc}$ (Prialnik and Kovetz 1995) and is (for a WD temperature $T_{\rm WD}$=10^7 K and for $\dot{M}_{\rm acc} \geq 10^{-10}$ $M_\odot$ yr^{-1}) approximated by

$$\log(\frac{\Delta M_{\rm crit}}{M_\odot}) \approx$$

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

Summarizing....

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

BUT NOTE :

$M_{dot} \sim 2.1\ 10^{-8}\ M_o\ yr^{-1}$ during a 22 years interval gives a total accreted mass : $M_{accr} \sim 4.6\ 10^{-7}\ M_o$

Table 6. A comparison between Yaron et al. (2005) grids and observations.

Param.	Model A	Model-B	Model-C	Model-D	Obs.
M_1	1.36	1.33	1.30	1.40	1.35± 0.05
$\dot{M}$	3.0 10^{-8}	5.0 10^{-8}	7.0 10^{-8}	1.0 10^{-8}	2.4±0.6 10^{-8}
M_{ign}	6.6 10^{-7}	1.03 10^{-6}	1.40 10^{-6}	2.0 10^{-7}	~5.3 10^{-7}
M_{ej}	6.4 10^{-7}	0.93 10^{-6}	1.30 10^{-6}	2.0 10^{-7}	(see Sect. 10.2)
τ	20	20.6	19.8	20.2	22
Ampl.	7.6	6.9	6.6	8.4	8.0
$v_{exp,max}$	-1500	-720	-572	-1760	-2000
$t_{3,vis}$	12	32	45	~ 6	90

Table 4. The basic quantities

Quantity	value
M_v^{max}	-6.81 ± 0.16
m_v^{max}	6.7 ± 0.1
A_v	0.79 ± 0.06
distance	3500 ± 350 pc
m_v	15.30 ± 0.05
M_v	1.79 ± 0.21
i	25 ± 5 degrees
$\Delta m_v(i)$	0.74 ± 0.06
M_v^{corr}	2.53 ± 0.23
L_{UV}	74 ± 15 $L_{\odot}$
L_{disk}	70 ± 15 $L_{\odot}$
M_1	$\sim$ 1.36 $M_{\odot}$
$\dot{M}$	$1.1 \pm 0.25 \times 10^{-8}$ $M_{\odot}$ yr^{-1}
$\dot{M}_{pre-OB}$	$2.2 \pm 0.5 \times 10^{-8}$ $M_{\odot}$ yr^{-1}

Anamnesis of the outbursts

Far longer optical decline time (t_3 ~ 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 ~ -1700 +- 300 km s^{-1}

Behavior similar to that observed in "classical" novae: optically thick shell. Instead, most RNe are "emission line" objects at maximum

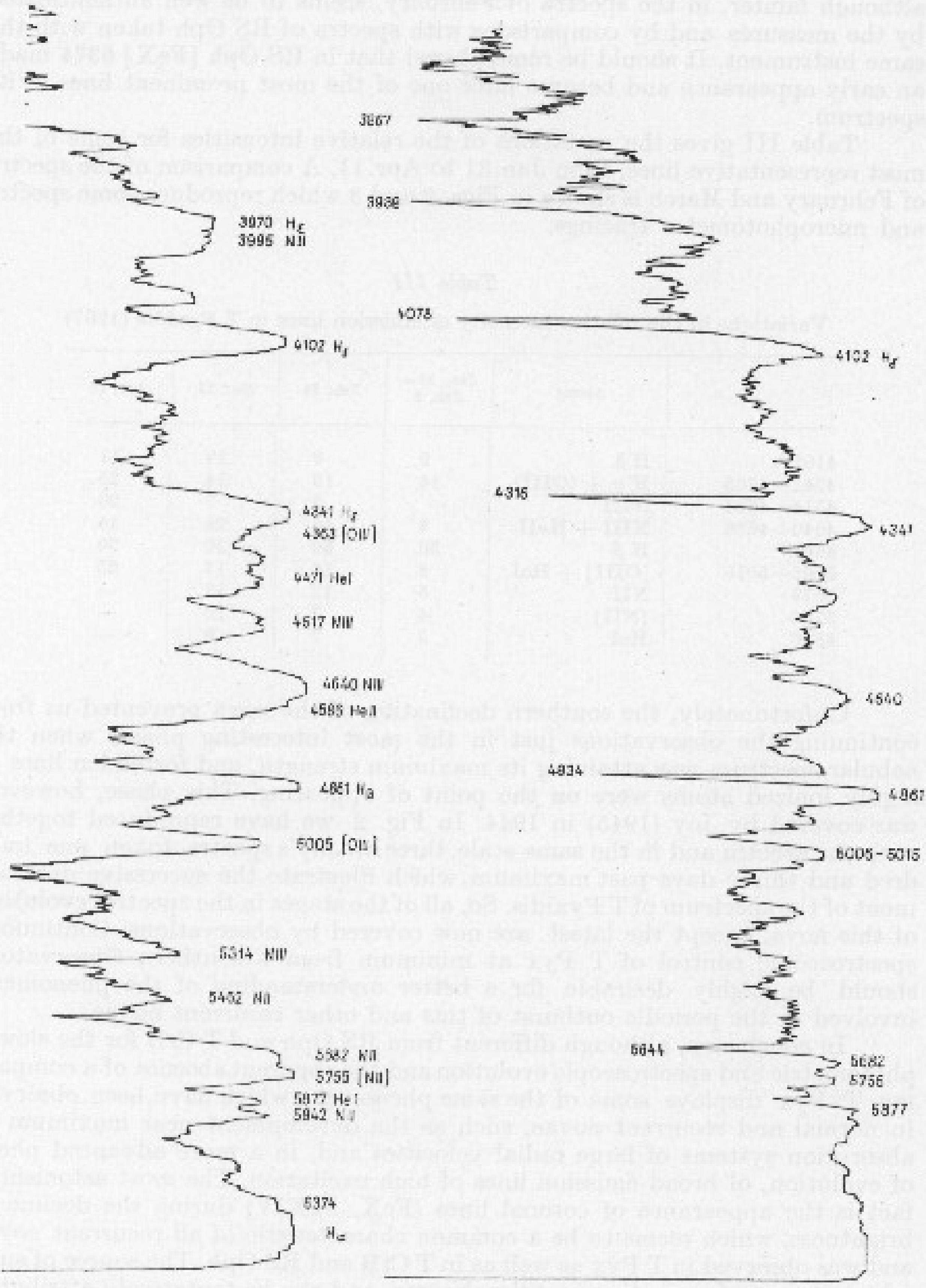
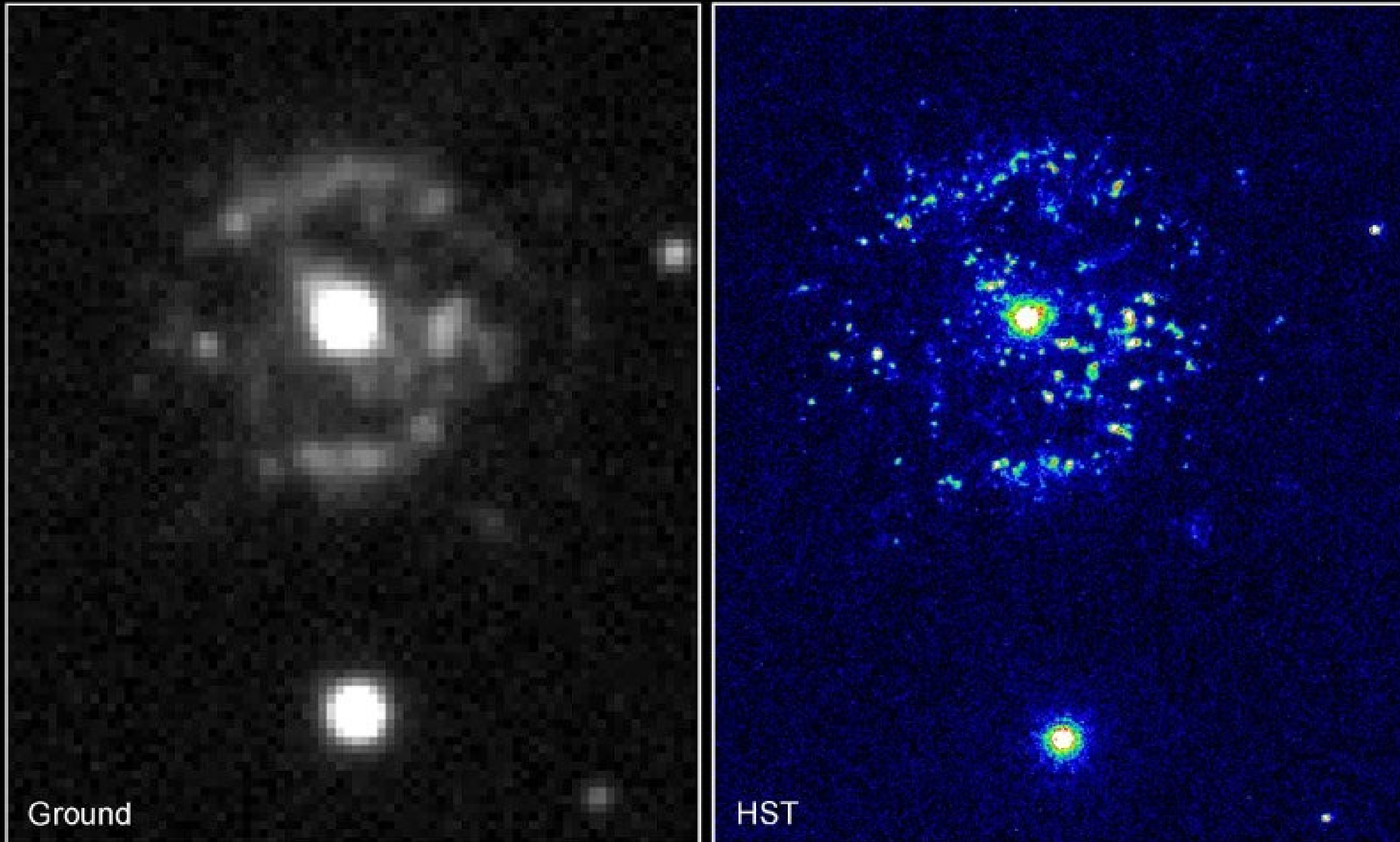


Fig. 3. Comparison of microphotometer tracings of spectra No. 1198 and 1222.



Recurring Nova T Pyxidis HST • WFPC2

PRC97-29 • ST ScI OPO • September 18, 1997

M. Shara and R. Williams (ST ScI), 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_{ej} ~ 7.7 x 10^{14} cm, N_e ~ 10^8 10^9 cm^{-3}, $M_H = N_e$ m $V = 1.5\ 10^{-4}$ M_o

N_h x R_{ej} = 3.0 x 10^{52} x R^{-2} [cm^{-2}] for a shell of 1.0x10^{-4} M_o (Williams, 1994). We have R_2=5.8 10^{29} [cm^2] and N_h x R_{ej} ~5.2 10^{22} [cm^{-2}]. Therefore, $M_{ej} > 10^{-4}$ required to produce an optically thick stage for about 60 days.

log M_{ej} = 0.74 log t2 (Della Valle et al., 2002) gives Mej ~ 10-4

M_{ej} = 6.0 10^{-8} $N_{H,24}$ $(V_{exp}$ x $t_3)^2$ M_o (Shore, 2002, 2008), gives M_{ej} ~ 1.5x10^{-4} – 1.5 x 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 $M_{ej} \sim 10^{-4}\ 10^{-5}\ M_o$

WE HAVE A PROBLEM HERE

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

Apparently, T Pyx has ejected more material than it has accreted. Serious mismatch between the 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".

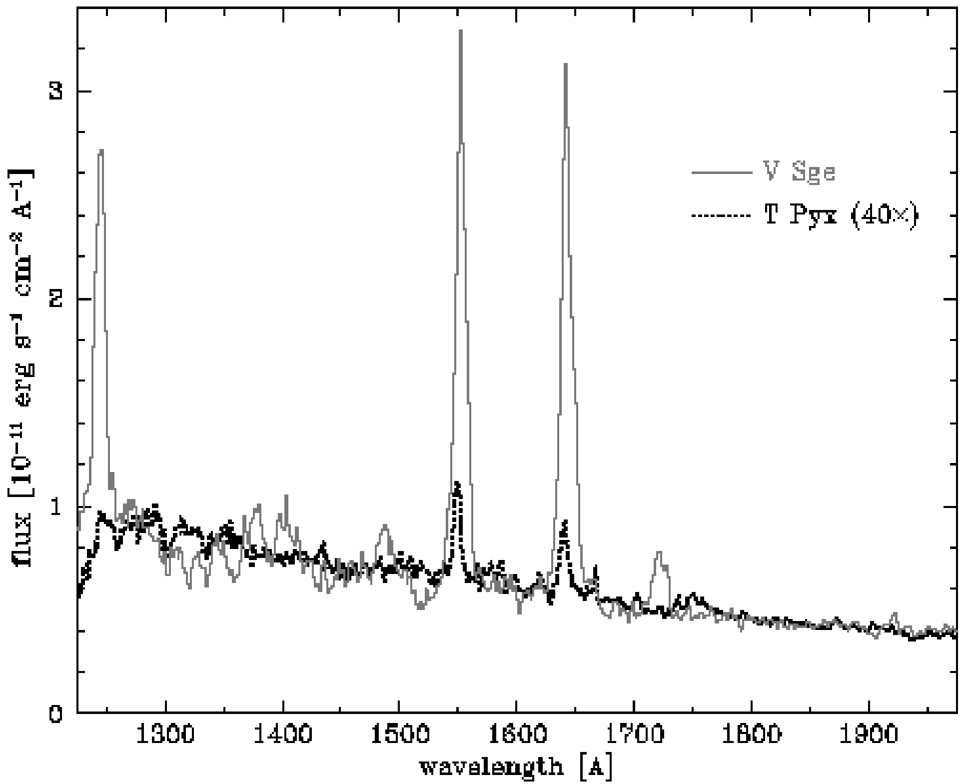


Fig. 3. Comparison between the reddening-corrected SWP spectra of the supersoft source V Sge (continuous line) and of T Pyx (dashed line). The continuum of T Pyx has been scaled to that of V Sge (multiplied by a factor 40). Note the prominence of the high ionization lines of NV λ 1240, CIV λ 1550, HeII λ 1640, and NIV λ 1719 in V Sge, in contrast with their moderate intensity or absence in T Pyx.

The UV spectrum of T Pyx is of much lower strength and excitation as compared to that of V Sge (SSS)

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 ~ 2.4x105 k.

Very weak and flat source.

We predict that, fortunately, any form of stellar suicide in the near future is extremely unlikely

XMM – Newton Observations of T Pyx

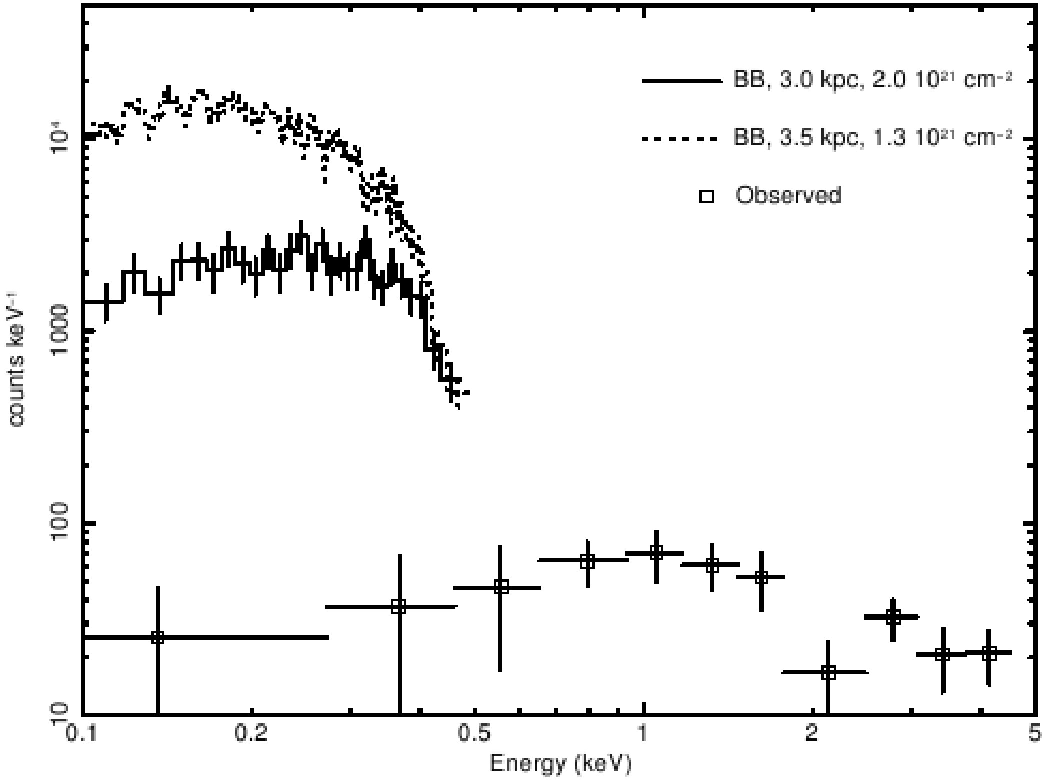


Fig. 4. The XMM-Newton EPIC-pn spectrum of T Pyx (bottom) compared with the simulations of a 20 ksec exposure of a blackbody of 2.4×10^5 K and a luminosity of 1×10^{37} erg s^{-1} computed with two assumptions: a distance of 3500 pc and a reddening E_{B-V}=0.25 (values assumed in this paper, dots), and 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_{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)

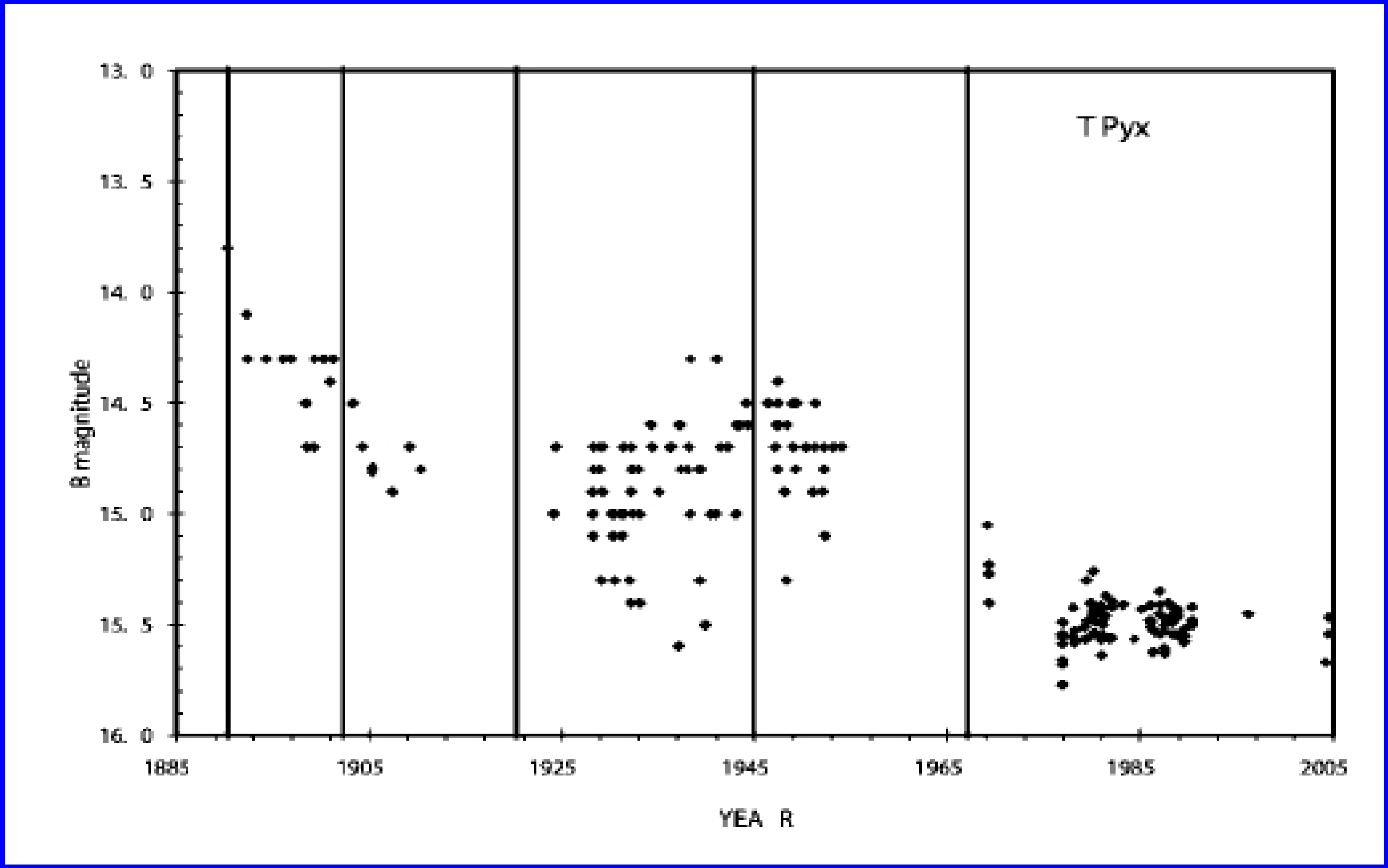


Table 3. M_1, R_1, the factor $\phi = (R_1/M_1)/(R_{1o}/M_{1o})$, the post-1967 mass accretion rate $\dot{M}$ (for L_{disk} = 70 $L_\odot$), the ignition mass, and the recurrence time $\tau = M_{ign}/\dot{M}$ (see Sect. 8).

M_1 ($M_\odot$)	R_1 ($10^{-3} R_\odot$)	ϕ	$\dot{M}$ ($10^{-8} M_\odot yr^{-1}$)	M_{ign} ($10^{-7} M_\odot$)	τ (yrs)
1.00	8.10	1.000	3.66	108.78	297.2
1.05	7.63	0.897	3.28	92.88	283.2
1.10	7.10	0.797	2.92	77.75	266.3
1.15	6.51	0.699	2.56	63.32	247.3
1.20	5.85	0.602	2.20	49.19	223.6
1.25	5.14	0.508	1.86	35.21	189.3
1.30	4.35	0.413	1.51	22.22	147.1
1.33	3.85	0.357	1.31	14.78	112.8
1.35	3.51	0.321	1.17	10.35	88.5
1.36	3.33	0.302	1.11	8.26	74.4
1.37	3.15	0.284	1.04	6.35	61.1
1.38	2.96	0.265	0.97	4.61	47.5
1.39	2.78	0.247	0.90	3.06	34.0
1.40	2.60	0.229	0.84	1.78	21.2

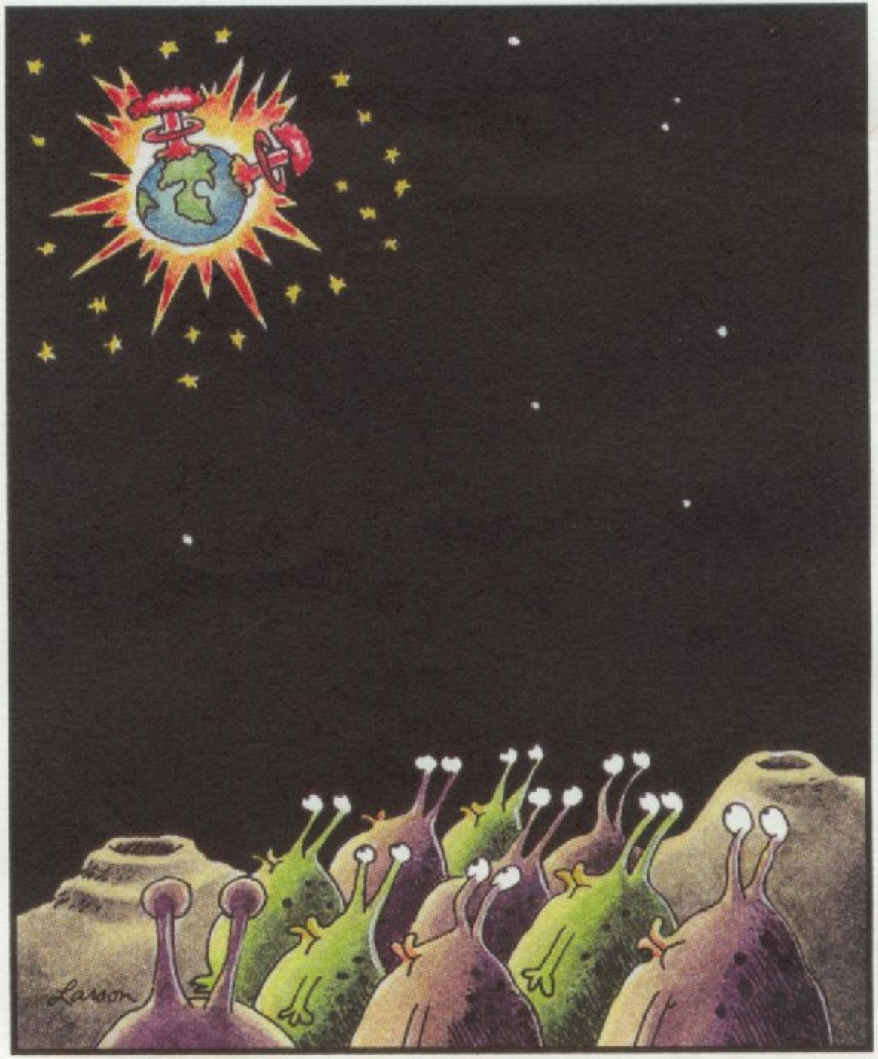
Summary and conclusions

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

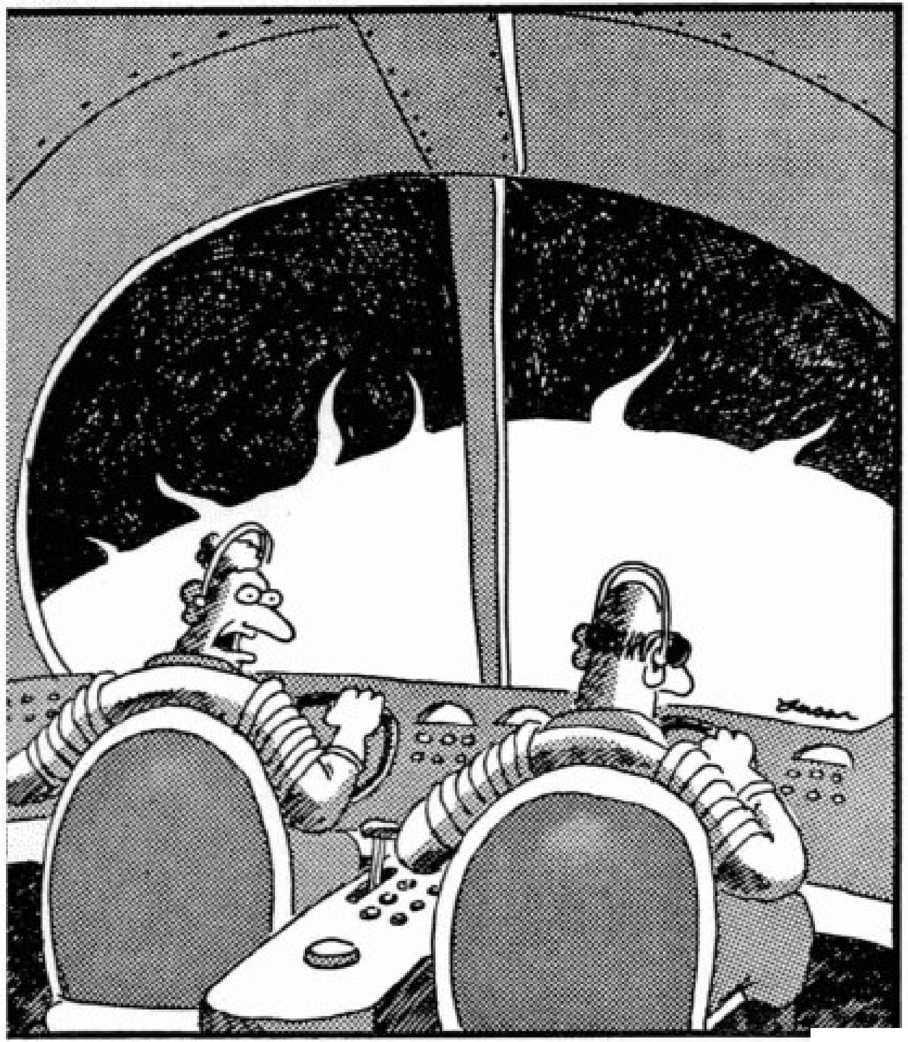
Spectroscopic and photometric data during the outbursts indicate an ejected mass $M_{ej} \sim 5\ 10^{-5}\ M_o$; therefore, T Pyx ejected far more material than it has accreted.

No way to reconcile this discrepancy; note that current nova models predict that $M_{ej} <= M_{accr}$!.

No evolution toward SN Ia, no SSS.

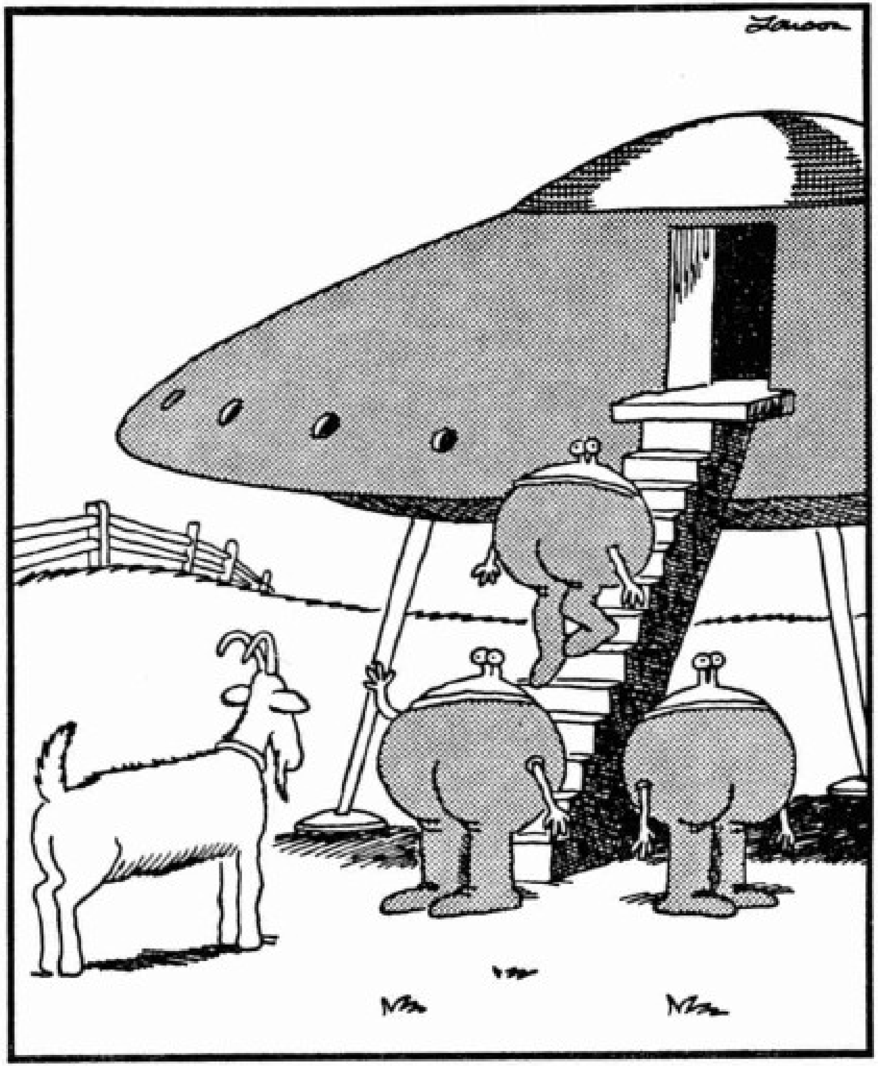


"Ooooooooooooooo!"

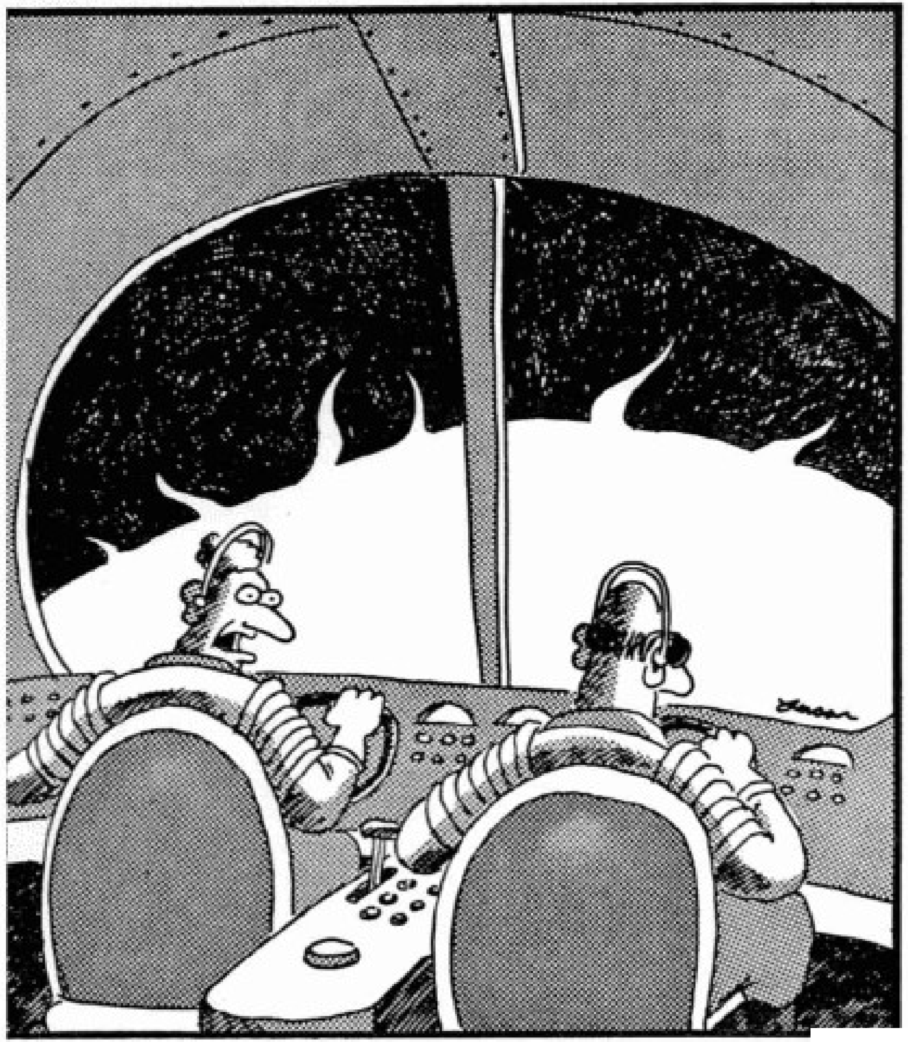


'It's no good, Dawson! We're being sucked in by the white dwarf's gravitational field and there's nothing we can do! ... And let me add those are my sunglasses you're wearing!"

Tempers flare when Professors Carlson and Lazzell, working independently, ironically set their time machines to identical coordinates.

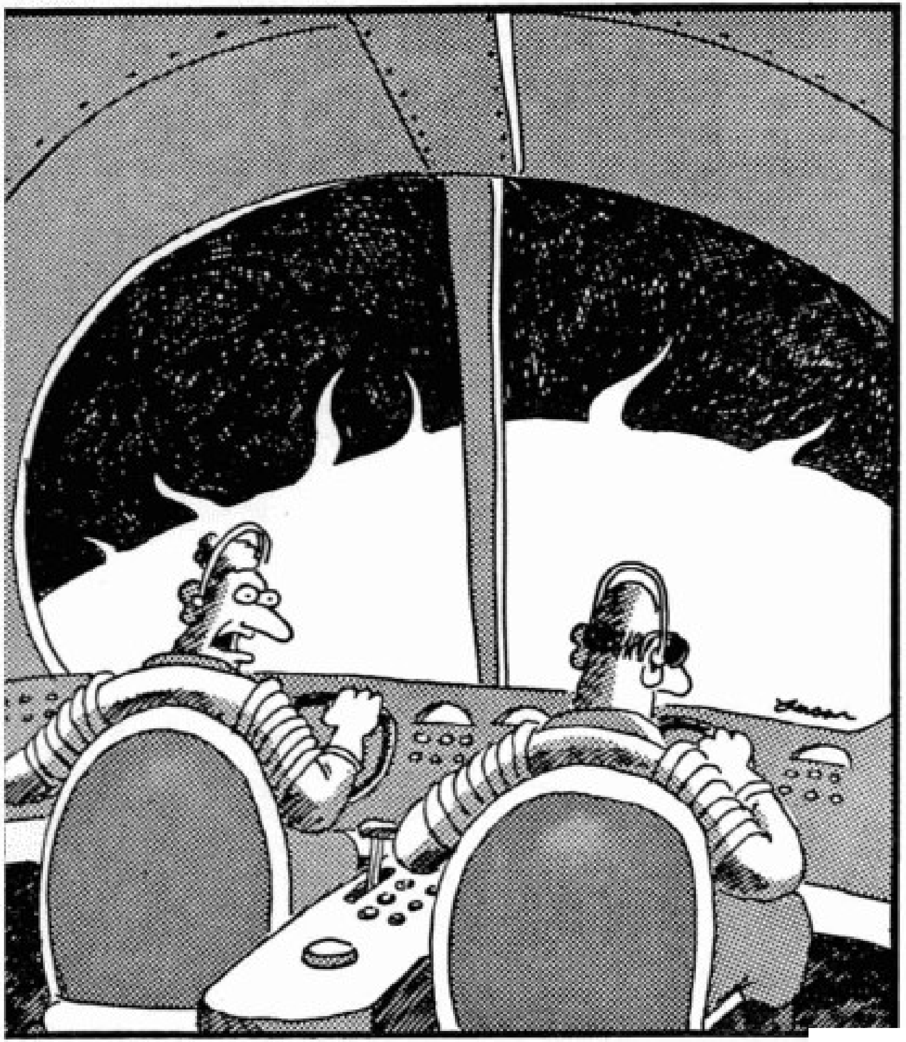


When worlds collide



'It's no good, Dawson! We're being sucked in by the white dwarf's gravitational field and there's nothing we can do! ... And let me add those are my sunglasses you're wearing!"

“Oooooooooooooo!”



'It's no good, Dawson! We're being sucked in by the white dwarf's gravitational field and there's nothing we can do! ... And let me add those are my sunglasses you're wearing!"