X-ray observations of classical novae
Theoretical implications

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- Origin of X-ray emission
- Summary of observational results (novae as SSS)
  ROSAT, Beppo-SAX, XMM-Newton & Chandra, Swift
- Theoretical models: classical and recurrent novae
Origin of X-ray emission (I)

• Residual steady H-burning on top of the white dwarf: photospheric emission from the hot WD:

\[ T_{\text{eff}} \approx (2-10) \times 10^5 \text{K} \quad (L \approx 10^{38} \text{erg/s}) \quad \rightarrow \quad \text{supersoft X-rays} \]

- detected by ROSAT/PSPC in only 3 classical novae, out of 39 observed up to 10 years after explosion:

- duration related to H-burning turn-off time. “Old” theory:
  \[ \tau_{\text{nuc}} \approx 100 \text{yr} \quad \text{observations:} \quad < 9 - 12 \text{ yr} \quad \text{typically:} \quad < 2 \text{yr} \]
Origin of X-ray emission (II)

- Internal (external) shocks in the ejecta: thermal plasma emission


- Reestablished accretion: emission “as a CV” (idem)

  - Hard (but also soft) X-rays, depending on the thermal plasma $T$
Compton degradation of $\gamma$-rays emitted by classical novae **CANNOT** be responsible of their *early hard X-ray emission*:

- Cut-off at 20 keV (photoelectric abs.)
- Fast disappearance: 2 days (w.r.t $T_{\text{max}}$, i.e., before visual outburst)

Observations – Supersoft X-ray emission

- EXOSAT and ROSAT discoveries:
  
  **GQ Mus (1983):** 1st detection of X-rays in a nova, EXOSAT (Ögelman et al. 1984). One of the longest supersoft X-ray phases: 9 yr Ögelman et al. 1993; Shanley et al. 1995; Orio et al. 2001; Balman & Krautter 2001


- BeppoSAX

  **V382 Vel (1999):** supersoft X-ray flux not constant; model atmosphere not a good fit; emission lines from highly ionized nebula (Orio et al. 2002); Chandra grating obs (Burwitz et al., Ness et al.). turn-off 7-9 months
Observations – Supersoft X-ray emission

Chandra and XMM-Newton: grating observations

- **V1494 Aql (1999):** burst and pulsations Drake et al. 2003;

XMM-Newton monitoring campaign: **V5115 Sgr V5116 Sgr 2005**

Swift: Ness 2007, Osborne

- **V723 Cas (1985):** L and T$_{\text{eff}}$ not well determined (BB) Ness et al. 2008 – Still SSS 12 yrs after outburst. Isn’t L a bit small for whole WD emission: $L > 5 \times 10^{36}$ erg/s?

- **V458 Vul (2007), V2491 Cyg (2008):** duration SS phase 10 d!

Ness, Takei, Hachisu

- **RS Oph - recurrent nova:** Bode (Swift), Nelson & Orio, Ness et al, Drake et al. (XMM & Chandra) – 60 days

- **M31 nova survey → Pietsch**
<table>
<thead>
<tr>
<th>Target</th>
<th>Discovery date</th>
<th>Date of observation – Time after outburst</th>
<th>Detection</th>
</tr>
</thead>
<tbody>
<tr>
<td>N Sgr 1998 V4633 Sgr</td>
<td>March 22</td>
<td>Oct. 11, 2000 – 934d, 2.6yr Mar. 9, 2001 – 1083d, 3.0yr Sep. 7, 2001 – 1265d, 3.5yr</td>
<td>YES but no SSS</td>
</tr>
<tr>
<td>N Sco 1998 V1142 Sco</td>
<td>October 21</td>
<td>Oct. 11, 2000 – 721 d, 2.0 yr Mar. 24, 2001 – 885 d, 2.4 yr Sep. 7, 2001 – 1052 d, 2.9 yr</td>
<td>2.6±0.3 2.2±0.4 1.2±0.2 (10⁻² cts/s)</td>
</tr>
</tbody>
</table>

- **No supersoft X-ray emission related to residual H-burning detected** → **all novae had already turned-off**
- 3 out of 5 were emitting [thermal plasma (+ BB)] spectrum → ejecta/accretion
<table>
<thead>
<tr>
<th>Target</th>
<th>Discovery date</th>
<th>Date of observation – Time after outburst</th>
<th>Detection</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td>YES marginal: (4.0±0.8)x10^-3 cts/s</td>
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<tr>
<td>N Sgr 2005a V5115 Sgr</td>
<td>March 28</td>
<td>Sep. 27, 2006 – 18months Apr. 4, 2009 – 49 months</td>
<td>YES supersoft source YES but no SSS</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>YES but no SSS</td>
</tr>
<tr>
<td>N Oph 2006a V2575 Oph</td>
<td>February 9</td>
<td>Sep. 4, 2007 – 19 months AO6</td>
<td>NO</td>
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<tr>
<td>N Oph 2006b V2576 Oph</td>
<td>April 6</td>
<td>Oct. 3, 2007 – 18months AO6</td>
<td>NO</td>
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</table>

**Supersoft X-ray emission related to residual H-burning found in 2 novae from 2005 (V5115 Sgr & V5116 Sgr) → novae had not turned off yet**
Nova Sgr 2005 b – V5116 Sgr – 610 days post-outburst

2.97 hours (orbital period)

EPIC MOS1 and MOS2
0.2-0.4 keV band

EPIC MOS1 and MOS2
0.4-0.6 keV band

EPIC MOS1 and MOS2, hardness ratio


CO white dwarf atmosphere:
$N_H=1.3 \times 10^{17} \text{cm}^{-2}, T=6.8 \times 10^5 \text{K}$

LOW: ONe white dwarf atmosphere:
$N_H=(1.3 \pm 0.1) \times 10^{19} \text{cm}^{-2}, T=(6.1 \pm 0.1) \times 10^5 \text{K}$,
$L=4.9 \pm 0.6 \times 10^{32} \text{erg/s (d/10 kpc)}$

HIGH: ONe white dwarf atmosphere:
$N_H=(1.5 \pm 0.2) \times 10^{21} \text{cm}^{-2}, T=(6.1 \pm 0.1) \times 10^5 \text{K}$,
$L=3.9 \pm 0.8 \times 10^{37} \text{erg/s (d/10 kpc)}$
Nova Sgr 2005 b – V5116 Sgr – 610 days post-outburst

RGS spectra

→ see poster Sala et al.

Supersoft X-ray sources: new developments - ESAC, 18-20 May 2009

M. Hernanz
1348 days post-outburst

L=(3-7)x10^{32} \text{ erg/s (10 kpc)}

Swift/XRT light light curve

SSS turn-off: \textbf{2 - 3 years} post-outburst
compatible with Hachisu & Kato (2007) prediction
SUMMARY of XMM-Newton campaign

• 11 novae have been observed between 3 months and 5 years after outburst (9 years)
• 4 non detected and 2 detected marginally
• Only 2, V5115 Sgr 2005a and V51116 Sgr 2005b, were still bright in supersoft X-rays, revealing remaining H-nuclear burning – one of them with a puzzling temporal behavior

• V2487 Oph 1998, clearly shows recovery of accretion in a magnetic CV (most probably an intermediate polar)
• V4633 Sgr 1998 shows either hot ejecta or accretion (or both)
• V2362 Cyg 2006: mainly hard X-rays (ejecta or accretion)
Different behaviours in X-rays of post-outburst novae (1-4 years old), as seen with XMM-Newton:

- supersoft, still burning H (not very often) - V5115 & V5116 Sgr(2005)

  WD properties: $M_{wd}$, $M_{env}$, chem. comp., turnover

  If absent, shows that $M_{ejected} > M_{accreted}$: $M_{wd}$ decreases

- soft and hard X-rays, reaching $E \sim 10$ keV

  ➢ *ejecta* (heated by shocks) - V4633 Sgr 1998: T and n distribution, chemical composition

  ➢ “cataclysmic-like” emission *accretion* - V2487 Oph 1998: accretion disk/stream, (magnetic field, periodicities)
Hydrodynamical models of nova explosions

### Initial Parameters and Main Characteristics of ONe Nova Models

<table>
<thead>
<tr>
<th>Parameter</th>
<th>ONe1</th>
<th>ONe2</th>
<th>ONe3</th>
<th>ONe4</th>
<th>ONe5</th>
<th>ONe6</th>
<th>ONe7</th>
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<tbody>
<tr>
<td>$M_{\text{env}}$ ($M_\odot$)</td>
<td>1.00</td>
<td>1.15</td>
<td>1.15</td>
<td>1.15</td>
<td>1.25</td>
<td>1.35</td>
<td>1.35</td>
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<tr>
<td>Mixing (%)</td>
<td>50</td>
<td>25</td>
<td>50</td>
<td>75</td>
<td>50</td>
<td>50</td>
<td>75</td>
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<tr>
<td>$\Delta M_{\text{env}}$ ($10^{-5} M_\odot$)</td>
<td>6.4</td>
<td>3.2</td>
<td>3.2</td>
<td>3.5</td>
<td>2.2</td>
<td>0.54</td>
<td>0.58</td>
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<tr>
<td>$t_{\text{acc}}$ ($10^5$ yr)</td>
<td>3.3</td>
<td>1.9</td>
<td>1.9</td>
<td>2.1</td>
<td>1.3</td>
<td>0.31</td>
<td>0.33</td>
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<tr>
<td>$t_{\text{rise}}$ ($10^6$ s)</td>
<td>20</td>
<td>46</td>
<td>13</td>
<td>11</td>
<td>6.8</td>
<td>2.5</td>
<td>2.1</td>
</tr>
<tr>
<td>$\epsilon_{\text{nuc, max}}$ ($10^{16}$ ergs g$^{-1}$ s$^{-1}$)</td>
<td>0.29</td>
<td>0.36</td>
<td>0.76</td>
<td>2.4</td>
<td>2.1</td>
<td>19</td>
<td>14</td>
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<td>$T_{\text{max}}$ ($10^8$ K)</td>
<td>1.98</td>
<td>2.21</td>
<td>2.19</td>
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<td>2.44</td>
<td>3.24</td>
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<td>$t_{\text{max}}$ (s)</td>
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<td>828</td>
<td>540</td>
<td>305</td>
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<td>150</td>
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<td>$\Delta M_{\text{ejec}}$ ($10^{-5} M_\odot$)</td>
<td>4.7</td>
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<td>2.6</td>
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<td>4100</td>
<td>6000</td>
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<td>$v_{\text{ejec}}$ (km s$^{-1}$)</td>
<td>1600</td>
<td>2100</td>
<td>2400</td>
<td>2500</td>
<td>1.4</td>
<td>0.44</td>
<td>0.34</td>
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<tr>
<td>$K$ ($10^8$ ergs)</td>
<td>1.3</td>
<td>1.1</td>
<td>1.2</td>
<td>1.9</td>
<td>1.4</td>
<td>0.9</td>
<td>1.3</td>
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</table>

- H mass fraction: $X$ 0.53 0.35 0.18  
- Global metallicity: $Z$ 0.27 0.50 0.74  
- $M_{\text{env}}-M_{\text{ejec}}$ ($10^{-5} M_\odot$): $M_{\text{rem}}$ 0.9 1.3 0.9  
- Luminosity ($10^4 L_\odot$): $L_{\text{plateau}}$ 4.3 4.9 5.4  
- time (turn-off) (yrs): $\tau_{\text{nuc}}$ 8.9 7.4 2.4 too long  

Starrfield 1998

\[
\tau_{\text{nuc}} = 400 \left( \frac{M_H}{10^{-4} M_\odot} \right) \left( \frac{L}{2 \times 10^4 L_\odot} \right)^{-1} \text{ yr}
\]


Supersoft X-ray sources: new developments - ESAC, 18-20 May 2009

M. Hernanz
Fig. 1. Total luminosity (left panel) and envelope mass (right panel) versus effective temperature for our white dwarf envelope models: ONe75 (dotted line), ONe50 (short dash), ONe25 (long dash), and CO50 (short dash–dot). Effective temperature is given in eV, \( kT_{\text{eff}} \) (eV) = \( 8.617 \times 10^{-5} T_{\text{eff}} \) (K). Solid lines indicate envelopes without convective regions. Five series of models are plotted for each chemical composition, corresponding to total masses 0.9, 1.0, 1.1, 1.2, and 1.3 \( M_\odot \). A line indicating the luminosity–effective temperature relation for constant photospheric radius is over-plotted in left panel for comparison.

Sala & Hernanz, A&A 2005
<table>
<thead>
<tr>
<th>Model</th>
<th>$M_e$</th>
<th>$L^{\text{plateau}}$</th>
<th>$kT_{\text{eff}}^{\text{max}}$</th>
<th>$T_{\text{eff}}^{\text{max}}$</th>
<th>$M_{\text{env}}^{\text{max}}$</th>
<th>$M_{\text{env}}^{\text{min}}$</th>
<th>$\Delta t_{\text{10 eV}}$</th>
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<tr>
<td></td>
<td>($M_\odot$)</td>
<td>($10^4 L_\odot$)</td>
<td>(eV)</td>
<td>($10^3$ K)</td>
<td>($10^{-6} M_\odot$)</td>
<td>($10^{-6} M_\odot$)</td>
<td>(days)</td>
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<td>ONe75</td>
<td>0.9</td>
<td>3.9</td>
<td>57</td>
<td>6.6</td>
<td>2.3</td>
<td>1.9</td>
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<td>1.0</td>
<td>4.4</td>
<td>64</td>
<td>7.4</td>
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<td>(X = 0.18)</td>
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<td>5.2</td>
<td>73</td>
<td>8.5</td>
<td>0.84</td>
<td>0.71</td>
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<td>1.2</td>
<td>5.7</td>
<td>86</td>
<td>9.9</td>
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<td>1.3</td>
<td>6.2</td>
<td>103</td>
<td>11.9</td>
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<td>0.15</td>
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<td>ONe50</td>
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<td>(X = 0.35)</td>
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<td>7.0</td>
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<td>1.2</td>
<td>78</td>
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<td>1.1</td>
<td>4.7</td>
<td>69</td>
<td>8.0</td>
<td>0.99</td>
<td>0.72</td>
<td>37</td>
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<td>1.2</td>
<td>5.2</td>
<td>81</td>
<td>9.4</td>
<td>0.45</td>
<td>0.35</td>
<td>14</td>
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<td>1.3</td>
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<td>98</td>
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<td>ONe25</td>
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<td>0.39</td>
<td>36</td>
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<td>5.2</td>
<td>93</td>
<td>10.8</td>
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<td>0.16</td>
<td>12</td>
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<td>CO50</td>
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<td>54</td>
<td>6.2</td>
<td>2.9</td>
<td>1.9</td>
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<td>(X = 0.35)</td>
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<td>7.1</td>
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<td>90</td>
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<td>70</td>
<td>8.1</td>
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<td>5.4</td>
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<td>99</td>
<td>14.7</td>
<td>0.19</td>
<td>0.15</td>
<td>6</td>
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</tbody>
</table>

\footnote{Time needed for the envelope to evolve from $kT_{\text{eff}} \approx kT_{\text{eff}}^{\text{max}} - 10$ eV to $kT_{\text{eff}}^{\text{max}}$.}
$L_{\text{plateau}}$ depends on $M_{\text{wd}}$ but also on $H$ content

\[
L_{\text{One}}^{\text{plateau}} (L_\odot) \approx 5.95 \times 10^4 \left( \frac{M_\odot}{M_{\text{wd}}} - 0.536 X_H - 0.14 \right)
\]

1.15 $M_\odot$ - ONe 50%

$L = 4.9 \times 10^{-4} L_\odot$

Sala & Hernanz, A&A 2005
$T_{\text{eff \ (max)}}$ depends on $M_{\text{wd}}$ but also on H content
$\log M_{\text{env}}^{\text{max}}(M_\odot) \simeq 0.42 X_H - \left(\frac{M_c}{M_\odot} - 0.13\right)^3 - 5.26$

$M_{\text{env}}^{\text{max}}$ depends on $M_{\text{wd}}$ but also on H content

Example: $1.15 M_\odot$ - ONe 50%

$L = 4.9 \times 10^{-4} \, L_\odot$ - $M_{\text{env}} = 7 \times 10^{-7} \, M_\odot$ (steady bur.) $\ll 1.3 \times 10^{-5} \, M_\odot$ (hydro models JH98)

- turn-off time $\approx \tau_{\text{nuc}} = 0.4 \, \text{yr} \ll 7.4 \, \text{yr}$ in better agreement with observations

- remnant H-rich envelope masses should be significantly reduced after outburst

Tuchmann & Truran (1998)
Quasi-static temporal evolution

\[ \Delta t = \epsilon \frac{\Delta M_{\text{env}} X_H}{L} \]
Quasi-static temporal evolution

\[ \Delta t = \epsilon \frac{\Delta M_{\text{env}} X_H}{L} \]
Constraints on models from ROSAT observations of V1974 Cyg 1992:

supersoft source during various months
Nova Cyg 1992. ROSAT observations

Day 255

F = 6 \times 10^{-10} \text{erg/cm}^2/\text{s}

kT_{BB} = 21 \text{eV}, kT_{br} = 0.32 \text{keV}

Day 434

F = 3.2 \times 10^{-9} \text{erg/cm}^2/\text{s}

kT_{BB} = 30 \text{eV} (kT_{br} = 0.002 \text{keV})

Day 511

F = 3.1 \times 10^{-9} \text{erg/cm}^2/\text{s}

kT_{BB} = 30 \text{eV} (kT_{br} = 0.002 \text{keV})

Day 635

F = 3 \times 10^{-11} \text{erg/cm}^2/\text{s}

kT_{BB} = 20 \text{eV}, kT_{br} = 0.29 \text{keV}
V1974 Cyg: ROSAT’s soft X-ray light curve

rise: until day 147
plateau: 18 months
BB fits not good – too large L

ONe WD atmospheres
MacDonald & Vennes
Table 1. ROSAT observational results for V1974 Cyg.

<table>
<thead>
<tr>
<th>Day after outburst</th>
<th>$K^{a,b}$</th>
<th>$R_{\text{photos}}^{c}$</th>
<th>$kT_{\text{eff}}^{b}$</th>
</tr>
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<tbody>
<tr>
<td>A 255</td>
<td>0.6–2.4</td>
<td>1.8–3.7</td>
<td>34.3–38.3</td>
</tr>
<tr>
<td>B 261</td>
<td>0.3–0.9</td>
<td>1.3–2.3</td>
<td>38.4–41.8</td>
</tr>
<tr>
<td>C 291</td>
<td>0.4–0.8</td>
<td>1.5–2.1</td>
<td>41.2–44.3</td>
</tr>
<tr>
<td>D 434</td>
<td>0.32–0.36</td>
<td>1.3–1.4</td>
<td>49.4–49.7</td>
</tr>
<tr>
<td>E 511</td>
<td>0.22–0.26</td>
<td>1.1–1.2</td>
<td>50.6–51.0</td>
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</tbody>
</table>

$^a$ Normalization constant of the white dwarf atmosphere model, $K = (R/D)^2$, where $R$ and $D$ are the photospheric radius and the distance to the source.

$^b$ Results from Balman et al. (1998).

$^c$ Photospheric radius for a distance of 2.5 kpc.

Comparison model-observation:
evolution of $T_{\text{eff}}$ & $R$ (or $L$) with time

➢ IMPORTANT:
$T_{\text{eff}}$ max. would directly constrain $M_{\text{wd}}$-chem., independently of distance

Sala & Hernanz, A&A 2005
Models that best explain the supersoft X-ray emission of V1974 Cyg 1992 and its evolution

- $M_{wd}=0.9 \, M_\odot$, 50% mixing with CO core (but V1974Cyg 1992 was a neon nova!)

  or

- $M_{wd}=1.0 \, M_\odot$, 25% mixing with ONe core

[in goog agreement with models of the optical and UV light curve (Kato & Hachisu, 2006)]

- $M_{\text{env}} \sim 2\times10^{-6} \, M_\odot$
Models of recurrent novae – TNR on accreting WDs

Search combinations of initial conditions leading to short recurrence periods:

- $P_{\text{rec}} = \frac{\Delta M_{\text{acc}}}{(dM/dt)} = 21$ years
  - $\Delta M_{\text{acc}}$: required accreted mass on top of the WD to power the outburst through a TNR
  - $M_{\text{wd}}^{\text{ini}}$? Accretion rate? $L_{\text{wd}}^{\text{ini}}$?
  - Accretion rate: related to mass loss from the red giant wind
- effective $dM/dt$ onto the WD: $2 \times 10^{-7} - 10^{-8}$ $M_\odot$/yr
Accreted masses to reach H-ignition conditions

\[
\dot{M} = 10^{-8} \, M_\odot/\text{yr}
\]

critical accreted mass does not depend only on \( M_{\text{wd}} \)

\[M_{\text{acc}} \left(10^{-6} \, M_\odot\right)\]

\[L_{\text{ini}}\]

\[M_{\text{WD}} \left(10^{-6} \, M_\odot\right)\]

Hernanz & José 2008
Recurrence Periods

\[ P_{\text{rec}} (\text{yr}) \]

\[ M = 10^{-8} M_\odot/\text{yr} \]

\[ L_{\text{ini}} \]

\[ M = 2 \times 10^{-7} M_\odot/\text{yr} \]

\& \[ L = 10^{-2} L_\odot \]

RS Oph: \( P_{\text{rec}} = 21 \text{ yr} \)

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# Models for the RS Oph outburst

\[ M_{\text{wd}} = 1.35-1.38 \, M_\odot \, - \, \frac{\text{d}M}{\text{d}t} = 2 \times 10^{-7} \, M_\odot/\text{yr} \, - \, L = 10^{-2} \, L_\odot \]

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Value</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>( M_{\text{wd}} (M_\odot) ) - ONe</td>
<td>1.35</td>
<td>1.38</td>
<td>No mixing; solar accretion</td>
</tr>
<tr>
<td>( T_{\text{peak}}(10^8 K) )</td>
<td>2.8</td>
<td>3.1</td>
<td></td>
</tr>
<tr>
<td>( M_{\text{acc}} (M_\odot) )</td>
<td>4.7 \times 10^{-6}</td>
<td>2.0 \times 10^{-6}</td>
<td></td>
</tr>
<tr>
<td>( M_{\text{eject}} (M_\odot) )</td>
<td>3.0 \times 10^{-6}</td>
<td>1.3 \times 10^{-6}</td>
<td></td>
</tr>
<tr>
<td>( t_{\text{TOT}} )</td>
<td>24 yr</td>
<td>10.4 yr</td>
<td></td>
</tr>
<tr>
<td>( \Delta M_{\text{wd}} (M_\odot) )</td>
<td>1.7 \times 10^{-6}</td>
<td>0.7 \times 10^{-6}</td>
<td></td>
</tr>
<tr>
<td>36% of ( M_{\text{acc}} )</td>
<td>35% of ( M_{\text{acc}} )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \Delta t ) (to ( M_{\text{Chandra}} ))</td>
<td>6.9 \times 10^5 yr</td>
<td>2.9 \times 10^5 yr</td>
<td></td>
</tr>
</tbody>
</table>

\( M_{\text{wd}} \) increases **BUT ONe WDs do not explode as SNIa**

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Supersoft X-ray sources: new developments - ESAC, 18-20 May 2009
Supersoft X-ray light curve of the recurrent nova RS Oph (Swift observations, Bode et al. 2006)

$M_{wd} = 1.35 \, M_\odot$

$M_{env} = 4 \times 10^{-6} \, M_\odot$

Kato & Hachisu, 2007

**FIG. 3.**—Same as those in Fig. 2, but together with the visual light curves. Hydrogen content in the envelope is $X = 0.12$ (dashed lines) and $X = 0.17$ (solid lines). These two models predict visual light curves as shown in the figure. Here we assume a $0.7 \, M_\odot$ red giant with a radius of 35 $R_\odot$ for the companion, an irradiated disk with a radius of 47 $R_\odot$ around the white dwarf, a binary orbital period of 455.72 days, and a binary inclination angle of $i = 33^\circ$ (Hachisu et al. 2006).
Summary

• Variety of behaviours of post-outburst novae: still need more observations.

• Grating spectra are very rich, but still lack of emission models (e.g. WD atmospheres) to interpret them. Blackbodies give wrong L and $T_{\text{eff}}$ & emission is often a mixture of photospheric and ejecta.

• WD Mass and envelope chemical composition (mainly H content) determine duration of SS X-ray phase.

• Duration of SS X-ray phase observed indicates in general $M_{\text{env}} < M_{\text{acc}} - M_{\text{eject}}$ from hydro models $\rightarrow$ mass loss (wind and/or others?)

• Recurrent novae: very short duration of SS phase compatible with small $M_{\text{env}}$. Challenging for theory: narrow parameter range: $M_{\text{wd}}$ extremely large & accretion rate large.

$\rightarrow$ main caveat for RNe as SNIIa scenario: not CO WDs but ONe.