The Recurrent Nova Class of Objects

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RS Ophiuchi (2006) and the recurrent nova phenomenon
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Introduction

- Recurrent Nova (RNe) - Small, heterogeneous group of CVs
- 10 members – 9 Galactic, 1 extragalactic (LMC)
- Classified based on more than one recorded nova outburst
- Outburst luminosity $M_v \leq -5.5$
- Recurrence period ~ decades
- Outburst mechanism – TNR in accretion layer on WD following accretion of matter from companion (e.g. Starrfield et al. 1985, Kato 1990, 1991, Hachisu et al 1999, Hachisu & Kato 2001)
- Accretion rate ~ $10^{-8} – 10^{-7}$ M_{sun} yr^{-1}

Members – Basic Parameters

	m_{max}	m_{min}	t_3 (d)	$<t_{rec}>$ (yr)	dist (kpc)	sec	P_{orb} (d)	Outburst (years)
T CrB	2.0p	10.2v	6.8	80	1.3	M3III	227.67	1866,1946
RS Oph	5.0v	11.5v	9.5	22	1.6	M0/2III	455.72	1898, 1907, 1933, 1945, 1958, 1967, 1985, 2006
V3890 Sgr	8.2v	17.0:	17.0	27	5.2	M5III		1962, 1990
V745 Sco	9.6v	19.0:	14.9	52	4.6	M6III		1937, 1989
U Sco	7.6v	18-19v	4.3	22	6-14	K2IV	1.23056	1863, 1906, 1917, 1936,1979, 1987, 1999
V394 CrA	7.0v	18.8B	10,5.5	38	5.0	K	0.7577	1949, 1987
LMC1990#2	10.9v	20:	5.3	22	49.4			1968, 1990
T Pyx	6.5v	15.2v	88	19	1-4.5		0.0762	1890, 1902, 1920, 1944, 1966
CI Aql	8.9v	17-17.8	36	42		K-MIV:	0.6184	1917, 2000
IM Nor	7.7v	19.5:	>50	82			0.1026	1920, 2002

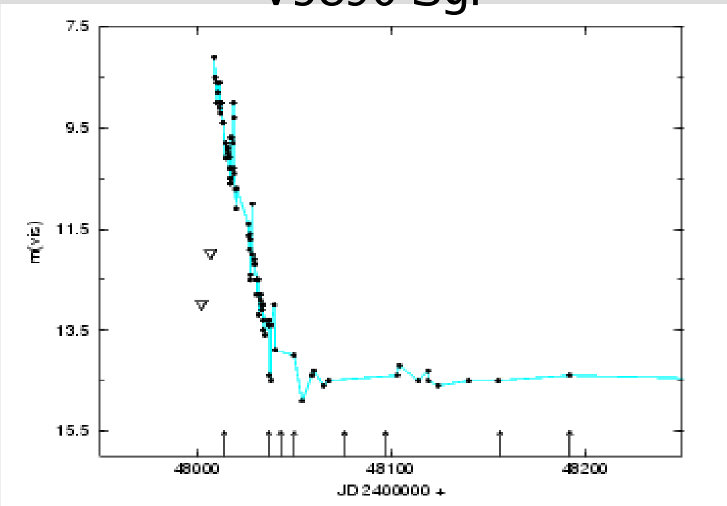
Long period binaries – hot WD + giant secondaries; similar to symbiotic systems
Short period binaries – WD + evolved main sequence secondaries; similar to classical novae

Long Period Binaries - Outburst

Members: RS Oph, TCrB, V3890 Sgr, V745 Sco

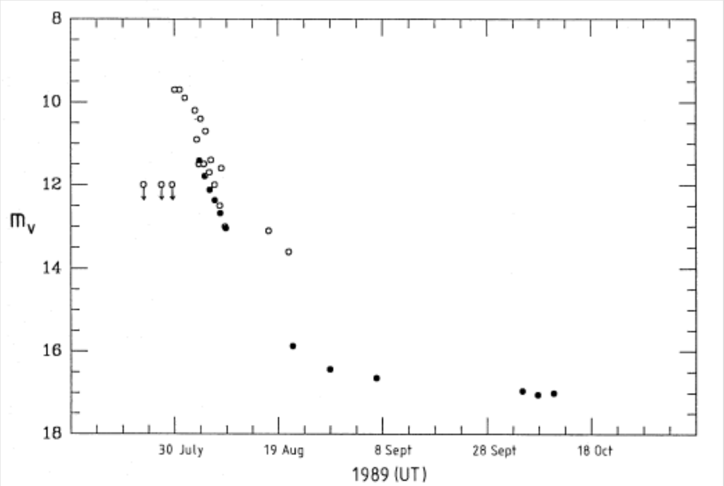
- Outburst properties very homogeneous
- Fast novae with a rate of decline ~0.3 mag/day
- Plateau seen in the optical light curve of RS Oph during decline (Hachisu et al); Secondary maximum seen in T CrB

V3890 Sgr



Williams et al. 2003

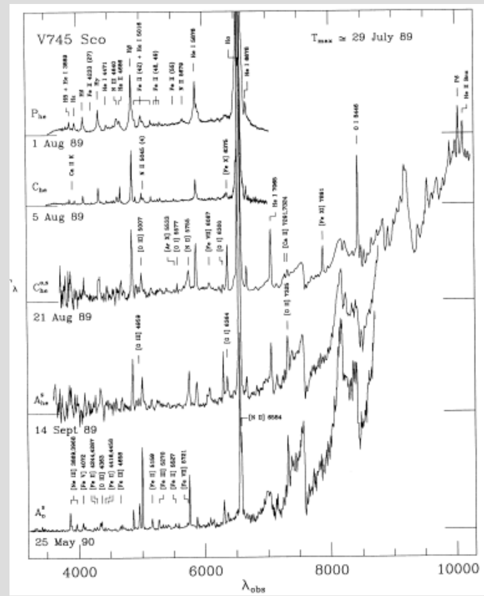
V745 Sco

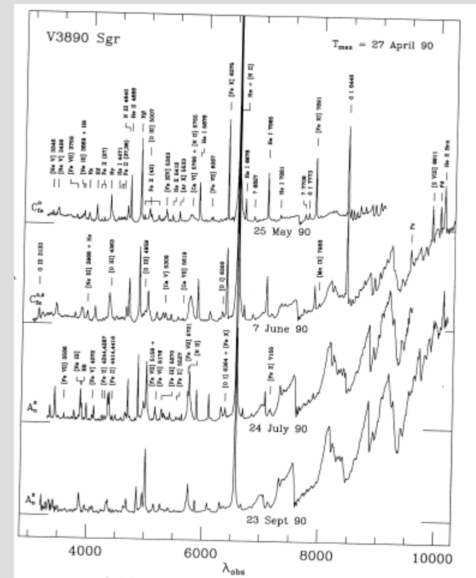


Sekiguchi et al. 1990

Long Period Binaries - Outburst

- Outburst spectrum characterized by broad emission lines (Vexp ~ 4000 km/s) that narrow with time
- Early phase spectrum shows permitted lines; followed by the presence of intense coronal and other high excitation lines; fade as nova enters nebular phase
- Contribution from giant secondary as nova fades
- RS Ophiuchi – most well studied system – X-rays and radio emission also
- Interaction of nova material with red giant wind material
- Mass ejected during outburst ~ 3-4 10^{-6} M_{sun}
- Indications that not all the accreted mass is ejected during outburst

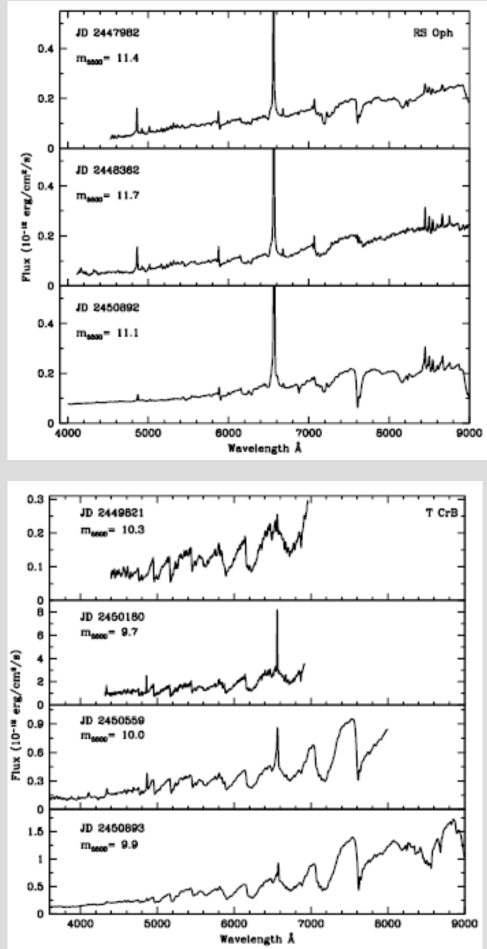




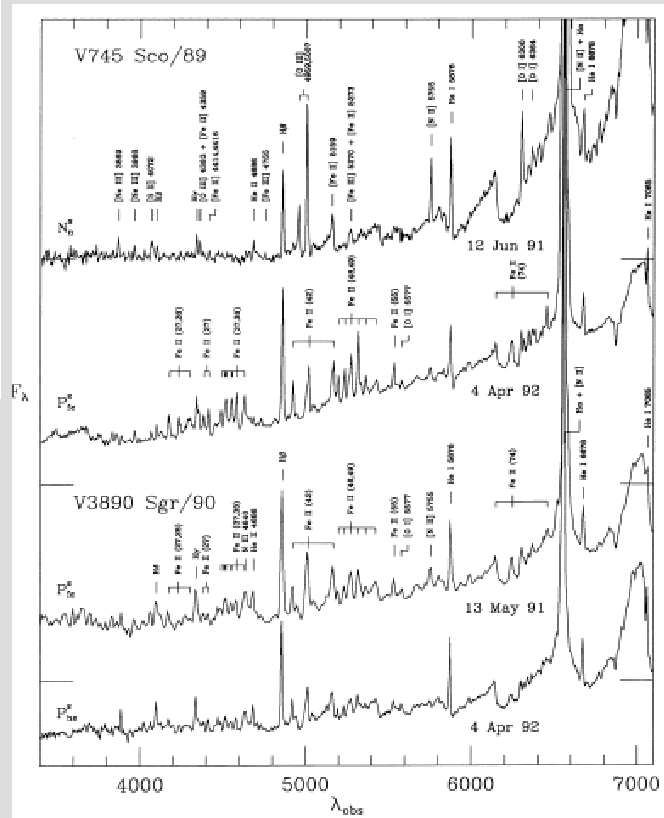
(Williams et al. 1991)

Long Period Binaries - Quiescence

- Optical spectrum - dominated by that of the giant secondary, with emission lines due to HI and He I superposed. FeII, CaII and OI 8446 lines also present (except TCrB). He II lines extremely weak or absent.
- UV spectrum – TCrB shows a relatively hot continuum, with emission lines and shell-like absorption features; RS Oph shows a flat continuum with a few weak emission lines (Selvelli et al, Dobrzycka et al.)



Anupama & Mikolajewska 1999

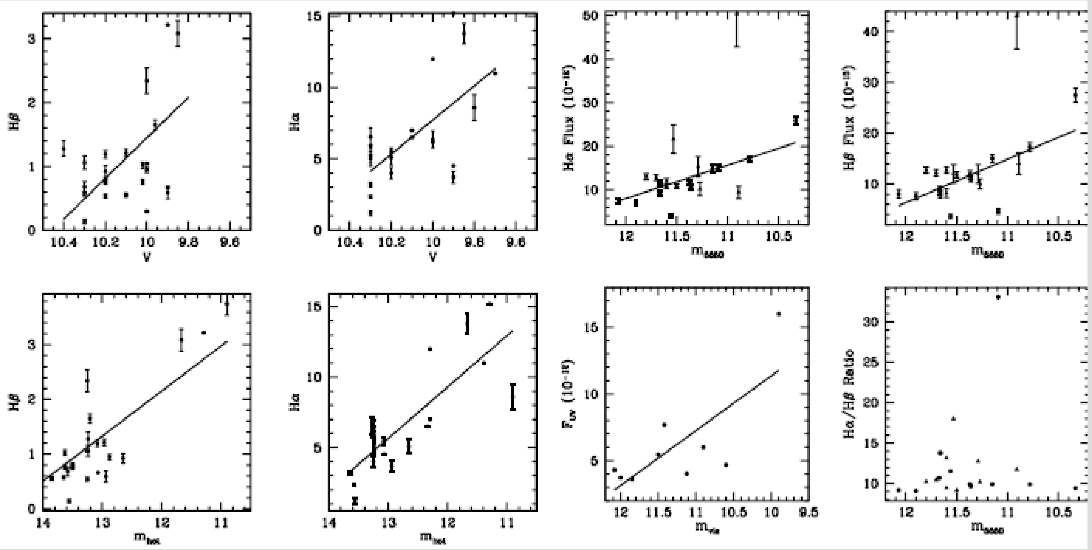


Williams et al. 1994

Long period binaries – Quiescence

- Variability detected in the UBV/visual magnitudes, UV fluxes and optical emission line fluxes on timescales of years (e.g. Iijima 1990; Anupama & Mikolajewska 1999) to minutes (Zamanov et al. 2005).
- Long term variability strongly correlated with the activity of the hot WD
- Observed UV+optical spectral characteristics of the hot component can be explained by a WD+AD embedded in an envelope of wind from the M giant secondary (Anupama & Mikolajewska, Stanishev et al. 2004)
- Variability due to (a) fluctuations in the mass accretion rate – variable mass transfer from companion or disc instability; (b) changes in the column density of the absorbing wind envelope that is optically thick

T CrB RS Oph



Correlation of H and H emission line fluxes in T CrB with the V mag (top left), and the V mag of the hot component m_{hot} (bottom left). Correlation of the H and H emission line fluxes in RS Oph with monochromatic mag at 5550A (top right). Correlation of the total UV flux with visual mag and the Balmer line ratios as a function of m_{5550} (bottom right).
(from Anupama & Mikolajewska 1999)

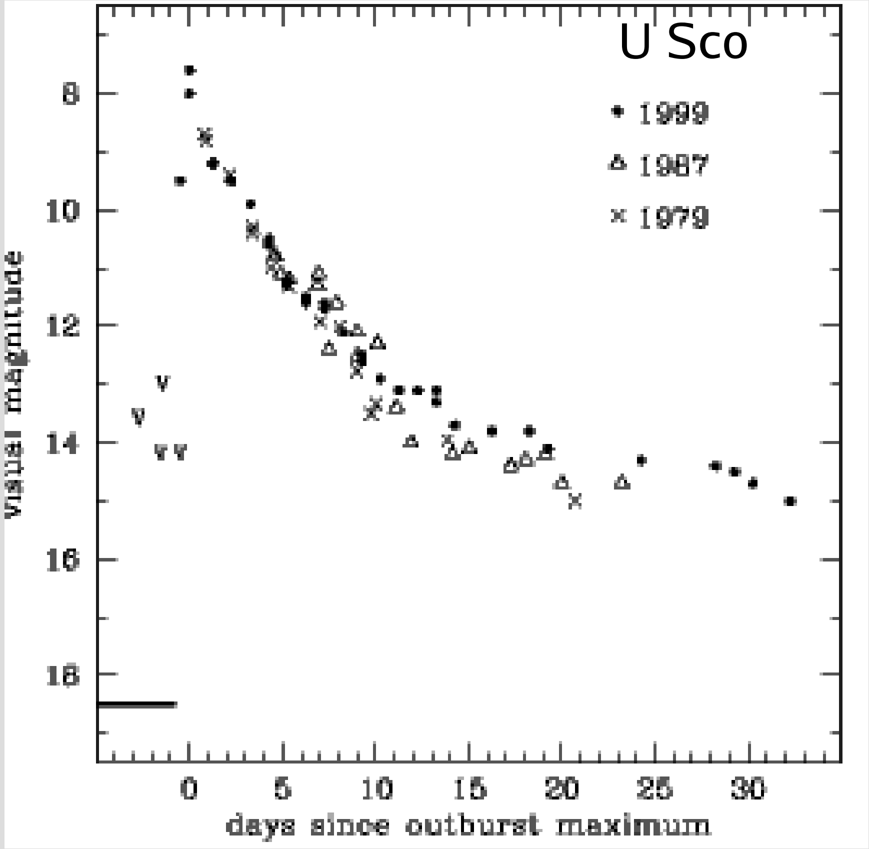
Short Period Binaries

Members: USco, V394 CrA,
Nova LMC 1990#2

CI Aql, IM Nor, T Pyx

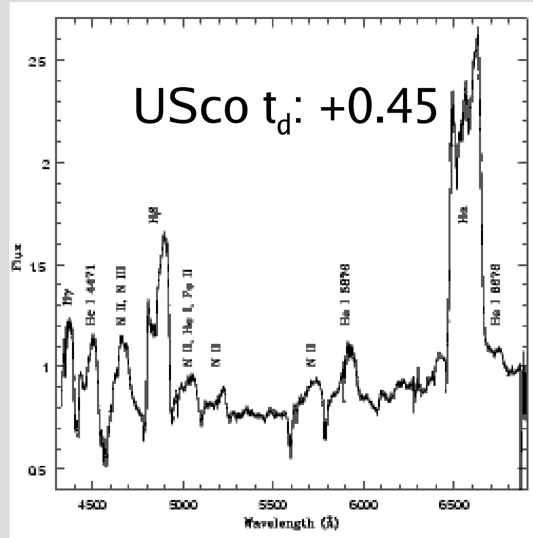
Outburst Properties -
Heterogeneous group

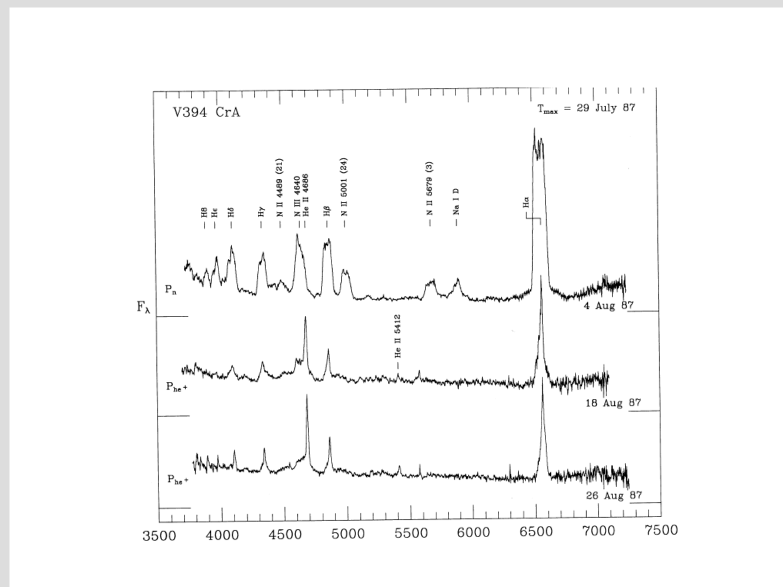
- USco, V394 CrA, Nova LMC 1990#2 very similar
- Very fast novae
- Outbursts very similar



Short Period Binaries – U Sco class (Outburst)

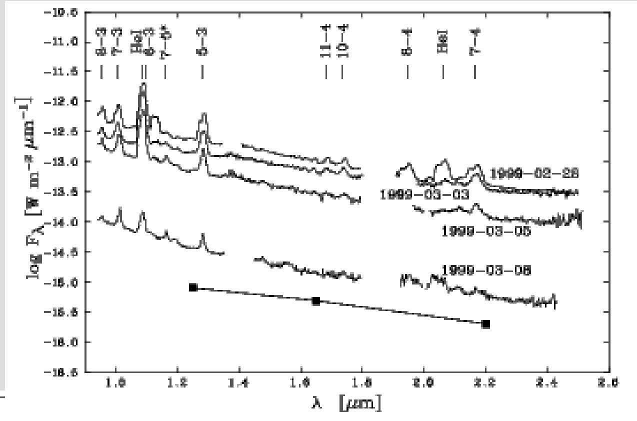
- Spectra characterized by extremely broad emission lines due to hydrogen Balmer, NIII, CIII and He I, with initial FWZI ~ 10000 km/s; (Munari et al. 1999, Anupama & Dewangan 2000)
- Weak P-Cyg detected in U Sco in the spectra < 1day (Iijima 2001; Anupama & Dewangan 2000)
- Rapid increase in the ionization levels

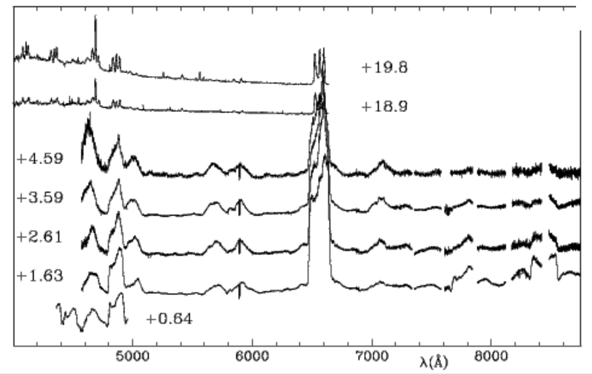


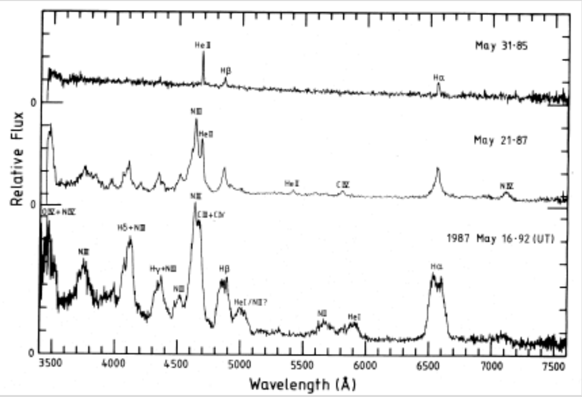


Short period binaries – USco class (outburst)

- IR spectra (U Sco) dominated by hydrogen and helium lines (Evans et al.)
- No forbidden lines detected in the spectra
- Spectral development very similar to He/N class of novae, and also very similar during all outburst
- Helium enriched (0.16-4)
- ~10^{-7} M_{sun} mass ejected during outbursts - observations indicate that not all the accreted material is ejected during the outburst





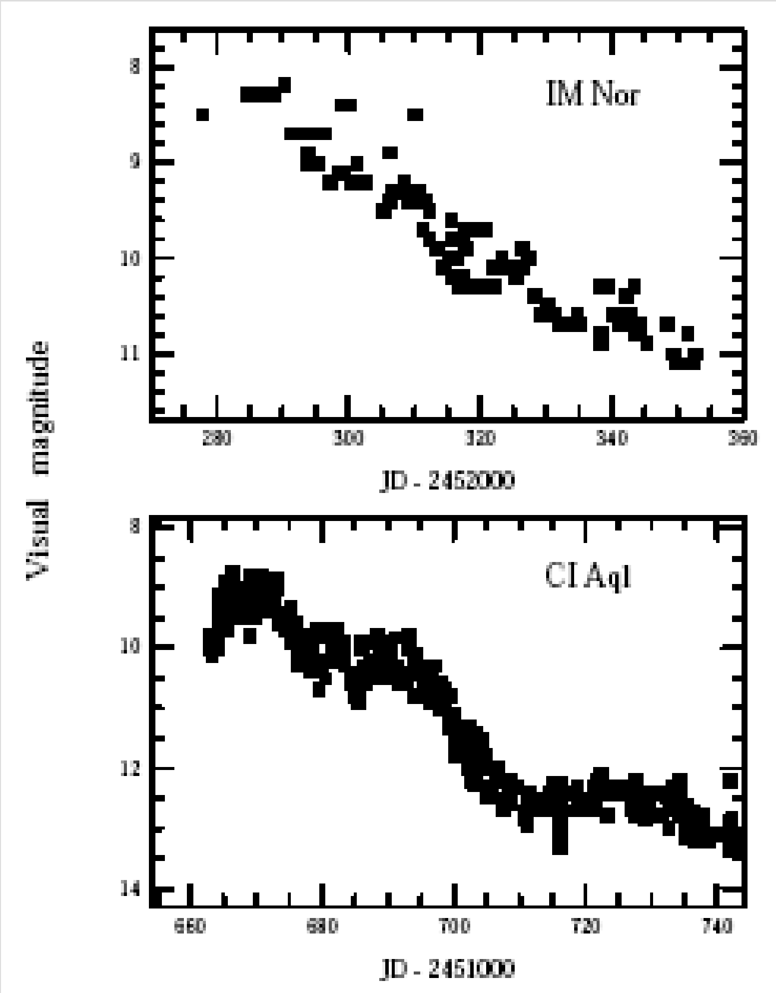


Short period binaries – U Sco class (quiescence)

- Quiescence spectrum dominated by He II lines (e.g. Hanes 1985, Duerbeck et al. 1993)
- Hydrogen lines are either absent or weak, blended with the rather strong HeII Pickering lines
- Helium enrichment attributed to accretion of helium enriched material from an evolved main sequence secondary
- USco - eclipsing as well as a double lined spectroscopic binary (Schaefer & Ringwald 1995, Hanes 1985)

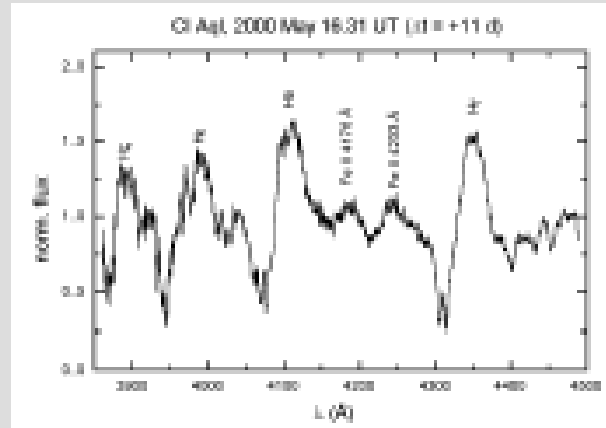
Short period binaries – TPyx, CI Aql, IM Nor (Outburst)

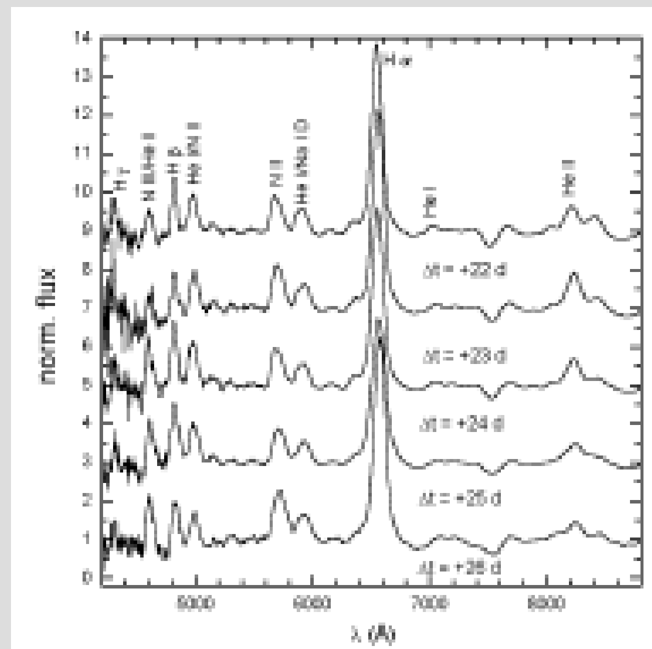
- Moderately fast to slow novae, with t_3 ranging from 36-80 days
- Plateau in light curve
- Orbital modulations superimposed
- NIR photometry indicate dust formation in CI Aql ~ 50 days after optical maximum (Schmeja et al 2000)



Short period binaries – T Pyx, CI Aql, IM Nor (outburst)

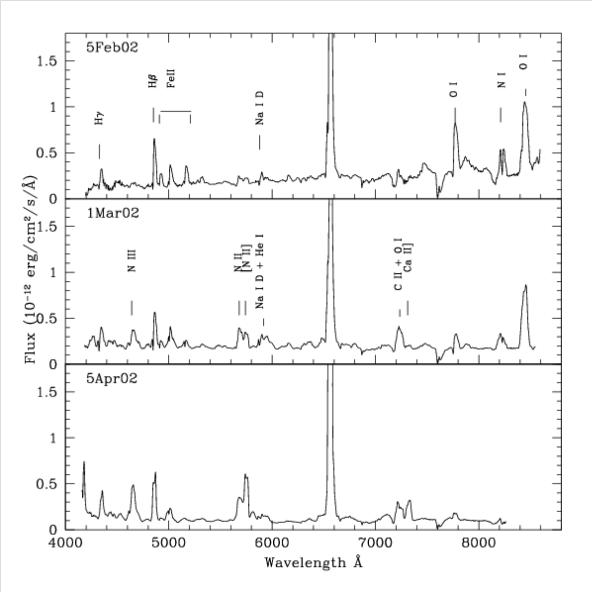
- Outburst spectra very similar in all three systems
- Early spectra show lines due to HI, FeII, NIII and OI with P-Cyg absorptions (Kiss et al. 2001, Matsumoto et al. 2001); lines due to NI and OI seen in the NIR spectra of CI Aql (Wilson & Dunscombe)
- Velocities range from ~800-2500 km/s
- Spectral development similar to classical novae
- Early spectra similar to ‘FeII’ class of novae



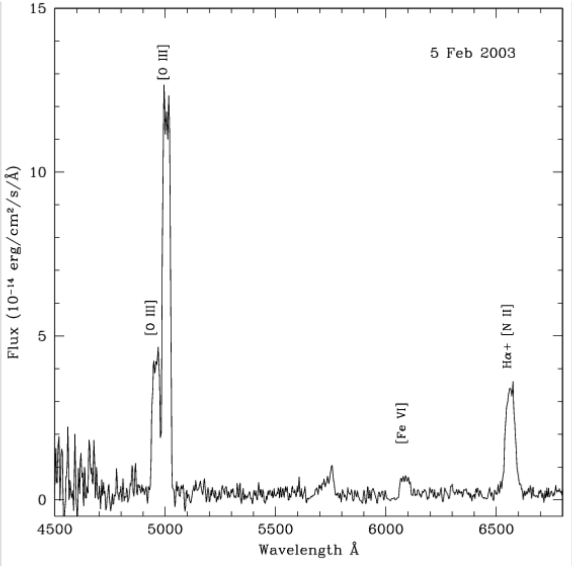


Short period binaries – T Pyx, CI Aql, IM Nor (outburst)

- Spectrum changes from ‘FeII’ class to ‘He/N’ class (Anupama 2003); spectral development very similar to the hybrid novae (Williams 1992)
- Fe II spectra probably originate from discrete massive shells, which are optically thick. As the expanding shells become optically thin, the spectrum changes to ‘He/N’
- [Ca VIII] coronal line detected in the NIR spectrum in CI Aql (Lynch et al. 2004) and [Fe XIV] 5303 line detected in T Pyx (Catchpole 1969)
- Mass ejected during outbursts ~10^{-5} M_{sun}, similar to the lower end of CNe



IM Nor



Short period binaries – T Pyx, CI Aql, IM Nor (quiescence)

- Systems quite heterogeneous at quiescence
- CI Aql - eclipsing binary
- Quiescence spectrum different from CNe, although the outburst spectrum is quite similar - weak emission lines due to HeII, CIII-NIII complex on a reddened spectrum
- Hydrogen Balmer lines in absorption or absent – emission filling similar to shell stars?
- Spectra suggest a K-M secondary, while orbital system suggests the secondary is evolved

Short period binaries – T Pyx, CI Aql, IM Nor (quiescence)

- Both IM Nor and T Pyx have orbital periods that are similar to classical novae
- Light curve of IM Nor indicates periodic brightness modulation with a range ~0.3 and a period 2.462h (Woudt & Warner 2003)
- Both systems lie in the period gap seen in dwarf novae, but probably not applicable to classical novae (Warner 1995)
- T Pyx has extremely blue colours at quiescence and a UV luminosity of $L_{uv}=90M_{sun}$ and a bolometric luminosity that is higher than expected for short-period CVs
- Shell composed of unresolved knots detected around T Pyx (Shara et al. 1997)

RNe as X-ray and radio sources

- RS Oph, U Sco, CI Aql, IM Nor all detected as X-ray sources during their recent outbursts (RS Oph - 1985 also)
- U Sco discovered as a supersoft X-ray source about 19-20 days after the 1999 outburst maximum (Kahabka et al 1999) – consistent with a TNR outburst on a massive WD; a hard X-ray component also detected – due to emission from a postoutburst strong shocked wind from the WD
- CI Aql detected as a soft X-ray source 14 and 16 months after the 2000 outburst (Greiner & Di Stefano 2002). X-ray emission was faint on both occasions without any noticeable change in the spectrum or intensity. Not luminous enough to be due to late-time H burning; either due to ionization of the circumstellar material or due to shocks within the wind and/or with the surrounding medium
- IM Nor detected as a hard X-ray source (CHANDRA observations) 6 months after outburst; not detected during CHANDRA observations 1 month after the outburst (Orio et al. 2005) – emission appears thermal, but additional components cannot be ruled out. Probable BB component luminosity insufficient to be caused by hydrogen burning on the central WD – nuclear burning had turned off or was in the process of turning off at this time
- RS Oph – both hard and soft components during outburst (more details in other talks presented during the conference). Very low luminosity component detected at quiescence, could be varying (Orio).
- Only RS Oph detected as a radio source in both low and high frequency regions. Low frequency emission clearly synchrotron in nature (Kantharia et al. 2007)

Summary

- RNe can be grouped into (a) long period binaries – systems with a hot WD and a red giant secondary, (b) short period binaries – systems with WD + evolved main sequence
- Long period binaries are very homogeneous – both during outburst and at quiescence
- Short period binaries are heterogeneous – further groups

USco type – U Sco, V 394 CrA, Nova LMC 1990 #2 - fast novae, He enriched

CI Aql – moderately fast nova, eclipsing binary, K-M evolved main sequence secondary similar to U Sco, but a very peculiar quiescence spectrum – red continuum, weak emission lines, Balmer lines in absorption or absent

T Pyx type – TPyx, IM Nor – slow novae, orbital period ~ few hours, very similar to classical novae

Summary

- Outbursts in RNe are TNR powered
- Light curves (U Sco, CI Aql, RS Oph, T CrB) show a plateau (secondary maximum in T CrB) during the decline – due to an accretion disc around WD which reappears a few to several days after optical maximum, irradiated by the WD photosphere (ref. Papers by Hachisu & Kato; Lederle & Kimeswenger)
- High accretion rates
- WD in RNe more massive than commonly found in classical novae – close to Chandrsekhar limit in the fast systems (RS Oph and U Sco type)
- Indications that not all the accreted material is ejected during outburst in the fast systems – WD accreting mass – SNe Ia progenitors
- The slow systems (CI Aql, IM Nor & TPyx) more likely decreasing their WD mass, similar to classical novae