Identifying and Quantifying Recurrent Novae Masquerading as Classical Novae

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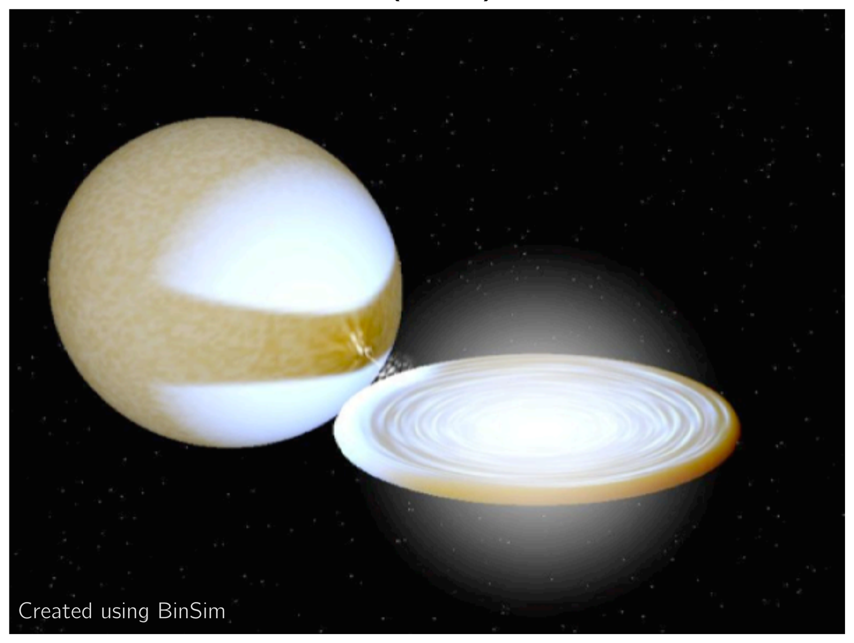
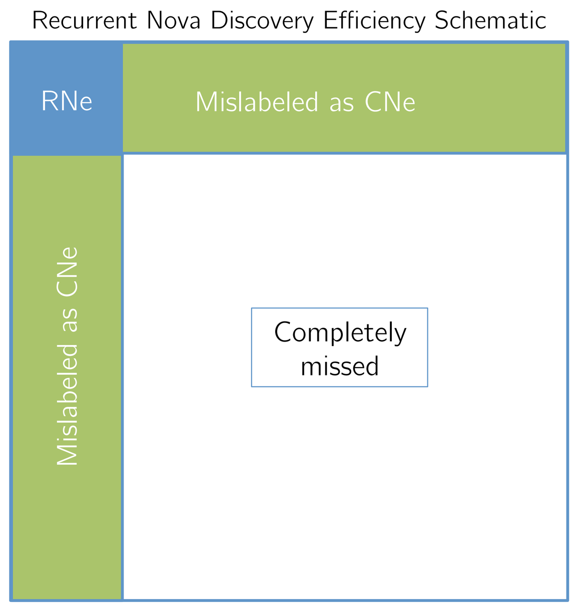
Recurrent Novae (RNe) Often Masquerade as Classical Novae



On average, only ~10% of all nova eruptions are seen (Shafter 2002). To confirm a recurrent nova (RN), two separate eruptions must be observed, each with only a 10% discovery efficiency. To complicate matters further, RN eruptions tend to be faster and fainter than normal novae, making them even more difficult to find. We know, therefore, that we must be missing many RN systems altogether, and must also have a significant number of systems classified as classical novae (CNe) that are actually RNe for which only one eruption has thus far been observed.

Although the eruption mechanisms are the same in CNe and RNe (thermonuclear runaway in the layer of accreted hydrogen on the surface of the white dwarf), RNe must have higher mass white dwarfs and higher accretion rates to power their frequent outbursts.

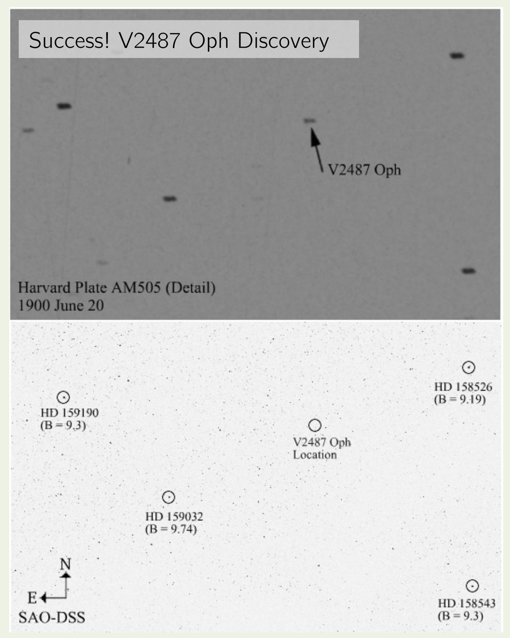


Good Recurrent Nova Candidates: Search for Future & Previous Eruptions!

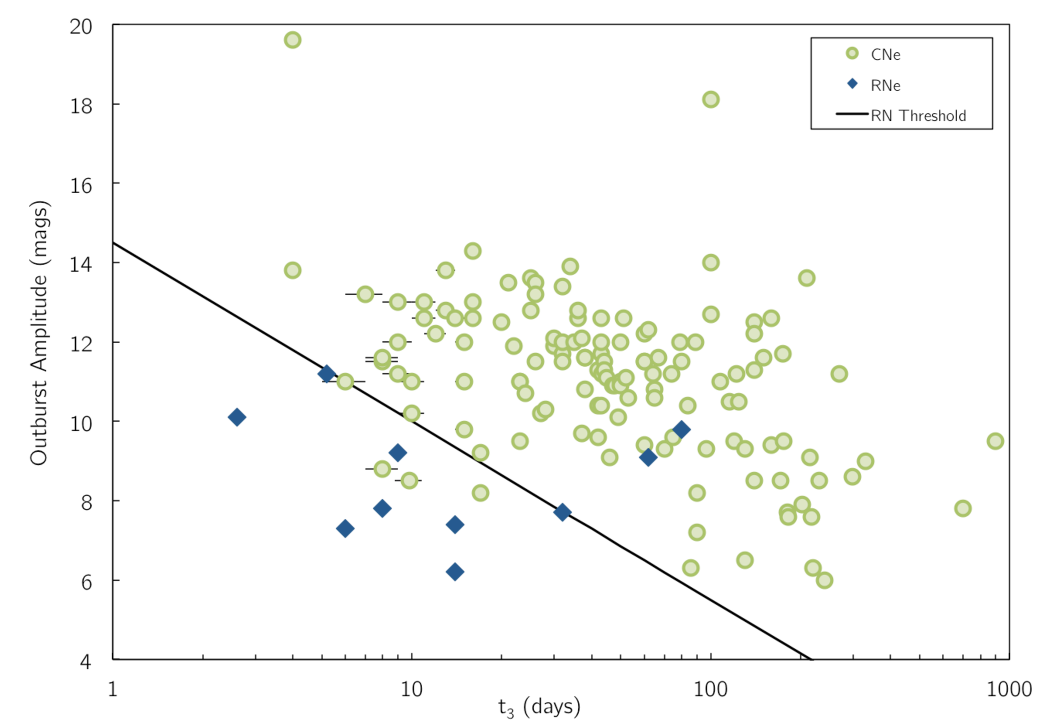
Taking into consideration all of the characteristics that indicate a system is actually recurrent, we can assemble a list of good RN candidate systems. We have an ongoing project using the plate archives at Harvard College Observatory and the Sonneberg Observatory to search for previous eruptions of these systems, which has had one success so far. An eruption of V2487 Oph (Nova Oph 1998) was discovered on Harvard Plate AM505, which was taken on 20 June 1900, making V2487 Oph the tenth known galactic recurrent nova. We continue to search for previous eruptions of our other good candidates, and encourage both professionals and amateurs to monitor them for upcoming eruptions as well.

Nova	Amplitude (mag)	t_3 (days)	Amp/t_3	FWHM Hα	He II	Highest Iron	Light Curve	P_{orb} (days)	$J-H$	$H-K$	Red Giant?	Other
V1721 Aql	>6 [1]	10: [2]	...	6450 [2]	...	...	...	...	...	...	...	Triple-Peaked Hα [3]
DE Cir	8.5 [4]	9.8 [1]	-1.54	5100 [5]	Yes [6]	...	...	...	0.529 [7]	0.245 [7]	No [8]	Triple-Peaked Hα [6]
CP Cru	10.2 [4]	10 [9]	0.2	2000 [10]	Yes [10]	...	...	0.944 [4]	...	...	...	...
KT Eri	7.7: [1]	10 [11]	-2.3	3200-3400 [12]	No [12]	No [13]	P [1]	737 [14]	0.46 [14]	0.7 [14]	Yes [8,14]	Triple-Peaked Hα [13]
V838 Her	13.8 [15]	4 [15]	2.01	5000 [16]	Yes [17]	Fe II [18]	P [15]	0.297635 [4]	0.666 [7]	0.104 [7]	No [8]	$M_{WD} = 1.35 M_\odot$, Triple-Peaked Hα [19,20]
V2672 Oph	>10 [1]	6: [1]	...	8000 [21]	Yes [22]	...	...	...	...	...	...	Triple-Peaked Hα [22]
V4160 Sgr	>12 [15]	3 [15]	...	4500 [23]	Yes [23]	...	S [15]	...	...	...	...	...
V4643 Sgr	>8.3 [15]	6 [15]	...	4700 [24]	...	...	S [15]	...	...	...	...	...
V4739 Sgr	>10.8 [15]	3 [15]	...	5510 [25]	...	...	S [15]	...	...	...	...	...
V477 Sct	11 [15]	6 [26]	0.001680627	2900 [27]	Yes [28]	...	...	...	...	...	...	$M_{WD} \sim 1.3 M_\odot$ [29]

[a]Reference Key: 1 = AAVSO database; 2 = Hounsell et al. (2011); 3 = Helton et al. (2008a); 4 = Downes et al. (2001); 5 = Liller et al. (2003); 6 = The STONY BROOK/SMARTS Spectral Atlas of Southern Novae; 7 = Simbad database; 8 = This Paper; 9 = Lyke et al. (2003); 10 = della Valle & Benetti (1997); 11 = Hounsell et al. (2010); 12 = Yamaoka et al. (2009); 13 = F. Walter 2010, private communication; 14 = Jurdana-Šepić et al. (2012); 15 = Strope et al. (2010); 16 = Feast et al. (1991); 17 = Iijima et al. (1991); 18 = della Valle et al. (1991); 19 = Kato et al. (2009); 20 = Iijima & Cassatella (2010); 21 = Ayani et al. (2009); 22 = Schwarz et al. (2009); 23 = Kingsburgh & English (1991); 24 = Ayani & Kawabata (2001); 25 = Vanlandingham et al. (2001); 26 = Munari et al. (2006); 27 = Fujii & Yamaoka (2005); 28 = Mazuk et al. (2005); 29 = Hachisu & Kato (2007);

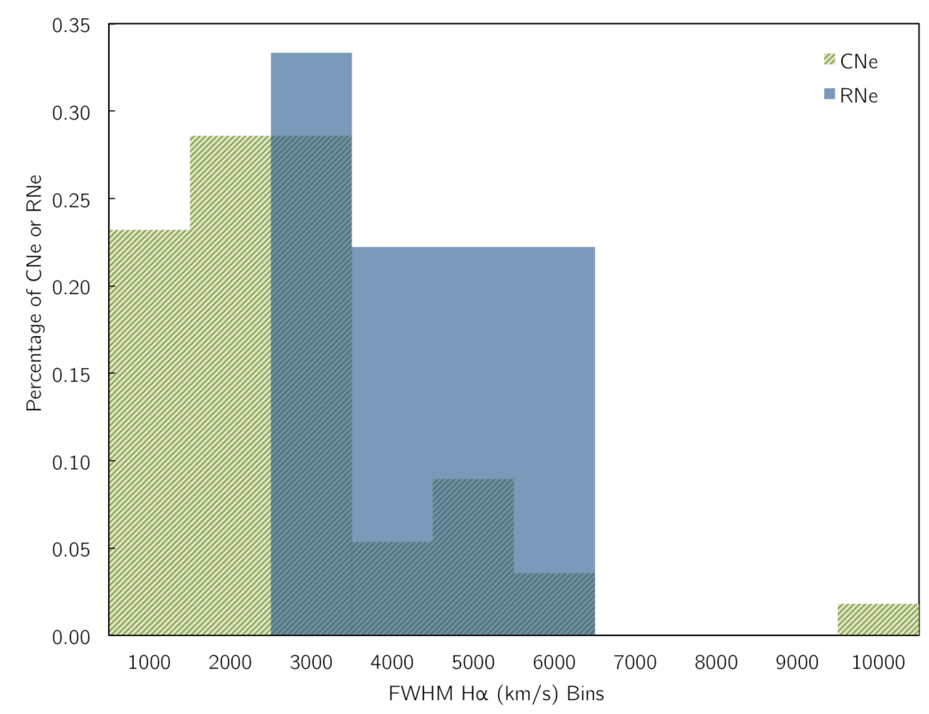


RN Marker #1: Location on Amplitude vs. t_3 Plot



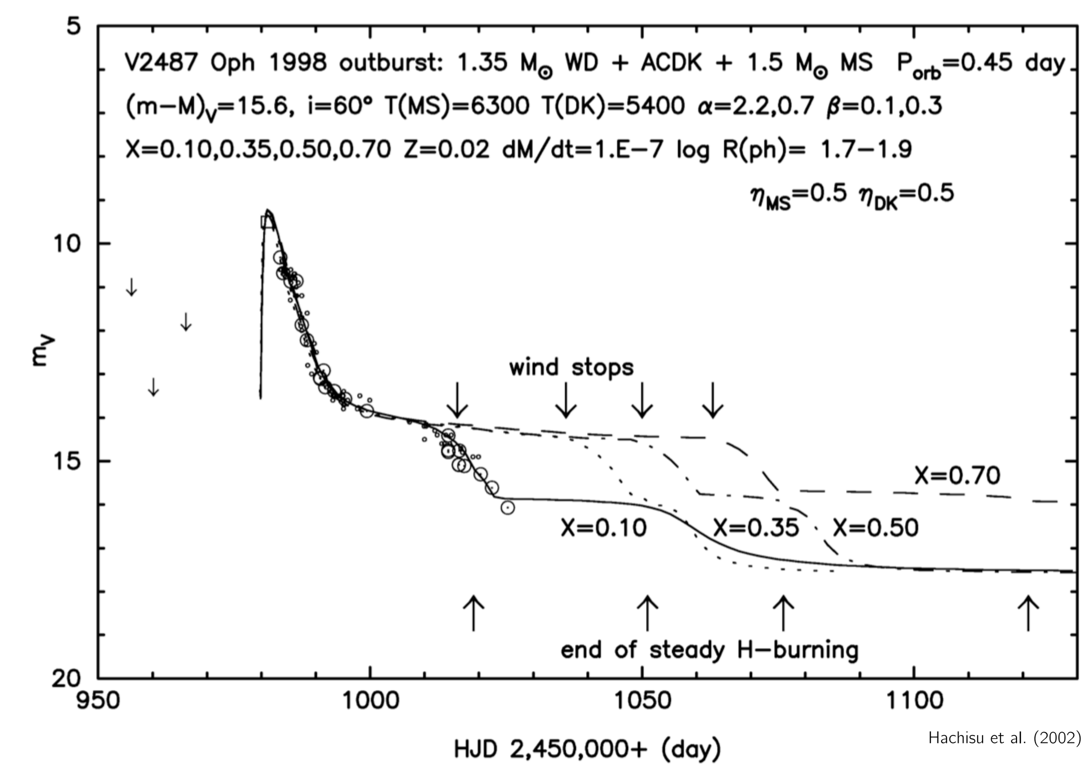
This relation, first published in Duerbeck (1987) and updated here, plots the amplitude of the nova eruption against the time over which the nova declines by 3 magnitudes from peak (t_3). The RNe are seen to mostly cluster together below a threshold of small amplitude and short t_3. (The two outliers are T Pyx and IM Nor, the two very short period systems.) There are a few CNe at or below this threshold as well, which marks them as possible RN candidates: LS And, DE Cir, and V1187 Sco are fully in the RN area, and V868 Cen, CP Cru, V4361 Sgr, V697 Sco, V723 Sco, and V477 Sct are right on the (somewhat fuzzy) border.

RN Marker #4: High Expansion Velocity (measured by FWHM of Hα)



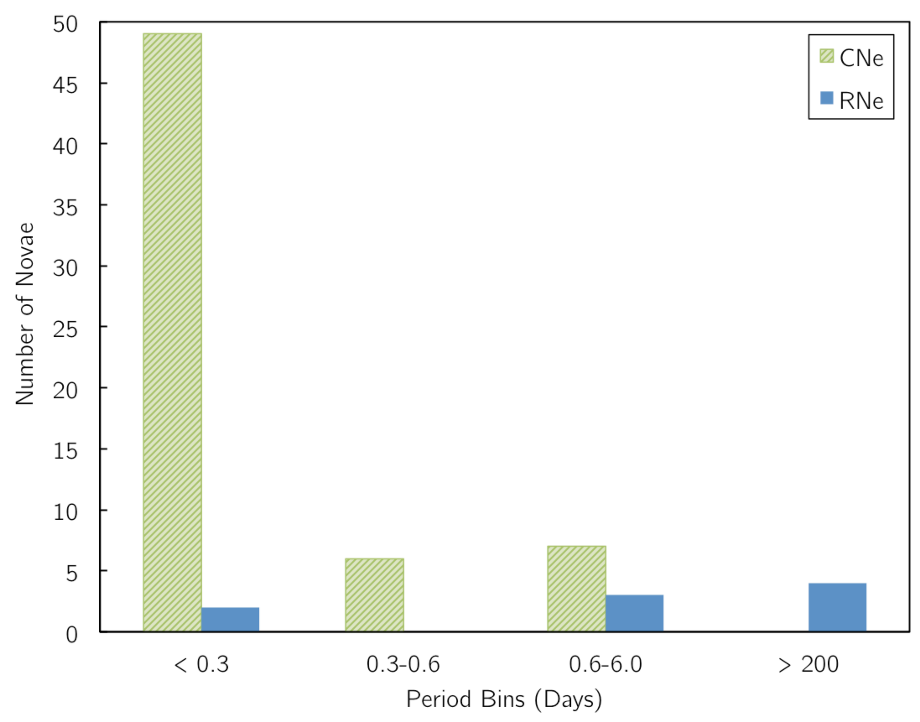
Recurrent novae have higher expansion velocities due to the presence of the high-mass white dwarf in the system, since the expansion velocity is proportional to the escape velocity, which is higher for higher mass central objects. The overlap in distributions of expansion velocities is due partly to the natural continuum between CNe and RNe, and partly to the misclassification of some RNe. The "CN" all the way at the high edge of the plot is actually V2487 Oph, which is now known to be a recurrent nova. Other good candidates from this criterion are V1721 Aql, DE Cir, V693 CrA, V2491 Cyg, V838 Her, V2672 Oph, V4160 Sgr, V4643 Sgr, V4739 Sgr, and V1142 Sco.

RN Marker #7: High Mass White Dwarf



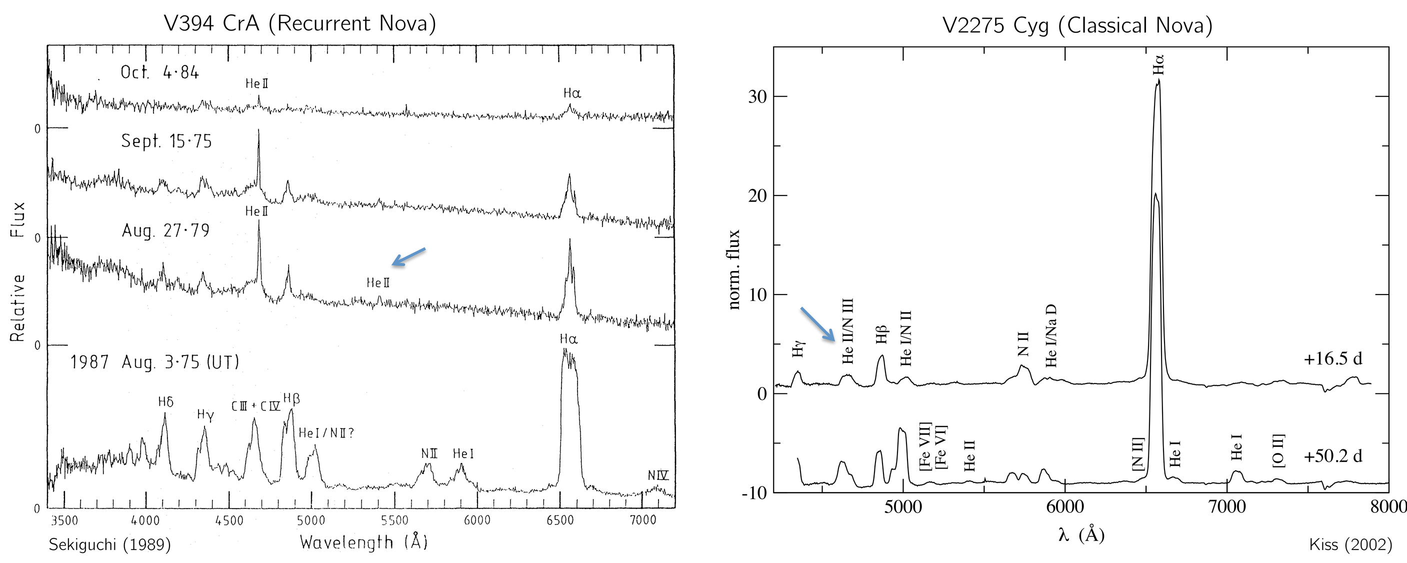
A variety of methods can be used to measure the mass of the white dwarf in a nova system, including light curve fitting such as that shown above, for V2487 Oph, from Hachisu et al. (2002). All of these methods are difficult and most are model-dependent, but any indication of a high-mass white dwarf is a strong marker for a likely RN candidate. Systems with white dwarf masses estimated to be > 1.2 $M_\odot$ are V693 CrA, V2491 Cyg, V838 Her, V445 Pup, V598 Pup, V5115 Sgr, V1188 Sco, V477 Sct, and V382 Vel.

RN Marker #2: Long Orbital Period (indicating Evolved Companion)



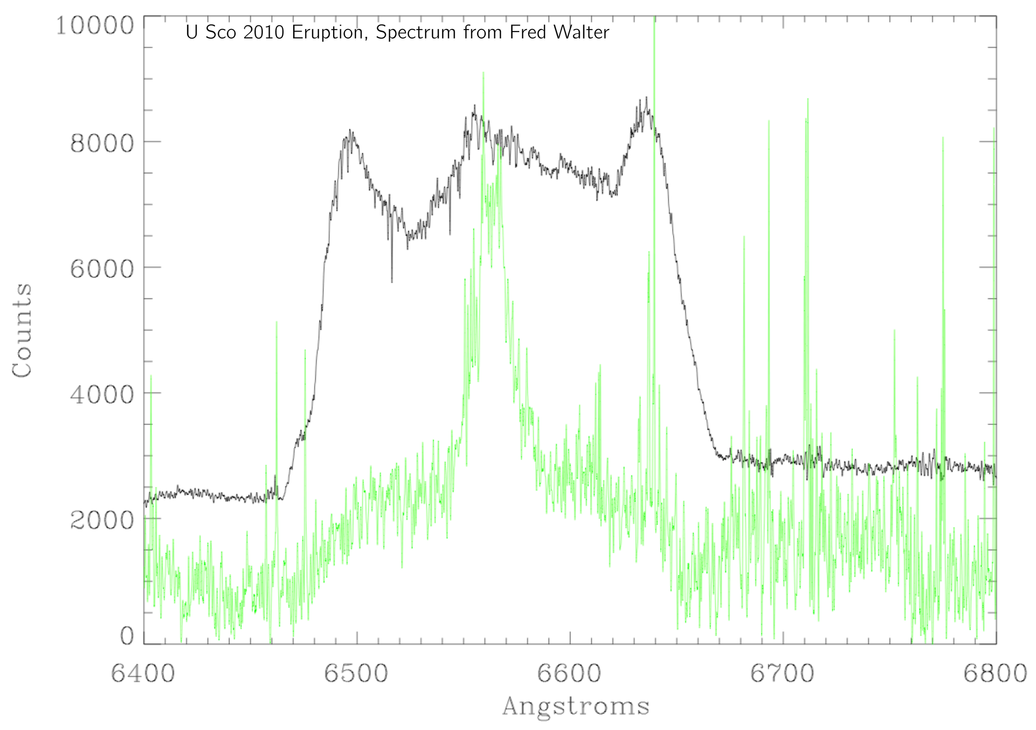
One way to drive the high accretion rate necessary for RNe is to have a massive, evolved companion star in orbit with the white dwarf. The evolutionary expansion of the companion contributes to the higher rate of Roche Lobe overflow, and thus accretion. The presence of an evolved companion can be deduced from a long orbital period. All but two of the known RNe have orbital periods longer than 0.6 days, while most of the CNe have periods shorter than 0.3 days. The CNe with long (> 0.6 day) orbital periods that are good possible RN candidates are V368 Aql, V723 Cas, CP Cru, V841 Oph, GK Per, V1017 Sgr, and X Ser.

RN Marker #5: High Excitation Lines Near Peak



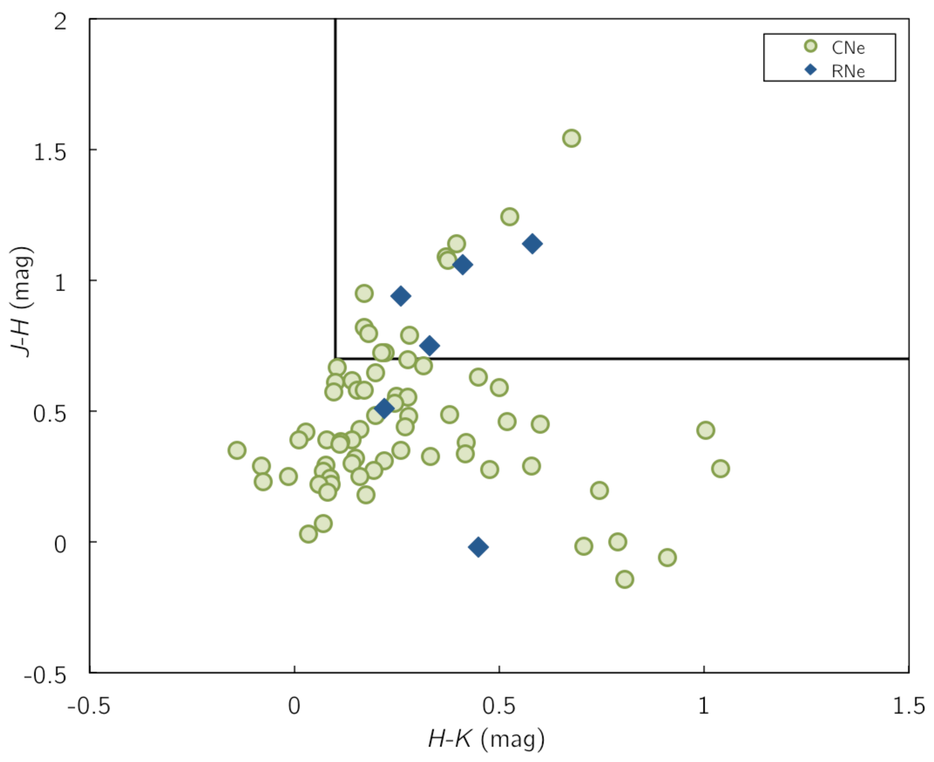
Because of the high-mass white dwarf, RN eruptions are very energetic. Evidence of this can be seen in the outburst spectra near peak, where high, and often forbidden, excitation lines can be seen in all of the RNe but only a few of the CNe. For this study we particularly focused on the presence of He II and Fe X (and above). There are fourteen systems that show He II near optical peak, four that show high iron lines, and one (CP Pup), that shows both He II and high iron, which marks it as an excellent candidate RN.

RN Marker #8?: Castellated (Triple-Peaked) Balmer Lines



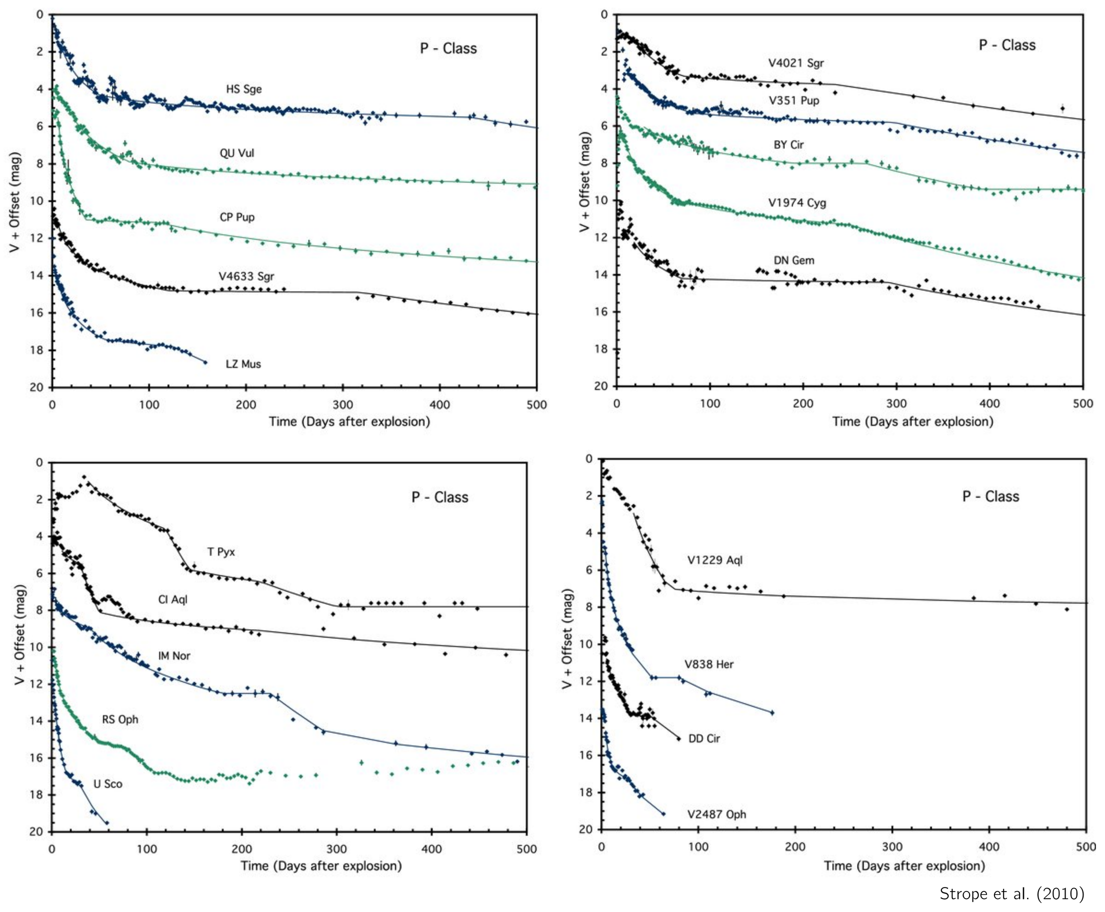
A recently proposed potential RN marker is the presence of castellated, or triple-peaked, Balmer lines very shortly after eruption. This spectrum of U Sco taken shortly after the discovery of the 2010 eruption, provided by Fred Walter via the STONY BROOK/SMARTS Atlas of (mostly) Southern Novae, shows these lines very clearly. This characteristic is currently not well-enough studied to be a certain marker of a short recurrence time, but as it has been seen in at least one galactic RN and two LMC RNe, it is intriguing and worthy of further study.

RN Marker #3: Infrared Excess (indicating Red Giant Companion)



Another way to identify evolved companion stars that can drive a high accretion rate is to look for infrared excesses indicative of a Red Giant Companion, which will not only have increased Roche Lobe Overflow but also the potential for wind accretion. The CNe with Red Giant companions, based on their observed infrared colors, are EL Aql, AR Cir, AP Cru, V794 Oph, KY Sgr, V732 Sgr, V1172 Sgr, V1310 Sgr, V4074 Sgr, V723 Sco, EU Sct, and FS Sct.

RN Marker #6: Plateau in Optical Light Curve



Plateaus in the optical light curves of nova eruptions were first noted as possible RN markers by Hachisu et al. (2008), and further investigated by Strope et al. (2010). Six to nine of the RNe have plateaus (depending on some interpolation and interpretation for poorly-observed eruptions), while only 17% of the CNe show them. All of the known Plateau-Class light curves are shown here, in this figure from Strope et al. (2010).

Recurrent Novae are more common than we realize/observe!

- Novae in general are hard to observe, and recurrent novae are even more difficult to find, yet we *do* see them!
- We can use this catalog to estimate the total Recurrent Nova Fraction, i.e. how many systems currently labeled as CNe are actually RNe.
- Using a time-limited sample of CNe from the Downes et al. (2001) catalog and its online counterpart, combined with the properties described here, we estimate a Recurrent Nova Fraction of 24% ± 4%.
- Using our extensive knowledge of nova discovery efficiencies and the number of recurrent novae known today, we estimate a Recurrent Nova Fraction of 12% ± 3%.
- Using our knowledge of each specific recurrent nova that has been discovered, we estimate a Recurrent Nova Fraction of 35%.
- These numbers vary widely, likely due to difficult-to-quantify systematic errors, but we can combine them to get an overall estimate of 25% for the Recurrent Nova Fraction, with errors of +10% and -5%.
- The details of these calculations can be found in Pagnotta & Schaefer (2014), submitted to ApJ.
- **The main takeaway is that there are a lot more recurrent novae out there than we have yet to discover!**

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