Searching For Recurrent Novae in M31

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Recurrent novae are novae that have had multiple outbursts observed. They are thought to be the leading candidates for Type Ia supernovae progenitors. Prior to this present attempt, 15 candidates have been identified in M31. The current search for RNe encompasses all M31 surveys until the present day and yields seven new RNe candidates, as well as a list of nine probable candidates. In discovering these candidates, a ratio for RNe outbursts compared to that of CNe outbursts, $n_{out}(RNe)/n_{out}(CNe)$, was calculated to be ~0.2.

Introduction

Novae are close binary systems, a subset of cataclysmic variable systems (Warner, 1995). These systems consist of a white dwarf (WD) primary and a cool main sequence star as the secondary star. The secondary star transfers matter onto the WD forming via accretion disk. A thermonuclear runaway (TNR) on the surface of the white dwarf leads to some of WD's accreted material to be ejected into space, resulting in the outburst that is observed. All novae are believed to be recurrent on timescales up to ~105 years, with the classification of recurrent novae usually reserved for systems with recurrence time less than ~100 years.

Livio & Truran note that the evolution of RNe systems could lead to Type Ia Supernovae (SNe Ia) explosions (1994). In order for this to situation to occur, they state that the WD ejects less matter than it accretes from its secondary star. For a more massive WD, subsequent outbursts might result in the WD increasing in mass and possibly reaching the Chandrasekhar limit. Following this possibility, Della Valle & Livio (1996) searched for recurrent novae in M31 using data that spanned over 70 years and included 321 novae. Their search yielded seven RNe (see Table 2a) and led to a recurrent nova rate (R_{RNe}) of 2.9 RNe yr^{-1}. Using calculated RNe birth rates as well as SNe Ia rates, they found that the number of RNe systems "born" each year only account for a few percent of the SNe Ia that occur every year. Shafter & Irby (2001) also searched for RNe after the discovery of 82 novae during their survey of M31. They discovered that eight of the 82 new novae detected were RNe candidates (see Table 3a).

Observations and Reduction

All observational data was obtained from the nine principle surveys of M31, including, Hubble (1929), Arp (1956), Rosino (1964, 1973), Rosino et al. (1989), Ciardullo et al. (1987, 1990b), Sharov & Alksnis (1991), Tomaney & Shafter (1992), Rector et al. (1999), Shafter & Irby (2001) & Darnley (2004). Data for an additional 12 novae was obtained from Ansari (2004) in a variable star search, and lastly, data for 60 novae comes from various IAU circulars spanning from 1982 to 2005. Table 1 lists the survey along with its respective nova identification prefix.

Table 1 - Survey Identification

Survey	ID
Hubble	H
Arp	A
Rosino, Rosino et al	R
Ciardullo et al.	C
Sharov & Alksnis	SA
Tomaney & Shafter	TS
Rector et al.	RJ
Shafter & Irby	199n-nn
Darnley	D
Ansari	NO
IAU/ Astronomers Telegram	IAnnnn.n / ATEL# nnn

Analysis

Arp (1956) introduced a standard X-Y axis system for M31 that placed the positive X-axis, with a position angle of 38°, on the major axis, positive X axis. Although Hubble (1929) had a similar standard system, where the X and Y axis were of opposite signs, Arp's system is more commonly used and it was decided that this RNe search would follow suit in its transformation of coordinates. The

surveys that recorded offsets in this system included Arp, Hubble, and Rosino (Hubble's offsets axis system was corrected for its opposite signs). The following transformation equations were used to transform the coordinates of all novae that were not initially in this system:

$$x' = [x \cdot \cos(\theta) - y \cdot \sin(\theta)] \cos(\delta)$$

and

$$y' = -x \cdot \sin(\theta) - y \cdot \cos(\theta)$$

The dimensions of the error box used by Della Valle & Livio were defined by examining the differences in the X and Y offsets of 16 novae that were independently discovered by different observers. The standard deviation for all 16 novae gave σ_x = 0'.12 and σ_y = 0'.10, resulting in the full dimensions of the box ΔX = 0'.24 and ΔY = 0'.20. Applying this error box to every nova, they found eight RNe matches accounting for a total of seven RNe candidates, which produced a total of 16 outbursts. When searching for these RNe, Della Valle & Livio saw that four (denoted by an asterisk in Table 2a) of the eight RNe matches had recurrence times less than 30 years, which is the mean time between outbursts for RNe. They confirmed these candidates by using CCD images and/or maps that were provided along with the surveys in which they were detected. Another interesting result was the recurrent nova R7 = R29 = R40 = H31.

Table 2 - Della Valle & Livio (1996) RNe candidates

RNe IN M31

Name (1)	Name (2)	X_1 (3)	Y_1 (4)	X_2 (5)	Y_2 (6)	ΔT (7)
R7	R40	0.1	2.9	0.1	2.8	6*
R29	R40	0.0	2.9	0.1	2.8	2*
R40	H31	0.1	2.8	0.0	2.7	38
R48	R79	−4.7	7.0	−4.7	7.1	5*
R66	R81	−11.0	−11.4	−11.0	−11.4	2*
H7	H79	−1.5	−1.95	−1.5	−2.0	10
R132.....	A10	−3.58	5.72	−3.7	5.7	28
R17	H53	2.9	−0.1	2.8	−0.2	32
R119.....	H51	−10.16	0.60	−10.2	0.5	57

a

ID_1	ID_2	$\sqrt{(\Delta X^2 + \Delta Y^2)}$	ΔT
R7	R40	0.10	6
R29	R40	0.14	2
R40	H30	0.14	38
R48	R79	0.10	5
R66	R81	0.00	2
H6	H78	0.00	10
R132	A10	0.10	29?
R17	H52	0.14	32
R119	H50	0.10	52?

b

Shafter & Irby also looked for RNe, but only compared the positions of the novae found during their survey against previously published novae positions. They found ten RNe matches accounting for eight RNe candidates (Table 3a) using the same criteria for their error box as that of Della Valle & Livio.

Table 3 - Shafter & Irby (2001) RNe candidates

ERUPTIONS OF RECURRENT NOVA CANDIDATES

Nova: This Work	Nova: Previous Work[a]	X_1[b] (arcmin)	Y_1[b] (arcmin)	X_2[b] (arcmin)	Y_2[b] (arcmin)	ΔT (yr)
1990-10	R138	1.2	−0.3	1.09	−0.35	6
	C18	1.2	−0.3	1.1	−0.4	6
1990-15	SA7	14.7	4.8	14.6	4.9	21
1993-13	R52	1.9	−0.7	2.0	−0.7	29
1993-14	H21	1.7	0.0	1.6	0.1	71
	R75	1.7	0.0	1.7	−0.1	26
1996-05	H40	4.9	−1.2	5.0	−1.3	72
1997-04	C12	−2.6	−0.9	−2.6	−0.8	14
1997-07	C01	−1.0	0.3	−0.9	0.3	15
1997-10	H64	1.0	1.1	0.9	1.2	71

[a] (R) Rosino 1964, 1973; Rosino et al. 1989. (C) Ciardullo et al. 1987. (SA) Sharov & Alksnis 1991. (H) Hubble 1929.
[b] X, Y coordinates use the convention of Arp 1956, with the X-axis oriented along the major axis of M31 (PA = 38°, $+X$ to the northeast and $+Y$ to the southeast; X_1 and Y_1 are this work, and X_2 and Y_2 are previous work.

a

ID_1	ID_2	$\sqrt{(\Delta X^2 + \Delta Y^2)}$	ΔT
1990-10	R138	0.15	6
	C18	0.19	6
1990-15	SA8	0.19	21
1993-13	R52	0.14	29
1993-14	H22	0.13	71
	R75	0.14	26
1996-05	H41	0.12	72
1997-04	C12	0.13	14
1997-07	C1	0.13	15
1997-10	H64	0.11	71

b

In this current search, I opted for an error circle of radius 0'.16, which is the diagonal of the error box used by both Della Valle & Livio and Shafter & Irby. In conducting my search for RNe, I

also confirmed, as a sanity check, both sets of RNe candidates found by Della Valle & Livio and Shafter & Irby. In doing this, I found a difference in ΔT, the interval between outbursts, for two of Della Valle & Livio's RNe candidates (noted by asterisk in Table 2b). In the end, I was able to compile a list of seven RNe candidates (Table 4) and a list of six probable candidates (Table 5). I created a probable list based on radial distance and the outburst time interval. Although two novae may have a short radial distance, the outburst interval was either half or less than half of the mean recurrence time. I was unable to confirm these probable candidates with CCD images and/or maps as did Della Valle & Livio.

The total number of novae outbursts decreases to 459 after accounting for the 64 novae independently observed in different surveys, as well as the 48 outbursts coming from 22 RNe candidates. In computing the number of RNe outbursts to that of CNe outbursts, we find that the ratio is $n_{out}(RNe)/n_{out}(CNe) \sim 0.11$. Capaccioli et al. (1989) show that the number of outbursts should be corrected for incompleteness and that the final number of nova outbursts is actually increased by 1/3. Della Valle & Livio arrive at a method which applies a corrective factor of $\sim(2/3)^{-2}$ to the number of RNe outbursts, and a factor of 1/3 to be applied the number of CNe outbursts. The corrected ratio of outbursts is now $n_{out}(RNe)/n_{out}(CNe) \sim 0.19$. The rate of RNe outbursts is determined by using the current nova rate of 37 novae yr^{-1} (Shafter & Irby 2001), as well as the ratio of nova outbursts, leading to $R_{RNe} \approx 7$ RNe yr^{-1} for M31.

Della Valle & Livio calculate the number of RNe progenitors as being $N = \Delta T_{rec} * R_{RNe}$, where ΔT is the mean recurrence time as N = 87. In this present study, the number of progenitors increases to 211. Della Valle & Livio derive a timeframe of $\sim(1\text{-}2) * 10^6$ yr in which the WD will accrete ~0.1-0.2 M_{sun}. Using this in conjunction with the progenitor population, N, we obtain a new birth rate of $(1\text{-}2)*10^{-4}$ yr^{-1} for M31 compared to the previous value $(4.4\text{-}8.7) * 10^{-5}$ yr^{-1} found by Della Valle & Livio. Comparing this to the SNe Ia rate for M31, 8.5*10-3 yr-1, shows that recurrent nova-type systems account for ~1%-2% of the SNe Ia rate.

Table 4 - Present study RNe candidates

ID_1	ID_2	$\sqrt{(\Delta X^2 + \Delta Y^2)}$	ΔT
C9	RJ39	0.10	14
C12	RJ13	0.12	14
RJ5	H51	0.09	73
RJ23	R60	0.16	34
RJ26	R57	0.14	35
RJ29	R76	0.16	32
R112	H19	0.10	55

Table 5 - Probable RNe candidates

ID_1	ID_2	$\sqrt{(\Delta X^2 + \Delta Y^2)}$	ΔT
C7	IA5814.1	0.11	10
IA5814.1	ATEL# 334	0.07	11
1997.10	ATEL# 346	0.15	7
1997.13	IA5121.1	0.14	7
R12	R91	0.10	14
R29	R108	0.10	14
C27	NO12	0.04	10
C27	IA8238.1	0.04	18
NO12	IA8238.1	0.08	8

Conclusions

This comprehensive RNe search has yielded seven RNe candidates, and including the RNe found by Della Valle & Livio and Shafter & Irby, the current total is now 22 RNe candidates. A list of nine probable candidates was also compiled. Although an error box was adopted in both their RNe candidate searches, the search radius used in this present study confirmed all of the 15 RNe candidates previously found. The inclusion of this new group of candidates along with the updated nova rate from Shafter & Irby has led to an increase in the rate of RNe outbursts, as noted by Della Valle & Livio, by a factor of about two. An unexpected result was the high percentage of candidates stemming from just one survey (Rector 1999). Although we were able to update the RNe outbursts ratio, the RNe rates, and other values calculated by Della Valle & Livio, the final results show that recurrent nova-type systems still only account for a few percent of the SNe Ia rates.

In looking at future work, we hope that frequent sampling of M31 and the introduction of a fainter limiting magnitude will aid in the detection of these fainter RNe. Future surveys that follow these two objectives and also provide accurate calculations of positions for new novae should lead to detection of more novae and higher confidence in selection of RNe candidates.

Acknowledgements

I would like to thank the San Diego State University Astronomy Department for providing the opportunity to participate in this research program, particularly the principal coordinator, Dr. Eric Sandquist, for his hard work in getting the program together. I'd especially like to thank Dr. Allen Shafter for suggesting this research topic.

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