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OPTICAL AND X-RAY OBSERVATIONS OF M31N 2007-12b: AN EXTRAGALACTIC RECURRENT NOVA WITH A DETECTED PROGENITOR?

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ABSTRACT

We report combined optical and X-ray observations of nova M31N 2007-12b. Optical spectroscopy obtained 5 days after the 2007 December outburst shows evidence of very high ejection velocities (FWHM H$\alpha \simeq 4500$ km s^{-1}). In addition, *Swift* X-ray data show that M31N 2007-12b is associated with a Super-Soft Source (SSS) which appeared between 21 and 35 days post-outburst and turned off between then and day 169. Our analysis implies that $M_{\rm WD} \gtrsim 1.3\ M_\odot$ in this system. The optical light curve, spectrum, and X-ray behavior are consistent with those of a recurrent nova. *Hubble Space Telescope* observations of the pre-outburst location of M31N 2007-12b reveal the presence of a coincident stellar source with magnitude and color very similar to the Galactic recurrent nova RS Ophiuchi at quiescence, where the red giant secondary dominates the emission. We believe that this is the first occasion on which a nova progenitor system has been identified in M31. However, the greatest similarities of outburst optical spectrum and SSS behavior are with the supposed Galactic recurrent nova V2491 Cygni. A previously implied association of M31N 2007-12b with nova M31N 1969-08a is shown to be erroneous, and this has important lessons for future searches for recurrent novae in extragalactic systems. Overall, we show that suitable complementary X-ray and optical observations can be used not only to identify recurrent nova candidates in M31, but also to determine subtypes and important physical parameters of these systems. Prospects are therefore good for extending studies of recurrent novae into the Local Group with the potential to explore in more detail such important topics as their proposed link to Type Ia Supernovae.

Key words: galaxies: individual (M31) – novae, cataclysmic variables – supernovae: general – white dwarfs

Online-only material: color figures

1. INTRODUCTION

Classical novae (CNe) are cataclysmic variable stars whose outbursts are due to a Thermonuclear Runaway (TNR) on the surface of a white dwarf (WD) in an interacting binary system (see, e.g., Starrfield et al. 2008). Recurrent Novae (RNe) are related to CNe, but have been seen to undergo more than one recorded outburst and may contain evolved secondary (mass-donating) stars (see Anupama 2008, for a review). Recurrent novae have been proposed as one of the primary candidates for the progenitors of Type Ia Supernovae (SNe; see, e.g., Kotak 2008, for a recent review).

At present, we know of a total of only 10 RNe in the Galaxy with confidence (based on two or more nova outbursts being observed). These RNe appear to fall into three main groups, viz.:

1. *RS Oph/T CrB* with red giant secondaries, consequent long orbital periods (∼several hundred days), rapid declines from outburst (∼ 0.3 mag day^{-1}), high initial ejection velocities ($\gtrsim$ 4000 km s^{-1}) and strong evidence of the interaction of the ejecta with the pre-existing circumstellar wind of the red giant (from observations of optical coronal lines, non-thermal radio emission and hard X-ray development in RS Oph; see papers in Evans et al. 2008);
2. The more heterogeneous *U Sco* group with members' central systems containing an evolved main sequence or sub-giant secondary with an orbital period much more similar to that in CNe (of order hours to a day), rapid optical declines (U Sco itself being one of the fastest declining novae of any type), extremely high ejection velocities ($v_{ej} \sim$ 10,000 km s^{-1}, from FWZI of emission lines for U Sco) but no evidence of the extent of shock interactions seen in RS Oph post-outburst (their post-outburst optical spectra resemble the "He/N" class of CNe— Williams 1992);
3. *T Pyx, CI Aql, IM Nor* are again short orbital period systems and although their optical spectral evolution post-outburst is similar, with their early time spectra resembling the "Fe II" CNe, they show a very heterogeneous set of moderately fast to slow declines in their optical light curves. This sub-group of RNe also seems to show ejected masses similar to those at the lower end of the ejected mass range for CNe with $M_{\rm ej} \sim 10^{-5}\ M_\odot$ (which appears to be 1 to 2 orders of magnitude greater than $M_{\rm ej}$ in the other two sub-groups of RNe).

The short recurrence periods of RNe require high mass WD accretors and relatively high accretion rates (e.g., Starrfield et al. 1988). Indeed, both RS Oph and U Sco appear to have WDs near to the Chandrasekhar mass limit. The WD mass in both these objects has been proposed as growing and therefore they are potential SNe Ia progenitors (see, e.g., Sokoloski et al. 2006; Kahabka et al. 1999, respectively).

The study of RNe is thus important for several broader fields of investigation including mass loss from red giants, the evolution of supernova remnants, and the progenitors of Type Ia SNe. Progress in determining the latter association in particular, as well as exploring the evolutionary history of these close

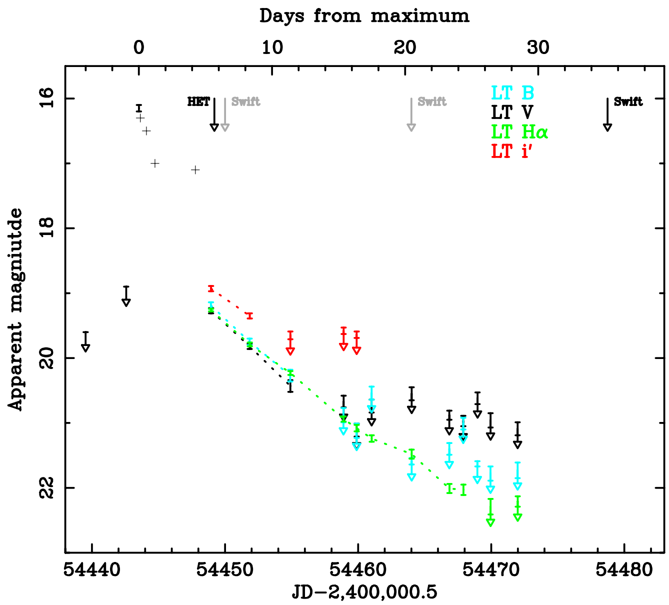

Figure 1. Optical light curve of M31N 2007-12b with data from Lee et al. (2007) and the "M31 (Apparent) Nova Page" provided by the International Astronomical Union, Central Bureau for Astronomical Telegrams (CBAT—http://www.cfa.harvard.edu/iau/CBAT_M31.html) comprising both R band and unfiltered CCD observations, plus data from the Liverpool Telescope (data points from $t \sim 5$ days after peak and in photometric bands as indicated). Times of *Swift* observations (upper limits gray; detection at $t = 35$ days bold) and HET spectroscopy are also shown.

(A color version of this figure is available in the online journal.)

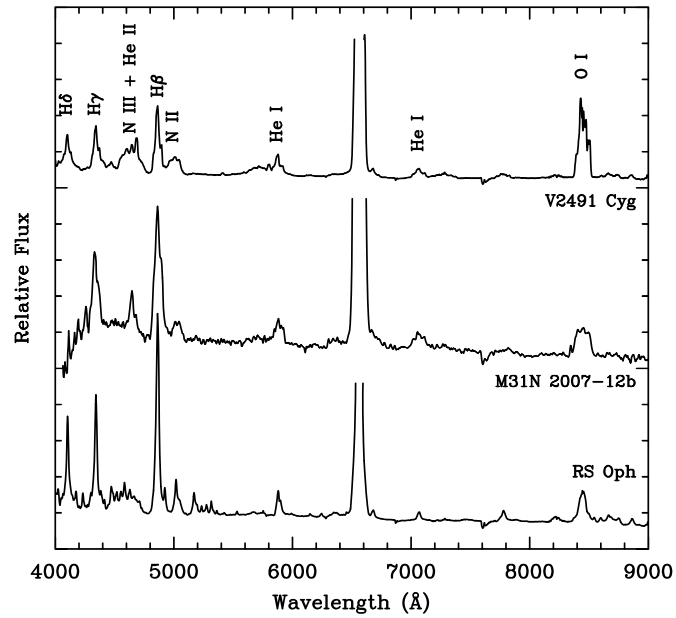

Figure 2. Low resolution spectrum of M31N 2007-12b taken with the LRS on the HET at $t = 5.2$ days after discovery. The spectrum would classify this object as a He/N Classical Nova following maximum light. Also shown for comparison are spectra of the Recurrent Nova RS Oph at around 6 days from outburst (Anupama 2008) and the supposed RN V2491 Cyg (from two co-added spectra at around 17 and 18 days after outburst; G. C. Anupama et al. 2010, in preparation)—see the text for further details. The Hα line in each spectrum has been truncated.

binary systems, is hampered by the relative rarity of Galactic RNe. However, since the time of Edwin Hubble, CNe have been observed in extragalactic systems, in particular M31 (see Shafter 2008, for a review). In total, over 800 CN candidates have been catalogued in M31 (Pietsch et al. 2007), and among these are thought to lie several RNe (see, e.g., della Valle & Livio 1996; Shafter et al. 2009b). Indeed, Pietsch et al. (2007) identified four candidates in their search for the X-ray counterparts of optical novae in M31 (see also Henze et al. 2009). In this paper, we present evidence for an object in M31 previously classified as being a CN as in fact being a recurrent nova. We use a combination of optical and X-ray observations to explore its more detailed nature, emphasize the need for careful exploration of archival material to confirm or rule out previous outbursts, and go on to point the way to more extensive observational programs in the future.

2. OBSERVATIONS OF THE 2007 OUTBURST

Nova M31N 2007-12b was discovered on 2007 December 9.53 UT (which we take as $t = 0$) by K. Nishiyama and F. Kabashima[6] at mag = 16.1–16.2 (unfiltered) and located at R.A. = $00^h43^m19\overset{s}{.}94 \pm 0\overset{s}{.}01$, decl. = $+41^\circ13'46\overset{''}{.}6 \pm 0\overset{''}{.}1$ (J2000). They reported that no object had been visible at this position on 2007 December 8.574 UT. Figure 1 gives details of these and other optical observations around peak. Broadband i', V, B plus narrowband Hα photometry was subsequently obtained with the RATCam CCD camera on the 2 m Liverpool Telescope (LT; Steele et al. 2004). LT photometry is part of a larger program of photometry and spectroscopy of novae in M31 (Shafter et al. 2009a) and began on 2007 December 14.94 UT ($t = 5.4$ days post-outburst) then continued for 23 days. The LT data were reduced using standard routines within the IRAF[7] and STARLINK packages, and calibrated against standard stars from Landolt (1992) and by using the secondary standards in M31 (Magnier et al. 1992; Haiman et al. 1994). The resulting light curves are shown in Figure 1.

The astrometric position of M31N 2007-12b was measured from an LT Sloan i'-band image taken on 2007 December 14.95 UT. This image was chosen as a compromise between good seeing and nova brightness. An astrometric solution was obtained using 21 stars from the Two Micron All Sky Survey (2MASS) All-Sky Catalogue (Cutri et al. 2003) which are coincident with resolved sources in the LT observation. We obtain a position for M31N 2007-12b of R.A. = $00^h43^m19\overset{s}{.}97 \pm 0\overset{s}{.}01$, decl. = $+41^\circ13'46\overset{''}{.}3 \pm 0\overset{''}{.}1$ (J2000; consistent with Nishiyama and Kabashima's measurement). It should be noted that the astrometric uncertainty is dominated by uncertainties in the plate solution.

Optical spectroscopy was obtained on 2007 December 15.2 UT ($t = 5.7$ days) with the 9.2 m Hobby Eberly Telescope (HET) using the Low Resolution Spectrograph (LRS; Hill et al. 1998). We used the $g1$ grating with a $1\overset{''}{.}0$ slit and the GG385 blocking filter, which covers 4150–11000 Å with a resolution of $R \sim 300$, although we limit any analysis to the 4150–8900 Å range where the effects of order overlap are minimal. Data reduction was performed using standard IRAF packages and the resulting spectrum is shown in Figure 2.

Kong & Di Stefano (2007) reported the detection of a Super-Soft X-ray Source (SSS) coincident with the position of the nova using the X-ray Telescope (XRT) on board the *Swift* satellite (Burrows et al. 2005). The detection was made serendipitously

6 http://www.cfa.harvard.edu/iau/CBAT_M31.html

7 IRAF is distributed by the National Optical Astronomy Observatories, which is operated by the Association for Research in Astronomy, Inc. under cooperative agreement with the National Science Foundation.

Table 1
Swift XRT Data

Date (day)	Obs ID	Exposure Time (ks)	Count Rate (s^{-1})
2007 Nov 24 (−15)	00031027001	7.27	<0.0017
2007 Dec 2 (−7)	00031027002	1.00	<0.0073
2007 Dec 3 (−6)	00031027003	3.63	<0.0037
2007 Dec 16 (+7)	00031027004	3.89	<0.0039
2007 Dec 30 (+21)	00031027005	4.02	<0.0034
2008 Jan 13 (+35)	00031027006	3.99	0.015 ± 0.002
2008 May 26 (+169)	00037719001	4.86	<0.0023

Notes. Upper limits are at the 90% confidence level; error on the detection is 1σ.

as part of a survey of SSSs in the M31 globular cluster Bol 194 on 2008 January 13.74 UT ($t = 35.2$ days) with an exposure time of 4 ks. They reported previous observations of the field on 2007 December 16 and December 30 that had not detected any source at that position. We have re-analyzed the XRT data for these epochs and also consulted the *Swift* data archive to review other X-ray observations of this field from 2007 November to 2008 May (see Table 1 and also Figure 1).

3. RESULTS AND DISCUSSION

Nova M31N 2007-12b lies within 1$''\!.$7 of the quoted position of M31N 1969-08a (R.A. = $00^{h}43^{m}19^{s}\!.9 \pm 0^{s}\!.3$, decl. = $+41^{\circ}13'45'' \pm 3''$ (J2000), i.e., coincident within the quoted measurement errors) which was discovered on 1969 August 16.0 UT (see Sharov & Alksnis 1991) and lies 7$'\!.$1 from the nucleus of M31. Peak visual magnitude was observed one day after the start of the 1969 outburst at $V = 16.4$. Subsequently, the nova declined at a rate of $\gtrsim 0.3$ mag day^{-1}, making this a very fast nova (Warner 2008). Supposed positional coincidence and similarities in their light curves led to the initial conclusion that the outbursts were from the same object. However, consultation of the original plate material for M31N 1969-08a showed that its position is in fact R.A. = $00^{h}43^{m}19^{s}\!.6 \pm 0^{s}\!.1$, decl. = $+41^{\circ}13'44'' \pm 1''$ (J2000, i.e., separated by $4''\!.8 \pm 1''\!.5$ from M31 2007-12b) and blinking of the 1969 and 2007 images confirmed they are indeed separate objects (see Figure 3).

Our optical spectroscopy on day 5.7, as shown in Figure 2, reveals strong and very broad (FWHM H$\alpha \simeq 4500$ km s^{-1}) Balmer, He I, and N III 464.0 nm emission lines consistent with the spectra of He/N CNe (Williams 1992). High emission line velocities and fast optical declines are associated with ejection from a high mass WD and are also typical of both the RS Oph and U Sco sub-classes of RNe (Anupama 2008). Of these two, the spectrum more closely resembles that of RS Oph around 3 days after the 2006 outburst (see Figure 2), than that observed in U Sco or the U Sco sub-class RN V394 CrA at similar phases after their outbursts in 1987 (Sekiguchi et al. 1988, 1989; Williams et al. 1991). However, the most striking spectral similarity is to the early optical spectrum of nova V2491 Cyg (again, see Figure 2) for which, although only one outburst has been observed, it has been suggested that it is an RN (Page et al. 2009) by virtue of its very fast optical decay and high ejection velocities together with its low outburst amplitude (ΔV = 8.5 mag, Jurdana-Sepic & Munari 2008) and detection as an X-ray source pre-outburst (Ibarra et al. 2009).

3.1. *Constraints from the X-ray Data*

Turning now to the X-ray spectra, we re-analyzed the *Swift* detection on day 35.2 referenced by Kong & Di Stefano (2007) using the *Swift* software version 2.9. Source spectra were extracted from the cleaned Photon Counting mode event lists using a 10 pixel extraction radius (1 pixel = $2''\!.36$). A total of 49 background-subtracted counts were found, with only one count at $\sim$0.9 keV and the rest at lower energies. As an initial guide, this super-soft spectrum was then fitted with an absorbed black body spectrum using XSPEC. We estimated the absorbing column as follows. Stark et al. (1992) derive a Galactic contribution to the column in this direction equivalent to $E_{B-V} = 0.1$. At the position of M31N 2007-12b in M31, following the methodology discussed in Darnley et al. (2006) and Section 3.2 below, and assuming that the nova is situated half way down the absorbing column internal to M31, we get $E_{B-V} = 0.25$. Thus the total extinction to the nova is estimated to be equivalent to $E_{B-V} = 0.35$, which in turn is equivalent to $N_{\rm H} = 2.1 \times 10^{21}$ cm^{-2}. The best fit to the data using this total column then gives $kT = 63^{+10}_{-8}$ eV (i.e., $T = 7.6 \pm 1.2 \times 10^{5}$ K) and for $d = 780$ kpc to M31 (Holland 1998; Stanek & Garnavich 1998) yields an absorption-corrected luminosity $L = (4.5^{+1.9}_{-1.4}) \times 10^{38}$ erg s^{-1} (i.e., around twice the Eddington luminosity for a 1.4 $M_{\odot}$ WD). We obtained non-detections at the source position in 2007 November/December and 2008 May as detailed in Table 1.

From the above observations with *Swift*, the SSS was not detected ~15, 7, and 6 days before outburst and at 7, 21 and 169 days afterward. We can estimate therefore that the SSS appeared between $t \sim 21$ and 35 days post-outburst and had turned off again at $t < 169$ days. A caveat here is that the onset of the SSS phase has shown extreme variability in a few objects so far (e.g., RS Oph; see Page et al. 2008), and there is the possibility that the first emergence was earlier than 21 days. We can, however, compare the observed behavior of the M31N 2007-12b SSS with the properties of this phase in possibly related Galactic novae. For example, we note that the appearance of the SSS in U Sco was around 19–20 days after the peak of the optical outburst in 1999 February (Kahabka et al. 1999). We used the model parameters for U Sco found by Kahabka et al. (1999) to generate a spectrum with the correct unabsorbed flux. In order to determine the predicted count rate in the *Swift* XRT if the source were placed in M31 at $d = 780$ kpc, the absorbing column was changed to $N_{\rm H} = 2.1 \times 10^{21}$ cm^{-2} but the normalization and derived kT were kept fixed. Finally, a new spectrum was generated to derive the predicted count-rate. Table 2 gives details of the parameters of this and other sources described below, together with their derived count rates.

It can be seen from Table 2 that with the spectral parameters given in Kahabka et al. (1999), the SSS emission seen in U Sco (d = 14 kpc) would not have been detectable by *Swift* at the distance of M31 in the exposure times used for M31N 2007-12b, although of course the U Sco SSS may have subsequently increased in brightness. In RS Oph (d = 1.6 kpc), the SSS emerged and then dominated the X-ray emission from $t \sim$ 29 days and turned off by $\sim$90 days (Page et al. 2008), i.e., consistent with the timescales in M31N 2007-12b. However, as can be seen from Table 2, even at the peak of its SSS emission, RS Oph would also have been undetected in M31 with the *Swift* XRT. In V2491 Cyg (d = 10.5 kpc), SSS emission became apparent after around 25 days (Page et al. 2009) and was sharply peaked at around 40 days. At the distance of M31, the *Swift* XRT

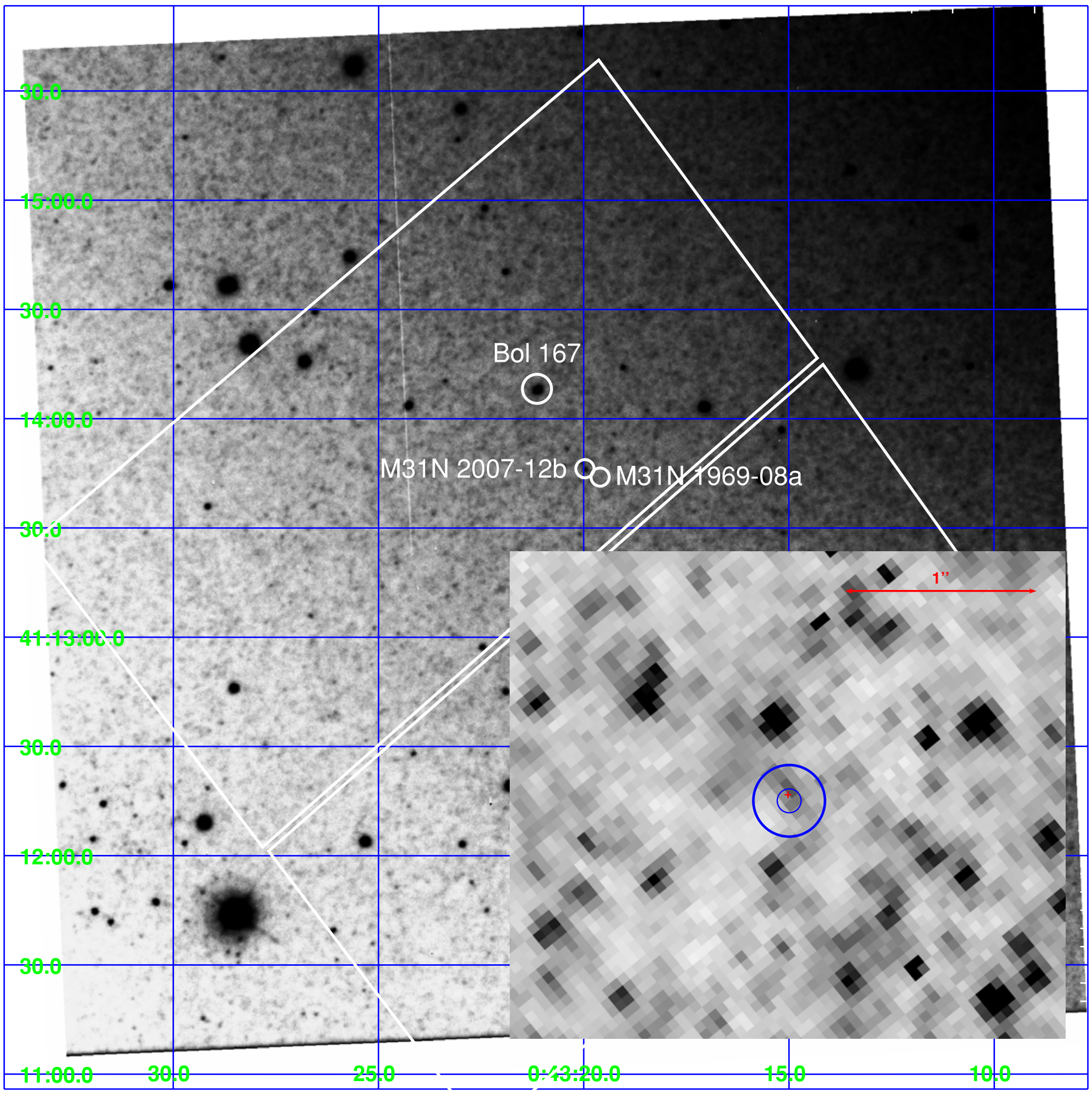

Figure 3. Main image: Liverpool Telescope Sloan-i' image of M31N 2007-12b taken on 2007 December 14.95 UT, field $4'.6 \times 4'.6$. The position of M31N 2007-12b and the new position of M31N 1969-08a are shown by the small white circles (left and right, respectively, circles have a diameter of $5''$). The white boxes indicate the approximate positions of the *HST* ACS-WFC field. Also shown is the position of the nearby globular cluster Bol 167. Inset: *HST* ACS-WFC image of the $\sim 3'' \times 3''$ region surrounding M31N 2007-12b. The inner blue circle indicates the 1σ ($1''.25$) radius search region for the progenitor, the outer circle the 3σ region, and the red cross indicates the position of the progenitor candidate.

(A color version of this figure is available in the online journal.)

Table 2
Parameters Used to Derive Predicted *Swift* Count Rates for the SSS phase in Other Novae if at the Distance and Absorbing Column of M31N 2007-12b (See the Text for Details)

Recurrent Nova	d (kpc)	$N_{\rm H}$ (cm^{-2})	kT_{BB} (eV)	Unabsorbed Flux (erg s^{-1} cm^{-2})	Predicted Count Rate (s^{-1})
U Sco[a]	14	2.2×10^{21}	107	5.4×10^{-10}	1×10^{-3}
RS Oph[b]	1.6	3.4×10^{21}	70	6.3×10^{-8}	1.1×10^{-3}
V2491 Cyg[c]	10.5	3.4×10^{21}	52	2.4×10^{-8}	9.4×10^{-3}

Notes.
[a] From Kahabka et al. (1999) and assuming the unabsorbed flux they quote is for the 0.1–10 keV energy range of the LECS/MECS of *BeppoSAX*.
[b] Fit to the *Swift* XRT data from day 50.5 after outburst during the SSS "plateau" phase. The unabsorbed flux is for the 0.3–10 keV energy range of the XRT. The $N_{\rm H}$ value used in the fit includes both interstellar and circumstellar components (see Page et al. 2008).
[c] Fit to the *Swift* XRT data from day 41.7 after outburst around the observed SSS peak count rate (Page et al. 2009). The unabsorbed flux is for the 0.3–10 keV energy range of the XRT.

observations reported here would have detected the V2491 Cyg SSS for a few days around this peak (again, see Table 2).

It is well established that the SSS arises from continued nuclear burning on the WD surface following the TNR which is gradually unveiled as the ejecta move outward (Krautter 2008). The deduced temperature and luminosity of the SSS in the case of M31N 2007-12b are consistent with this model. Simplistically, the timescale for uncovering and observed onset of the SSS phase is given by $t_{on} \propto M_{\rm H}^{1/2} v_{ej}^{-1}$ (Krautter et al. 1996), where $M_{\rm H}$ is the mass of H in the ejected envelope and $v_e j$ is the ejection velocity. Thus for the low ejected masses and high ejecta velocities found in RS Oph-type and U Sco-type RNe, t_{on} would be expected to be relatively short compared to that for the T Pyx sub-class of RNe or its value for most CNe.

The turn-off time since outburst for nuclear burning, $t_{\rm rem}$, is a steep function of WD mass. MacDonald (1996) finds for example $t_{\rm rem} \propto M_{\rm WD}^{-6.3}$. Generally in CNe this timescale is much longer than that observed in M31N 2007-12b (although Pietsch et al. 2007, make the point that this might be ascribed in part to a selection effect). For example, in one of the best studied cases, the moderately fast CN V1974 Cyg, 511 days $< t_{\rm rem} <$ 612 days (Balman et al. 1998) with $M_{\rm WD} \sim 1\ M_\odot$ (Hachisu & Kato 2006). From Starrfield et al. (1991), $t_{\rm rem} <$ 169 days implies $M_{\rm WD} \gtrsim 1.3\ M_\odot$. Similarly, the timescale after outburst for the onset of the SSS phase, $t_{\rm on}$, is also a function of $M_{\rm WD}$ in the sense that $t_{\rm on}$ is likely to be shorter for systems containing a high mass WD. As noted above, both U Sco and RS Oph have very short observed $t_{\rm on}$ of $\lesssim$ 20 days (Kahabka et al. 1999) and $\lesssim$ 30 days (Bode et al. 2006) respectively. In both cases, the WD mass is determined to be approaching the Chandrasekhar mass limit of $M_{\rm Ch} \sim 1.4\ M_\odot$ (Kahabka et al. 1999; Hachisu et al. 2007). Similarly, the WD mass in V2491 Cyg is estimated to be $> 1.3\ M_\odot$ (Hachisu & Kato 2009; Page et al. 2009). In addition, we note that envelope composition may also be important in determining the duration of the SSS phase. However, with $t_{on} <$ 35 days and $t_{\rm rem} <$ 169 days, $M_{\rm WD} > 1.3\ M_\odot$ for the range of envelope compositions presented in Hachisu & Kato (2006) and in particular, $M_{\rm WD} > 1.35\ M_\odot$ for the cases of (fast) Neon novae they present.

3.2. *A Search for the Progenitor System*

If M31N 2007-12b arose from an RN system of the RS Oph sub-type, it would contain a red giant secondary. We thus explored its detection at quiescence in archival *Hubble Space Telescope (HST)* imagery. The *HST* is capable of resolving giant branch stars within M31 (see Figure 4). The positions of both M31N 2007-12b and M31N 1969-08a lie within a pair of archival *HST* Advanced Camera for Surveys (ACS) Wide Field Channel (WFC) images (prop. ID 10273) taken in August 2004 using the F814W ($\sim I$) and the F555W ($\sim V$) filters. Point-spread function (PSF) fitting photometry was performed on all detected objects in both *HST* pass-bands using DOLPHOT, a photometry package based on HSTphot (Dolphin 2000). We used the relations given in Sirianni et al. (2005) to transform from these filters to Johnson-Cousins *V* and *I*.

To isolate the position of M31N 2007-12b within the *HST* data, we computed the spatial transformation between the LT and Gaussian convolved *HST* data using 23 stars resolved and unsaturated in both images. This approach is independent of the astrometric calibration of both fields and hence yields the most accurate results. The uncertainty in the derived transformation is small when compared to the 0.22 pixel (0$''$.06) average positional error of the nova in the LT data. This positional uncertainty in the LT data equates to a 1.25 pixel positional uncertainty (1σ) within the *HST* data.

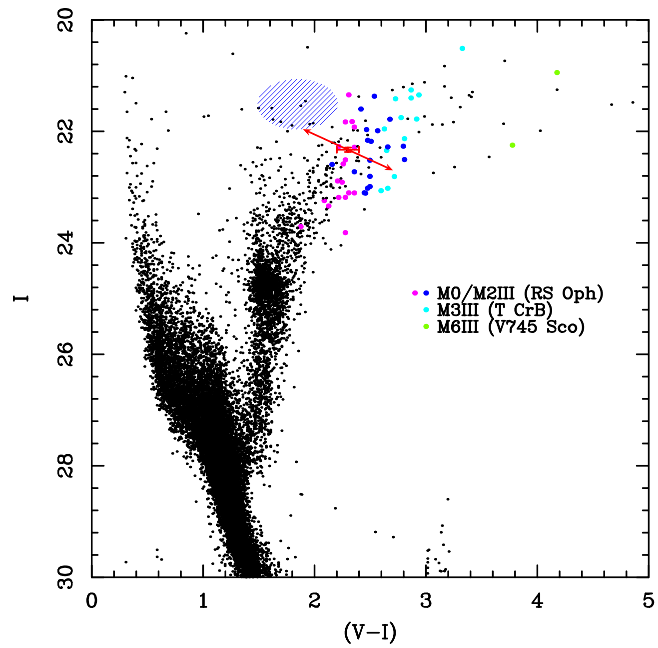

Figure 4. Color–magnitude diagram showing the *Hipparcos* data set (Perryman & ESA 1997), with parallax and photometric errors < 10%. The *Hipparcos* stars have been moved to the position of M31 assuming $(m-M)_0 = 24.43$ (Freedman & Madore 1990), an estimated extinction towards M31 of $E_{B-V} = 0.1$ mag (Stark et al. 1992), and an internal extinction of $E_{B-V} = 0.25$. The red point shows the candidate for the progenitor of M31N 2007-12b. The colored points are known M0/M2III (RS Oph), M3III (T CrB), and M6III (V745 Sco) secondary stars of RNe (Anupama 2008). The dark blue hatched ellipse shows the location of a quiescent RS Oph system (with the major and minor axes of the ellipse relating to 1σ scatter from the mean). The red arrow shows the extent of the likely effects of internal extinction ($\Delta E_{B-V} = \pm 0.25$).

(A color version of this figure is available in the online journal.)

There is a resolved object just inside 1σ from the LT position (separated 1.12 *HST* pixels or 0.89σ) seen in the *HST* F555W image (see the inset of Figure 3). We find that this object has $V = 24.61 \pm 0.09$ and $I = 22.33 \pm 0.04$, hence a color of $V - I = 2.3 \pm 0.1$. It should be noted that there is a cosmic ray track very close to this object's position in the F814W image, hence the *I*-band photometry may have been adversely affected by the subtraction of the cosmic ray. There are no other resolved stars within 1.90 *HST* pixels or 1.52σ.

Shown in Figure 4 is the position on a color–magnitude diagram of the object spatially coincident with M31N 2007-12b. This object (assuming no additional internal M31 extinction) lies in the M0/M2III (RS Oph secondary, purple and dark blue dots respectively) and M3III (T CrB secondary, light blue dots) region of the Giant Branch. The probability of finding such a star ($20 < I < 23$, $1.5 < V - I < 2.5$) at least as close to the predicted position by chance is only 3.4%. We note as an aside that we have explored the region around M31N 1969-08a and found no significant spatial coincidence with any pre-existing stellar source.

We estimate the mean *I*-band extinction across an Sb galaxy, such as M31, to be $A(I) = 0.8$ mag, equivalent to $E_{B-V} = 0.54$ (Holwerda et al. 2005). However, we can estimate that the average extinction experienced by an object at this position in M31 would be $A(r') = 0.7$ magnitudes, equivalent to $E_{B-V} = 0.25$ (Darnley 2005, see above).

We also calculate the position of a quiescent RS Oph system on this diagram. We use the LT *V* and i' luminosities of RS Oph in the time range of 400–1300 days following the 2006 outburst (see Darnley et al. 2008, for days 400–600) to estimate the mean quiescent magnitudes, $\langle V \rangle = 11.03 \pm 0.03$, $\langle i' \rangle = 9.34 \pm 0.02$. These magnitudes were then corrected for the extinction towards RS Oph ($E_{B-V} = 0.7 \pm 0.1$; Snijders 1987) and the distance to RS Oph ($d = 1.6 \pm 0.3$ kpc; Bode 1987). The Sloan-i' flux was transformed to the Johnson-Cousins system, and the system was placed at the distance of M31 and reddened by an amount equal to the extinction towards that galaxy. We find that the expected mean quiescent magnitude of an RS Oph-like system in M31 (without any internal extinction) is $\langle I \rangle = 21.0 \pm 0.5$ with a color of $\langle V - I \rangle = 1.3 \pm 0.4$. Further correcting for the expected average internal M31 extinction yields, $\langle I \rangle = 21.5 \pm 0.5$, $\langle V - I \rangle = 1.8 \pm 0.4$. We note that these values of quiescent magnitudes and colors include contributions from other sources than the secondary (e.g., any accretion disk).

4. CONCLUSIONS

M31N 2007-12b shows several characteristics consistent with it being a recurrent nova. These include the rapidity of its optical decline, extremely high ejection velocities, and early emergence of its SSS phase. The early post-outburst optical spectrum also shows some similarities to that of RS Oph, but most closely resembles that of the proposed RN V2491 Cyg. Furthermore, we have found a coincident pre-outburst stellar source from archival *HST* observations that resides in the same region of the color–magnitude diagram as RS Oph. If this is indeed the quiescent nova system, this is the first time that this has been identified in a nova in M31. This finding also implies an outburst amplitude of $\Delta V \simeq 8.5$ mag, very similar to that given by Jurdana-Sepic & Munari (2008) for nova V2491 Cyg, although around 1 mag greater than that for RS Oph. The observed flux from the SSS detected in M31N 2007-12b is also more consistent with that of the short-lived peak at around 40 days in V2491 Cyg than that of the SSS in RS Oph. On the other hand, the secondary maximum reported in the light curve of V2491 Cyg at around $t =$ 15 days is not apparent in our LT data for M31N 2007-12b.

Among the Galactic RNe, both U Sco and RS Oph sub-types have been proposed as progenitors of Type Ia SNe as $M_{\rm WD} \sim M_{\rm Ch}$, and it has been concluded that there is a net accumulation of mass on the WD over time (Kahabka et al. 1999; Hachisu et al. 2007). Determination of the true nature of Type Ia progenitors is of course a very important quest for contemporary astrophysics, but still remains a controversial area. Recurrent novae have been one of the favored systems, but there are likely to be more problems in explaining the lack of H in SNIa spectra for RS Oph-like than for U Sco-like RNe. Certainly, the paucity of Galactic examples remains a hindrance to further progress. We have shown that it is now possible to identify RNe in M31, and even to determine their sub-type, via a suitable set of complementary observations. However, from our experience, we caution that identifying RNe from positional (near) coincidence of two or more outbursts can be precarious (e.g., see Shafter et al. 2009b). All RN candidates should be thoroughly explored through precise astrometry of the original images, where available. Furthermore, ambiguities of distance and host stellar population are negated for novae in M31, and the soft X-ray absorbing column is low, compared to their Galactic counterparts. Thus, the prospects are good for extending our studies of RNe, and in particular exploring any relationship to supernovae, from the Milky Way to potentially a much larger and better-defined sample of objects in the Andromeda galaxy.

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