PHOTOMETRIC AND SPECTROSCOPIC PROPERTIES OF NOVAE IN THE LARGE MAGELLANIC CLOUD

A. W. Shafter
Department of Astronomy, San Diego State University, San Diego, CA 92182, USA
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ABSTRACT

The photometric and spectroscopic properties of the 43 known LMC nova candidates are summarized and reviewed. Of these, photometric data sufficient to establish decline rates are available for 29 novae, while spectroscopic data sufficient to establish the spectroscopic classes are available for 18 systems. Half of the 18 novae belong to the Fe\textsc{ii} class, with the remaining nine belonging to either the He/\textsc{N} or the Fe\textsc{iii} classes. As seen in previous nova studies of M31 and M33, the He/\textsc{N} and Fe\textsc{iii} novae have on average faster photometric developments than do their Fe\textsc{ii} counterparts. Overall, the available photometry confirms earlier studies, and shows conclusively that LMC novae have faster rates of decline than do novae in the Galaxy and M31. It appears that the increased fraction of faster, He/\textsc{N} and Fe\textsc{iii} novae observed in the LMC compared with M31 is almost certainly the result of differences in the underlying stellar population between the two galaxies. We propose that the younger population seen in the LMC compared with M31’s bulge (where most of the novae are found), produces progenitor binaries with higher average white dwarf masses. The higher mean white dwarf mass not only produces a larger fraction of fast, He/\textsc{N} novae compared with M31, but also results in a relatively large recurrent nova population.

Key words: galaxies: individual (LMC) – galaxies: stellar content – novae, cataclysmic variables

Online-only material: color figures

1. INTRODUCTION

Over the past two decades it has become widely accepted that the observed properties of novae—the peak luminosity, the rate of decline, and the character of the post-eruption spectrum—are strongly affected by the underlying stellar population (e.g., see Shafter 2008, and references therein). In studies of Galactic novae, Duerbeck (1990) proposed the idea of two distinct populations of novae: a relatively young population of rapidly fading novae found in the solar neighborhood, the so-called “disk” novae, and a population of slower developing “bulge novae,” which are concentrated toward the Galactic center. At about the same time, Williams (1992) argued that the spectra of Galactic novae could be divided into one of two principal spectroscopic classes. Novae that display prominent Fe\textsc{ii} emission (the “Fe\textsc{ii}” novae) are characterized by P Cygni line profiles, a slow photometric evolution, lower expansion velocities, and lower levels of ionization, compared to novae with strong lines of He and N (the “He/\textsc{N}” novae). The spectroscopic types are believed to be related to fundamental properties of the progenitor binary such as the white dwarf mass, and are possibly dependent on the underlying stellar population (e.g., Della Valle & Livio 1998).

In order to explore the effect of stellar population on nova properties, Shafter et al. (2011a, 2011b, 2012) studied the spectroscopic properties of novae in the Local Group galaxies M31 and M33. In M31 (and the Galaxy), Fe\textsc{ii} novae make up ∼80% of novae that have been observed spectroscopically, while in M33, preliminary evidence suggests that Fe\textsc{ii} novae make up a significantly smaller fraction of novae. Among the 91 M31 novae with known spectroscopic class studied by Shafter et al. (2011b), no clear dependence of a nova’s spectroscopic type on spatial position (and presumably stellar population) in M31 was found. This result may be misleading, however, since the high inclination of M31’s disk to our line of sight makes it difficult to assign a given nova an unambiguous spatial position within the galaxy, particularly near the apparent center of M31 where the foreground disk is superimposed on the galactic bulge.

Despite this problem, the available photometric data did suggest that rapidly declining novae have a slightly more extended spatial distribution, as expected for a disk population. Given the difficulties in isolating stellar populations within a given galaxy, it would appear that a more promising approach to exploring differences in nova populations would be to compare nova properties between galaxies with differing Hubble types where population synthesis models have predicted they should vary (e.g., Yungelson et al. 1997).

In this paper, we review all available photometric and spectroscopic observations of novae in the Large Magellanic Cloud (LMC) up to the end of 2012. We then compare their properties with those of novae in M31, M33 and the Galaxy with the goal of furthering our understanding of how nova properties vary with stellar population.

2. SPECTROSCOPIC CLASSIFICATION OF NOVAE

Nova outbursts are the result of a thermonuclear runaway (TNR) in the degenerate surface layers of an accreting white dwarf in the progenitor binary. The TNR ejects some or all of the accreted material, and in some cases may dredge up material from the white dwarf itself. Spectra of novae shortly after eruption (days to weeks) are dominated by prominent Balmer emission lines. In addition, the immediate post-eruption spectra often display prominent emission lines of either Fe\textsc{ii} or He and N in various stages of ionization (Williams 1992). The former group, which represents ∼80% of Galactic and M31 novae (Shafter 2007; Shafter et al. 2011b), shows spectra dominated by low excitation, relatively narrow lines (FWHM H\alpha ≤ 2000 km s\textsuperscript{−1}) that are flanked by P Cygni absorption components characteristic of an expanding, optically thick gas. The remaining ∼20% of novae, the “He/\textsc{N}” systems, display higher excitation emission lines that are generally broader (FWHM of H\alpha ≥ 2500 km s\textsuperscript{−1}) that are characterized by more rectangular, castellated or flat-topped profiles. A small fraction of novae, which appear to have characteristics of both classes, are referred to as either “hybrid” or broad-lined Fe\textsc{ii} (Fe\textsc{iii}) novae. These
systems appear similar to Fe II novae shortly after eruption, but their emission lines are broader. Later, they may evolve to display a classical He/N spectrum, but have not been seen to evolve into typical narrow-lined Fe II novae. Empirically, spectral classifications made within the first few weeks after eruption seem to be robust; and, with the exception of the hybrid novae, do not appear to be sensitive to the precise phase in the evolution of the outburst. That said, additional time-resolved spectroscopic observations of novae throughout their outburst development will be required before the stability of the spectral classification can be fully assessed.

The properties of the progenitor binary that determine the nova’s spectroscopic class are not completely understood. While it seems clear that the He/N spectrum must be produced in a relatively low-mass ejecta consisting of an optically thin shell of gas that is ejected at high velocity in the eruption (Williams 1992, 2012), the origin of the Fe II emission spectrum is more uncertain. The conventional explanation has been that Fe II spectra are produced in the optically thick wind that results from the expulsion of massive ejecta from the white dwarf’s surface (Williams 1992). More recently, however, Williams (2012) has suggested that the Fe II emission spectrum is produced predominantly in gas stripped from the secondary star during the eruption. In this picture, nova binaries with large mass ratios, \( q = M_\text{sec}/M_\text{wd} \), where the secondary star subtends a relatively large angle as seen from the white dwarf, would be expected to be more likely to produce Fe II spectra.

Regardless of whether the emission originates in the wind or in material stripped from the secondary star, Fe II novae are likely to harbor low-mass white dwarfs. Models show that the accreted mass required to trigger a TNR (the ignition mass) is primarily a function of the white dwarf mass and temperature, with the latter being strongly influenced by the rate of accretion onto the white dwarf’s surface. Thus, novae harboring low-mass white dwarfs accreting slowly will have the largest accreted masses and the longest recurrence times between eruptions. Assuming the ejected mass is proportional to the accreted mass, such systems will be more likely to produce the large ejected masses required to produce an optically thick wind. In addition, the high mass ratios favored in systems with low mass white dwarfs will act to increase the interaction of this wind with the secondary star, further facilitating the production of an Fe II spectrum. In He/N novae, on the other hand, it is thought that a relatively small amount of gas is ejected quickly from a relatively massive white dwarf, with little contribution from a wind. In this case, the spectrum will be dominated by emission from a high-velocity shell ionized by the hot white dwarf resulting in a nova of the He/N spectroscopic class. Thus, it appears that a study of the spectroscopic classes of novae can shed light on the white dwarf mass distribution in a nova population.

3. NOVAE IN THE LMC

A total of 43 suspected nova eruptions have been observed in the LMC since the first nova was discovered in 1926 (Luyten 1926). Five of these recorded outbursts are uncertain (LMCN 1952, 1966, 1996, 1998 and 1999), and another three (LMCN 1990-02a, 2004-10a, and 2009-02a) almost certainly represent the second outburst of a previously known system, and are therefore recurrent novae (RNe). Thus, the likely number of independent nova systems identified in the LMC as of the end of 2012 is 35. Given the challenges associated with obtaining spectra of transient sources like novae, it is perhaps surprising that spectroscopic observations sufficient to determine the spectroscopic class is available for more than half of these novae.

Specifically, an analysis of published spectroscopic data has allowed us to assign tentative spectroscopic classes: Fe II, Fe IIb (hybrid), or He/N, for a total of 22 LMC novae. Of these 22, 17 spectroscopic classes are reasonably secure. A summary of the properties of all known LMC nova candidates, including their spectroscopic classes where known, is given in Table 1, with the spatial distribution of the novae shown in Figure 1. Below we summarize the spectroscopic properties of the 20 LMC novae for which spectroscopic classifications are possible. When available, we have also included estimates of the magnitude reached at peak brightness and the rate of decline, \( v \).

Often the rate of decline is parameterized in terms of the number of days a nova takes to fade either two or three magnitudes from maximum light, \( t_2 \) or \( t_3 \).

1. LMCN 1970-03a. LMCN 1970-03a was discovered by MacConnell & Gomez (1970) on an objective prism plate taken on 1970 March 8.2 UT. MacConnell (1970) describes that objective prism spectrum as follows: “H is very bright, flat-topped, and broad and faint, broad Fe II emission at \( \lambda 4924 \) and \( \lambda 5018 \) is present.” Although, line widths are not given, based on MacConnell’s description, it appears that LMCN 1970-03a is most likely a broad-lined Fe II nova. The nova was discovered at \( V \sim 12 \), unfortunately, with no light curve information available.

2. LMCN 1970-11a. LMCN 1970-11a was discovered in decline, with maximum light not covered by available observations. Based on extrapolation of available data, Capaccioli et al. (1990) estimate that LMCN 1970-11a reached \( V \sim 10.5 \)–11.0. Available observations showed...
that the nova faded quite rapidly, with Graham & Araya (1971) estimating a decline rate of 0.25 mag per day. Spectra obtained by Havlen et al. (1972) starting 9 days after the estimated date of maximum light on 1970 October 30 shows the nova to be a member of the Fe II spectroscopic class. They deduce a shell velocity of −1560 km s$^{-1}$, and estimate that the nova may have reached $V = 10.8$ at maximum light.

3. LMCN 1977-03a. LMCN 1977-03a was discovered by Graham (1977) on 1977 March 12. According to Cantera & Schwartz (1977) the nova reached $V = 10.7$ and suffered a reddening of $E(B-V) = 0.11$. If we adopt a ratio of
total-to-selective extinction of $R = 3.2$, and a distance modulus $\mu_o = 18.50$ (Freedman et al. 2001), we find an absolute magnitude at maximum light, $M_V = -8.2$. A subsequent analysis of the nova by Cantera & Thompson (1981) found that $t_2(V) = 11$ days and $t_3(V) = 21$ days, respectively. These authors also reported spectroscopic observations near the time of maximum light that are consistent with the identification of LMCN 1977-03a as an Fe ii system.

4. **LMC 1978-03a.** LMCN 1978-03a was discovered by Graham & Rojas (1978) on 1978 March 29 UT at $V = 12$, and later confirmed by Graham (1978). An objective prism spectrum obtained at the time of discovery was described by Graham (1979), and shows the Balmer series in emission. An inspection of the published spectrogram suggests that the FWZI of H\(\beta\) is $\sim 2400$ km s\(^{-1}\). Additionally, there is a hint that N\(\text{iii}\) $\lambda 4640$ may be present. A pre-maximum objective prism spectrum was also obtained by Graham (1979) on 1978 March 17 UT as part of routine monitoring of the LMC. The spectrum showed narrow Balmer absorption, and may indicate that the true maximum of the nova occurred much earlier that the reported discovery on March 29. An extrapolation of the light curve from March 29 suggests that the nova could have reached $V \sim 9.5$–10 at maximum light and faded with a rate of $\sim 0.5$ mag per day (Graham 1978). We estimate that the spectral classification occurred $\sim 10$ days after maximum light.

5. **LMCN 1981-09a.** LMCN 1981-09a was discovered by J. Maza on 1981 September 30.371 UT at $m_{pg} \sim 12$, and later confirmed by J. Maza and P. Jekabsons on October 6.85 UT. A day later, on October 7.64 UT, A. A. Page found that the nova had brightened to $m_{pg} = 11.8$. An objective prism spectrum obtained by H. Duerbeck near the time of maximum light showed very strong and broad H\(\alpha\) emission (FWHM = 3800 km s\(^{-1}\)), along with Fe ii and N\(\text{ii}\) emission. These data suggest that LMCN 1981-09a is a Fe ii nova, or hybrid nova. A summary of all early observations can be found in Maza et al. (1981). Unfortunately, little light curve information exists, and a reliable estimate of the fade rate is not available.

6. **LMCN 1988-03a.** LMCN 1988-03a was discovered by G. Garradd on 1988 March 21.484 UT at $V \sim 11.4$ (Garradd & Tregaskis 1988). A series of spectroscopic observations made in the first month following discovery revealed relatively narrow Balmer and Fe ii emission features (Schwarz et al. 1998; Drechsel et al. 1990), indicating that the nova is a member of the Fe ii nova class. An analysis of the light curve by Hearnsflew et al. (2004) indicated that the nova reached $V = 11.2 \pm 0.3$ and declined moderately rapidly, with $t_2(V) = 22.5 \pm 4$.

7. **LMC 1988-10a.** The second nova observed in 1988 was also discovered by G. Garradd on 1988 October 12.48 UT at $V = 11.3$ (McNaught et al. 1989), before brightening to $V = 10.3$ on October 13.75 UT (Sekiguchi et al. 1989). Extensive spectroscopic observations by Sekiguchi et al. (1989) revealed prominent He, N, and Balmer emission lines (FWZI $\sim 6000$ km s\(^{-1}\)) characteristic of the Fe/N novae. An analysis of the light curve, also by Sekiguchi et al. (1989), established that the nova faded relatively rapidly with $t_2(V)$ and $t_3(V)$ values of 5 and 10 days, respectively.

8. **LMCN 1990-01a.** LMCN 1990-01a was discovered on 1990 January 16.47 UT at magnitude 11.5 (McNaught et al. 1990). Spectra obtained by Dopita & Rawlings (1990) between one and two weeks post-discovery reveal broad (FWHM $\sim 5600$ km s\(^{-1}\)), flat-topped Balmer and He i emission early on followed by increasing He ii and [Ne iii] lines by January 30. These data establish LMCN 1990-01a as an ONe nova, and a member of the He/N spectroscopic class. An analysis of the light curve by Liller & Shida (2005) suggests that the nova reached $V = 9.7$ at maximum light (although maximum was not observed directly) and that the nova faded rapidly at a rate of 0.59 mag per day. With an estimated reddening, $E(B-V) = 0.22 \pm 0.07$ (Vanlandingham et al. 1999), the nova may have reached $M_V = -9.6$.

9. **LMCN 1990-02a.** LMCN 1990-02a was discovered at the position of LMCN 1968-12a by Liller on 1990 February 14.1 UT at $V = 11.2$, making it the first recurrent nova to be recognized in the LMC (Sekiguchi & Stobie 1990; Shore et al. 1991; Williams et al. 1990). Spectroscopic observations by Sekiguchi et al. (1990) and Shore et al. (1991) obtained approximately a week post discovery established that the nova was a member of the He/N spectroscopic class. The nova was observed to fade rapidly, dropping and estimate 4.5 magnitudes in the week since discovery. Liller & Shida (2005) estimate that the nova likely reached $V = 10.2$ and faded at a rate of $\sim 0.59$ mag per day.

10. **LMCN 1991-04a.** LMCN 1991-04a was discovered on the rise to maximum (Liller et al. 1991). The nova reached $V \sim 9.0$ on 1991 April 24 UT, making it the brightest nova ever observed in the LMC (Shore et al. 1991; Della Valle & Kaeufl 1992) near maximum light. Hearnshaw et al. (2004) obtained approximately a week post discovery that the nova was a member of the Fe ii nova class. The nova was observed to fade relatively rapidly, with relativelv broad Balmer emission lines (FWHM $H\alpha = 2500$ km s\(^{-1}\)), along with a prominent C\(\text{iii}/N\(\text{iii}\) blend at $\lambda 464.5$ nm (Della Valle et al. 1991). Thus, it appears that LMCN 1991-04a may be a member of the Fe ii spectroscopic class.

11. **LMCN 1992-11a.** LMCN 1992-11a was discovered by Liller (1992) at $R = 10.7$ on 1992 November 11.21 UT. Subsequent photometry showed that the nova reached $V = 10.2 \pm 0.2$ and faded relatively quickly with $t_2(V) = 6.9 \pm 1.1$ days and $t_3(V) = 13.7 \pm 1.6$ days (Hearnshaw et al. 2004). Spectroscopic observations by Della Valle & Kaeufl (1992) and Duerbeck et al. (1992) near maximum light clearly establish that the nova is a member of the Fe ii nova spectroscopic class.

12. **LMCN 1995-02a.** LMCN 1995-02a was discovered at $m = 10.7$ by Liller (1995) on 1995 March 2.11 UT. An analysis of the light curve by Hearnshaw et al. (2004) revealed that the nova reached $V = 10.35 \pm 0.5$ and subsequently faded with characteristic times of $t_2(V) = 11 \pm 3$ days and $t_3(V) = 19.6 \pm 3.2$ days. Limited spectroscopic observations by Della Valle et al. (1995) obtained at or near maximum light suggest that the nova was likely a member of the Fe ii nova class.

13. **LMCN 2000-07a.** LMCN 2000-07a was discovered by Liller & Stubbings (2000) on 2000 July 13.4 UT. Although maximum light was not covered, Hearnshaw et al. (2004) estimate that the nova reached $V = 10.7 \pm 0.5$ and that it subsequently faded with $t_2(V)$ and $t_3(V)$ times of 8 and 20 days, respectively. Photometry by Greiner et al.
obtained approximately 3 days after discovery by Duerbeck & Pompei (2000) established that the nova was a member of the Fe II spectroscopic class.

14. **LMCN 2002-02a.** LMCN 2002-02a was yet another nova discovered by Liller (2002). According to his discovery images, the nova reached \( V = 10.5 \) on 2002 March 3.066 UT. Liller & Shida (2005) estimate that the nova reached \( V = 10.1 \) at maximum light. Subsequent photometric and spectroscopic follow-up observations by Mason et al. (2005) obtained approximately a week post discovery established that LMCN 2002-02a was a member of the Fe II spectroscopic class, and that it faded with a \( t_2 \approx 12 \) days. Subramaniam & Anupama (2002) give \( t_3 = 23 \) days, suggesting a slightly slower rate of decline, possibly based on the Liller & Shida (2005) estimate of \( v = 0.1 \) day\(^{-1}\).

15. **LMCN 2003-06a.** LMCN 2003-06a was discovered by Liller et al. (2003) on 2003 June 19 UT. Liller is known about the spectroscopic properties of this nova, but H. Bond reported that the emission lines were very broad (Liller et al. 2003). An analysis of a blue spectrum (\( \lambda 3900–4500 \) Å) obtained 11 days post discovery kindly provided by H. Bond (2012, private communication) shows that FWHM (\( H_\gamma \)) \( = 3600 \) km s\(^{-1}\). The nova appears to be either an Fe IIb, or more likely an He/N system. Liller & Shida (2005) estimate a decline rate of 0.25 mag per day.

16. **LMCN 2004-10a.** LMCN 2004-10a was discovered by Liller (2004) on 2004 October 20.193 UT near the position of LMCN 1937-11a (YY Dor). Spectroscopic observations by Bond et al. (2004) and by Mason et al. (2004) during the first week post discovery clearly establish the nova as belonging to the He/N class, consistent with its identification as a recurrent nova. Limited photometric observations suggest that the nova reached \( V \approx 10.9 \), and faded at a rate of \( \sim 0.17 \) mag per day (Liller & Shida 2005).

17. **LMCN 2005-09a.** LMCN 2005-09a was unusual in that it was identified on 2006 July 18 UT via its X-ray emission approximately 10 months after eruption (Read et al. 2009). Analysis of archival photometry from the All Sky Automated Survey (Pojmanski 2002) revealed that the nova erupted sometime between 2005 September 18 and 30, when it was observed at \( V \approx 12 \). The very limited photometric data suggested that the nova faded relatively rapidly, with \( t_2(V) \approx 8 \) days. The only spectroscopic data were obtained by Read et al. (2009) more than a year after eruption. Although a reliable spectroscopic classification is not possible this long after eruption, Read et al. (2009) have speculated that the nova might have been an Fe II system.

18. **LMCN 2005-11a.** LMCN 2005-11a was discovered by Liller et al. (2005) on 2005 November 22.065 UT at \( m \approx 12.8 \). An analysis of the light curve by Liller et al. (2007) shows that the nova likely reached \( V = 11.5 \) and then faded very slowly with \( t_2(V) = 63 \) days and \( t_3(V) = 94 \) days. Spectroscopic observations by Walter et al. (2005, 2012) starting 2 days post discovery show the object to be a member of the Fe II spectroscopic class.

19. **LMCN 2009-02a.** LMCN 2009-02a was discovered by Liller (2009) on 2009 February 5.067 UT at \( m \approx 10.6 \). The eruption likely represents a recurrence of the poorly observed nova, LMCN 1971-08a (M. F. Bode et al. 2013, in preparation). Spectroscopic observations by Orio et al. (2009) are consistent with the classification of the nova as a member of the He/N class. Limited photometric observations suggest that the nova faded rapidly. Based on the V-band photometry of Walter et al. (2012), we estimate \( t_1 \approx 8 \) days and \( v \approx 0.37 \) day\(^{-1}\).

20. **LMCN 2009-05a.** LMCN 2009-05a was discovered at \( m \approx 12.1 \) on 2009 May 4.994 UT Liller & Monard (2009). Photometric and spectroscopic observations by Walter et al. (2012) starting 3 days post discovery show that the object was a slowly fading Fe II nova. Based on the Walter et al. (2012) V-band photometry, we estimate \( t_3 \approx 80 \) days and \( v \approx 0.037 \) day\(^{-1}\).

21. **LMCN 2012-03a.** LMCN 2012-03a was discovered by J. Seach on 2012 March 26.397 UT at \( m = 10.7 \) (Liller et al. 2012). The nova was observed to fade very rapidly after discovery, with Walter et al. (2012) estimating \( t_2 \approx 1.1 \) days and \( t_3 \approx 2.1 \) days. However, the available observations do not provide tight constraints on the time of maximum light (and thus maximum brightness), so these estimates are uncertain. Spectroscopic observations on March 27.0 UT shortly after discovery revealed the object to be a member of the He/N spectroscopic class (Prieto 2012).

22. **LMCN 2012-10a.** LMCN 2012-10a was discovered on 2012 November 04.358 UT by Wyrzykowski et al. (2012) as part of the OGLE-IV search for transients in the LMC. An examination earlier data shows that the nova reached maximum light between 2012 October 22.374 and 25.310 UT. The October 25, 310 UT image showed the nova saturated, with an I-band magnitude between 11 and 12. Wyrzykowski et al. (2012) estimate \( t_3(I) \) and \( t_5(I) \) times of 10 and 15 days, respectively. Subsequent spectroscopy by Walter et al. (2012) starting \( \sim 1 \) week post maximum reveals the nova to be a likely member of the He/N spectroscopic class.

### 3.1. Global Photometric Properties

It has long been recognized that a nova’s luminosity at maximum light and its rate of decline are correlated. The resulting Maximum Magnitude versus Rate of Decline (MMRD) relation was first applied to Galactic novae by McLaughlin (1945). Since that time, there have been numerous characterizations the MMRD relation for Galactic (e.g., Cohen 1985; Downes & Duerbeck 2000) and extragalactic nova populations (e.g., Capaccioli et al. 1990; Della Valle & Livio 1995; Darnley et al. 2006). A common finding of all of these studies is that there appears to be considerable intrinsic scatter in the MMRD relation that cannot be explained solely by observational uncertainties. A recent study by Kasliwal et al. (2010) has revealed a number of apparently faint, yet relatively rapidly fading novae in M31, which has caused the authors to question whether an MMRD relation is justified at all. In order to re-examine the MMRD relation for the LMC, we have reviewed available photometric observations and produced estimates of maximum magnitudes and rates of decline for the 29 nova outbursts summarized in Table 2. Values of the absolute magnitude at maximum have been estimated by adopting a distance, \( d_{\text{LMC}} = 18.50 \) (Freedman et al. 2001), and, when unknown, assuming a reddening \( E(B-V) = 0.12 \) (Imara & Blitz 2007). When not reported directly, decline rates, \( v \), have been estimated from \( v = 2/t_2 \) or \( v = 3/t_3 \). If both \( t_2 \) and \( t_3 \) are available, an average of the resulting decline rates is adopted.

In Figure 2 we have plotted the MMRD relation for LMC novae based on our estimate of the absolute \( V \) magnitudes at maximum light and the measured rates of decline (parameterized as \( \log 100v \)). For most novae, peak brightness was not well
covered by observations, making both the magnitude at maximum light and the fade rate uncertain. Given these unknown errors, we have not attempted to apply any corrections to convert observations in the photographic or unfiltered "white light" bandpasses to the visual band, nor have we included formal error bars when plotting the points. Despite the considerable observational uncertainties, a general MMRD relation is apparent, with the more luminous novae appearing to generally fade the fastest. A linear least-squares fit to the data (excluding the three lower limits) gives the following relation:

$$M_V(\text{max}) = -(1.52 \pm 0.24)\log 100\nu - 6.27 \pm 0.32.$$  (1)

For comparison, we have also plotted the corresponding relation for M31,

$$M_V(\text{max}) = -(1.70 \pm 0.08)\log 100\nu - 5.87 \pm 0.10.$$  (2)

found by Shafter et al. (2011b), which, in light of the considerable uncertainties, appears consistent with our LMC result.

Although there is some overlap in fade rates of He/N and Fe ii novae, as found in M31 (Shafter et al. 2011b) and M33 (Shafter et al. 2012), it is clear that the He/N novae are generally "faster" than their Fe ii counterparts. Of the nine novae with $t_f$ times less than or equal to 10 days (log $100\nu \geq 1.5$), none are confirmed Fe ii novae; five are He/N or suspected He/N, one is a possible Fe ii nova, and three are of unknown spectroscopic type. Conversely, the five lowest novae with known spectroscopic type are all Fe ii systems. It should be noted here that Fe ii systems are not confined to the slowest or least luminous novae. Indeed, there appears to be a rare class of very luminous, and slowly rising, Fe ii novae, one of which is LMCN 1991-04a, which we have argued is likely a member of the Fe ii class. Two other notable examples of highly luminous Fe ii novae with somewhat narrower emission lines are M31N 2007-11d (Shafter et al. 2009) and SN 2010U (Czezkala et al. 2012).

It has been argued for some time that the novae in the LMC generally faded from maximum light more quickly than novae in the Galaxy or in M31 (e.g., Della Valle & Duerbeck 1993). In Figure 3, we compare the fade rates for our complete sample
Figure 2. The MMRD relation for LMC novae with measured fade rates. Fe\textsc{ii} novae are represented by filled red circles, while He/N and Fe\textsc{ii}b novae are shown as filled blue squares (open symbols represent tentative spectroscopic types). Novae of unknown spectroscopic type are shown as “+” symbols. The three novae with $M_V$ shown as upper limits are systems where maximum light was missed, and no estimate of the peak brightness is available. The dashed line represents a linear least-squares fit to the data as given in Equation (1). For comparison, the dotted line (given by Equation (2)) shows the MMRD relation from Shafter et al. (2011b) for their sample of M31 novae.

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

Figure 3. The cumulative distribution of the fade rates for the LMC novae compared with those of the Galaxy (dotted line) and M31 (broken line). The LMC novae are considerably “faster” than their Galactic and M31 counterparts. A Kolmogorov–Smirnov test confirms that the distributions are markedly different with $KS \sim 0$.

of LMC novae with those available for the Galaxy and M31 from Tables 5 and 6 of Downes & Duerbeck (2000) and Shafter et al. (2011b), respectively. In agreement with earlier results, it is clear from Figure 3 that the LMC novae are considerably “faster” than their Galactic and M31 counterparts.

3.2. Global Spectroscopic Properties

Of the 18 novae listed in Table 1 having sufficient data for a firm spectroscopic class to be assigned, half are members of the Fe\textsc{ii} spectroscopic class, with the other half being members of the He/N or Fe\textsc{ii}b classes.\footnote{Seven are He/N class, with just one Fe\textsc{ii}b (LMCN 1981-09a). LMCN 2003-06a is likely an He/N system, but the limited spectral coverage does not allow an Fe\textsc{ii}b classification to be ruled out.} For an additional three novae sufficient data exist to assign a tentative spectroscopic class, with LMCN 1978-03a a likely Fe\textsc{ii} system, and 1970-03a and 1991-04a likely being broad-lined Fe\textsc{ii} (Fe\textsc{ii}b) novae. LMCN 2005-09a has been tentatively classed as an Fe\textsc{ii} system by Read et al. (2009) based on a single spectrum taken more than a year post eruption. In reality, the spectroscopic class of this nova is

of the He/N or Fe\textsc{ii}b classes.\footnote{Seven are He/N class, with just one Fe\textsc{ii}b (LMCN 1981-09a). LMCN 2003-06a is likely an He/N system, but the limited spectral coverage does not allow an Fe\textsc{ii}b classification to be ruled out.}
unknown. The fraction of Fe II novae in the LMC (~50%), like that found in M33 (Shafter et al. 2012), is significantly lower than the fraction (~80%) seen in M31 and the Galaxy (Shafter et al. 2011b; Shafter 2007).

To further explore the spectroscopic properties of the LMC novae, in Table 3 we have collected all published measurements of the Hα emission-line widths (which reflect the expansion velocities of the ejected gas where the lines are formed). As is now well established from prior spectroscopic surveys of novae, the emission-line widths are strongly correlated with spectroscopic class. As in previous surveys of novae in M31 and M33 (Shafter et al. 2011b, 2012), the novae belonging to the He/N class are characterized by Hα FWHM > 2500 km s^{-1}, while the Fe II systems have FWHM values typically less than 2000 km s^{-1}. It is thought that the Balmer emission lines associated with the He/N novae, with their broad, rectangular, and flat-topped profiles, are formed in discrete, optically thin shells that are ejected at relatively high velocity from near the white dwarf’s surface at the onset of eruption.

Not surprisingly, the emission-line widths (expansion velocities) are also clearly correlated with the rate at which the nova fades in brightness. The low mass ejecta associated with rapidly expanding shells are expected to become optically thin more quickly than in more massive ejecta, resulting in faster rates of decline. For the LMC novae, Figure 4 shows the relationship between the fade rate and the FWHM of Hα. The dashed line shows the best-fit linear relation given by

\[ \log_{10} v = (1.01 \pm 0.25) \log \text{FWHM}_{\text{H} \alpha} - 2.04 \pm 0.85 \]  

while the dotted line shows a corresponding relation given by

\[ \log_{10} v = (1.05 \pm 0.34) \log \text{FWHM}_{\text{H} \alpha} - 2.50 \pm 1.08 \]  

for a sample of M31 novae from Shafter et al. (2011b). In addition to highlighting the sharp distinction in line widths between the Fe II and the He/N novae, the figure clearly shows that novae with broad emission-line widths fade the fastest as expected. The He/N, which all have a FWHM_{Hα} > 2500 km s^{-1}, have a mean fade rate \( \langle \nu(\text{He}/N) \rangle = (0.54 \pm 0.45) \) d^{-1}, while the Fe II novae have a mean fade rate \( \langle \nu(\text{Fe} II) \rangle = (0.15 \pm 0.09) \) d^{-1}. It is unclear whether the slight offset between the LMC and M31 relations given by Equations (3) and (4) is significant. If so, and the LMC novae do in fact fade somewhat faster for a given Hα emission-line width compared with M31 novae, the difference could be due to a lower metallicity (and hence opacity) in the expanding shells of LMC novae that causes ejecta of all masses to become optically thin sooner, resulting in a population of novae with generally faster rates of decline.

### 3.3. The Spatial Distribution of LMC Novae

The LMC is an irregular galaxy of Hubble type Irr/SB(r)sm (de Vaucouleurs et al. 1991). The luminosity profile has been the subject of several studies, which have established the presence of a barred disk seen near face-on, with a brightness distribution that drops off exponentially from the center of the galaxy. Figure 1 shows the projected positions of the 40 known LMC nova candidates from Table 1 superimposed over an image of the galaxy. Of these 40, spectroscopic classes are known or suspected for 21 of the novae. To study their distributions, we have plotted the Fe II systems as red circles and the He/N and Fe IIb novae as blue squares. The novae appear to be distributed uniformly across the face of the galaxy, with no obvious dependence of spectroscopic class on spatial position. As has been noted in previous studies (e.g., Subramaniam & Anupama 2002), there may be a slight enhancement of novae southeast of the bar, with a relative dearth in the 30 Dor region (northeast of the bar). In addition, as pointed out by van den Bergh (1988), despite the enhanced luminosity, novae do not appear to be strongly associated with the central bar itself.

We can make a more quantitative study of the nova distribution by comparing the nova density with that of the background light. According to the photometry of de Vaucouleurs & Freeman (1972), the disk of the LMC is oriented at an inclination angle \( i = 27^\circ \), with a position angle \( PA = 170^\circ \). Based on these parameters, we have computed the projected distance of each nova from the center of the galaxy. The radial light distribution is then computed assuming an exponential disk with a central brightness of 21.16 mag arcsec^{-2}, and a scale length \( r_0 \approx 98.7 \) based on the V-band photometry of Gallart et al. (2004). Figure 5 shows the resulting cumulative nova distribution compared with the background V-band light. The fit appears to be quite good, with a Kolmogorov–Smirnov (KS) test indicating that the distributions would be expected to differ by more than that observed 5% of the time if they were drawn from the same parent population. Thus, there is no reason to reject the hypothesis that the novae follow the light distribution of the LMC.

| Nova       | FWHM (km s^{-1}) | ν (day^{-1}) | Phase (days) | Type | References |
|------------|------------------|-------------|-------------|------|------------|
| LMCN 1970-11a | 1500             | 0.25        | 9, 10, 11   | Fe II | 1         |
| LMCN 1977-03a | 1600             | 0.16        | 1           | Fe II | 2         |
| LMCN 1980-06a | 1500             | 0.50        | 10          | Fe II | 3         |
| LMCN 1981-09a | 3800             | 0.08        | 1           | Fe IIb| 4         |
| LMCN 1988-03a | 1400             | 0.084       | 4, 17, 31   | Fe II | 5, 6       |
| LMCN 1988-10a | 3000             | 0.35        | 1, 19, 49   | He/N | 7         |
| LMCN 1990-01a | 5600             | 0.59        | 7, 16       | He/N | 8         |
| LMCN 1990-02a | 5500             | 0.59        | 8           | He/N | 9, 10      |
| LMCN 1990-04a | 2500             | 0.35        | 18          | Fe IIb| 11        |
| LMCN 1992-11a | 900              | 0.25        | 1           | Fe II | 12, 13     |
| LMCN 1995-02a | 1500             | 0.17        | 1           | Fe II | 14        |
| LMCN 2000-07a | 1700             | 0.20        | 3           | Fe II | 15        |
| LMCN 2002-02a | 2150             | 0.15        | 6, 11       | Fe II | 16        |
| LMCN 2003-06a | 3600             | 0.25        | 11          | He/N | 17        |
| LMCN 2004-10a | 4000             | 0.17        | 1, 5        | He/N | 18, 19     |
| LMCN 2005-11a | 900              | 0.032       | 2           | Fe II | 20, 22     |
| LMCN 2009-02a | 4200             | 0.37        | 3           | He/N | 21, 22     |
| LMCN 2009-05a | 1000             | 0.037       | 7           | Fe II | 22        |
| LMCN 2012-03a | 5700             | 1.5         | 1           | He/N | 23        |
| LMCN 2012-10a | 3600             | 0.20        | 10          | He/N | 22        |

Notes:

a Time elapsed between maximum light and spectra used for classification.

b References. (1) Havlen et al. 1972; (2) Canterna & Thompson 1981; (3) Graham 1979; (4) Maza et al. 1981; (5) Drechsel et al. 1990; (6) Schwarz et al. 1998; (7) Sekiguchi et al. 1989; (8) Dopita & Rawlings 1990; (9) Sekiguchi et al. 1990; (10) Shore et al. 1991; (11) Della Valle et al. 1991; (12) Della Valle & Kaeufl 1992; (13) Duerbeck et al. 1992; (14) Della Valle et al. 1995; (15) Duerbeck & Pompei 2000; (16) Mason et al. 2005; (17) H. Bond 2012, private communication; (18) Bond et al. 2004; (19) Mason et al. 2004; (20) Walter et al. 2005; (21) Orio et al. 2009; (22) Walter et al. 2012; (23) Prieto 2012.

c Velocity based on displacement of P Cyg absorption.

d Mean of values from Drechsel et al. (1990) and Schwarz et al. (1998).

e FWHM estimate assumed to be half of the FWZI.

f Recurrent nova: LMCN 1968-12a.

g Recurrent nova candidate: LMCN 1937-11a (YY Dor).

h Recurrent nova candidate: LMCN 1971-08a.
Figure 4. The dependence of the fade rate on nova expansion velocity (as reflected by the FWHM of Hα). The symbols have the same meaning as in Figure 2. There is a clear trend of increasing fade rate with increasing Hα emission line width. The dashed and dotted lines reflect the best-fit relations given in the text (Equations (3) and (4)) for the LMC and a sample of M31 novae from Shafter et al. (2011b), respectively.

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

Figure 5. The cumulative distribution of the LMC novae compared with the cumulative distribution of the background V light. The nova distribution follows the light distribution well (KS = 0.52).

4. DISCUSSION AND CONCLUSIONS

It has long been suggested that there exists two populations of novae, a “bulge” population and a “disk” population, with the former associated with an older bulge and thick disk population (Pop II) and the latter with a younger (Pop I), thin-disk component. The distinction is based upon limited observational data suggesting that bulge novae are generally less luminous and have slower photometric development when compared with their disk counterparts (Duerbeck 1990; Della Valle et al. 1992). There is also evidence to suggest that the spectroscopic class of Galactic novae is affected by stellar population, with He/N novae having a smaller distribution of scale heights from the midplane of the Galactic disk Della Valle & Livio (1998). This finding is explained as the result of the larger white dwarf masses in novae associated with a younger disk population, which eject smaller accreted masses at higher velocities compared with novae from older stellar populations.

There have been numerous studies of the relatively large and equidistant sample of novae in the nearby spiral galaxy M31, going all the way back to the early work of Hubble (1929). Recently, Shafter et al. (2011b) considered a total of 91 M31 novae with available spectroscopic data and found no evidence that spectroscopic class was sensitive to spatial position within the galaxy. They did, however, find that novae at larger galactocentric radius faded slightly more quickly than novae closer to the center. A caveat to their analysis is that the high inclination of M31’s disk to our line of sight makes it
difficult to clearly separate the disk and bulge component of the galaxy. This is a particular problem in the central regions of the galaxy (where most novae occur) where the foreground disk is projected onto the central bulge.

Rather than attempting to disentangle separate nova populations from a single galaxy like M31, it would appear that a better approach to studying nova populations would be to compare the properties of novae in galaxies with differing Hubble types and differing stellar populations. With that goal in mind, Shafter et al. (2012) considered the spectroscopic classes and rates of decline for the available sample of novae in M33, an essentially bulgeless galaxy with a dominant disk population. Although there were only 8 novae with known spectroscopic class in M33 compared with the 91 available for M31 (where the overall nova rate is ∼10× higher), there was already sufficient data to suggest that the mix of spectroscopic classes was dissimilar in the two galaxies at the 99% confidence level. In M31, approximately 80% of the novae are members of the Fe




bulges and elliptical galaxies. This difference results from higher average white dwarf masses expected in recently formed nova progenitor binaries (e.g., de Kool 1992; Tutukov & Yungelson 1995; Politano 1996). The higher white dwarf masses enable a TNR to be triggered with a smaller accreted (and ejected) mass, resulting not only in faster photometric evolutions and a higher He/N nova fraction, but also in shorter average recurrence times and a higher nova rate. Indeed, the LMC has the highest luminosity-specific nova rate measured for any galaxy (Della Valle et al. 1994; Shafter 2008).

Finally, we note that, of the 35 confirmed nova systems in the LMC, 3 are recurrent. The fraction of RNe, which approaches 10% (or ∼16% of the number of outbursts recorded) appears to be significantly higher than that seen in M31, where a total of only ∼8–15 RN systems (representing ∼15–30 eruptions) have been identified out of a total of more than 900 nova eruptions cataloged. Although these fractions are certainly lower limits to the true fraction because of the observational selection against the discovery of multiple outbursts, these selection effects should affect the LMC and M31 observations comparably. Thus, it appears likely that the higher recurrent nova fraction observed in the LMC is indeed real. Nova recurrence times are believed to be determined principally by two parameters, the white dwarf’s mass and its accretion rate (Townsley & Bildsten 2005). Short recurrence times are predicted for novae having either high white dwarf masses, high accretion rates, or both. While it is true that among Galactic systems, RNe in the T Pyx subclass appear to achieve their short recurrence times as a result of high accretion rates rather than from high white dwarf masses (e.g., Darnley et al. 2012), it is hard to understand why novae in the LMC would have systematically higher accretion rates compared with novae in M31. Rather, it would appear more plausible to attribute the higher fraction of RNe in the LMC to higher mean white dwarf masses associated with the younger population of novae in this galaxy. This conclusion is further supported by the fact that the RN candidates in the LMC are all members of the He/N spectroscopic class, where systems harboring massive white dwarfs are expected to dominate.

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