A SPECTROSCOPIC AND PHOTOMETRIC SURVEY OF NOVAE IN M31

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ABSTRACT

We report the results of a multi-year spectroscopic and photometric survey of novae in M31 that resulted in a total of 53 spectra of 48 individual nova candidates. Two of these, M31N 1995-11e and M31N 2007-11g, were revealed to be long-period Mira variables, not novae. These data double the number of spectra extant for novae in M31 through the end of 2009 and bring to 91 the number of M31 novae with known spectroscopic classifications. We find that 75 novae (82%) are confirmed or likely members of the Fe II spectroscopic class, with the remaining 16 novae (18%) belonging to the He/N (and related) classes. These numbers are consistent with those found for Galactic novae. We find no compelling evidence that spectroscopic class depends sensitively on spatial position or population within M31 (i.e., bulge versus disk), although the distribution for He/N systems appears slightly more extended than that for the Fe II class. We confirm the existence of a correlation between speed class and ejection velocity (based on line width), as in the case of Galactic novae. Follow-up photometry allowed us to determine light-curve parameters for a total of 47 of the 91 novae with known spectroscopic class. We confirm that more luminous novae generally fade the fastest and that He/N novae are typically faster and brighter than their Fe II counterparts. In addition, we find a weak dependence of nova speed class on position in M31, with the spatial distribution of the fastest novae being slightly more extended than that of slower novae.

Key words: galaxies: individual (M31) -- novae, cataclysmic variables

Online-only material: color figures, machine-readable table

1. INTRODUCTION

Classical novae form a subclass of the cataclysmic variable stars. They are semidetached binary star systems where a late-type Roche-lobe-filling star transfers mass to a white dwarf companion (e.g., Warner 1995, 2008). If the mass accretion rate onto the white dwarf is sufficiently low to allow the accreted gas to become degenerate, a thermonuclear runaway (TNR) will eventually ensue in the accreted envelope, leading to a nova eruption. These eruptions can reach an absolute magnitude as bright as \( M_V \approx -10 \) (e.g., Starrfield et al. 2008), making them among the most luminous explosions in the universe. Their high luminosities and rates (\( \sim 50 \text{yr}^{-1} \)) in a galaxy like M31; Shafter & Irby 2001; Darnley et al. 2006) make novae powerful probes of the properties of close binaries in different (extragalactic) stellar populations. The most thoroughly studied extragalactic system is M31, where more than 800 novae have been discovered over the past century (e.g., see Pietsch et al. 2007e; Shafter 2008, and references therein).

Despite this large number of novae discovered, very few follow-up studies of their photometric, or particularly their spectroscopic, properties have been attempted. Most recent M31 surveys have been undertaken through narrowband filters in order to take advantage of the fact that novae fade more slowly in H\( \alpha \) than they do in the continuum (e.g., Ciardullo et al. 1987; Shafter & Irby 2001). Such observations are ideal for determining the rate and spatial distribution of novae within a galaxy, but not for characterizing the nova light curves. As shown by Ciardullo et al. (1990a) the H\( \alpha \) light curves are not simply correlated with the peak luminosity as are the broadband light curves. Moreover, most of the broadband light-curve data for M31 novae come from the early photographic studies of Arp (1961) and Rosino (1964, 1973), as summarized by Capaccioli et al. (1989), and from observations in Crimea and Latvia during the period between 1977 and 1990 (Sharov & Alksnis 1992).

Similarly, spectroscopic data for M31 novae have, until recently, also been limited. The dearth of available spectra is not surprising given that novae in M31 are by definition transient, and relatively faint, reaching peak brightnesses in the range \( m_V \approx 18 \) to \( m_V \approx 15 \) mag before fading back to quiescence. Furthermore, since their eruptions are not predictable in advance, spectroscopic observations require not only timely access to large telescopes, but coordination with a photometric survey dedicated to discovering suitable targets. Humason (1932) was the first to report spectroscopic observations of classical novae in M31, and it was not until more than half a century later that Ciardullo et al. (1983) published the spectra of four H\( \alpha \) emission-line sources, which they identified as classical novae in eruption. The number of nova spectra has increased dramatically in recent years thanks to greater access to queue scheduling on large telescopes, such as the Hobby-Eberly Telescope (HET).

In order to better understand the spectroscopic properties of novae in M31, and to study any variation with spatial position in the galaxy, we began a multi-year M31 nova survey in the fall of 2006 using the HET. The program was motivated in large part by the work of Williams (1992), who realized that the spectra
of Galactic novae (taken within a few weeks of eruption) can be divided into one of two principal spectroscopic types: Fe II and He/N. These types are believed to be related to fundamental properties of the progenitor binary such as the white dwarf mass. As part of our HET program, we have measured the spectra of 26 M31 novae (representing ~1/3 of the total for which spectra are available), making it the most significant spectroscopic follow-up study of Local Group novae since the pioneering work of Tomany & Shafter (1992). To supplement these data, we have included 21 M31 nova spectra obtained over the years with the Lick Observatory 3 m Shane reflector. Finally, in order to characterize the light curves, we have employed a variety of telescopes to acquire broadband photometric measurements of many of the novae in our spectroscopic sample. Here, we report the results of our survey.

2. OBSERVATIONS

2.1. Spectroscopy

During the early part of our survey, optical spectra were obtained primarily with the Lick 3 m Shane reflector using the Kast double spectrograph (Miller & Stone 1993), although the observation of M31N 1990-10b was taken with the older UV Schmidt spectrograph (Miller & Stone 1987). Most spectra were acquired in one of two basic instrument configurations. One used the D55 dichroic beamsplitter to split the spectrum over ~5200–5500 Å, with blue light being passed through the 600/4310 grism and red light being reflected off a 300/7500 (or 600/5000) grating. The resulting combined spectra cover the range ~3300–10000 Å (~3300–7900 Å), with the 2′ wide slit giving a spectral resolution of ~6 Å in the blue and ~11 Å (6 Å) in the red. The other setup removed the beamsplitter and all light was sent to a 600/5000 grating on the red side, providing ~6 Å resolution over the range ~4300–7000 Å.

The data were reduced using standard techniques (e.g., Foley et al. 2003). Routine CCD processing and spectrum extraction were completed with IRAF,9 and the data were extracted with the data were extracted with the IRAF routines to flat-field the data and to optimally extract the spectra. These were placed on relative flux scales through comparison with observations of spectrophotometric standards routinely used at the HET. The data were not corrected for absorption by Earth’s atmosphere, and telluric absorption features are visible in some of the spectra. A summary of the Lick observations is given in Table 2.

Through the Hipparcos mission, the proper motions of many of the nova progenitors were determined. One reason we undertook this study was to use the proper motions of these nova progenitors to measure the peculiar motion of the M31 halo and thereby place constraints on the size and mass of the M31 halo. To perform this analysis, we measured the proper motions of many of the nova progenitors in our sample and then compared these to the proper motions of other nova progenitor systems. The results of our analysis are presented in Table 3.

2.2. Photometry

To complement our spectroscopic survey, we were able to amass sufficient photometric observations to produce light curves for many of the novae in our survey. Our primary motivation was to measure nova fade rates ($t_2$) that could then be correlated with other properties, such as spectroscopic class. The photometric data consist both of targeted (mostly B- and V-band) observations, which were obtained primarily with the Liverpool Telescope (LT; Steele et al. 2004) and the Faulkes Telescope North (FTN; Burgdorf et al. 2007), and survey images (mainly $R$ band), taken over the years with a variety of telescopes. The LT

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9 IRAF is distributed by the National Optical Astronomy Observatory, which is operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.

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Table 1

| Nova          | R.A. (12000.0) | Decl. (12000.0) | UT Date | Coverage (Å) |
|---------------|---------------|----------------|---------|-------------|
| M31N 1990-10b | 00:42:36.2    | 11:15:47.0     | 1990 Nov 11 | 3900–7100  |
| M31N 1992-11b | 00:42:36.2    | 11:15:47.0     | 1992 Nov 18 | 3500–9500  |
| M31N 1993-06a | 00:42:49.2    | 10:47:17.5    | 1993 Jun 26 | 4200–7100  |
| M31N 1993-08a | 00:42:45.1    | 11:14:27.0    | 1993 Sep 12 | 3500–9500  |
| M31N 1993-10a | 00:42:47.7    | 11:18:01.0    | 1993 Nov 8  | 3500–9500  |
| M31N 1993-11a | 00:42:50.1    | 11:17:28.0    | 1993 Nov 17 | 4300–7100  |
| M31N 1998-09d | 00:42:46.6    | 11:14:49.2    | 1998 Sep 20 | 3500–7000  |
| M31N 1999-09d | 00:42:49.7    | 11:15:05.6    | 1999 Sep 10 | 3500–7000  |
| M31N 1999-08f | 00:42:41.1    | 11:19:22.2    | 1999 Sep 17 | 3500–7000  |
| M31N 1999-10a | 00:42:49.7    | 11:16:32.0    | 1999 Oct 8  | 3500–7000  |
| M31N 2001-01a | 00:42:03.3    | 11:12:11.5    | 2001 Oct 20 | 3500–9500  |
| M31N 2001-12a | 00:42:41.4    | 11:16:24.5    | 2002 Feb 11 | 3500–7900  |
| M31N 2002-01b | 00:42:33.9    | 11:18:23.9    | 2002 Feb 11 | 3500–7900  |
| M31N 2002-08a | 00:42:30.9    | 11:06:13.1    | 2002 Sep 13 | 3500–9500  |
| M31N 2004-09a | 00:42:26.8    | 11:46:8.0     | 2004 Sep 10 | 3500–9500  |
| M31N 2004-09a | 00:42:40.2    | 11:14:42.5    | 2004 Sep 10 | 3500–9500  |
| M31N 2004-11a | 00:42:42.1    | 11:18:27.9    | 2004 Nov 19 | 3500–9500  |
| M31N 2004-11b | 00:42:07.4    | 11:18:04.7    | 2004 Nov 19 | 3500–9500  |
| M31N 2005-01a | 00:42:28.3    | 11:16:36.2    | 2005 Jan 16 | 3500–9500  |
| M31N 2005-07a | 00:42:50.7    | 11:20:39.8    | 2005 Aug 1  | 3500–9500  |
| M31N 2008-08d | 00:45:48.5    | 13:02:22.2    | 2008 Sep 8  | 3500–9500  |

Notes.

4 All observations obtained with the Shane 3 m reflector.

5 Due to ambiguity in the data logs from 1993 November, it is possible that the dates of observation (and thus the spectra) for these two novae are reversed.
photometry and astrometry software package developed by M. Velen and P. Pravec at the Ondřejov Observatory; see Pravec et al. (1994), respectively. Five to ten comparison stars were used for individual brightness measurements. \(B\), \(V\), and \(R\) magnitudes for comparison stars located in the M31 field were taken from Massey et al. (2006). Finally, in the case of images taken using the Sloan Digital Sky Survey (SDSS) \(g'\) and \(r'\) filters, we computed \(g'\) and \(r'\) magnitudes for comparison stars from \(BVRI\) magnitudes taken from Massey et al. (2006) using empirical color transformations between the SDSS \(ugriz\) system and the Johnson–Cousins \(UBVRI\) system published by Jordi et al. (2006). A summary of all of our photometric observations is presented in Table 3.

Between our targeted and archival observations, we were able to produce light curves for a total of 47 of the 91 M31 novae with measured spectra (46 spectra from the present survey and 45 from the literature). The light curves are presented in Figures 13. Before turning to a discussion of this wealth of data, we briefly review our present understanding of nova populations, both in the Galaxy and in M31.

### 3. NOVA POPULATIONS

#### 3.1. Background

It has been conjectured, based both on Galactic and extragalactic observations, that there may exist more than one population of novae (e.g., Della Valle et al. 1992; Della Valle &
Livio 1998; Shafter 2008; Kasliwal et al. 2011, and references therein). Initially, Galactic observations suggested that novae associated with the disk were on average more luminous and faded more quickly than novae thought to be associated with the bulge (e.g., Duerbeck 1990; Della Valle et al. 1992). However, the interpretation of Galactic nova data is complicated by the need to correct for interstellar extinction, which can be significant and varies widely with the line of sight to a particular nova. Furthermore, extinction hampers the discovery of a significant fraction of objects: although Galactic novae occur at an estimated rate of \( \sim 30–35 \text{ yr}^{-1} \) (Shafter 1997, 2002), only about one in five of these is discovered and subsequently studied in any detail. Consequently, although much has been learned from the study of Galactic novae, it is clear that these data are not ideal for establishing the population characteristics of novae.

Nova eruptions are luminous enough to be detected as far away as the Virgo cluster. However, despite the considerable data amassed in recent years, evidence for distinct nova populations in extragalactic systems is conflicting. Ciardullo et al. (1990b) argued that a galaxy’s nova rate was independent of the galaxy’s Hubble type, and therefore independent of the galaxy’s dominant stellar population. A few years later, based largely on the same data, but with different assumptions regarding the luminosity normalization, Della Valle et al. (1994) proposed that nova rates and light-curve properties (e.g., rate of decline from maximum light) did in fact vary between galaxies of differing Hubble types, with late-type systems such as M33 and the Magellanic Clouds having generally faster fading novae and higher luminosity-specific nova rates. However, subsequent studies (e.g., Shafter et al. 2000; Ferrarese et al. 2003; Shafter & Williams 2004) have questioned these results, arguing that (given the considerable uncertainties that plague the determination of luminosity-specific nova rates) the available data are insufficient to establish any significant correlation. Further, the broader implications of the argument by Della Valle & Duerbeck (1993) that novae in the Large Magellanic Cloud (LMC) generally were brighter and faded faster than those seen in the older stellar populations of the Galaxy or M31’s bulge has been called into question by Ferrarese et al. (2003) who showed that novae in M49, the first-ranked Virgo elliptical galaxy, generally faded at least as fast as novae in the LMC.

### 3.2. The Spatial Distribution of Novae in M31

The nearby Sb spiral, M31, is by far the most thoroughly studied extragalactic system, with observations of novae going back to Hubble (1929). Spanning \( \sim 4 \text{ deg} \) on the sky, M31 is well-resolved spatially and offers a convenient target for the study of nova populations. In a classic nova survey from the mid 1950s, Arp (1961) reported the discovery of 30 M31 novae with the 60 in reflector at the Mount Wilson Observatory. Three principal conclusions of Arp’s study (augmented by data from Hubble 1929) were that (1) the frequency of novae dropped off more sharply than the galaxy’s light, (2) the nova density decreased within \( \sim 4' \) of the nucleus, and (3) the frequency distribution of nova maximum magnitudes is bimodal, with peaks \( m_{pg} \approx 16.0 \) and \( m_{pg} \approx 17.5 \text{ mag} \) (also see Capaccioli...
Figure 3. Spectra of the M31 novae M31N 1999-06a, 1999-08f, 1999-10a, 2001-12a, and 2002-01b, taken 75, 19, 6, 58, and 35 days post discovery, respectively. All are Fe\textsc{ii} novae with the exception of 1999-08f, where the type is uncertain, and 2002-01b, where the broad H\alpha line suggests that the object may be an He/N system.

et al. 1989). A subsequent survey by Ciardullo et al. (1987) using H\alpha imaging confirmed that the nova spatial distribution is more centrally concentrated than the background light; in fact the distribution was consistent with a purely bulge population. The central “hole” in the nova distribution noted by Arp was not seen in the H\alpha data and was assumed to be an artifact of the poor contrast against the bright nuclear background in Arp’s photographic images.

Several more recent studies of the spatial distribution of M31 novae have confirmed the association with M31’s bulge population (e.g., Capaccioli et al. 1989; Shafter & Irby 2001; Darnley et al. 2004, 2006), but a major uncertainty in these studies is whether a significant fraction of disk novae are being missed due to internal extinction within the galaxy (see also Hatano et al. 1997). Taken at face value, the association of novae with M31’s bulge population came as a surprise given that Galactic novae have long been recognized to have a significant disk population (e.g., Duerbeck 1984, 1990). To address this discrepancy, Ciardullo et al. (1987) proposed the idea that a significant fraction of the novae in M31’s bulge could have been formed in the dense cores of the galaxy’s globular clusters and subsequently been ejected into the bulge through three-body interactions within the clusters, through tidal disruption of some clusters, or a combination of both processes.

3.3. The Spectroscopic Classification of Galactic Novae

A promising new approach for studying nova populations is to consider the character of a nova’s spectrum within a few weeks after maximum light. When analyzing a large sample of Galactic nova spectra, Williams (1992) realized that the novae could be naturally segregated into two principal spectroscopic classes (Fe\textsc{ii} and He/N) based on the emission lines in their spectra. Novae displaying prominent Fe\textsc{ii} emission (the Fe\textsc{ii} novae) usually show P Cygni absorption profiles, evolve more slowly, have lower expansion velocities, and show lower levels of ionization, compared to novae with strong He and N (the He/N novae). Complicating this division is the fact that a small fraction of novae initially exhibit Fe\textsc{ii} emission lines along with broad (full width at half-maximum intensity [FWHM] \(\gtrsim 2500\) km s\(^{-1}\)) Balmer emission before going on to develop spectra typical of the He/N novae. Such systems are referred to as either hybrid or Fe Iib nova. Both Fe\textsc{ii} and He/N novae (although more often the He/N systems) occasionally go on to develop strong Ne emission in their post-outburst spectra, which suggests that the higher-mass ONe white dwarfs may be found in both classes of novae.

Della Valle & Livio (1998) analyzed the spatial distribution of a sample of 22 Galactic novae with data suitable for determining their spectroscopic class. By restricting their sample to novae with well-determined distances (i.e., from expansion parallax), they were able to use the observed positions to estimate the distance of each nova from the Galactic plane. They discovered that the fastest and brightest novae were primarily associated with the He/N spectroscopic class, and that the progenitors
were preferentially located close to the Galactic plane (i.e., $z \lesssim 100$ pc). Fainter and dimmer novae, on the other hand, were more typically members of the Fe \textsc{ii} class and were found at much greater heights (up to $z \gtrsim 1000$ pc). Thus, they concluded that the progenitors of the He/N novae were associated with a younger stellar population that is thought to contain a higher proportion of massive white dwarfs.

The precise mechanism that leads to the formation of two distinct post-eruption spectra is not well understood, but is thought to depend most sensitively on the mass of the white dwarf. Systems with relatively massive white dwarfs reach the critical density and temperature for a TNR after accreting a relatively small amount of hydrogen-rich material from the companion star (Starrfield et al. 2008; Townsley & Bildsten 2005). Once the TNR takes place, some fraction of this small accreted mass is ejected at high velocity in the form of a discrete shell. In systems with lower mass white dwarfs, more material is accreted prior to the TNR, and this larger amount of gas is ejected in a combination of a low-mass shell (early in the outburst), and an optically thick wind (shortly thereafter). It is this optically thick wind which is thought to be responsible for the formation of the P Cyg profiles seen in the lower excitation Fe \textsc{ii} nova spectra. Thus, the fact that spectroscopic observations appear to offer a powerful discriminant between nova systems of varying white dwarf mass from differing stellar populations provided the principal motivation for our spectroscopic survey of novae in M31.

4. THE M31 NOVA SURVEY

4.1. Spectroscopic Class

Through the end of 2009, a total of 837 nova candidates have been discovered in M31 since the observations of Hubble (1929) began nearly a century ago (Pietsch et al. 2007c).13 Of these, spectra are now available for a total of 91 M31 novae, including the 46 from our present survey. As described above, novae spectra are, in principle, divisible into one of three primary classes: Fe \textsc{ii}, He/N, and hybrid (or Fe \textsc{Ib}) novae. In practice, however, it is often difficult to make an unambiguous classification. Spectra are taken at different times after eruption, and the signal-to-noise ratio can vary widely from spectrum to spectrum. In addition, a nova can, on occasion, show characteristics of more than one class. For example, during the course of our spectroscopic survey, we identified three novae (M31N 2007-10a, 2007-10b, and 2007-11b) that might have been traditionally classified as He/N or hybrid, but which do not share all of the characteristics of those classes. These spectra are dominated by prominent but narrow ($\text{FWHM} < 2000$ km s$^{-1}$) lines of H, He\textsc{i}, and He\textsc{ii}, with weaker N\textsc{iii} and Fe\textsc{ii} emission features occasionally seen. In the basic scheme of Williams (1992), such novae would be difficult to classify. Henceforth, we will refer to these objects as narrow-line He/N, or He/Nn, novae.

The spectra of all novae included in our survey (see Figures 1–12) were examined and subsequently classified into one of six groups: Fe \textsc{ii}, likely Fe \textsc{ii} (Fe \textsc{ii}+), He/N, likely He/N

13 See also http://www.mpe.mpg.de/~m31novae/opt/m31/index.php
Fe\textsc{ii} \sim \textit{vae}), Fe\textsc{ii} \textit{He} novae (He sign of nitrogen lines). This is the prototype of our new class of the narrow-lined prominent Fe\textsc{ii} hybrid objects, we reserve the hybrid classification for those novae with members of the hybrid class. Rather than referring to all of these novae as weak Fe\textsc{ii} displaying prominent Balmer and He\textsc{ii} lines. The nova is not typical of either the Fe\textsc{ii} class (no Fe\textsc{ii} lines) or the He/N class (the lines are narrow and there is no sign of nitrogen lines). This is the prototype of our new class of the narrow-lined He nova (He/N).

Figure 7. Spectra of the M31 novae M31N 2007-02b, 2007-06b, 2007-08d, and 2007-10a, taken 7, 37, 21, and 14 days post discovery, respectively. M31N 2007-02b is likely to be an Fe\textsc{ii} nova, although the broad component in the Balmer lines is often seen in hybrid novae. M31N 2007-06b is an He/N nova that originated in the M31 globular cluster Bol 111 (Shafter & Quimby 2007). M31N 2007-08d is an Fe\textsc{ii} system. M31N 2007-10a is an unusual nova displaying prominent Balmer and He lines. M31N 2007-08d was observed twice, shortly after eruption when the P Cyg line profiles were clearly evident, and roughly two weeks later after the continuum had faded considerably.

He/N or Fe IIb systems. More recently, however, Shafter (2007) has reviewed all available spectroscopic data for Galactic novae, finding that only 20 out of the 94 systems (\sim 21\%) with sufficient spectroscopic data available for classification appeared to be He/N or hybrid systems. This is consistent with the fraction found in our M31 survey. The relatively large fraction of He/N and Fe IIb systems included in the Della Valle & Livio (1998) study, in particular, may be the result of their sample selection, which was restricted to novae with distances determined from expansion parallax. Such novae are more likely to be nearby and thus located in the Galactic disk.

4.1.1. The Spatial Distribution of Spectroscopic Class

The apparent concentration of He/N and hybrid/Fe IIb novae toward the disk of the Galaxy (Della Valle & Livio 1998) is an intriguing finding, and it would be of considerable interest if it could be confirmed in M31. While it is not possible to determine the height of a given nova above M31’s galactic plane, we can explore differences in the spatial distributions between the different spectroscopic classes. Based on the Galactic results of Della Valle & Livio (1998), one might expect that the He/N and related systems would be preferentially associated with the disk of M31, while the Fe\textsc{ii} systems would perhaps display a more centrally concentrated, bulge-like distribution.

In Figure 14, we have plotted the projected positions of the 91 M31 novae with known spectroscopic class. Despite the expectation that the He/N nova distribution might be more extended compared to the Fe\textsc{ii} systems, there appears to be no obvious dependence of spectroscopic type with spatial position.
Figure 9. Spectra of the M31 novae M31N 2007-11e, 2007-12a, 2007-12b, and 2007-12d, taken 8, 10, 6, and 4 days post discovery, respectively. M31N 2007-11e and M31N 2007-11a are typical Fe\textsuperscript{ii} novae, while M31N 2007-12b and M31N 2007-12d are both examples of He/N novae.

Figure 10. Spectra of the M31 novae M31N 2008-08d (two spectra), 2008-09a, 2008-09c, and 2008-10a, taken 14, 57, 10, 6, and 11 days post discovery, respectively. All four novae are of the Fe\textsuperscript{ii} spectral type.

Figure 11. Spectra of the M31 novae M31N 2008-10b (two spectra), 2009-01a, and 2009-02a, taken 15, 20, 6, and 2 days post discovery, respectively. M31N 2008-10b is an Fe\textsuperscript{ii} nova that was observed twice. The first spectrum of M31N 2008-10b and the spectra of M31N 2009-01a and M31N 2009-02a display P Cyg profiles indicating that they were observed shortly after eruption.

in the galaxy. This impression can be misleading, however, since the high inclination of M31 to the plane of the sky ($i \approx 77^\circ$) makes it difficult to assign an unambiguous position within M31 to a given nova. This is particularly true for novae near the center of M31 where the foreground disk is superimposed on the galactic bulge. On the other hand, novae observed at a large galactocentric radius ($\gtrsim 15'$) are likely to be associated with the disk of the galaxy. In order to approximate the true position of a nova within M31, we have assigned each nova an isophotal radius, defined as the length of the semimajor axis of an elliptical isophote (computed from the $R$-band surface photometry of Kent 1987) that passes through the observed position of the nova.

In Figure 15, we show the cumulative distributions of the Fe\textsuperscript{ii} and He/N (and hybrid) novae plotted as a function of their isophotal radius. Although it appears that the He/N-hybrid distribution may be slightly more extended than the Fe\textsuperscript{ii} distribution, a Kolmogorov–Smirnov (K-S) test reveals that the distributions would be expected to differ by more than that observed 81% of the time if they were drawn from the same parent population. When only a subset of the novae with well-established spectroscopic types is considered, this probability decreases slightly to 73%.

The interpretation of these results is complicated by the fact that our spectroscopic data are drawn from a sample of M31 novae that may not be spatially complete. As mentioned earlier, although the CCD surveys conducted in H\alpha are essentially complete in the innermost regions of the galaxy, they did not typically cover the full disk of M31. In recent years the situation has improved with the availability of wide-field surveys, such as
the ROTSE-IIIb program, which have provided good coverage over most of the galaxy. Given the nature of the M31 surveys, we suspect that our spectroscopic sample may be biased somewhat toward novae at smaller galactocentric radii (where, historically, the galaxy has been more frequently monitored), and thus may favor one spectroscopic class over the other. Nevertheless, such a bias should not affect the distributions of Figure 15 in a differential sense: both Fe\n and He/N novae are detectable throughout the galaxy. Another potential source of bias involves the fact that the He/N novae are on average brighter and faster fading than the Fe\n systems (see Section 4.2.1 below). One could argue that the brighter He/N novae might be easier to detect against the bright background of the bulge. However, this advantage would be offset to some degree by the fact that these novae generally fade more quickly, making them more likely to be missed in synoptic surveys. Consequently, we conclude, as did Di Mille et al. (2010) based on a smaller sample of novae, that there is no compelling evidence from the observed spatial positions of the novae in our sample that the Fe\n and He/N novae arise from different stellar populations in M31.

4.1.2. Nova Expansion Velocity

One of the defining properties of the He/N spectroscopic class is that the emission-line widths are considerably broader than those seen in the Fe\n novae. Specifically, Williams (1992) found that the emission lines of Galactic novae in the He/N class are characterized by a half-width at zero intensity (HWZI) \( > 2500 \text{ km s}^{-1} \). Empirically, we have found that for most nova line profiles, the HWZI roughly equals the FWHM; since the latter is the more easily measured quantity, we have adopted it to characterize the spectra in our survey. The values of the FWHM and the equivalent widths of H\( \alpha \) and H\( \beta \) in our nova spectra are given in Table 5.

Although the emission-line width is expected to be correlated with the expansion velocity of the nova ejecta, the FWHM does not necessarily yield the expansion velocity directly. In an idealized nova, the broad emission features typically seen in an He/N system are believed to be formed mainly in a discrete, optically thin shell ejected at relatively high velocity from near the white dwarf’s surface. In this case, the line profiles are expected to be flat-topped and nearly rectangular in appearance, with the FWHM closely approximating the ejection velocity of the shell. In the Fe\n systems, however, the lines are mainly produced in a wind, which originates at a distance above the surface of the white dwarf that varies as the outburst evolves. Thus, the escape velocity for this wind is smaller than that at the white dwarf’s surface. As a result, the expansion velocity (and hence line width) may depend on the time elapsed since eruption.
When comparing the emission-line widths of the novae in our sample, it must be kept in mind that our spectroscopic data were obtained at varying times after eruption, and thus do not necessarily reflect the relative expansion velocities accurately. Nevertheless, as Figure 16 illustrates, a clear difference between the ejection velocities of the two principal classes of nova (Fe II and He/N) is apparent. Without exception, the novae belonging to the He/N class are characterized by Hα FWHM > 2500 km s⁻¹, while the Fe II systems all have Hα FWHM less than this value. Interestingly, although He/N novae display prominent lines of helium as do the standard He/N systems, they are narrow-line objects that resemble a typical Fe II nova at times (e.g., see M31N 2007-11b in Figure 8). In addition, they often do not display prominent lines of nitrogen as do the typical He/N systems.
4.2. Photometric Properties

To further explore the properties of the novae in our survey, whenever possible we have augmented our spectroscopic data with available photometric observations. Few light curves are available for the novae in our spectroscopic sample that erupted prior to the start of our HET survey in 2006. Nevertheless, when the entire set of spectroscopic novae is considered, we have sufficient photometric data to estimate decline rates for half of the sample.

A convenient and widely used parameterization of the decline rate is $t_2$, which represents the time (in days) for a nova to decline 2 mag from maximum light. According to the criteria of Warner (2008), novae with $t_2 \lesssim 25$ days are considered “fast” or “very fast,” with the slowest novae characterized by $t_2$ values of several months or longer. Rates of decline, and corresponding values of $t_2$, have been measured (for all novae with sufficient photometric coverage) by performing weighted linear least-squares fits to the declining portion of the light curves that extend up to 3 mag below peak. In an attempt to account for
systematic errors in the individual photometric measurements, the weights used in the fits were composed of the sum of the formal errors on the individual photometric measurements plus a constant systematic error estimate of 0.1 mag. The net effect of including the systematic error component was a reduction of the relative weighting of points with small formal errors and a corresponding increase in the formal errors of the best-fit parameters and in the uncertainties in \( t_2 \) derived from them.

Because our photometric observations do not always begin immediately after discovery, and the date of discovery does not always represent the date of eruption, we have made two modifications to our photometric data in order to better estimate the light-curve parameters. First, when available, we have augmented our light-curve data with the discovery dates and magnitudes given in the catalog of Pietsch et al. (2007e).\(^{15}\) Second, for some novae we have modified (brightened) the peak magnitude slightly through an extrapolation of the declining portion of the light curve up to 2.5 days pre-discovery in

\(^{15}\) See also http://www.mpe.mpg.de/~m31novae/opt/m31/index.php
cases where upper flux limits (within 5 days of discovery) are available. The light-curve parameters resulting from our analysis are given in Table 6.

4.2.1. MMRD Relations

If we adopt a distance modulus for M31 of \( \mu_0 = 24.38 \) mag (Freedman et al. 2001) and a foreground reddening, \( E(B - V) = 0.062 \) mag (Schlegel et al. 1998), we can compute the absolute magnitude at maximum light, and thereby produce calibrated maximum-magnitude versus rate-of-decline (MMRD) relations. The MMRD relations (the peak absolute magnitude versus \( \log t_2 \)) for the \( B, V, \) and \( R \) light curves are shown in Figures 17, 18, and 19, respectively. These plots illustrate not only that the peak nova luminosity is correlated with the rate of decline (i.e., the brightest novae generally fade the fastest), as was first studied extensively by McLaughlin (1945) for Galactic novae, but that the He/N systems are typically among the brightest and fastest novae. Weighted, linear
least-squares fits to our $B$, $V$, and $R$-band\footnote{The $R$-band MMRD relation includes $r'$-band data for novae where $R$-band observations are not available. When both $R$ and $r'$ observations are available for a given nova, only the more extensive data set is used.} data yield

\begin{align}
M_B &= -9.75 \pm 0.11 + (1.69 \pm 0.085) \log t_2, \\
M_V &= -9.78 \pm 0.10 + (1.70 \pm 0.080) \log t_2,
\end{align}

and

\begin{align}
M_R &= -10.89 \pm 0.12 + (2.08 \pm 0.077) \log t_2, \\
M_V &= -11.32 \pm 0.44 + (2.55 \pm 0.32) \log t_2.
\end{align}

respectively. The peculiar He/Nn object M31N 2007-10b, which has particularly scanty light-curve coverage, has a relatively large uncertainty in the peak magnitude. For comparison, in Figure 17 we show the theoretical $M_B$ versus $\log t_2$ relation of Livio (1992), while in Figure 18 we include the Galactic $M_V$ relation from Downes & Duerbeck (2000):
The slope of our M31 $V$-band MMRD relation is shallower than that for the Galactic data, and the M31 data are also systematically fainter than expected from the best-fitting Galactic relations. The latter discrepancy, in particular, as well as some of the scatter generally seen in the MMRD relations, is likely due to the fact that we have only corrected the M31 data for Galactic foreground extinction, not for extinction internal to M31. Based on these comparisons, it appears that the M31 nova sample perhaps suffers as much as 0.5 mag of extinction from within M31 itself, especially in the disk of the galaxy. This value is consistent with an estimate of $A(r) = 0.5$ mag adopted by Darnley et al. (2006) based on the mean for Sb galaxies (Holwerda et al. 2005). In addition, our estimates of maximum light are based upon the magnitude at discovery, which will underestimate the peak luminosity in some cases. If we divide the novae in our sample into two groups, those with isophotal radii $r \leq 10'$ and those with $r > 10'$, we find that the latter sample is slightly fainter at peak by an average of $\sim 0.4$ mag ($16.6 \pm 1.1$ versus $17.2 \pm 0.9$ mag), although the difference is not statistically significant.
In agreement with the results of the Galactic study by Della Valle & Livio (1998), it appears that the He/N novae are on average “faster” than their Fe II counterparts. Indeed, although our sample is dominated by Fe II systems, three of the four fastest novae are He/N or related (He/Nn) systems. On the other hand, with the exception of the He/Nn nova M31N 2007-10b, we do not find strong evidence for a significant population of fast, but relatively faint, novae that apparently do not follow the classic MMRD relation. As discussed by Kasliwal et al. (2011), it is possible that these novae arise from progenitors containing high $M$ (hot) and relatively massive white dwarfs, similar to what is expected for recurrent novae. Perhaps such novae are related to the class of He/Nn novae described earlier.

Given that the He/N novae generally fade more quickly than the Fe II systems, and that He/N novae have significantly higher expansion velocities based on their emission-line widths, the expansion velocity should be inversely correlated with the light-curve parameter, $t_2$. In Figure 20 we have plotted the measured $t_2$ value (based on the V band when possible) versus the measured Hα FWHM for the 25 novae in our survey where it
is possible to measure both parameters. As expected, there is a clear trend of faster novae exhibiting higher expansion velocities. The one exception is the He/Nn nova, M31N 2007-10a, which apparently evolved quite quickly despite its relatively slow expansion velocity. Based on these data (excluding M31N 2007-10a), a weighted linear least-squares fit yields the following:

$$\log t_2 (d) = 6.84 \pm 0.10 - (1.68 \pm 0.02) \times \log [H\alpha\text{FWHM (km s}^{-1})]. \quad (5)$$

This relation can be compared with a similar one for Galactic novae found by McLaughlin (1960). A major factor in the discrepancy between the two may arise because in McLaughlin’s relation the expansion velocities are derived from the absorption-line minima (P Cyg profiles) measured near maximum light. Typically, such velocities are only 20% to 50% of those inferred from the emission-line FWHM. The scatter in our data, particularly for the slower novae, is probably due in part to the time dependence of the derived velocities, as referred to in Section 4.1.2 above.
| Nova         | $\Delta\alpha$ | $\Delta\delta$ | $\alpha$  | Discovery | Type   | References* |
|--------------|----------------|----------------|-----------|-----------|---------|-------------|
| M31N 1981-09a| 2.47           | 5.78           | 16.4(H)   | Fe ii     | 1       |             |
| M31N 1981-09b| 0.82           | 3.10           | 17.6(B)   | Fe ii     | 2       |             |
| M31N 1981-09c| 2.56           | 3.21           | 15.0(H)   | Fe ii     | 3       |             |
| M31N 1981-09d| 2.17           | 8.07           | 15.8(H)   | Fe ii     | 4       |             |
| M31N 1986-08a| 0.56           | 4.98           | 16.3(H)   | Fe ii     | 5       |             |
| M31N 1987-09a| 2.57           | 10.57          | 19.4(B)   | Fe ii     | 6       |             |
| M31N 1987-10a| 0.33           | 2.28           | 18.4(B)   | Fe ii     | 7       |             |
| M31N 1989-08a| 6.49           | 10.36          | 17.9(B)   | Fe ii     | 8       |             |
| M31N 1989-08b| 0.61           | 3.04           | 14.5(w)   | Fe ii     | 9       |             |
| M31N 1989-08c| 2.17           | 1.78           | 16.6(B)   | Fe ii     | 10      |             |
| M31N 1990-10b| 0.97           | 3.04           | 14.5(w)   | Fe ii     | 11      |             |
| M31N 1991-01b| 0.56           | 3.91           | 17.5(R)   | Fe ii     | 12      |             |
| M31N 1991-02b| 2.17           | 5.44           | 17.6(B)   | Fe ii     | 13      |             |
| M31N 1992-01b| 2.57           | 1.72           | 17.5(R)   | Fe ii     | 14      |             |
| M31N 1992-11b| 0.33           | 3.03           | 16.5(B)   | Fe ii     | 15      |             |
| M31N 1993-11b| 0.14           | 1.64           | 15.8(B)   | Fe ii     | 16      |             |
| M31N 1993-11c| 0.63           | 2.17           | 16.7(H)   | Fe ii     | 17      |             |
| M31N 1993-11d| 0.01           | 1.00           | 17.5(R)   | Fe ii     | 18      |             |
| M31N 1993-11e| 0.01           | 1.00           | 17.5(R)   | Fe ii     | 19      |             |
| M31N 1993-11f| 0.01           | 1.00           | 17.5(R)   | Fe ii     | 20      |             |
| M31N 1993-11g| 0.01           | 1.00           | 17.5(R)   | Fe ii     | 21      |             |
| M31N 1993-11h| 0.01           | 1.00           | 17.5(R)   | Fe ii     | 22      |             |
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4.2.2. Spatial Distribution of Nova Speed Class

The question of whether the photometric properties of novae in M31 (e.g., peak brightness, fade rate) vary with spatial position in the galaxy (and possibly with stellar population) has yet to be thoroughly studied. Most recent surveys, which have concentrated primarily on the discovery of novae either for the purpose of measuring the spatial distribution, the overall rate, or both, lack the high cadence required to produce useful nova light curves. Light-curve data, when available, often only cover H or the R band where the relationship between fade rate and peak luminosity is weak or absent (e.g., Ciardullo et al. 1990a). As mentioned earlier, available broad-band nova data come largely from the photographic surveys of Arp (1961), Rosino (1964, 1973), and Sharov & Alksnis (1992). As noted above, the observation by Arp (1961) that the apparent magnitude distribution for M31 appeared to be bimodal, with peaks corresponding to $M_B \approx -8.5$ and $M_B \approx -7.0$ mag at the distance of M31, was later taken as evidence for the existence of two nova populations (e.g., Capaccioli et al. 1989).

The available light-curve data from previous surveys can be used to augment the extensive photometry obtained as part of our survey to study the variation of nova speed class with spatial position in M31. In particular, Capaccioli et al. (1989) have summarized the light-curve properties (peak magnitude and rate of decline) for novae in the Hubble (1929), Arp (1961), and Rosino (1964, 1973) surveys. From this compilation, we have selected the “high quality” data from their Table VI to supplement the light curves given in Table 6. Using this combined data set, we have assembled values of $t_2$ for a total of 74 novae. Of these, 35 values based on $B$-band observations to be as consistent as possible with data from earlier surveys.

| Nova      | $\Delta \cos \delta$ | $\Delta \delta$ | $a$  | Discovery | Type | References |
|-----------|-----------------------|-----------------|------|-----------|------|------------|
| M31N 2008-07b | 8.08                  | -6.08           | 26.01| 19.0(g)   | Fe   | 23         |
| M31N 2008-08a | 0.12                  | 0.98            | 1.09 | 16.8(R)   | Fe   | 24,25      |
| M31N 2008-08b | 1.51                  | 0.07            | 1.69 | 16.4(R)   | He/N| 24,25      |
| M31N 2008-08c | -0.72                 | 10.15           | 18.72| 16.8(R)   | Fe   | 25         |
| M31N 2008-08d | 33.62                 | 106.41          | 109.45| 18.1(w)   | Fe   | 26         |
| M31N 2008-09a | -10.85                | -8.26           | 14.26| 18.1(g)   | Fe   | 3          |
| M31N 2008-09c | 1.33                  | -14.25          | 30.22| 17.6(g)   | Fe   | 3          |
| M31N 2008-10a | 9.51                  | 38.60           | 65.42| 17.1(w)   | Fe   | 3          |
| M31N 2008-10b | 3.40                  | -1.98           | 6.19 | 18.3(R)   | Fe   | 25,27      |
| M31N 2008-11a | -13.58                | -10.11          | 18.51| 16.5(R)   | He/N| 3          |
| M31N 2008-12b | 3.85                  | 1.72            | 4.43 | 16.8(w)   | Fe   | 28         |
| M31N 2009-01a | 22.44                 | 7.39            | 48.17| 18.5(w)   | Fe   | 3          |
| M31N 2009-02a | 11.11                 | 20.52           | 26.38| 16.8(w)   | Fe   | 3          |
| M31N 2009-08a | 2.57                  | 1.35            | 3.00 | 17.2(H)   | Fe   | 29         |
| M31N 2009-08b | 15.93                 | 32.73           | 45.52| 17.1(w)   | Fe   | 30         |
| M31N 2009-08d | 0.45                  | -0.52           | 0.81 | 17.2(R)   | Fe   | 31         |
| M31N 2009-08e | -1.54                 | 1.89            | 3.54 | 17.8(w)   | Fe   | 32         |
| M31N 2009-09a | -3.45                 | -12.13          | 17.38| 17.6(w)   | Fe   | 33         |
| M31N 2009-10a | 27.78                 | 48.61           | 61.67| 17.1(w)   | Fe   | 34         |
| M31N 2009-10b | -4.43                 | 0.60            | 6.17 | 14.7(R)   | Fe   | 35         |
| M31N 2009-10c | 0.26                  | -0.19           | 0.37 | 17.2(H)   | Fe   | 36         |
| M31N 2009-11a | 3.81                  | 24.99           | 48.41| 17.6(R)   | Fe   | 37         |
| M31N 2009-11b | -0.89                 | -7.09           | 10.56| 18.4(R)   | Fe   | 23,38      |
| M31N 2009-11c | 4.91                  | -3.83           | 12.92| 17.0(R)   | Fe   | 39         |
| M31N 2009-11d | 17.37                 | 2.79            | 35.48| 16.4(r)   | Fe   | 40         |
| M31N 2009-11e | -1.70                 | -3.16           | 3.86 | 17.4(R)   | Fe   | 41         |

Notes.

a References. (1) Ciardullo et al. 1983; (2) Tomaney & Shafer 1992; (3) this work; (4) Pietsch et al. (2005); (5) Hatzidimitriou et al. 2007; (6) Pietsch et al. 2007d; (7) Shafer & Quimby 2007; (8) Barsukova et al. 2007b; (9) Rau et al. 2007b; (10) R. Quimby (2007, private communication); (11) Gal-Yam & Quimby 2007; (12) Rau et al. 2007a; (13) Rau et al. 2007b; (14) Barsukova et al. 2007a; (15) Cirol et al. 2007; (16) Shafer et al. 2009; (17) Di Mille et al. 2007; (18) Bode et al. 2009; (19) Rau & Centko 2007; (20) Rau et al. 2008 (21) Reig et al. 2008; (22) Barsukova et al. 2008; (23) Kasliwal et al. 2011; (24) Di Mille et al. 2008b; (25) Di Mille et al. 2010; (26) Chornock et al. 2008; (27) Di Mille et al. 2008a; (28) Kasliwal et al. 2008; (29) Valsee et al. 2009; (30) Rodriguez-Gil et al. 2009; (31) Di Mille et al. 2009a; (32) Medvedev et al. 2000; (33) Barsukova et al. 2009b; (34) Fabrika et al. 2009a; (35) Barsukova et al. 2009a2; (36) Fabrika et al. 2009b; (37) Chornock et al. 2008; (38) Kasliwal 2009; (39) Hornoch et al. 2009c; (40) Hornoch et al. 2009a; (41) Hornoch & Pejcha 2009

b The line with of 4400 km s$^{-1}$ reported by D. C. Leonard referred to an estimate of the full width at zero intensity, not the FWHM. Analysis of the original spectrum reveals the object to be a classic Fe nova.
Figure 14. Spatial distribution of the 91 M31 novae with known spectroscopic class (see Table 4). The Fe II and Fe II: novae are indicated by filled and open red circles, respectively. The He/N and He/N: novae are represented by filled and open blue squares, respectively. The gray ellipses represent elliptical isophotes from the surface photometry of Kent (1987).

In Figure 21, we have plotted separately the spatial distributions of the “fast” and “slow” novae. It appears that the slower novae (red circles) are perhaps more centrally concentrated than the fast sample (blue squares). This impression is confirmed when we consider the cumulative distributions shown in Figure 22. A K-S test reveals that the two distributions would be expected to differ by more than they do 23% of the time if they were drawn from the same parent distribution. Thus, our data are consistent with the notion that “faster” novae, both in the Galaxy (Duerbeck 1990; Della Valle et al. 1992) and in M31, are more associated with the disk population than are the slower novae. We caution, however, that selection effects could potentially complicate the interpretation of this result. As was pointed out earlier in our discussion of spectroscopic class, our nova sample is not likely to be spatially complete. It is possible that we may be preferentially missing faster novae in the outer regions of the galaxy where the temporal sampling of the surveys has perhaps been less frequent. If so, our conclusion that the faster novae appear to be more spatially extended would actually be strengthened. Taken at face value, our results suggest that the photometric characteristics of novae are likely affected by changes in the underlying stellar population.

4.3. Discussion of Selected M31 Novae

Below we highlight several individual novae of particular significance. These objects have either been detected as a super-soft X-ray source (SSS), or have been observed extensively, both photometrically and spectroscopically, or have some peculiarity that warrants further discussion.

4.3.1. M31N 1993-10g and 1993-11c

As part of a program of follow-up spectroscopy of Local Group transients, one of us (A.V.F.) obtained spectra of two novae in the bulge of M31 on 1993 November 8 and 17 (UT dates are used throughout this paper). The positions of the two objects are near that of two novae discovered in the survey by Shafter & Irby (2001), M31N 1993-10g and 1993-11c, which are separated by ~49′. Unfortunately, the original observing logs are no longer available, so we are unable to make an unambiguous connection between the two spectra and the two novae. Based on approximate coordinate information in the FITS header for the spectrum taken on 1993 November 17, we have made the tentative assignments indicated in Figures 1 and 2. The spectrum we have associated with M31N 1993-11h is clearly that of an Fe II nova, while that of 1993-11c is less certain but consistent with an Fe II classification.

Both novae have been identified as possible recurrent nova candidates by Shafter & Irby (2001). The position of M31N 1993-10g is coincident with 1964-01a to within 9′8, while that of 1993-11c is within 3′6 and 6′5 of 1967-12a and 1923-02a, respectively. Given that the coordinates for novae discovered on photographic plates are not known precisely in many cases, these
both appear to be plausible recurrent nova candidates. However, both novae are located only ~2′ from the nucleus of M31 where the nova density is high, increasing the probability of a chance positional coincidence. For a given observed separation $s$, we can compute the probability of a chance coincidence, $P_C$, by considering the nova density in an annulus of area $A$, centered at the position of each nova. Specifically,

$$P_C = 1 - \exp \left[ \frac{\pi s^2}{A} \right].$$

where $n$ is the number of novae in the annulus and $s = \pi s^2/A$. In both cases of interest here, we find that $P_C \lesssim 0.95$, making it highly likely that the two outbursts were a chance coincidence from separate objects, and therefore not from a recurrent nova.

### 4.3.2. M31N 1995-11e

M31N 1995-11e was identified during the nova survey of Shafter & Irby (2001), who first recorded the object on 1995 November 28 at $m_{14a} = 18.1$ mag. The object evolved quite slowly, reaching $m_{14a} = 17.9$ mag after approximately a month before slowly fading. Then, on 2008 July 6.8, K. Nishiyama and F. Kabashima (Miyaki-Argenteus Observatory, Japan) found that the object had appeared again at $m_{14a} \approx 18.7$ mag before reaching $m_{14a} \approx 18$ mag on September 9. Our spectrum presented here (see Figure 12) and originally reported by Shafter et al. (2008) clearly shows that the object is a long-period red variable star (i.e., a Mira variable) and not a nova.

### 4.3.3. M31N 2001-10a

M31N 2001-10a was discovered as part of the POINT-AGAPE (Darnley et al. 2004) and the Naini Tal microlensing surveys (Joshi et al. 2004). Our spectroscopic data and $r'$-band photometry show that M31N 2001-10a was a relatively slowly evolving Fe II nova characterized by $t_2 = 73$ days. X-ray observations reported by Henze et al. (2010, 2011) show the nova to be a long-lived SSS that was still detectable more than 7 yr post outburst. The long duration of the SSS phase is indicative of prolonged burning on the surface of the white dwarf. This is expected for the relatively large accreted mass associated with slowly evolving outbursts on a low-mass white dwarf.
### Table 6 (Continued)

| Nova     | Filter | $M_{\text{max}}$ | Fade Rate (mag day$^{-1}$) | $t_2$ (days) |
|----------|--------|------------------|-----------------------------|--------------|
| M31N 2009-08d | $i'$  | $-7.00 \pm 0.15$ | $0.081 \pm 0.012$ | $24.7 \pm 3.6$ |
| M31N 2009-08e | $B$  | $-7.05 \pm 0.11$ | $0.006 \pm 0.001$ | $351.1 \pm 84.5$ |
| M31N 2007-07e | $R$  | $-7.34 \pm 0.11$ | $0.014 \pm 0.001$ | $142.3 \pm 9.0$ |
| M31N 2007-08b | $B$  | $-7.15 \pm 0.11$ | $0.111 \pm 0.005$ | $18.0 \pm 8.8$ |
| M31N 2006-07a | $V$  | $-7.28 \pm 0.11$ | $0.112 \pm 0.005$ | $17.8 \pm 8.8$ |
| M31N 2006-07b | $V'$ | $-7.44 \pm 0.11$ | $0.086 \pm 0.004$ | $23.1 \pm 1.2$ |
| M31N 2006-07c | $i'$  | $-6.47 \pm 0.12$ | $0.074 \pm 0.006$ | $26.9 \pm 2.2$ |
| M31N 2006-08a | $B$  | $-7.23 \pm 0.24$ | $0.072 \pm 0.017$ | $27.9 \pm 6.5$ |
| M31N 2006-08b | $V$  | $-7.18 \pm 0.11$ | $0.063 \pm 0.008$ | $31.7 \pm 3.9$ |
| M31N 2006-09b | $e'$  | $-7.34 \pm 0.20$ | $0.055 \pm 0.008$ | $36.2 \pm 5.2$ |
| M31N 2006-09c | $V'$  | $-7.34 \pm 0.17$ | $0.077 \pm 0.019$ | $25.9 \pm 6.5$ |
| M31N 2006-10a | $B$  | $-7.04 \pm 0.11$ | $0.006 \pm 0.001$ | $121.3 \pm 8.0$ |
| M31N 2006-10b | $R$  | $-7.04 \pm 0.25$ | $0.012 \pm 0.001$ | $163.7 \pm 15.4$ |
| M31N 2007-02b | $B$  | $-7.15 \pm 0.11$ | $0.123 \pm 0.007$ | $16.2 \pm 0.9$ |
| M31N 2007-03a | $B$  | $-7.28 \pm 0.11$ | $0.132 \pm 0.006$ | $15.2 \pm 0.7$ |
| M31N 2007-03b | $B$  | $-9.55 \pm 0.11$ | $0.250 \pm 0.007$ | $8.0 \pm 0.2$ |
| M31N 2007-04a | $B$  | $-9.68 \pm 0.11$ | $0.224 \pm 0.005$ | $8.9 \pm 0.2$ |
| M31N 2007-04b | $B$  | $-9.84 \pm 0.11$ | $0.156 \pm 0.010$ | $12.8 \pm 0.8$ |
| M31N 2007-05a | $B$  | $-8.75 \pm 0.13$ | $0.134 \pm 0.008$ | $14.9 \pm 0.8$ |
| M31N 2007-05b | $V$  | $-8.24 \pm 0.14$ | $0.124 \pm 0.011$ | $16.1 \pm 1.4$ |
| M31N 2007-05c | $i'$  | $-8.14 \pm 0.25$ | $0.065 \pm 0.020$ | $30.6 \pm 9.4$ |
| M31N 2007-06a | $B$  | $-6.65 \pm 0.11$ | $0.095 \pm 0.007$ | $21.1 \pm 1.6$ |
| M31N 2007-06b | $B$  | $-6.78 \pm 0.11$ | $0.092 \pm 0.005$ | $21.7 \pm 1.2$ |
| M31N 2007-06c | $B$  | $-6.94 \pm 0.11$ | $0.096 \pm 0.009$ | $20.8 \pm 1.9$ |
| M31N 2007-07a | $B$  | $-5.85 \pm 0.11$ | $0.022 \pm 0.004$ | $92.5 \pm 16.6$ |
| M31N 2007-07b | $B$  | $-5.99 \pm 0.11$ | $0.027 \pm 0.004$ | $74.8 \pm 10.6$ |
| M31N 2007-08a | $B$  | $-6.14 \pm 0.11$ | $0.023 \pm 0.002$ | $88.0 \pm 6.6$ |
| M31N 2007-08b | $B$  | $-7.28 \pm 0.11$ | $0.048 \pm 0.003$ | $42.0 \pm 2.7$ |
| M31N 2007-08c | $B$  | $-7.84 \pm 0.14$ | $0.062 \pm 0.005$ | $32.5 \pm 2.4$ |
| M31N 2007-09a | $B$  | $-7.57 \pm 0.11$ | $0.046 \pm 0.004$ | $43.1 \pm 3.6$ |
| M31N 2007-09b | $B$  | $-7.85 \pm 0.11$ | $0.178 \pm 0.007$ | $11.2 \pm 0.4$ |
| M31N 2007-09c | $B$  | $-7.98 \pm 0.11$ | $0.276 \pm 0.025$ | $7.2 \pm 0.7$ |
| M31N 2007-10a | $B$  | $-8.84 \pm 0.11$ | $0.122 \pm 0.013$ | $16.3 \pm 1.7$ |
| M31N 2007-10b | $B$  | $-7.56 \pm 0.20$ | $0.036 \pm 0.002$ | $55.7 \pm 3.1$ |

Figure 17. B-band maximum-magnitude vs. rate-of-decline relation (MMRD) from our photometric survey. The Fe II, He/N, and He/Nn novae are represented by filled red circles, filled blue squares, and open blue squares, respectively. The solid line represents the best-fit relation determined from a weighted linear least-squares analysis (Equation (1)), while the dashed line represents the theoretical relation from Livio (1992). Despite the considerable scatter, the data follow the expected trend with the brightest novae generally fading the fastest. (A color version of this figure is available in the online journal.)
Figure 18. V-band MMRD relation from our photometric survey. The symbols have the same meaning as in Figure 17. The solid line is the best-fit relation given by Equation (2), while the dashed line represents the Galactic V-band relation from Downes & Duerbeck (2000).

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

Figure 19. R-band MMRD relation. The symbols have the same meaning as in Figure 17. The best-fit relation is given by Equation (3). Note the tight group of luminous Fe II novae (M31N 2005-01a, 2007-11d, and 2009-10b) with $M_V \lesssim -9$ mag.

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

4.3.4. M31N 2005-01a

M31N 2005-01a, discovered by Hornoch (2005) on 2005 January 07.89, was a particularly luminous nova that was well-covered photometrically near maximum light, reaching $R = 15.04$ mag (see Figure 13). Our spectrum (see Figure 4), taken 8 days post discovery when the nova was near maximum, shows that the object was clearly an Fe II system. It appears to be one of a small number of luminous Fe II novae ($M \lesssim -9.0$ mag) similar to M31N 2007-11d and 2009-10b (see Figures 17–19).

4.3.5. M31N 2005-07a

M31N 2005-07a, discovered by K.H. on 2005 July 27.909 at $R = 18.4$ mag, reached $R = 17.4$ mag on July 29.919. Our spectrum (see Figure 4), taken ~2 days post discovery when the nova was near maximum, is characterized by narrow He emission and a number of extremely weak features that may include He and N emission. We tentatively classify the object as an Fe II: system, but it is possibly related to the He/Nn novae.

4.3.6. M31N 2005-09b

M31N 2005-09b was discovered in the outskirts of M31 by Quimby et al. (2005) on September 1.23 using the 0.45 m ROTSE-IIIb telescope at the McDonald Observatory. The nova reached $m = 16.5$ mag (unfiltered) a day later on September 2.23. Optical spectra by D. C. Leonard (2005, private communication) and Pietsch et al. (2006) reveal moderately broad Balmer ($\Delta v_{\text{FWHM}} \approx 2000$ km s$^{-1}$, HWZI $\approx 2200$ km s$^{-1}$), Fe II, Na D, and He I emission features. The nova is consistent with membership in the Fe II spectroscopic class; however, the emission-line width is at the high end of what is normally seen in Fe II novae, and the nova could be plausibly included in the Fe IIb or hybrid class.

4.3.7. M31N 2006-09c

M31N 2006-09c was discovered independently by Quimby (2006), K. Itagaki, P. Kušnírak, and K.H. on 2006 September 18. It was detected ~150 days post discovery by both the IRAC and IRS instruments on the Spitzer Space Telescope as part of an infrared survey of selected M31 novae recently conducted by Shafter et al. (2011). No evidence of an infrared excess characteristic of dust formation was apparent at the time of these observations. The nova was also detected as a weak SSS by Henze et al. (2011) and originally classified as an Fe II nova by Shafter et al. (2006). Our R-band photometry shows that $t_2 = 26$ days, indicating a moderate rate of decline typical of the Fe II class.

4.3.8. M31N 2006-10a

M31N 2006-10a was a relatively faint nova discovered at $R = 18.7$ mag on 2006 October 25.8 by K.H. Our observations (see Figures 5 and 13) reveal the object to be a slowly evolving Fe II nova. It was also observed by Shafter et al. (2011) ~110 days post discovery as part of their Spitzer survey. M31N 2006-10a showed the clearest evidence of the 10 novae observed by Spitzer for a near-infrared excess (in this case peaking at $\lambda \approx 4$ $\mu$m), suggestive of dust formation. They went on to estimate the total mass of dust formed to be ~$2 \times 10^{-6} M_{\odot}$ under the assumption that the dust was carbon based. Henze et al. (2011) found no evidence of X-ray emission from this nova during the time of their observations.

4.3.9. M31N 2006-10b

M31N 2006-10b was discovered independently by K. Itagaki on 2006 October 31.583 and by R. Quimby and F. Castro at $m \approx 16.4$ mag on unfiltered CCD images taken 2006 October 31.09. The time of maximum light is well constrained by Itagaki’s image from October 30.530 (limiting mag 20.0), which shows no evidence of the nova. Although the light curve is not complete near maximum light, the available evidence suggests that the nova faded quite rapidly, with estimates of $t_2(B) = 21$ days and $t_2(V) = 11$ days.

We obtained two spectra of the nova, the first ~1 day post discovery on 2006 November 1 and the other ~3 weeks later on 2006 November 23. M31N 2006-10b can be technically considered a “hybrid” nova given that Fe II emission was seen the

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17 See http://www.cbat.eps.harvard.edu/CBAT_M31.html#2006-09c, and http://www.mpe.mpg.de/~m31novae/opt/m31/M31_table.html

18 See http://www.cbat.eps.harvard.edu/CBAT_M31.html#2006-09c

19 See http://www.cbat.eps.harvard.edu/CBAT_M31.html#2006-10b
2.5 3 3.25 4
log Hα FWHM (km/s)

0.5 1 1.5 2
log t2

Figure 20. Dependence of the light-curve parameter $t_2$ on nova expansion velocity (as reflected by the FWHM of Hα). With the exception of M31N 2007-10a, there is a clear trend of decreasing $t_2$ with increasing Hα emission-line width. The red filled circles represent Fe II novae, while the filled (open) blue squares represent He/N (He/Ne and He/N) novae, respectively. The dashed line reflects the best-fit relation given in Equation (5), while the dotted line gives the Galactic relation of McLaughlin (1960).

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

day after discovery, but by the time of the second observation the spectrum had clearly evolved into that of a classic He/N nova. The object was observed 102 and 110 days post discovery by Shafter et al. (2011) as part of their Spitzer survey. It was marginally detected by the IRAC, but not with the IRS, 86 and 77 days after discovery, respectively.

4.3.11. M31N 2007-02b

This nova was discovered by one of us (K.H.) on 2007 February 3. It was classified as a likely hybrid nova by Pietsch et al. (2007d) based on possible He and N emission in the spectrum. Our spectrum, taken on 2007 February 10.06, suggests that the object is an Fe II system (see Figure 7), although there appears to be a broader component in the Hα and (possibly) the Hβ emission lines that is often seen in the hybrid systems. The light curve measured in the $R$ band yields $t_2(R) = 35$ days, which is typical of an Fe II nova but would be somewhat slow for a hybrid system. The object was also detected as an SSS by Henze et al. (2011) and was still detectable 2 yr after eruption. Such a long active SSS phase is characteristic of a relatively large accreted mass. We conclude that the object was likely an Fe II nova.

4.3.12. M31N 2007-06b

M31N 2007-06b was discovered as part of the ROTSE-IIIb program at McDonald Observatory on 2007 June 19.4 at $m = 16.8$ mag (unfiltered) and found to be spatially coincident with the M31 globular cluster Bol 111. The nova faded by at least 1 mag in $\sim 9$ days suggesting $t_2 \lesssim 18$ days. Spectroscopic observations by Shafter & Quimby (2007) revealed the nova to be a member of the He/N spectroscopic class. The object was subsequently detected as an SSS by Pietsch et al. (2007a).

4.3.13. M31N 2007-07f

M31N 2007-06b was discovered by Quimby et al. (2007) as part of the ROTSE IIIb program at McDonald Observatory on 2007 June 19.4 at $m = 16.8$ mag (unfiltered) and found to be spatially coincident with the M31 globular cluster Bol 111. The nova faded by at least 1 mag in $\sim 9$ days suggesting $t_2 \lesssim 18$ days. Spectroscopic observations by Shafter & Quimby (2007) revealed the nova to be a member of the He/N spectroscopic class. The object was subsequently detected as an SSS by Pietsch et al. (2007a).
Unlike the other He/N systems (M31N 2007-10a and 2007-10b), the light-curve evolution of 2007-11b was not particularly fast, with $t_2(B) = 25$ days and $t_2(V) = 45$ days, respectively.

4.3.18. M31N 2007-11d

M31N 2007-11d was an unusually bright and slowly rising nova discovered by K. Nishiyama and F. Kabashima on November 17.57, and subsequently studied extensively by Shafter et al. (2009). The early spectrum was that of a classic Fe\,\textsc{ii} system: narrow Balmer and Fe\,\textsc{ii} emission lines flanked to the blue by pronounced P-Cyg absorption features. Another spectrum obtained $\sim$2 weeks later revealed moderately broad Balmer and Fe\,\textsc{ii} emission lines (FWHM H$_\alpha$ = 2260 km s$^{-1}$) with weak He\,\textsc{i} and O\,\textsc{i} emission (see Figure 8). The nova faded moderately rapidly ($t_2[V] = 9.5$ days) for an Fe\,\textsc{ii} nova and was apparently not detected as an SSS source despite what must have been a relatively large accreted mass. It was also observed, but not detected, with the Spitzer IRS (Shafter et al. 2011).

4.3.19. M31N 2007-11g

M31N 2007-11g was discovered by Ovcharov et al. (2007) on 2007 November 28.716 at $R \approx 18.7$ mag. Our spectrum, presented in Figure 12 and originally reported by Shafter et al. (2007), clearly shows that the object is not a nova, but rather a long-period Mira variable in M31.

4.3.20. M31N 2007-12b

M31N 2007-12b was a relatively bright and rapidly evolving He/N nova. It was discovered on 2007 December 9.53 by K. Nishiyama and F. Kabashima at $m_1 = 16.1$–16.2 mag (unfiltered), and independently by K.H. on December 10.73 at $R = 17.0$ mag.\textsuperscript{25} Subsequent spectroscopic observations revealed the object to be a rapidly declining ($t_2 = 8.7[B], 7.2[V]$ days) He/N system (see Figure 9 and Table 6). Initially, the object was thought to be a recurrent nova given its close proximity to the position of M31N 1969-08a; however, subsequent astrometry established that the two novae were, in fact, distinct objects.

Archival Hubble Space Telescope observations of the pre-outburst location of M31N 2007-12b (Bode et al. 2009) revealed the presence of a coincident stellar source with magnitude and color very similar to those of the Galactic recurrent nova RS Ophiuchi, where the red giant secondary star dominates the light at quiescence. This discovery, coupled with the rapid photometric evolution and the object’s detection by the Swift satellite (Burrows et al. 2005) as an SSS (Kong & Di Stefano 2008), was interpreted by Bode et al. (2009) as strong evidence that M31N 2007-12b is, nevertheless, a recurrent nova system.

4.3.21. M31N 2007-12d

M31N 2007-12d was discovered independently by Henze et al. (2007) and K. Nishiyama and F. Kabashima\textsuperscript{26} on 2007 December 17.57. Although no detailed light-curve data exist, Henze et al. (2011) estimated a rapid decline with $t_2 \approx 4$ days. Our spectrum (see Figure 9) reveals the nova to be a classic He/N system with broad emission lines of H, He, and N (FWHM H$_\alpha$ $\approx$ 5000 km s$^{-1}$) indicating a high expansion velocity. The nova was detected briefly ($< 20$ days) as an SSS by Henze et al. (2011).

4.3.14. M31N 2007-08d

This object was discovered by Pietsch et al. (2007b) at $R = 18.7$ mag on 2007 August 24.081. Our spectrum (see Figure 7) reveals narrow Balmer, He\,\textsc{i} $\lambda\lambda$4921, 5016, 5876, and He\,\textsc{ii} $\lambda$4686 emission, with only a trace of Fe\,\textsc{ii}, possibly blended with He\,\textsc{i} at 5169 \AA. M31N 2007-10a is the prototype of our proposed He/N spectroscopic class. The nova faded rapidly with $t_2(B) \approx t_2(V) \approx 7$ days and was not subsequently detected as an SSS by Henze et al. (2011), nor as an infrared source in the Spitzer survey of Shafter et al. (2011).

4.3.15. M31N 2007-10a

M31N 2007-10a was discovered by K. Itagaki on October 5.606 and independently by Pietsch et al.\textsuperscript{22} The spectrum was classified by Gal-Yam & Quimby (2007) as an Fe\,\textsc{ii} nova, but our spectrum (see Figure 7) reveals narrow Balmer, He\,\textsc{i} $\lambda\lambda$4921, 5016, 5876, and He\,\textsc{ii} $\lambda$4686 emission, with only a trace of Fe\,\textsc{ii}, possibly blended with He\,\textsc{i} at 5169 \AA. M31N 2007-10a is the prototype of our proposed He/N spectroscopic class. The nova faded rapidly with $t_2(B) \approx t_2(V) \approx 7$ days and was not subsequently detected as an SSS by Henze et al. (2011), nor as an infrared source in the Spitzer survey of Shafter et al. (2011).

4.3.16. M31N 2007-10b

M31N 2007-10b is the best example from our survey of a faint but fast nova similar to the class of novae discovered by Kasliwal et al. (2011). The nova was discovered by Burwitz et al. (2007) at $R = 17.8$ mag, who were able to constrain the time of maximum to within a day of 2007 October 13.26, and independently by K.H. and P. Kušnirák.\textsuperscript{23} The nova faded unusually quickly; our $B$, $V$, and $R$ light curves suggest $t_2 \approx 3$–4 days. Rau et al. (2007b) classified the object as an He/N nova based on a spectrum obtained $\sim$3 days post discovery, and noted that the emission lines were unusually narrow (FWHM H$_\alpha$ = 1450 ± 100 km s$^{-1}$) for this class. Based on the available photometric and spectroscopic data, we suggest that the object is a member of our proposed He/N class. Consistent with its rapid evolution, the object was detected by Henze et al. (2011) as an SSS with an X-ray duration of less than 100 days.

4.3.17. M31N 2007-11b

M31N 2007-11b, our third example of an He/N nova, was discovered by Pietsch et al. (2007c) and independently by E. Ovcharov and A. Václcheva.\textsuperscript{24} Although our spectrum (see Figure 8) appears to be quite similar to that of an Fe\,\textsc{ii} nova (albeit with weak Fe\,\textsc{ii} emission), subsequent spectra by Rau (2007) and Barsukova et al. (2007a) showed that the object quickly developed prominent, narrow (FWHM H$_\alpha$ = 1430 ± 100 km s$^{-1}$) Balmer, He\,\textsc{i}, and He\,\textsc{ii} emission lines.

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\textsuperscript{22} See http://www.cbat.eps.harvard.edu/\textsc{cbat}\_m31.html\#2007-10a

\textsuperscript{23} See http://www.cbat.eps.harvard.edu/\textsc{cbat}\_m31.html\#2007-10b

\textsuperscript{24} See http://www.cbat.eps.harvard.edu/\textsc{cbat}\_m31.html\#2007-11b

\textsuperscript{25} See http://www.cbat.eps.harvard.edu/\textsc{cbat}\_m31.html\#2007-12b

\textsuperscript{26} See http://www.cbat.eps.harvard.edu/\textsc{cbat}\_m31.html\#2007-12d
M31N 2009-10b was discovered by K.H. and P. Kušnirák on 2009 October 9.986 (Hornoch 2009), and independently by K. Itagaki on October 11.414.27 It was an unusually bright nova that reached $R = 14.7$ mag (Hornoch et al. 2009b) before fading relatively rapidly ($t_2 \approx 10$ days in $B$ and $V$). Spectroscopic observations by Di Mille et al. (2009b) and Barsukova et al. (2009a) show conclusively that the nova belongs to the Fe II spectroscopic class, making it quite similar to M31N 2007-11d.

5. CONCLUSIONS

Whether there exist two distinct populations of classical novae is an important but unanswered question. In an attempt to gain further insight, we have conducted a major spectroscopic survey of novae in the nearby galaxy M31. These data have allowed us to determine spectroscopic classes for a total of 46 novae, more than doubling the number previously available. Specifically, after combining our data with published spectra, we have now been able to compile a list of spectroscopic classes for a total of 91 novae that erupted prior to 2010. In addition, we have undertaken photometric observations of many of the recent novae in this group in order to measure their light curves (i.e., their peak brightness and rate of decline). Whenever possible, we have augmented our photometric observations with light-curve data from the literature.

Our combined spectroscopic and photometric survey has allowed us to explore the spatial distribution of novae in M31 to a greater extent than has been possible previously. An analysis of these data has enabled us to arrive at the following conclusions.

1. As part of this survey we have found that $\sim 80\%$ of the M31 novae with available spectra belong to the Fe II class. The remaining $\sim 20\%$ are composed of nova whose spectra are characterized by H, He, and N emission lines, with Fe II emission features either weak or absent. Usually these latter systems display relatively broad (FWHM $\gtrsim 2500$ km s$^{-1}$) lines typical of the He/N spectroscopic class; however, a small fraction of these systems (e.g., M31N 2007-10a, 2007-10b, and 2007-11b) are characterized by relatively narrow-line widths (FWHM $\lesssim 2000$ km s$^{-1}$). We refer to the latter systems as narrow-line He/N, or He/Nn, novae. The relative percentages of Fe II and He/N (and related) novae are similar to those found for Galactic novae (Shafer 2007; Della Valle & Livio 1998).

2. We have presented photometric observations with sufficient coverage to determine light-curve parameters (peak brightness and rate of decline) for most of the novae in our spectroscopic survey, and for approximately half of all novae with known spectroscopic classifications. These data have allowed us to confirm that novae in the He/N and He/Nn classes have generally faster light-curve evolution than the more common Fe II objects. When the light-curve parameters for the entire sample are considered, we find that the brighter novae generally fade the fastest; they are consistent with an MMRD relation. Similarly, we find that the ejection velocities inferred from line widths are higher for the faster novae, as is the case for their Galactic counterparts.

3. Under the assumption that there exist two separate populations of novae (bulge and disk populations), it is believed that the disk population, with their generally more massive white dwarfs, should produce novae that are on average brighter and faster than their counterparts in the bulge population (Duerbeck 1990; Della Valle et al. 1992). To test this prediction further, we have explored the photometric behavior (specifically $t_2$) of novae as a function of spatial position in M31. After supplementing photometric data from our survey with decline rates from the “high quality” light-curve sample given by Capaccioli et al. (1989), we were able to generate a sample of 74 M31 novae with well-determined fade rates. This sample was subsequently divided into two groups: those with $t_2 \lesssim 25$ days (the “fast” sample) and those with $t_2 > 25$ days (the “slow” sample). A comparison of the spatial distributions for the two samples shows that the fast novae are in fact more spatially extended from the core of M31 than the slow novae, as expected in the two-population scenario.

4. We have also explored the possibility that the spectroscopic class of M31 novae varies with spatial position in the galaxy, as would be expected if the He/N and related novae contain more massive white dwarfs. Surprisingly, as shown in Figures 14 and 15, the spatial distribution shows only a hint that Fe II objects may be more centrally concentrated (i.e., associated with the bulge of M31), and there is no compelling evidence for a dependence on spectroscopic class. Specifically, a K-S test shows an $81\%$ probability that the Fe II and He/N distributions would differ more than what is observed if they were drawn from the same overall distribution. This result suggests that the average white dwarf mass in nova systems may not be as strongly dependent on spatial position (and hence stellar population) in M31 as suggested by the photometric data.

Taken together, our spectroscopic and photometric data do not provide compelling evidence in support of the hypothesis that there exist two populations of novae in M31. Nevertheless, our light-curve data can be interpreted as mildly suggestive of a weak dependence of nova-speed class on spatial position (stellar population) within the galaxy. Furthermore, our spectra are not inconsistent with the possibility that spectroscopic type may be sensitive to stellar population. Whatever sensitivity there may be, however, appears to be weak, if it exists at all.

A major step forward in the understanding of nova populations generally, and the spectroscopic classification specifically, will likely require additional spectra and light-curve data for novae erupting in galaxies spanning a range of morphological types. For example, a sample of light curves and spectra from novae arising in the extreme Population II environment of an elliptical galaxy will be particularly instructive. The Large Synoptic Survey Telescope, when it becomes operational, will generate a large sample of Virgo cluster nova light curves that will undoubtedly shed new light on the question of nova populations. Spectra of novae in Virgo cluster galaxies can then be obtained with LRSs currently available on 10 m class telescopes.

The work presented here was made possible through observations obtained from facilities based throughout the world. Spectra were obtained with the Lick Observatory Shane 3 m telescope operated by the University of California and with the Marcardo Low-Resolution Spectrograph on the Hobby-Eberly Telescope, which is operated by McDonald Observatory on behalf of the University of Texas at Austin, the Pennsylvania State University, Stanford University, the Ludwig-Maximilians-Universität, Munich, and the George-August-Universität, Göttingen. Photometric observations were made using the Liverpool Telescope, which is operated on the island of La Palma by Liverpool John

27 See http://www.cbat.eps.harvard.edu/CBAT_M31.html#2009-10b
Moores University (LJMU) in the Spanish Observatorio del Roque de los Muchachos of the Instituto de Astrofisica de Canarias with financial support from the UK Science and Technology Facilities Council. Faulkes Telescope North (FTN) is operated by the Las Cumbres Observatory Global Telescope network. Data from FTN were obtained as part of a joint programme between Las Cumbres Observatory and the LJMU Astrophysics Research Institute. Photometric observations were also obtained at the Centro Astronómico Hispano Alemán (CAHA) Observatory at Calar Alto, operated jointly by the Max-Planck Institut für Astronomie and the Instituto de Astrofísica de Andalucía (CSIC), with the 6 m telescope of the Special Astrophysical Observatory (SAO) of the Russian Academy of Sciences (RAS), operated under the financial support of the Science Department of Russia (registration number 01-43), with the Vatican Advanced Technology Telescope (the Alice P. Lennon Telescope and the Thomas J. Bannan Astrophysics Facility), with the 1.3 m McGraw-Hill and the 2.4 m Hiltner telescopes at the MDM Observatory, with the 2.5 m Isaac Newton Telescope operated on the island of La Palma by the Isaac Newton Group in the Spanish Observatorio del Roque de los Muchachos of the Instituto de Astrofisica de Canarias, with the 2.1 m telescope of the Kitt Peak National Observatory, National Optical Astronomy Observatory, which is operated by the Association of Universities for Research in Astronomy (AURA), Inc., under cooperative agreement with the National Science Foundation, and with the 0.84 m telescope of the Observatorio Astronómico Nacional, Parque Nacional de Tenerife, with financial support from the UK Science and Technology Facilities Council. Faulkes Telescope North (FTN) is operated by the Las Cumbres Observatory Global Telescope Network Facilities Council. Faulkes Telescope North (FTN) is operated by the Las Cumbres Observatory with financial support from the UK Science and Technology Facilities Council. Faulkes Telescope North (FTN) is operated by the Las Cumbres Observatory with financial support from the UK Science and Technology Facilities Council.
