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M31N-2007-06B: A NOVA IN THE M31 GLOBULAR CLUSTER BOL 111

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ABSTRACT

We report spectroscopic observations of the nova M31N-2007-06b, which was found to be spatially coincident with the M31 globular cluster Bol 111. This nova is the first out of more than 700 discovered in M31 over the past century to be associated with one of the galaxy's globular clusters. A total of three spectra of the nova were obtained 3, 6, and 36 days after discovery. The data reveal broad (FWHM ~ 3000 km s^{-1}) Balmer, N ii, and N iii emission lines and show that the nova belongs to the He/N spectroscopic class. The He/N class of novae are relatively rare, making up roughly 15% of the novae with measured spectra in M31 and roughly 20%–25% of the Galactic novae for which spectroscopic data are available. The implications of a nova, particularly an He/N nova, occurring in a globular cluster are discussed.

Subject headings: galaxies: individual (M31) — galaxies: stellar content — globular clusters: general — globular clusters: individual (Bol 111) — novae, cataclysmic variables

1. INTRODUCTION

Classical novae are semidetached binary stars where the Roche lobe–filling component (typically a cool, near–main-sequence star) transfers mass to a white dwarf companion (Warner 1995). If the rate of accretion is low enough to allow the accreted material to become sufficiently degenerate, a thermonuclear runaway (TNR) eventually ensues, driving substantial mass loss from the system and leading to a nova eruption. Luminosities as high as $M_V \simeq -9$ are often observed at the peak of eruption, making novae second only to gamma-ray bursts and supernovae in the energetics of their outbursts. Their high luminosities ($-6 \lesssim M_V \lesssim -9$) and frequencies of occurrence (~50 yr^{-1} in a galaxy like M31) make them potentially powerful probes of the evolution of binary systems in different (extragalactic) stellar populations.

The standard picture for the formation of a nova system is through the common envelope evolution of an initially detached progenitor binary, leading to the formation of a short-period, semidetached system with the red dwarf transferring mass to its white dwarf companion (Paczyński 1976; Meyer & Meyer-Hofmeister 1979). Population synthesis studies based on this formation mechanism have predicted that the proportion of fast and bright novae—like Type Ia supernovae, which are thought to have similar progenitors—is expected to be higher in younger stellar populations that contain, on average, more massive white dwarfs (Yungelson et al. 1997). Since novae with massive white dwarfs are expected to have shorter recurrence times between eruptions, the luminosity-specific nova rate (LSNR) should also be higher in younger populations. Despite these predictions, the weight of observational evidence suggests the opposite: that the LSNR is at least as high (and perhaps higher) in ellipticals and in spiral bulges, compared with early-type galaxies (e.g., Williams & Shafter 2004).

The most thoroughly studied extragalactic system is M31, where more than 700 novae have been discovered since the pioneering work of Hubble early in the 20th century (e.g., Darnley et al. 2006; Pietsch et al. 2007; Shafter 2007, and references therein). A principal conclusion reached by these studies is that, contrary to the predictions of population synthesis models, M31 novae appear to belong primarily to the galaxy's bulge population. This surprising result led Ciardullo et al. (1987) to speculate that the bulge nova rate may be enhanced by nova binaries that were spawned in M31's globular cluster system and subsequently injected into the bulge by three-body encounters in clusters (McMillan 1986), by tidal disruption of entire clusters, or by both.

To test the possibility that white dwarf accretors are also enhanced in the clusters themselves, searches for novae in M31's globular cluster system were undertaken by Ciardullo et al. (1990b) and by Tomaney & Shafter (1992). In the former study, Ciardullo et al. examined 54 globular clusters that fell within their prior M31 bulge nova surveys (Ciardullo et al. 1987; Ciardullo et al. 1990a). They found no nova eruptions, and they were able to show that novae were several times less likely to be found in globular clusters than were high-luminosity X-ray sources, where roughly ~20% are associated with globular clusters (Crampton et al. 1984). In the latter study, Tomaney & Shafter used a multifiber spectrograph to monitor more than half ($\gtrsim$200) of M31's globular clusters over an effective survey time of almost a year. Once again, no novae were found, which suggests that any enhancement of novae in M31's globular clusters was less than that of the high-luminosity X-ray sources.

The situation changed recently when, as part of the ROTSE-IIIb program, Quimby et al. (2007) discovered a nova, M31N-2007-06b, that was spatially coincident with the M31 globular cluster system Bol 111. In this Letter we report spectroscopic observations of M31N-2007-06b, which clearly establish that the nova belongs to the He/N spectroscopic class proposed by Williams (1992). After describing the spectroscopic observations in the next section, we conclude by discussing the implications of an He/N nova arising in a globular cluster.

2. OBSERVATIONS

We discovered nova M31N-2007-06b on June 19.38 UT as part of the Texas Supernova search (Quimby 2006; see Fig. 1). The nova was found at an unfiltered magnitude of 16.96 ± 0.07 (cal-

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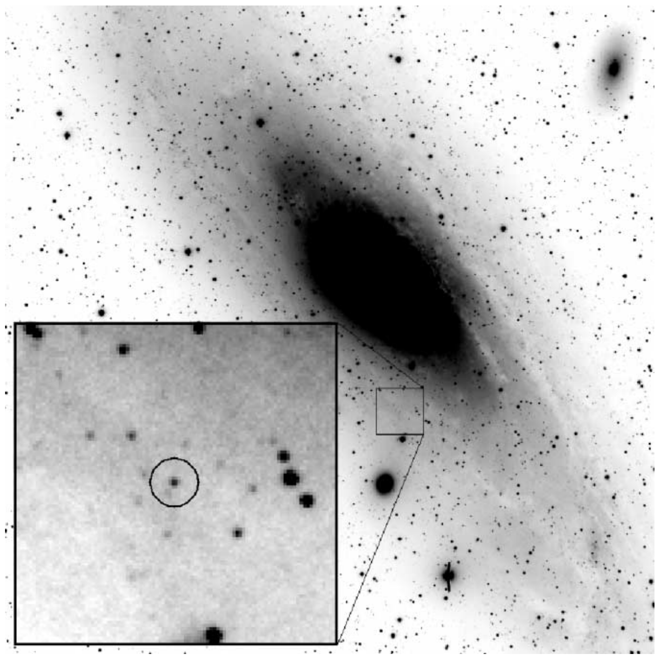

FIG. 1.—Messier 31 as observed by ROTSE-IIIb. The larger image is a co-addition of 103 images taken between 2004 December and 2006 June, and the inset shows the ROTSE-IIIb data from 2007 June 19. The light from the globular cluster is visible in the reference image (*boxed*).

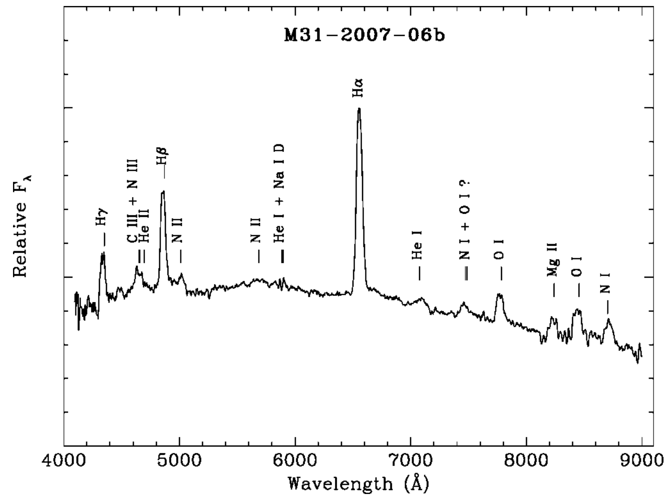

FIG. 2.—Low-resolution spectrum of M31N-2007-06b taken with the LRS on the HET 3 days after discovery on 2007 June 18. Note the broad Balmer, N II, and N III lines and the lack of significant Fe II emission characteristic of the He/N class of novae.

ibrated against the USNO-B1.0 R2) after removal of the static background using a modified version of the PSF-matched image-subtraction code supplied by the Supernova Cosmology Project (Perlmutter et al. 1999). It was 16.89 ± 0.06 mag on June 21.38, suggesting that the discovery came near and likely just prior to maximum light. It was not present to a limiting magnitude of 17.88 on June 15.38. By June 30.33, the nova had faded to below 17.89, placing a lower limit on the fade rate of >0.11 mag day^{-1}. M31N-2007-06b is located at $\alpha = 00^h42^m33.13^s$, $\delta = +41°00'26.3''$ (J2000.0; $\pm 0.4''$ in each coordinate). This position is consistent to within the errors of the core of the cataloged M31 globular cluster Bol 111 (Galleti et al. 2004), which appears to be relatively old and metal-poor (Jiang et al. 2003).

Spectroscopic observations were carried out with the Low Resolution Spectrograph (LRS; Hill et al. 1998) on the 9.2 m Hobby-Eberly Telescope (HET) beginning June 22.44. We used the *g*1 grating with a 2.0″ slit and the GG385 blocking filter, which covers 4150–11000 Å with a resolution of $R \sim 300$, although we limit our analysis to the 4150–8900 Å range, where the effects of order overlap are minimal. Additional HET/LRS spectra were obtained on June 25.42 and July 25.34 UT with the *g*2 grism ($R \sim 650$ covering 4300–7300 Å).

Our initial spectrum, which was taken roughly 3 days after eruption, is shown in Figure 2. The spectrum is characterized by strong and broad (FWMH $\simeq 3000$ km s^{-1}) Balmer emission lines, as well as permitted lines of singly and doubly ionized nitrogen at 5001 and 4640 Å, respectively. The spectrum is clearly that of a classical nova. The presence of broad Balmer, N II, and N III emission lines, coupled with the absence of significant Fe II emission features, establishes that the nova is a member of the He/N class in the system of Williams (1992). The significance of this classification will be discussed in § 3.2.

The higher resolution follow-up spectra, which were obtained ∼1 week and ∼5 weeks after eruption, are shown in Figure 3. As the nova faded, absorption features (e.g., Hβ, Mg *b* λ5167, 5173, 5183, and Na D λ5890, 5896) from the underlying globular cluster became visible in the spectrum, providing us with the opportunity to compare the radial velocities of these features with those of the nova emission lines. If M31N-2007-06b erupted in Bol 111, the radial velocities should be consistent, whereas in the (highly) unlikely event of a chance superposition of the nova on the cluster, no such agreement would be required. Despite the fact that accurate (absolute) radial velocities are not possible to achieve at our spectral resolution, it is reassuring that the measured emission-line velocity in our final spectrum, -320 km s^{-1} (based on Hα and Hβ), is consistent with a mean velocity of -300 km s^{-1} derived from the globular cluster absorption features.[2] We conclude that the weight of the available evidence strongly supports the conclusion that M31N-2007-06b is indeed associated with Bol 111.

[2] We note that the published radial velocity of Bol 111 is -414 ± 14 km s^{-1} (Galleti et al. 2006). Most of the ∼100 km s^{-1} discrepancy with our measurement is likely due to a small zero-point error in our absolute wavelength calibration of order 1 pixel at our resolution.

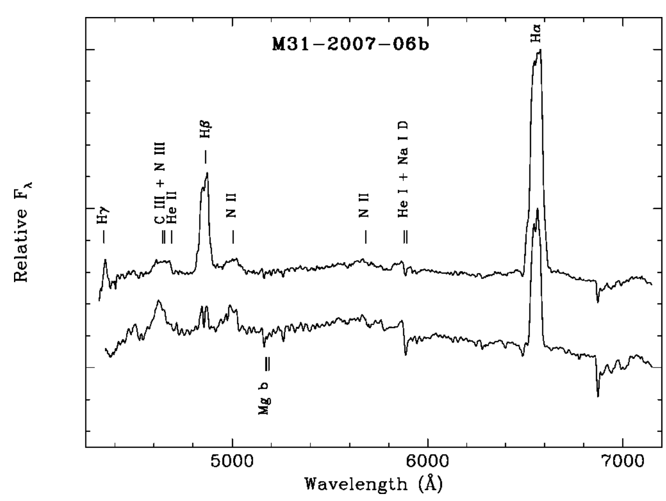

FIG. 3.—Follow-up spectra of M31B-2007-06b taken with the LRS on the HET (*upper spectrum*: ∼1 week after eruption; *lower spectrum*: ∼5 weeks after eruption). As the nova fades, note the increasing contamination by light from the globular cluster Bol 111, resulting in Balmer and Mg *b* absorption features.

TABLE 1
Putative Properties of Nova Populations

Property	Bulge Population	Disk Population
Environment	Population II	Population I
Light-curve evolution	Slow	Fast
Mean recurrence times	Longer	Shorter
White dwarf composition	CO	ONe
Dust formation?	Yes	No
Williams (1992) spectral class	Fe II	He/N

3. DISCUSSION

3.1. *Are Novae Enhanced in Globular Clusters?*

It has long been recognized that the number of X-ray sources per unit mass is of order a hundred to a thousand times higher in globular clusters, compared with the rest of the Galaxy (Clark 1975; Katz 1975). A similar enhancement of X-ray sources has been seen in M31's globular cluster population (Crampton et al. 1984; Di Stefano et al. 2002; Trudolyubov & Priedhorsky 2004). The realization that these X-ray sources are the result of dynamical interactions involving neutron stars has led to the expectation that globular clusters should produce an even greater number of close red dwarf–white dwarf binaries, including novae (Hertz & Grindlay 1983; Di Stefano & Rappaport 1994). After initially disappointing searches, recent observations with *HST* and *Chandra* have started to reveal increasing numbers of these binaries in Galactic globular clusters (Edmonds et al. 2003; Heinke et al. 2003; Knigge et al. 2002; Pooley et al. 2002). To date, two classical novae have been observed in the cores of Galactic globular clusters: T Sco in M80 (Luther 1860; Pogson 1860; Sawyer 1938) and an anonymous nova near the core of M14, which was observed in 1938 (Hogg & Wehlau 1964). More recently, Shara et al. (2004) have discovered a nova coincident with a globular cluster of M87.

Taken at face value, the discovery of a single nova in one of M31's ~300 globular clusters over the past ~90 years yields a rough lower limit on the frequency of novae in globular clusters of $f \sim 4 \times 10^{-5}$ novae per cluster per year. This result is consistent with a what one would expect if novae were not enhanced with respect to the field, where given that the M31 globular cluster system represents roughly 0.05% of M31's total mass in stars (Barmby & Huchra 2001), a global nova rate of ~50 yr^{-1} (Shafter & Irby 2001; Darnley et al. 2006) suggests that we can expect to observe ~2 novae per century in M31's globular cluster population. However, it is clear that our lower limit on f is unrealistically conservative. In particular, the effective survey time is significantly less than 90 years, as M31 has been monitored only sporadically during this time. In addition, novae are considerably more difficult to detect against the background cluster light than they are in the field. Thus, it is likely that many globular cluster novae have gone undetected, making it likely that the specific frequency of novae in globular clusters is significantly higher than that in the field.

We conclude this discussion by noting that the number of nova binaries in globular clusters may be significantly higher than the observed frequency of nova eruptions would suggest. In particular, the discussion above implicitly assumes that the mean recurrence time for novae in globular clusters is the same as that for field novae, whereas this may not be the case. As shown by numerous studies, the frequency of nova events depends primarily on three parameters: the mass accretion rate and the mass and temperature of the white dwarf (Livio 1992; Townsley & Bildsten 2005). For a given mass accretion rate, nova systems with relatively massive white dwarfs will have shorter recurrence times between eruptions because less accreted mass is required to trigger a TNR. Furthermore, as shown by Townsley & Bildsten (2005), the recurrence times are particularly sensitive to $T_{\rm wd}$, with significantly less accreted envelope mass required to achieve a TNR on hotter white dwarfs. Since the accretion rate and white dwarf temperature are coupled, the observed nova rates are essentially a function of the mass transfer rate and white dwarf mass. If these parameters differed systematically between novae in different stellar populations, with an older population, for example, containing on average cooler and less massive white dwarfs, then the number of nova binaries in globular clusters could be significantly higher than the number of observed outbursts suggests.

3.2. *Nova Populations*

In recent years, there has been a growing body of evidence that there indeed exist two distinct populations of novae. Duerbeck (1990) was first to formally postulate the existence of two nova populations: a relatively young population that he called "disk novae," associated with novae found in the solar neighborhood and in the LMC, and "bulge novae," which were concentrated toward the Galactic center and the bulge of M31, and characterized by generally slower outburst development. Shortly thereafter, Della Valle et al. (1992) showed that the average scale height above the Galactic plane for fast novae appeared smaller than that for novae with slower rates of decline, and Williams (1992) noted that Galactic novae could be divided into two classes on the basis of their spectral properties: specifically, the relative strengths of the Fe II and He and N emission lines. Novae with prominent Fe II lines (the Fe II novae) usually show P Cygni absorption profiles, tend to evolve more slowly, have lower expansion velocities, and have a lower level of ionization than novae that exhibit strong lines of He and N (the He/N novae). In addition, these He/N novae often display very strong neon lines, suggesting that the seat of the eruption is a relatively massive ONe white dwarf. Such novae do not appear to produce the copious carbon-rich dust that is often formed in nova ejecta arising from the lower mass CO white dwarfs (Gehrz et al. 1998). Additional support for the two-population scenario was provided by Della Valle & Livio (1998), who looked into the spatial distribution of Galactic novae with known spectral class and reliable distance estimates. From a sample of 27 novae, they noted that Galactic novae that could be classified as He/N were more concentrated toward the Galactic plane and tended to be faster and more luminous than their Fe II counterparts.

Following these studies, a general picture (summarized in Table 1) has begun to emerge in which the disk novae are thought to arise on generally more massive (often ONe) white dwarfs associated with systems found in younger stellar populations. Since less accreted mass is required to achieve a TNR on a more massive white dwarf, typical disk novae would then be expected to expel less material and to evolve more quickly than their bulge counterparts with lower mass white dwarfs (Della Valle & Livio 1998; Livio 1992). Furthermore, the smaller amount of accreted matter required to achieve a TNR will lead to shorter recurrence times for novae with massive white dwarfs (e.g., Gil-Pons et al. 2003). The fact that Galactic recurrent novae appear to have massive white dwarfs is consistent with this picture (Hachisu & Kato 2001). Since the nova ejecta is thought to be contaminated with material dredged up from the underlying white dwarf, it is generally accepted that novae arising on CO white dwarfs produce carbon-rich ejecta, and eventually carbon-rich dust, while novae arising on the more massive ONe white dwarfs evolve to become "neon novae," characterized by significant Ne line emission (Gehrz et al. 1985). Finally, according to Williams (1992), systems that eject a relatively small amount of mass in a thin shell tend to display the higher excitation He/N spectra, whereas those that eject mass in a continuous wind produce lower excitation Fe II spectra with P Cygni features.

Given the expectation that He/N novae are thought to be primarily associated with younger stellar populations, it may seem surprising that the first nova identified in an M31 globular cluster is a member of this class. However, as in the field, selection effects strongly influence the discovery of novae in globular clusters. Furthermore, since novae with massive white dwarfs are more luminous and have shorter recurrence times than those of low-mass systems, it should not be surprising that a significant fraction of the *observed* globular cluster novae harbor massive white dwarfs (and show He/N spectra), even if such systems are less common in globular clusters than in the field. In M31, generally, ~15% of M31 novae with measured spectra fall into the He/N class, whereas available evidence suggests that the percentage of He/N novae in the Galaxy is even higher, ~20%–25% (A. W. Shafter 2007, in preparation). If this difference is found to be statistically significant, it is possible that the slightly higher fraction of He/N novae observed in the Galaxy reflects the slightly later Hubble type of the Milky Way, compared with M31.

4. CONCLUSIONS

Our principal conclusions can be summarized as follows:

1. The nova M31N-2007-06b is spatially coincident, to within observational errors ($\pm 0.4''$ in each coordinate), with one of the galaxy's globular clusters (Bol 111). This discovery marks the first time a nova has been associated with a globular cluster in M31; it is only the second extragalactic nova to arise in a globular cluster (the other being the nova found by Shara et al. 2004 in one of M87's globular clusters).

2. Our spectroscopic observations clearly establish that M31N-2007-06b is a member of the He/N type in William's (1992) classification system. Although such novae are expected to be more common in younger stellar populations, like that associated with M31's disk, the shorter recurrence times and the higher luminosities expected for these novae strongly enhance their discovery probability in any stellar population.

3. Taken at face value, out of the more than 700 novae discovered in M31 over the past century, the association of a single nova with a globular cluster is consistent with the hypothesis that novae in globular clusters are not enhanced relative to the field. However, given the difficulty in detecting globular cluster novae, it is almost certain that a significant number of novae in M31's globular cluster system have been missed over the past century, making an enhancement over the field seem likely. Clearly, a more thorough and systematic monitoring campaign of M31's globular cluster system, over many years, will be required before a definitive conclusion can be reached.

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Facility: HET.

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