ERUPTING DWARF NOVAE IN THE LARGE MAGELLANIC CLOUD

MICHAEL M. SHARA,1 SASHA HINKLEY, AND DAVID R. ZUREK1
American Museum of Natural History, 79th Street and Central Park West, New York, NY 10024; mshara@amnh.org, shinkley@amnh.org, dzurek@amnh.org

Received 2003 July 28; accepted 2003 August 27

ABSTRACT

We report the first likely detections of erupting dwarf novae (DNe) in an external galaxy: the Large Magellanic Cloud. Six candidates were isolated from approximately a million stars observed every second night over 11 nights with the Cerro Tololo Inter-American Observatory 8K × 8K Mosaic2 CCD imager. Artificial dwarf nova and completeness tests suggest that we are seeing only the brightest of the LMC DNe, probably SS Cygni–like cataclysmic variables (CVs), but possibly SU UMa type cataclysms undergoing superoutbursts. We derive crude but useful limits on the LMC DN surface density and on the number of DNe in the LMC. Many thousands of CVs in the Magellanic Clouds can be discovered and characterized with 8 m class telescopes.

Key words: Magellanic Clouds — novae, cataclysmic variables — stars: dwarf novae

1. INTRODUCTION

The study of cataclysmic variables (CVs) in our Galaxy is plagued by the same problem that afflicts so many other areas of astrophysics: uncertainty in the distances to, and hence luminosities of, the objects being studied. A second and no less severe problem is the space density and spatial distribution uncertainties caused by our parochial view of the Milky Way. While we can detect erupting Galactic classical novae several kiloparsecs from the Sun, most other CVs are located closer than about 500 pc. The reason is simple: novae often achieve $10^5 L_\odot$, rivaling the most luminous objects in our Galaxy for weeks at a time, while dwarf novae (DNe), nova-like variables, and their magnetic cousins rarely exceed 10 $L_\odot$. Astronomers have succeeded in cataloging barely a thousand Galactic CVs in over a century of searching. Only for a handful are ironclad distances published from Hubble Space Telescope (HST) parallaxes (Harrison et al. 1999; McArthur et al. 1999, 2001). Expansion parallaxes for classical novae contribute another 20 or so reasonably secure distances and luminosities (see Warner 1995 for a summary).

It would clearly be of enormous benefit to CV science if hundreds or thousands of CVs, all at the same distance, could be located. Accurate luminosity functions and bias-free period distributions and eruption frequencies would become available to confront inadequately constrained theoretical models. New subclasses of CVs might be discovered and systematic variations in outburst properties and binary orbital distributions would likely be uncovered.

The situation is improving for CVs in a few special places: the crowded cores of globular clusters. Recent detections of dozens of CV candidates in 47 Tuc (Grindlay et al. 2001; Knigge et al. 2002) allow for the first time the comparative study of many cataclysms all at the same distance. Unfortunately, HST and the Chandra X-Ray Observatory are essential for follow-up studies, and these telescopes are two of the rarest commodities in astrophysics. It may be decades before the newly discovered CVs are fully characterized. Worse, many of these CVs probably formed by tidal captures and/or evolved violently under the influences of passing stars. Only one globular DN is easily resolved and studied from the ground: V101 in M5 (Margon, Downes, & Gunn 1981; Shara, Potter, & Moffat 1990). Its rather long (5.79 hr) period (Neill et al. 2002) warns us that it may be anomalous. CVs in the cores of globular clusters have much to teach us, but they are likely to be very different from field CVs.

The outlook is potentially more promising in the Magellanic Clouds. As in the case of globular clusters, all CVs discovered in the Clouds are at nearly the same distance, so direct luminosity comparisons are meaningful. Spatial densities of field LMC and SMC stars are roughly comparable to those in the neighborhood of the Sun, rather than those typical of globular cluster cores, so tidal encounters almost never happen. CVs in the Clouds must form and evolve via ordinary binary evolution, just as in the field in our own Galaxy. It is certainly true that the metallicities of the red dwarf companions to the white dwarfs in Magellanic CVs will usually be lower than those in the Galaxy. Lower metallicity is a much less drastic effect (Stehle, Kolb, & Ritter 1997) than dynamical interactions (Hurley & Shara 2002) in globular clusters, so direct comparisons between Galactic and Magellanic CVs should be extremely fruitful. Finally, the Clouds must be home to 104 or more CVs (see below), an enormous sample likely to contain every subtype of CV we know, and perhaps some that we do not yet recognize.

Before carrying out Galaxy-LMC population comparisons, we must, of course, find CVs in the Clouds. Since 1897 about 35 erupting classical novae have been spotted in the LMC and SMC. Accurate ($1''–2''$) positions for most of these and recovery of some in deep $U$, $B$, and $V$ images has recently occurred (Shara, Graham, & Zurek 2003). The current sample of quiescent Cloud novae is important to follow up but will grow in number only very slowly. This is because all classical novae must recur (Ford 1978) with inter-eruption times of at least 10$^4$ yr. Thus, the many thousands of classical novae that exist in the Clouds will only slowly reveal themselves via eruptions over many millennia.
As dwarf novae (a substantial subpopulation of CVs) reveal themselves through outbursts every few weeks to months, almost all DNe in any given field should be identifiable, at least in principle, in a deep survey of order 6–12 months in length. Luminous erupting DNe should achieve $U \sim 22.0$, $V \sim 22.5$ near maximum (see § 6) and thus be detectable except in the most crowded LMC fields.

Surveying the entire LMC and SMC often enough to find nearly all erupting DNe is a daunting observational program that can and will eventually be undertaken. In this paper we report a much more modest but realistic feasibility study to demonstrate, for the first time, the existence of erupting DNe in the LMC. We also derive a crude estimate of the total number of luminous DNe in the LMC.

In § 2 we present the observational strategy and database, while the photometry calibrations are described in § 3. Completeness tests are detailed in § 4, and the six erupting DN candidates are shown in § 5. Simulations of erupting DNe in the LMC are compared with these candidates in § 6. We discuss whether the candidates could be other kinds of variables, and the implications for CV numbers and space densities if the candidates are true DNe in § 7. We briefly summarize our results in § 8.

2. OBSERVATIONS

To maximize our chances of detecting erupting LMC DNe, we requested the longest dark run with the largest telescope (the 4 m) and widest field imager (Mosaic2 8K × 8K) available in 1999 at the Cerro Tololo Inter-American Observatory (CTIO). We were awarded the dark nights of 1999 December 2, 4, 6, 8, 10, and 12. All nights were clear, with seeing mostly in the range 1.3–1.8. Because DNe are usually remarkably blue ($U−V ∼ −0.7$ is a good rule of thumb; though much redder values do occur [Bailey 1980]), we opted to image our chosen LMC field in $U$ and $V$ filters. Two to eight images were obtained each night in each filter, with total exposure times (typically) of 2.5 hr in $U$ and 1 hr in $V$. A detailed log is given in Table 1. The plate scale was 0.270 pixel$^{-1}$, and our total field of view (FOV) was 1362 arcmin$^2 = 0.38$ deg$^2$.

The LMC field we chose is centered at R.A. 05h33m36.7 and decl. $−70^\circ 33'44''$ (J2000.0). The FOV was chosen because five erupting classical novae (the novae of 1948, 1970a, 1970b, 1981, and 1988a) have been observed in the area covered by our CCD array—more than any other location in or near the LMC. We were thus able to monitor these five old novae “for free” while searching for erupting dwarf novae. The results of the old nova monitoring will be reported elsewhere (Shara et al. 2003). An overall view of the location of this field within the LMC is shown in Figure 1, with a magnified view of the eight CCD fields superposed. The field is at the southeastern end of the LMC bar and crowding is significant. The large surface density of stars hampered efforts to detect faint DNe but was critical to maximizing the chances of detecting at least a few bright erupting DNe.

The individual Mosaic2 2048 × 4096 images were combined using the MONTAGE2 routine contained within the stand-alone DAOPHOT package. On a given night individual frames were taken with a total vertical dither of ~10 pixels. These frames were run through DAOPHOT’s matching program DAOMASTER to derive the subpixel frame-to-frame shifts. These shifts were passed to MONTAGE2, which produced a sky-subtracted median image of the individual frames.

3. PHOTOMETRY CALIBRATION

The calibrations were derived from a set of standard magnitudes taken from the central region of M67 as given in Montgomery et al. (1993). To ensure that the central region of M67 was observed on all eight chips, the cluster was observed over two nights on the “right-hand” side of the array and then later on the “left-hand” side. However, the left-hand side was observed on the fifth night and was therefore unusable because of poor seeing. Nevertheless, the zero points between chips were consistent to within 0.05 mag, and the zero points derived for the right-hand side were used for the entire data set.

Because of the variable seeing, there also exist very subtle differences in the photometry on a night-to-night basis. Thus, in addition to the global zero-point calibration uncertainty described above, there also exist night-to-night zero-point corrections on the order of 0.05–0.1 mag. These corrections were found by first searching for the least variable (most constant) stars that returned valid photometry for all of the six nights. This was done in an iterative manner to locate stars with variability at least 3 times less than the average of the ensemble. Once this goal was achieved, a night-to-night average was calculated, and this was subtracted from the photometry of the returned candidates. None of these rather small uncertainties has any effect on the candidate detections and conclusions of this paper.

4. COMPLETENESS TESTS

Accurate photometry and astrometry of any source is limited not only by the source’s brightness but also by the degree of crowding in the field. Simulations were performed
to determine the efficiency of recovery of a collection of synthetic stars within a representative subregion of the data set as a function of brightness. These simulations use the actual point-spread function (PSF) for a given night and filter, yielding a measure of the effective plate limit and the overall detection sensitivity of these observations and data reductions.

First, the same small subregion of the entire field was chosen in both the $U$ and $V$ bands and from each of the six nights. The stars in this 500 x 500 pixel subimage showed crowding typical of the rest of the data set (~4000 stars in the subimage). Moreover, the star brightness range in the overall data set was well matched by the range in this subimage.

Next, in order to generate a set of synthetic stars, the ADDSTAR routine contained within DAOPHOT was used to place 100 copies of the PSF randomly across an image and at a set brightness. This was repeated 10 times, for a total of 1000 synthetic stars at a given brightness, night, and filter. Then ALLSTAR returned photometry on all the stars from these 10 runs. The fraction of the input synthetic stars that were recovered gives the level of completeness for that given brightness. A synthetic star was considered “recovered” if it was measured within $\pm 0.5$ mag of its input value. The entire procedure was then repeated with a different brightness for the input synthetic stars. A total magnitude range of $\sim$18.5–24.0 for both the $U$ and $V$ filters was covered in increments of 0.25 mag each. The results are shown in Figures 2a and 2b.

Each of the completeness curves reflect well the seeing of each night. For example, the completeness for the third night (best seeing) is 70% at $U = 22$, and 40% at $V = 23$, typical of an LMC DN near eruption maximum. On the fifth night (the worst seeing night) the completeness at these same magnitudes is barely 2%–3%. Fortunately, every night’s imagery, except that of night 5, was deep enough and complete enough for us to expect to see at least $\sim 10%$–20% of all erupting DNe at or near peak brightness.

5. CANDIDATE DWARF NOVAE

For a field with such a high stellar density ($\sim$1000 stars arcmin$^{-2}$), the construction of a good PSF is hampered
most by neighboring stars crowding the PSF stars. Much effort was expended to automate the search for variables entirely, comparing lists of PSF photometry stars on successive nights. Night-to-night seeing changes produced many candidates in the automated search that were rejected upon visual inspection. Rejection of a candidate invariably occurred because the "candidate" revealed itself to be an artifact created by overlapping PSFs of several stars, changing with the seeing from night to night.

The dwarf nova candidates were ultimately found by blinking rapidly through the best four of the six nightly frames to look for any subtle changes in the appearance of the stellar field. Dwarf novae should rise from invisibility to easily detectable in the 48 hours between observations. To look for changes on a fairly detailed level, each chip was visually divided into 32 subregions and blinked rapidly. Brightening from previously empty regions of the sky is easily seen. A star that is ramping up or down in brightness by 0.5–1.0 mag can also be easily detected since the transition between the first and last night is very prominent. Artificial dwarf novae placed in the frames were visually detected with efficiencies similar to the completeness curves of Figure 2.

To be recognized as a candidate, a variable had to be visible in both the U and V medianed frames of at least one of the six nights and to have varied by over 1 mag in both filters between any two nights. This selection method initially revealed 14 dwarf nova candidates from the entire data set. A second criterion was then applied to weed out short-period, large-amplitude variables: no candidate could vary significantly (more than about 1.0 mag) from frame to frame during any one night. It is certainly true that the light output of many CVs "flickers" on timescales of seconds to hours, and that some CVs undergo short, deep eclipses. We nevertheless adopted this conservative approach to eliminate non-CV, short-period eclipsing binaries. Inspection of each night’s individual images confirmed that seven candidates were likely eclipsing binaries, and one candidate was so crowded that we cannot say for sure that it is a real variable. The eclipsing variables may be useful for LMC distance determinations or other projects, and so we supply their finder charts and coordinates in Figure 8 and Table 3, respectively.

We are thus left with six good candidate erupting DNe. We define a good candidate as one that is seen in both U and V on at least one night, on all images in each filter of that night, and whose variability characteristics are consistent with those of at least one well-studied Galactic dwarf nova (see next section). The nightly images of the six DN candidates are shown in Figure 3, and their photometry is presented in Figure 4. The Poisson error is the dominant photometric error in these plots, although read noise and sky noise also have been incorporated into the error bars shown. We defer a discussion of these candidates and their implications until after the next section, where we simulate expected DN images and light curves.

6. SIMULATIONS OF KNOWN DWARF NOVAE

To complement the completeness tests described in § 4, simulations of eruptions of several well-known and characterized Galactic dwarf novae, artificially placed in the actual LMC data, were needed. Eruptions of SS Cyg, U Gem, SS Aur, AR And, and EM Cyg were all simulated in a relatively uncrowded but otherwise representative patch of the LMC field (an uncrowded field was chosen to highlight the photometric appearances of LMC DNe, unhindered by the crowding or incompleteness addressed in Fig. 2). The images from these simulations are shown in Figure 5.
The three dwarf novae SS Cyg, U Gem, and SS Aur have accurately determined parallaxes (Harrison et al. 1999) and, using their well-tabulated apparent magnitudes (Warner 1995), the absolute magnitudes are easily calculated. The absolute magnitudes for AR And and EM Cygni were obtained from Warner (1995). These five objects were chosen to cover the range of absolute magnitudes seen for erupting and quiescent DNe. Our simulated dwarf novae all reflect the rise, plateau, and decline times from Szkody & Mattei (1984), start at quiescence on the first night of observations, and attain maximum brightness on the second observing night (48 hours later), have all been placed at the distance of the LMC, and, with one exception noted below, use mean \( U-V \) colors from Bruch & Engel (1994). We have assumed that the LMC DNe are dimmed by \( A_V = 0.5 \), in accord with Clementini et al. (2003). PSF photometry was performed on these frames; the resulting light curves and retrieved photometry are shown in Figure 6.

An additional simulated SS Cygni eruption sequence (labeled “SS Cyg sequence 2” in Fig. 6) incorporated more detailed information about this object’s color evolution with time. During its eruption, SS Cygni becomes distinctly more red, reaching \( U-V \approx 0.2 \) before attaining maximum brightness Bailey (1980). This second SS Cyg sequence utilizes these colors and has been shifted by 1 day in phase. That is, the first simulated observation of this second sequence catches the dwarf nova on the rise. (“SS Cygni sequence 1” shows the artificial DN in quiescence on the first night.) This second SS Cyg sequence was included because it mimics rather well the overall observed light curves of DN candidates SHZ1, SHZ4, and SHZ6, though the latter two objects are still redder than the simulated DN. We regard this difference as minor because reddening does vary strongly and on small spatial scales across the LMC (Gochermann & Schmidt-Kaler 2002).

It is clear from Figure 5 that we are unlikely to have been able to detect erupting DNe such as U Gem, SS Aur, AR And, or EM Cyg—all are too intrinsically faint to be detected in our crowded fields. If our candidates are really DNe, they are much more likely to be SS Cygni, or possibly SU UMa–type CVs in superoutburst.

7. INTERPRETATION

7.1. Have We Found Erupting LMC Dwarf Novae?

Comparison of the six candidates shown in Figure 3 with the LMC-DN simulation images shown in Figure 5 (particularly “SS Cyg Sequence 2”) demonstrates that the brightness and variability behaviors of our candidates are
broadly consistent with those expected of luminous erupting dwarf novae in the LMC. This is further supported by comparison of the measured and simulated light curves of Figures 4 and 6, respectively. However, it is by no means certain that all or even some of the six variables shown in Figure 3 are really LMC erupting dwarf novae.

What are the other possible variables that might mimic LMC DN behavior? Among these are chance superpositions of background supernovae or classical novae, gamma-ray bursts (GRBs), microlensing events, Milky Way variables along the line of sight to the LMC, and non-CV LMC variables. The microlensing hypothesis can immediately be discarded because of the nongray light-curve behaviors, nonsymmetric shapes of the light curves and (in most cases) overly long time at maximum light.

GRB afterglows typically achieve $R$ or $I \sim 20$ one day after outburst. While the peak brightness of these variables is in accord with the GRB hypothesis, we can eliminate this possibility because none of the candidates declines quickly enough to be a GRB. Large area, multiepoch surveys for faint variables (e.g., Hawkins & Veron 1987) show that the surface density of our variables is far too high for them to be field RR Lyraes, classical novae, or supernovae.

The brightness and moderately blue colors of the candidates rule out other types of Galactic variables. RR Lyraes in the Galaxy or LMC would be considerably brighter, and flare stars do not match the observed nightly brightness profiles and/or blue colors.

A final possibility to consider is that some of our candidates might be Galactic or LMC eclipsing binaries (see Table 2 for coordinates). Galactic binaries would have to be rather low luminosity systems (say $M \sim 10–15$) and thus much redder than observed to appear at $m \sim 20–22$. Eclipsing LMC systems would range in luminosity from $M \sim 0$

![Fig. 5. Simulated images of erupting Galactic dwarf novae placed in the LMC. See text for details.](image)

![Fig. 6. Simulated light curves of the dwarf nova of Fig. 5. The “dips” and magnitude limits on night 9 are due to the particularly poor seeing of that epoch.](image)

| Candidate | R.A. (J2000.0) | Decl. (J2000.0) |
|-----------|----------------|----------------|
| SHZ1      | 5 30 42.60     | -70 47 32.5    |
| SHZ2      | 5 31 38.25     | -70 38 33.7    |
| SHZ3      | 5 34 42.07     | -70 49 23.6    |
| SHZ4      | 5 35 10.66     | -70 28 02.0    |
| SHZ5      | 5 35 47.75     | -70 24 10.2    |
| SHZ6      | 5 35 24.47     | -70 23 55.4    |

**Note.**—Units of right ascension are hours, minutes, and seconds, and units of declination are degrees, arcminutes, and arcseconds.
(SHZ6) to $M \sim 2.5$ (SHZ3 and SHZ5), corresponding to A-type main-sequence stars. The amplitudes of light variation in SHZ1, SHZ3, SHZ4, SHZ5, and SHZ6 are greater than 0.7 mag and thus preclude equal mass (and brightness) binaries, but a hot pre–white dwarf plus a cooler companion star could mimic the observed light curves for SHZ1, SHZ5, and SHZ6.

As noted earlier, we see no sign of significant variability for any of the six candidates on the individual frames taken during the 2 to 5 hours of observations during each of the six nights of the run. The candidates’ light curves support their tentative identifications as DNe, though some may turn out to be other kinds of variables.

To be absolutely certain of these objects’ identities will require challenging follow-up observations. Four possible confirmation techniques are the following:

1. Spectra near quiescence (to demonstrate the presence of Balmer emission lines) would be definitive proof, but the DNe are then expected to be near 25th mag—beyond the likely capability of even an 8 m telescope in such crowded fields.

2. Imagery every night or two for several months with a 4 m class telescope should reveal repeated eruptions separated by weeks to months. Such a program would also distinguish erupting CVs from LMC eclipsing binaries, where the emergence of a hot, blue star from eclipse—seen only at one epoch—can be confused with a genuine DN eruption. This can be done, but will be very demanding of large telescope time.

3. Ultraviolet imagery of the fields of the six candidate dwarf novae with HST might reveal UV-bright objects, as the spectral energy distributions of most CVs rise sharply into the UV.

4. Several hours of time-resolved UV or optical photometry, again with HST, might reveal the flickering and/or orbital modulation characteristic of CVs.

7.2. Expected Dwarf Nova Populations in the LMC

Space density estimates of CVs near the Sun suggest $10^{-5}$ stars pc$^{-3}$ (Patterson 1998). Space density estimates of all types of stars in the solar neighborhood yield $10^{-1}$ stars pc$^{-3}$, suggesting that about one CV exists in the Galaxy—and probably in the LMC—for every 10$^4$ stars. The LMC displays a $V$-band luminosity of −18.1, corresponding to a mass of $10^{10} M_\odot$ (Cox 1999) and a population of a few times $10^{10}$ stars.

If the Galaxy and LMC manufacture CVs with similar efficiencies and rates, then we estimate a total LMC CV population today of a few times $10^6$ objects. About half of known CVs are DNe (Downes et al. 2001), which suggests a total LMC DN population of order $10^6$. These DNe are spread across the $10^2 \times 10^3$ surface of the LMC. Erupting classical novae are observed to be distributed quite uniformly across the face of the LMC (van den Bergh 1988), consistent with them belonging to an old population. A surface density of 10,000 DNe deg$^{-2}$ across the LMC is thus expected.

7.3. Detections versus Expected Detections

The size of our FOV was 1362 arcmin$^2 = 0.38$ deg$^2$, which should include $0.38 \times 10,000 = 3800$ DNe. The average time between eruptions for 21 well-studied Galactic DNe is 29 days (Szkody & Mattei 1984). The length of our observing run (11 nights) suggests that any DN erupting on the nine nights between nights 2 and 10, inclusive, could have been detected (if it became sufficiently luminous). Hence $(9/29) \times 3800 \sim 1200$ DNe eruptions should have occurred in our FOV that were (at least in principle) detectable.

The 4 m telescope seeing varied significantly over the six nights on which we observed, as clearly seen in the completeness curves of Figure 2. Only on the second, third, and sixth nights were conditions good enough to allow straightforward detection (with 20%–40% completeness due to crowding) of DNe reaching $U \sim 22$–23. Assuming (conservatively) that we missed half of all DNe because only three of six observing nights were “good” and that we missed 80% of all eruptions even on the three “good” nights because of crowding, we might still have expected to have detected $0.2 \times 0.5 \times 1200 = 120$ erupting DNe.

The apparent brightness of a dwarf nova depends both on the underlying binary system inclination and orbital period. Nearly face-on disks and longer orbital periods (which have larger and brighter disks) will dominate a magnitude-limited sample (Paczynski & Schwarzenberg-Czerny 1980; Warner 1986). High-inclination systems will be up to 2 mag fainter than those seen nearly face-on and will therefore be lost in a sample that is detecting only the brightest tip of the distribution.

Longer period systems will have larger and brighter disks and thus might be expected to dominate our sample. However, the number of short-period DNe ($P < 2$ hr) is twice the number of long-period systems ($P > 3$ hr), and it is these short-period systems that undergo SU UMa–like superoutbursts. SU UMa superoutbursts typically last ~3 weeks, and system brightenings might match those observed for our six candidates. This will be clearer when parallaxes are available for at least a few SU UMa CVs.

The fact that we detected at most six DNe when (an admittedly simple) model predicts 120 suggests that many erupting systems were too faint to be detected. This is in accord with the model light curves of Figure 6 and reinforced by the simulated images of Figure 5 showing that DNe such as U Gem, SS Aur, and EM Cyg would all have been missed in our survey, and even (relatively luminous) AR And would have been possible but challenging to detect. What fraction of DNe are at least as luminous as SS Cyg or SU UMa at maximum? Unfortunately, the answer is unknown, because the distances to all but four Galactic DNe are too uncertain to yield a believable luminosity distribution. (We note that the canonical literature distance to the prototypical DN, SS Cyg, was in error by a factor of 2 until HST parallaxes became available in 2000). If our six candidates are all bona fide erupting DNe in the LMC (of either SS Cygni or SU UMa type), this suggests that 95% of all DNe are less luminous than these prototypical dwarf novae. This percentage rises if fewer than six of our candidates are really DNe.

8. CONCLUSIONS

We have carried out an 11 day survey for erupting dwarf novae in the Large Magellanic Cloud, during which we imaged 0.38 deg$^2$ in $U$ and $V$ filters on alternate nights.
Artificial DN and completeness tests confirm that we imaged faint enough (to 23rd mag on the better nights) to detect SS Cygni–like eruptions. Six candidates were isolated from approximately a million stars observed with the CTIO 8K × 8K Mosaic2 CCD imager. If these are true LMC DNe, then they are among the most luminous of outbursting dwarf novae in the Clouds: SS Cygni–like outbursts or possibly SU UMa–like superoutbursts. We estimate the total LMC DN population as $10^6$, and the LMC surface density as $10^4$ DNe deg$^{-2}$. This suggests that at least 95% of erupting LMC DNe are fainter than the six candidates we present and were thus missed.

An extra magnitude in sensitivity and improvements in spatial resolution will likely lead to the discovery of thousands of DNe in the Magellanic Clouds.

We are indebted to the Cerro Tololo Inter-American Observatory directors Robert Williams and Malcolm Smith for the generous allocation of observing time for this project. We also thank Tony Moffat, Darragh O’Donohue, Brian Warner, and an anonymous referee for valuable comments.

APPENDIX

While the time coverage we have of the seven variables noted in §5 is far too sparse for any attempt at period determination, we include their coordinates in Table 3 and finder charts (in $U$ and $V$, minimum and maximum) in Figures 7 and 8.

| Candidate | R.A. (J2000.0) | Decl. (J2000.0) |
|-----------|----------------|----------------|
| V1        | 5 33 25.77     | −70 52 05.7    |
| V2        | 5 30 45.36     | −70 50 42.9    |
| V3        | 5 33 28.53     | −70 46 08.2    |
| V4        | 5 33 02.97     | −70 35 57.6    |
| V5        | 5 32 33.25     | −70 28 48.5    |
| V6        | 5 31 01.26     | −70 18 11.6    |
| V7        | 5 36 39.89     | −70 37 53.5    |

Fig. 7.—Individual exposures in $U$ and $V$ bands of the seven eclipsing binaries/variables at their maximum and minimum brightnesses.
Fig. 8.—Same as Fig. 1, except the seven variables (probably eclipsing variables) discussed in the text are shown as numbered circles (with prefix “V” in the insert).

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