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Discovery of New Eruptive Cataclysmic Variables Using the MACHO Database

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ABSTRACT. We report the results of a search in the MACHO light-curve database that aims to find new cataclysmic variables. The targets were selected from variables toward the Magellanic Clouds and Galactic bulge using as main criteria the amplitude of photometric variability and color indices. These criteria provided a total of 3720 variables that were visually inspected for novae, recurrent novae, or dwarf novae eruptions. Dwarf novae type outbursts were recognized in 28 objects, while a second sample of 38 less probable candidates was also selected. Some characteristics of the light curves of the cataclysmic variables identified are described, and when possible, a classification in a subtype is assigned to the system. The coordinates of each selected target were cross correlated against X-ray survey databases in order to search for possible point-source identifications. The detected dwarf novae in the direction of the bulge are probable members of the Galactic disk population.

1. INTRODUCTION

The study of variable stars is a very important and active area of modern astrophysics. Research in this field might provide information about a number of physical processes, the comprehension of which is of vital importance to understanding the structure and evolution of stars, galaxies, and even of the universe itself. For example, the calibration of Galactic and extragalactic distance scales depends on our knowledge of pulsating variables of the types RR Lyrae, Cepheids, etc. The impact of a detailed view of supernova Ia light-curve properties is key to constraining current cosmological models, and dedicated photometric surveys are being carried out, with the aim of detecting of high-z supernovae. On the other hand, processes of mass transfer/accretion disk formation in binary systems have been studied using X-ray sources, cataclysmic variables, and symbiotic stars. The latter objects also offer the possibility of studying matter in extreme conditions of gravity, density, and magnetic fields.

Cataclysmic variables (CVs) are interacting binary systems in which a white dwarf accretes matter from a "normal" late-type dwarf star (G to M spectral types) via Roche-lobe overflow. Depending on the strength of the magnetic field of the white dwarf, the accretion might occur via a disk if the white dwarf presents weak or absent magnetic field (dwarf novae subclass), or via a stream/column in strongly magnetized systems (AM Herculis or polars).

Several subclasses of CVs might be identified according to the main properties of their light curves over long timescales, and the relevance of the white dwarf magnetic field. In nova-type systems, an eruption with an amplitude of 6–19 mag occurs, which is explained as the result of a thermonuclear runaway of hydrogen-rich accreted matter on the white dwarf surface. The dwarf nova subclass is characterized by recurrent and smaller outbursts. Typical time intervals between the eruptions range from a few tens to hundreds of days, while the amplitude is typically from 2 to 5 mag. The eruptions in these systems are explained by the sudden rise in the matter accretion rate from the disk onto the white dwarf. Several subtypes of dwarf novae are recognized, the most common being the U Gem, Z Cam, and SU UMa subtypes. A textbook review of CV properties can be found in Warner (1995).

Cataclysmic variables, in particular, have an important role among interacting binary systems in general. The fact that such objects present short orbital periods (a few hours) permits more detailed analyses of the processes of accretion via a disk, which is important in several astrophysical scenarios, since the accretion of matter with disk formation is expected to be present in a large number of objects, ranging from quasars to young stellar objects. In the case of a disk around a white dwarf, most of the energy is released in the UV and optical wavelengths, making the study of accretion phenomena possible using a variety of observational techniques. For example, indirect imaging techniques such as Doppler tomography and eclipse mapping methods have provided access to details about the structure and emission properties of the accretion in many CVs.

The known sample of CVs comprises some 1200 systems, 70% of which exhibited eruptions. Eruptive CVs can be divided into dwarf novae (∼520 objects) and classical plus recurrent novae (∼310 objects), with a very small classification overlap (Downes et al. 2003). The apparent distribution in the sky between dwarf novae and novae presents some striking differences: dwarf novae are almost spherically distributed, indicating a nearby sample selection, while the novae may be detected at greater distances in the Galaxy and present a well-defined bulge plus old disk population distribution, with a large concentration of them found toward the Galactic bulge. While the statistics on some types of variable stars are improving rapidly as they are found by the hundreds (or even thousands) in ours and in other galaxies, the population of known CV subclasses is still poorly sampled, preventing a more detailed analysis of their galaxy distribution and evolution. More recently, the discovery of many novae in M87 (Shara & Zurek 2002) may lead to a significant improvement in the comparative study of nova populations in M31 (Shafter & Irby 2001) and other galaxies. Most of the known CVs have been discovered by their photometric variability, which may be due to eruptive behavior or the presence of eclipses and/or orbital modulations. Some new CVs were also found by their blue broadband colors and/or emission-line spectra (Cieslinski et al. 1998), while a fraction of CVs, specifically magnetized systems, were identified by their distinctive X-ray emission. In this paper we describe an extensive use of the former method on the basis of a deep photometric monitoring survey.

The interest in variable stars has recently increased as a result of the identification of many new variables of several types in the course of long-term monitoring programs such as MACHO, OGLE, etc., whose main objective was to find dark matter in the Galaxy via microlensing effect (e.g., Alcock et al. 2001; Udalski et al. 1997). The strategy used by these surveys is to observe several million stars as frequently as possible for long time intervals (years). Such synoptic observations are very appropriate for finding new eruptive variables, including CVs. Finding new eruptive CVs is particularly important because it allows for more reliable statistical studies of homogeneous subclasses with reasonably well-defined physical properties. A previous and similar search using OGLE observations was recently pursued by Cieslinski et al. (2003, hereafter Paper I), while the search for CVs in the MACHO database is the subject of the present paper. The observations and the criteria used for selecting candidates are described in § 2. The results and a discussion of a few implications of our findings is given in § 3. Finally, a summary of the main results of this study is presented in § 4.

2. OBSERVATIONS AND SELECTION OF TARGETS

2.1. The MACHO Photometry

The MACHO project repeatedly imaged ∼67 million stars in a total of 182 observation fields toward the Galactic bulge, LMC and SMC, to detect the phenomenon of microlensing (Alcock et al. 1997). The observations were taken between 1992 and 2000 at the Mount Stromlo and Siding Springs Observatories' 1.3 m Great Melbourne Telescope with the dual-color wide-field MACHO camera. This data set consists of ∼90,000 *V*- and *R*-band observations and when field overlap is considered, the 182 fields observed cover approximately 80 deg^2. The MACHO camera images were taken with non-standard V_M and R_M bands. These values can be converted to the standard Kron-Cousins system *V* and *R* using the photometric calibrations given in Alcock et al. (1999).

The stars observed toward the LMC and SMC are mostly giants, except for a small number of foreground-disk main-sequence stars. Observations toward the Galactic bulge have exposure times of 150 s, while toward the LMC and SMC they are 300 and 600 s, respectively. The median *seeing* of the data set is roughly 2″, and measurements reach stars with $V_{\rm KC}$ magnitudes between 21 and 22. The photometry of the MACHO project was carried out using a fixed-position point-spread function photometry package derived from the DoPhot package (Schechter et al. 1993) called SoDoPhot (Bennett et al. 1993).

The photometric observations were generally uniformly spaced during the period that the Galactic bulge was observable at Mount Stromlo (March to October). However, a few fields in the LMC and Galactic bulge have variations in observation frequency, because of changes in the observing strategy. The least sampled fields have only ∼50 observations, while the most sampled fields have ∼2000 observations. Furthermore, a small number of the bulge fields were only observed in the last few years of the project.

2.2. The Selection Criteria

In our selection of candidates, we searched for positive excursions from the baseline magnitude. This approach primarily follows the analysis of the Paper I. However, as there are a number of differences in the process of data acquisition between the MACHO and OGLE-II programs, the method of analysis was modified to account for these differences. For instance, the MACHO data consist of two observations taken simultaneously rather than one individual observation, as in the OGLE-II data. This simultaneity in the MACHO observations can be used as a strong filter against noise spikes: if a CV goes into outburst, this should be apparent to some extent in both observations. As we are looking for objects that deviate occasionally from a relatively constant baseline value, we first determined the mode of each light curve in the MACHO var-

TABLE 1
DWARF NOVA CANDIDATES

MACHO ID (1)	V (2)	$(V-R)$ (3)	ΔV[c] (4)	$\Delta(V-R)$[d] (5)	Range[e] (6)	Coverage (%) (7)	N[f] (8)	τ[g] (9)	α (J2000.0) (10)	δ (J2000.0) (11)
101.20784.2398	19.3	0.76	1.6	−0.4	2411	56	31	45	18 04 47.20	−27 07 48.35
102.23250.3841	20.1	0.67	1.9	−0.4	2398	41	23	45	18 10 30.87	−27 27 26.76
104.20129.2662[a]	18.7	0.41	3.2	−0.3	2412	57	58	25	18 03 06.03	−27 30 45.53
104.20906.960	17.6	0.69	1.5	−0.3	2412	58	4	...	18 05 07.12	−27 43 09.13
108.19205.3394	19.7	0.84	2.2	−0.2	2400	66	19	80	18 01 00.00	−28 24 18.24
108.19597.3208	19.7	0.77	2.2	0.7	2400	61	...	...	18 02 05.03	−28 18 33.37
113.19455.4698	20.6	0.9	2.8	−0.6	2430	62	21	70	18 01 35.45	−29 07 30.67
115.22182.3452	19.8	0.72	2.0	−0.4	2327	39	3	...	18 07 57.61	−29 18 14.62
118.18664.5336	20.7	0.8	2.0	−0.5	2380	62	19	80	18 00 01.22	−29 50 38.52
118.19052.2032	20.5	0.78	2.5	−0.5	2306	61	18	80	18 00 51.55	−29 56 52.04
124.21890.1808	19.5	0.56	2.1	−1.1	2327	37	21	40	18 07 32.11	−31 23 56.33
128.21143.1295[a]	19.7	0.86	1.4	−0.4	2389	54	9	140	18 05 34.22	−29 12 04.11
148.26333.1860	19.7	0.76	1.8	−0.3	2293	35	4	...	18 17 48.46	−29 52 14.03
149.28010.6410	19.8	0.62	1.4	−0.2	2288	36	3	...	18 21 44.67	−30 47 09.43
150.29315.3459	21.0	0.59	2.1	−0.3	1960	35	5	...	18 24 48.95	−30 23 49.68
152.25800.1458	20.9	0.66	2.3	−0.2	2252	19	7	60	18 16 35.10	−30 44 06.06
153.28005.3041	20.7	0.52	2.2	−0.3	1960	37	7	100	18 21 53.55	−31 06 41.77
153.28010.620	20.1	0.42	1.9	−0.2	1960	36	4	...	18 21 44.59	−30 47 08.93
156.27609.1548	...	...	...	...	1904	13	5	...	18 20 55.04	−31 28 57.92
159.26395.2298	19.4	0.66	1.7	−0.4	2297	45	7	150	18 17 57.85	−25 47 02.24
17.2832.2606[b]	...	...	...	...	2718	82	...	...	04 57 42.21	−69 40 30.66
172.31712.790	19.5	0.43	2.9	−0.3	1944	24	11	40	18 30 24.36	−26 37 55.82
178.23006.4293[a]	20.1	0.79	1.7	−0.4	1673	56	3	...	18 09 58.25	−26 20 59.36
178.23266.5982[a]	20.8	0.89	2.7	−0.3	1674	52	9	97	18 10 35.28	−26 23 39.40
179.22103.2421	21.3	0.5	1.7	0.0	1625	46	14	50	18 07 51.71	−25 53 55.56
180.22371.886	18.9	1.07	1.5	−0.4	1602	51	8	100	18 08 30.52	−25 21 49.29
301.46117.1481	20.6	0.93	2.8	−0.6	1661	56	10	90	18 32 52.65	−13 18 04.28
304.35057.1192	20.6	0.64	3.0	−0.4	1642	59	2	...	18 14 34.84	−22 37 42.42
307.35708.4691	...	...	...	...	1643	50	22	37	18 15 34.42	−23 59 12.69
308.36914.3615	20.9	0.85	2.2	−0.2	1587	47	7	100	18 17 32.98	−21 59 12.78
311.36888.1587	19.8	0.92	2.8	−0.5	1638	58	6	160	18 17 29.87	−23 43 55.99
401.48296.2600	19.7	0.52	3.5	−0.4	1676	54	3	...	17 58 32.45	−27 52 44.42

NOTE.—Units of right ascension are hours, minutes, and seconds, and units of declination are degrees, arcminutes, and arcseconds.
[a] 104.20129.2662 ≡ V5099 Sgr, 128.21143.1295 ≡ Bul_sc33_703, 178.23006.4293 ≡ Bul_sc16_2143, 178.23266.5982 ≡ Bul_sc17_1447.
[b] Target in the LMC direction.
[c] Maximum observed outburst amplitude.
[d] Outburst color amplitude (see text).
[e] Light curve time length (days).
[f] Estimated number of outbursts.
[g] Estimated outburst recurrence time (days; see text).

iable star database by binning each curve into 20 bins. Only values within 5 σ of the median were included in these bins.

Most of the stars in the variable database belong to several types of red giants. Because of the substantial range in the variability characteristics of these stars, it is likely that a few red giant variables will pass almost any variability filters aimed at detecting CVs. To eliminate the bulk of these variables from consideration, we disregarded stars with baseline $V-R$ colors greater than 2. In a second selection step, we removed stars that did not have data points more than 0.5 mag above the baseline in two consecutive observations. These high points were required to be of at least 3 σ significance in both bands. It should be noted that we used a much lower amplitude cut than that used in the Paper I, because the observations were taken simultaneously and because the determination of the outburst amplitude is complicated (as we outline in § 3). This selection makes it possible to disregard noise spikes and problems with individual observations, such as those due to bad weather. There were several thousand stars in the variable database satisfying these initial selection conditions. To reduce this to a more manageable number, we applied a few more selections based on the known shapes of CV light curves, and empirical trial and error.

We expected that CVs exhibiting outburst flares would be relatively flat, with a few positive excursions from the baseline. Therefore, in our first selection from the initial candidate list,

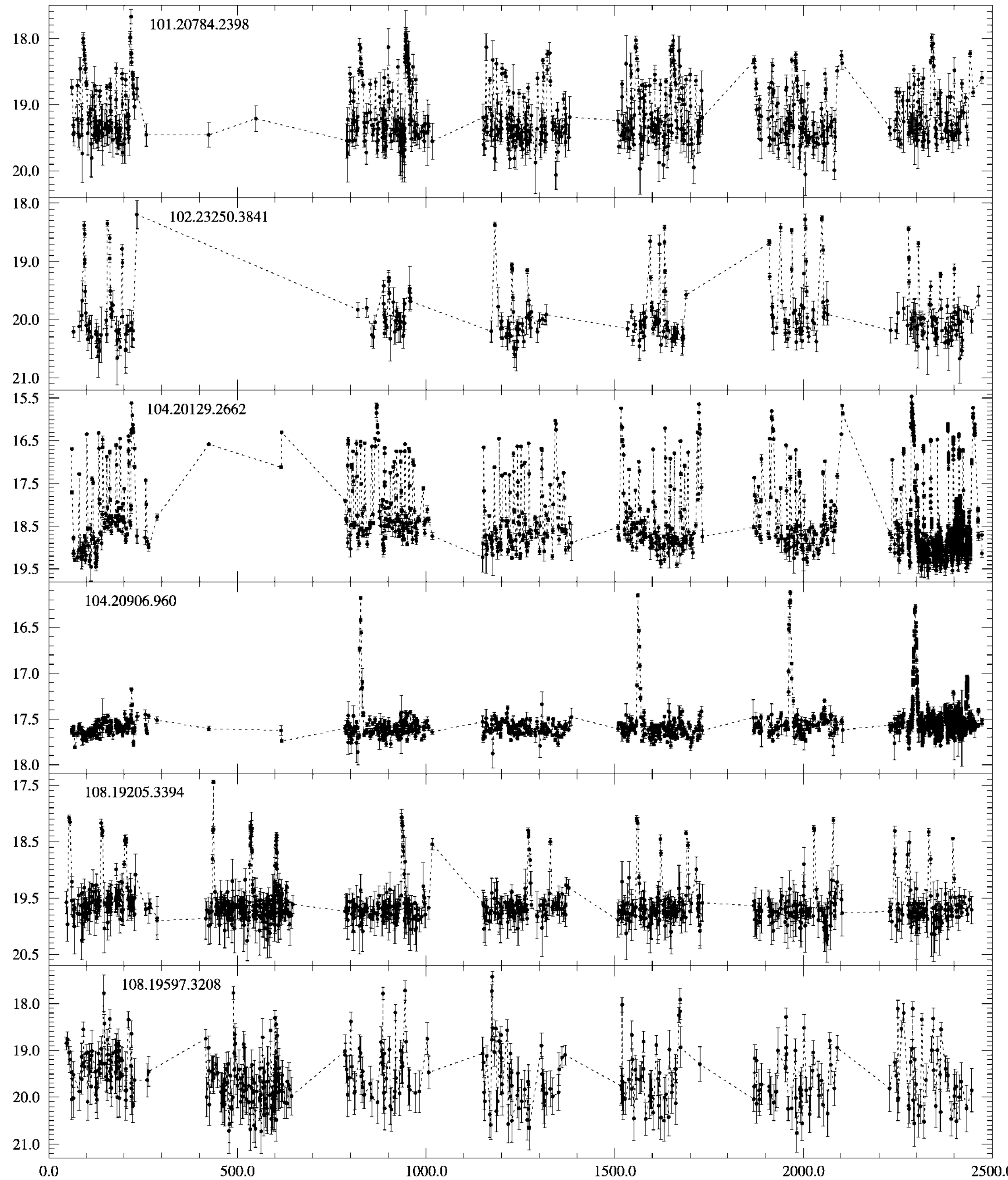

FIG. 1.—MACHO *V*-band light curve vs. HJD (2449000+) for the objects identified in the present survey as dwarf novae. For the sake of clarity, the points have been connected by a dashed line, and points with error bars larger 0.5 mag are not shown.

we required that less than 15% of the points in a light curve be 3 σ below the baseline, and less than 40% be above it. It has been previously noted that CV outburst colors are blue. Therefore, we also required that the amplitude of the outburst data points be greater in *V* than in *R* bands, as this property is unlikely in other types of variables, which tend to have larger *R*-band variations than *V*-band ones. This removes many spurious candidates from selection. In a second set of selections from the initial candidate list, we removed the necessity of a *V*-band amplitude greater than the *R* band. Instead, we required that the amplitude in either the *V* or *R* bands be greater than 1 mag. In this selection we only required that more than 30% of the points in a light curve be 3 σ below the baseline and less than 50% be above it.

In order to verify the nature of the selected variables, the light curve of each one was visually inspected in both passbands, taking into account the estimated magnitude errors. Points below the detection limit, or nights without reliable mea-

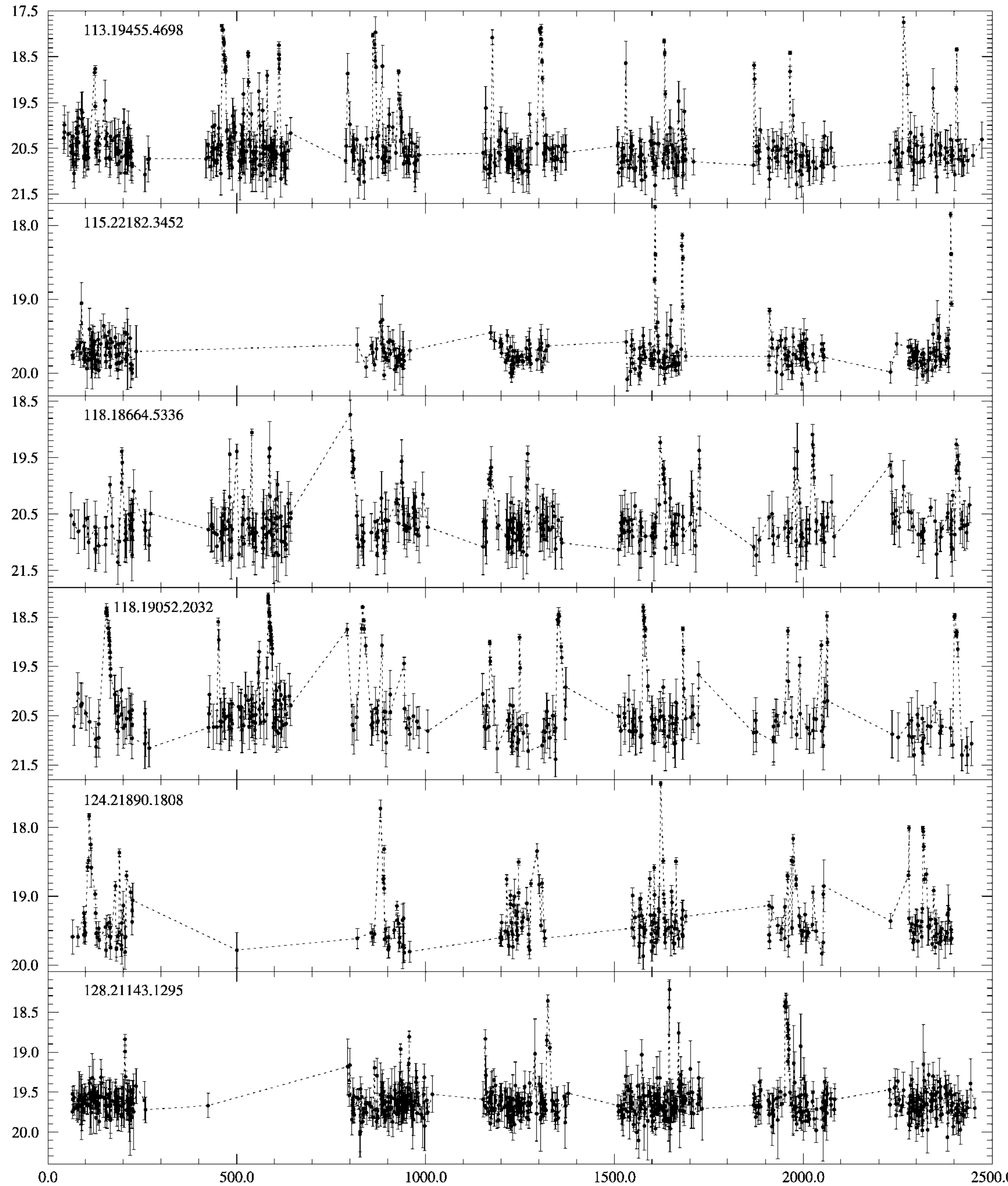

FIG. 1.—*Continued*

surements are automatically rejected. The diversity of novae and dwarf novae light-curve morphologies associated with the variety of light-curve types that are selected by the simple amplitude criterion make any automatic identification algorithm a difficult task to be implemented in practice. After some experience with automatic identification codes, we found it difficult to design a robust algorithm capable of identifying all types of dwarf novae light curves, considering the sampling, time resolution, and different noise levels found in MACHO light curves. Visual selection is highly versatile, however, and in order to avoid an excessively subjective discrimination of the light curves, we imposed some criteria for validating true CV candidates. The objects with light curves presenting recurrent outburst activity having amplitudes and timescales consistent with dwarf nova eruptions were selected and designed as "grade A" candidates. These curves show a well-sampled

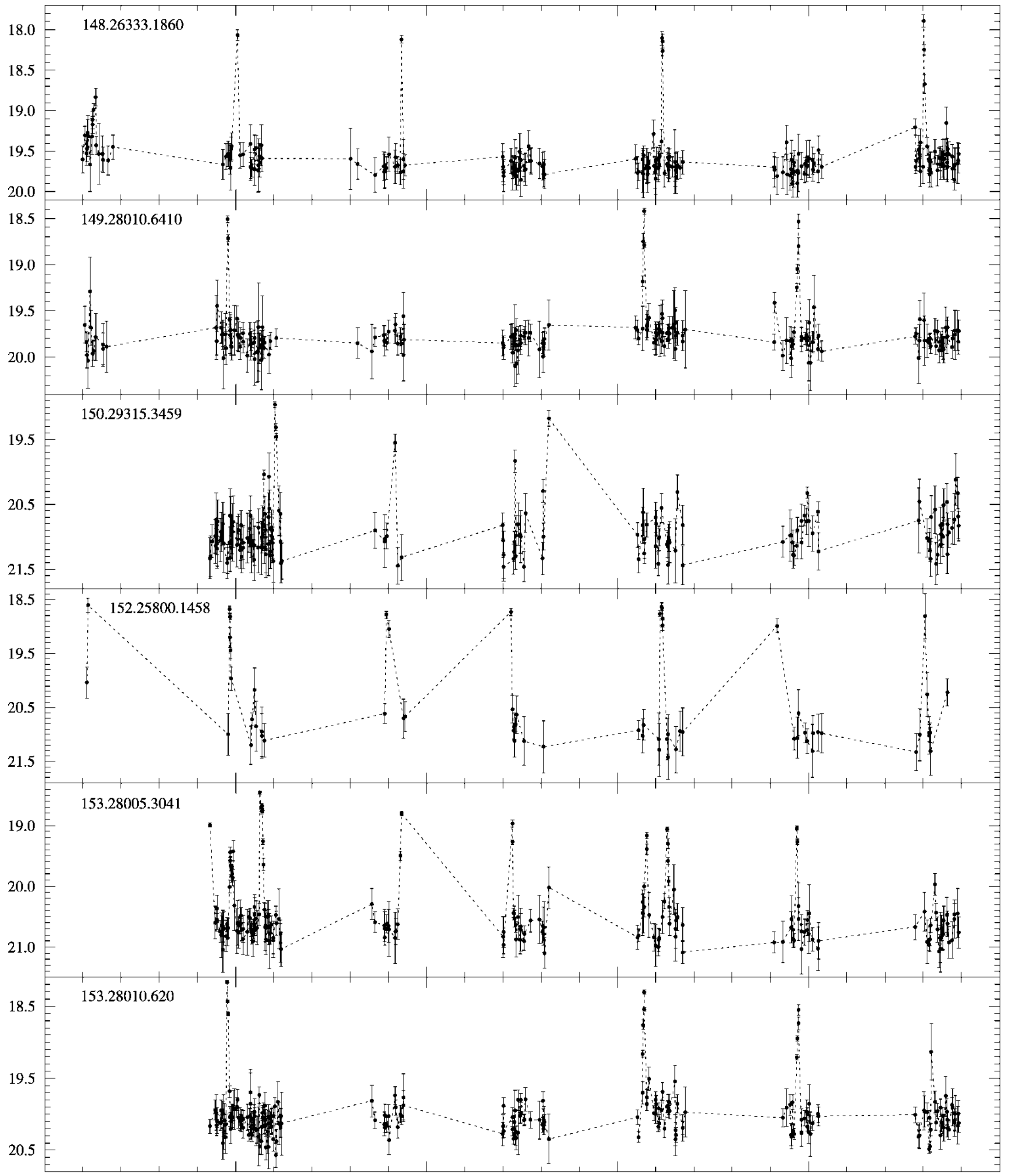

FIG. 1.—*Continued*

set of outbursts. Objects with noisy or fragmentary light curves, which make it difficult to assign a CV classification, or with light curves that can be associated with other types of variables, were classified as "grade B" candidates.

In this paper we focus on presenting and commenting on the list of grade-A objects and also listing the grade-B identifications. The coordinates in the grade-A list were compared with those in the current list of known CVs (Downes et al. 2003) and also with the SIMBAD database, aiming to recognize known CVs in our selection and also reject objects that, in fact, belong to other classes of variables. A caveat regarding the limitations of our selection process ought to be mentioned here: the use of the brightness amplitude variation for selecting CV candidates is not appropriate for discovering nonerupting systems or those that did not present an eruption during the MACHO time coverage. Thus, such systems were not identified in our survey, even if they are bright and present variability on short timescales (flickering).

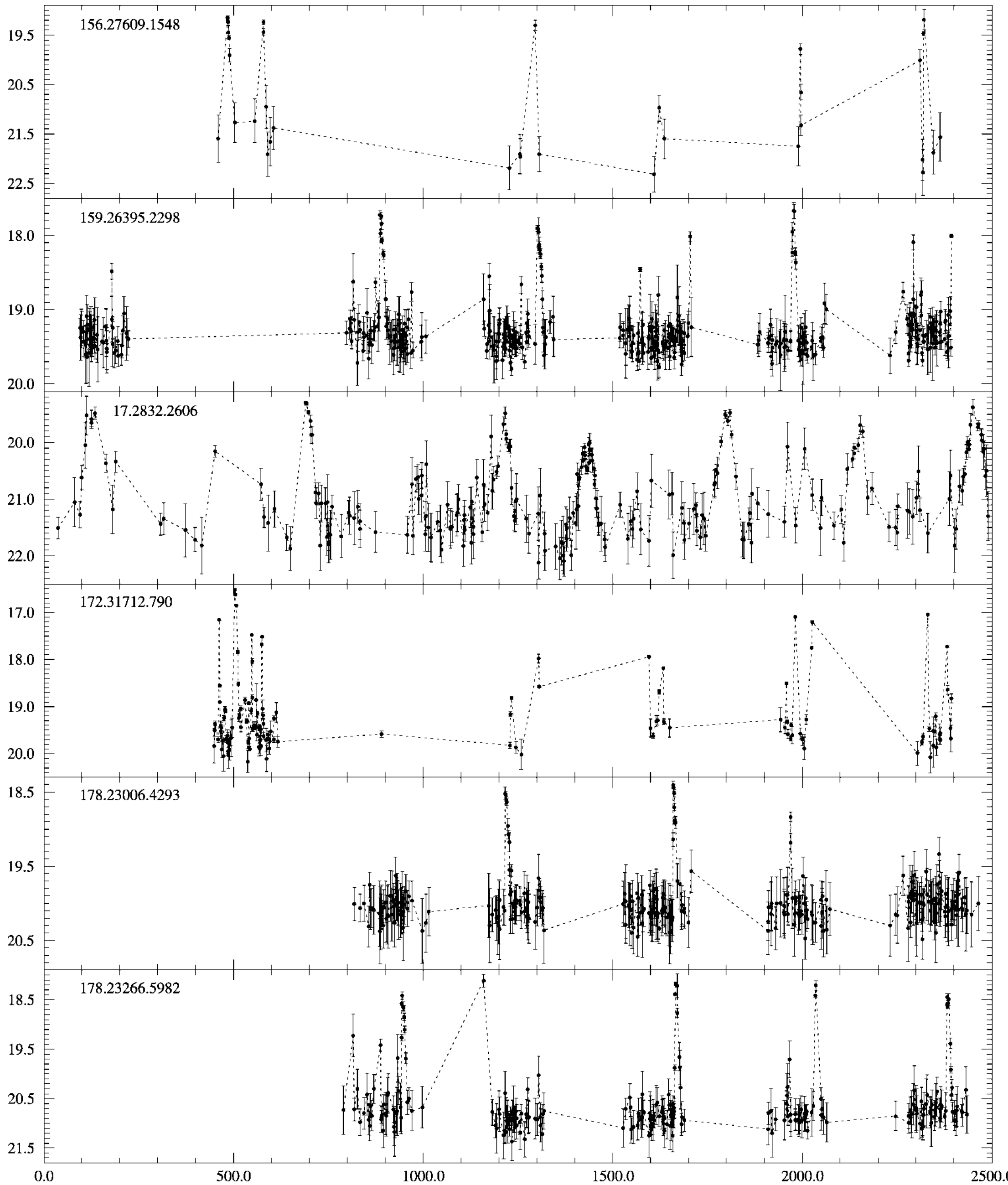

FIG. 1.—*Continued*

3. RESULTS AND DISCUSSION

We have identified a total of 28 new dwarf nova candidates. They are listed in Table 1, while the individual light curves are shown in Figure 1 (note that four CVs are already known). Table 1 also lists some properties inferred from light-curve data, which include the target name in the MACHO database (col. [1]), the median quiescent magnitude level between outbursts (col. [2]), the median quiescent color index ($V-R$; col. [3]), the maximum outburst amplitude in the V band (col. 4), the outburst color amplitude (col. [5]), the length of the light curve (col. [6]), the percentage of light curve length covered by observations (col. [7]), the estimated number of outbursts sampled by the data (col. [8]), and the estimated recurrence time interval between outbursts (col. [9]). Finally, columns [10] and [11] give the coordinates of the targets. The recurrence time τ was calculated by dividing the light curve length T_f–T_i by the number of observed eruptions. This value was divided by the fractional coverage aiming to correct our estimate

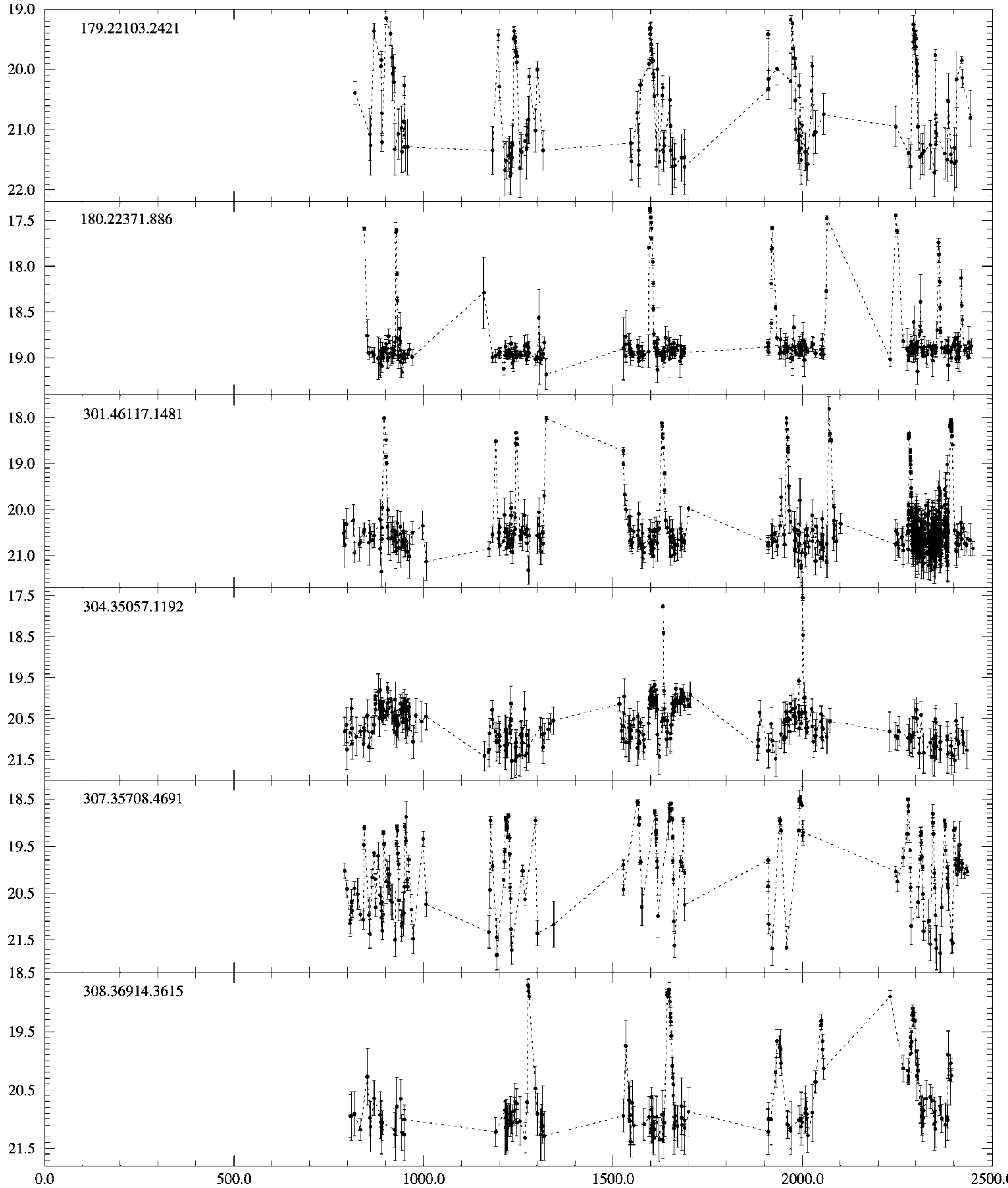

FIG. 1.—*Continued*

for the incomplete sampling. Note that such a value for the recurrence time is not well defined for systems in which few (less than five) eruptions were recorded, and was omitted in these cases. The 38 selected grade-B objects are shown in Table 2, which gives their coordinates and the beginning and ending times of the MACHO data coverage (in HJD). Very few candidates were found in the direction of the LMC and SMC. Only one grade-A candidate was selected from the LMC fields. This result may be tentatively explained by the fact that typical dwarf novae in the LMC or SMC have quiescent magnitudes beyond our detection limits, and no baseline level could be established for most of these objects. We verify that five out of eight previously known dwarf novae inside the MACHO bulge fields were effectively selected by our search. At present, the Downes et al. (2003) catalog lists only five dwarf novae or stars suspected with quiescent magnitude brighter than 19.0 inside the MACHO bulge fields. Three other dwarf novae that were al-

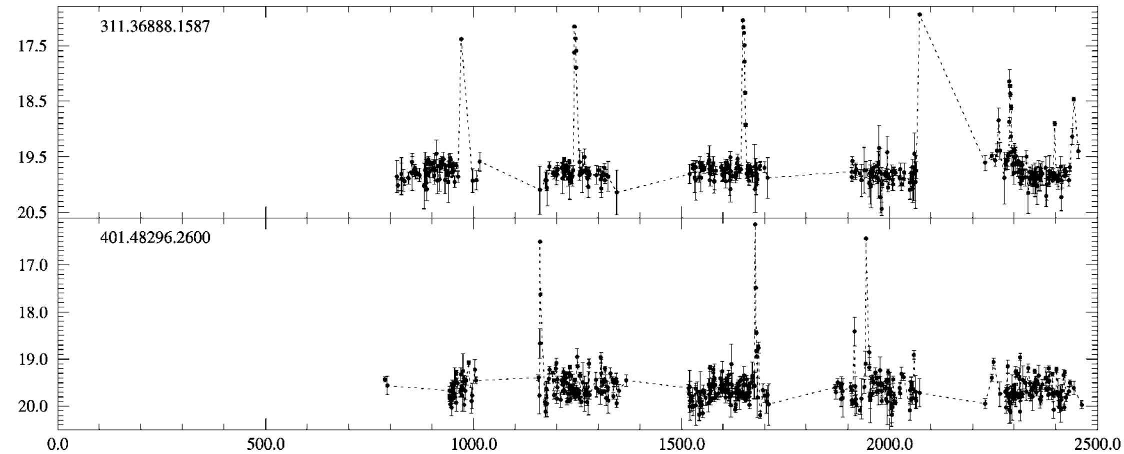

FIG. 1.—*Continued*

ready found by the search of OGLE data (Paper I) were also selected as grade A using MACHO light curves (this work).

Dwarf novae may be discovered by observational properties other than their distinct photometric behavior. The selection efficiency using photometric variability criteria, in particular, is affected not only by the outburst amplitude and quiescence level, but also by its recurrence time. Systems with frequent outbursts are more easily found accidentally or even by photometric surveys with limited time coverage. Considering the time coverage of the MACHO database, we should be able to find the majority of the dwarf novae with quiescent magnitude above our detection limit and that are located within the searched fields. A search of the HEASARC database failed to correlate any of our candidates with nearby X-ray sources. In fact, if a F_x to F_{opt} ratio below 0.5 were considered, then the expected X-ray flux would be too low for detection in most of the available ROSAT/PSPC exposures for which the limiting flux is $F_{0.5-2.5\ \mathrm{keV}} \sim 10^{-13}$ (ergs cm^{-2} s^{-1}; Verbunt et al. 1997). On the other hand, deep *Chandra* images eventually should have been able to detect at least the brightest dwarf novae in our sample (e.g., Edmonds et al. 2003).

The determination of magnitudes of the CV candidates is complicated by stellar blending in the crowded Galactic bulge and Magellanic fields. In many cases the white dwarf companion is a faint main-sequence star. Most main-sequence stars at the distance of the Galactic bulge are not detectable, because they are too faint, and reddening can be more than a few magnitudes. However, if these objects are within a couple arcseconds of a brighter star (or group of stars) that is monitored, they may be detectable.

The SoDoPhot photometry program uses a template warm-start method to monitor stars. Here a high signal-to-noise ratio template with good seeing is used to determine a list of stars to photometer. The coordinates of the stars are transformed to the coordinates of the same stars in other observations. In this way, stars can be photometered in even very poor seeing conditions. However, if an event occurs that is not associated with one of the template-list stars, the program tends to associate that flux with the nearest star or group of stars. This situation has been well documented for microlensing events with sources that are not from the template lists. This results in a large blend fraction in the microlensing light curve fitting process. However, this is also possible for other transient events, such as passing asteroids and CVs.

In our selection, we found a number of candidates that were within a couple arcseconds of other candidates. It is extremely unlikely that these findings are not associated with each other, given the number of candidates and the size of the area surveyed. These are cases in which the outburst was large enough to be measured, but the baseline magnitude was too faint to be detected in the template image. The flux from the outburst had been split between the nearest stars. It is also likely that many of the candidates without nearby detections are also blended with the other stars. In these cases the CV happens to be close enough to a monitored star that the flux is not shared with another monitored star. Because of these complications, it is not possible to determine the magnitude of the CV candidates in these cases. However, we can put upper limits on the magnitudes based on the monitored fluxes. Future high-resolution observations can be performed to determine accurate baseline magnitudes in these cases.

3.1. Outburst Amplitude and Color of the CV Candidates

The selected dwarf nova candidates present outburst amplitudes ranging from 1 to 3 mag. For most systems the amplitudes in both *V* and *R* passbands are, as expected, well correlated (Fig. 2*a*). The amplitudes quoted represent the maximum recorded value among several outburst events. The corresponding color index variations (comparing quiescent state and maximum light) are shown in Figure 2*b*. Detailed color information

TABLE 2
Other Possible Dwarf Nova Candidates

MACHO ID	α (J2000.0)	δ (J2000.0)	T_i (HJD 2,449,000+)	T_f (HJD 2,449,000+)
103.24414.4271	18 13 21.75	−27 48 36.69	67.285	2393.005
105.21419.3841	18 06 11.57	−28 07 46.30	61.265	2450.957
109.20247.4850	18 03 24.67	−28 17 23.52	46.282	2450.971
114.19973.4162	18 02 51.70	−29 15 13.93	50.280	2450.878
114.20882.3609	18 05 08.58	−29 16 52.04	50.280	2450.879
118.18790.4766	18 00 12.02	−30 05 15.91	54.278	2445.983
119.20610.3305	18 04 34.47	−30 05 11.61	46.277	2472.906
121.22812.3138	18 09 36.02	−30 37 20.43	61.293	2393.003
128.21149.4807	18 05 32.38	−28 50 57.28	66.263	2453.888
148.26330.809	18 17 54.78	−30 03 53.95	97.287	2393.039
148.26586.2310	18 18 24.33	−30 23 37.14	97.287	2393.039
153.27488.3450	18 20 36.33	−30 54 01.50	429.290	2393.075
155.26570.1617	18 18 30.39	−31 26 07.97	97.310	2393.056
156.28129.900	18 22 06.93	−31 27 42.42	429.279	2393.081
157.26295.1160	18 17 50.40	−32 26 41.80	429.295	2393.059
158.27182.2976	18 19 48.99	−25 18 37.79	96.283	2393.034
159.26266.4219	18 17 39.73	−25 40 24.38	95.308	2392.981
161.24700.3300	18 13 51.50	−26 07 35.27	66.303	2392.983
161.25086.2455	18 14 42.54	−26 22 10.33	66.303	2392.983
167.23785.873	18 11 51.02	−26 26 48.64	65.300	2392.997
173.33003.1207	18 33 17.91	−27 13 08.59	426.284	2364.184
176.19349.6100	18 01 15.62	−27 27 47.22	788.267	2392.961
177.25623.3642	18 15 57.73	−25 15 33.16	789.268	2462.924
178.24048.3166	18 12 20.91	−26 14 02.97	787.297	2463.900
179.21843.4365	18 07 17.88	−25 52 56.96	788.247	2462.937
179.22489.4690	18 08 50.26	−26 10 57.42	788.247	2462.937
301.46282.3402	18 32 53.26	−13 30 34.40	789.258	2450.910
302.45426.2942	18 31 29.12	−14 31 11.31	789.261	2453.921
302.45594.2132	18 31 52.17	−14 33 44.65	789.261	2453.921
303.44749.3841	18 30 22.34	−14 53 51.97	789.264	2453.932
305.36409.813	18 16 48.52	−22 03 14.34	787.274	2392.978
306.35724.3178	18 15 41.56	−22 56 22.85	787.277	2392.975
306.35887.1487	18 15 47.28	−23 17 29.73	787.277	2392.975
306.35892.4598	18 15 46.93	−22 58 47.87	787.277	2392.975
306.36560.3266	18 17 00.49	−23 13 02.88	787.277	2392.975
311.37055.2070	18 17 54.72	−23 50 25.73	787.294	2453.943
311.37389.3983	18 18 25.94	−23 55 30.81	787.294	2453.943
311.37730.3783	18 18 49.85	−23 36 38.23	787.294	2453.943

Note.—Units of right ascension are hours, minutes, and seconds, and units of declination are degrees, arcminutes, and arcseconds.

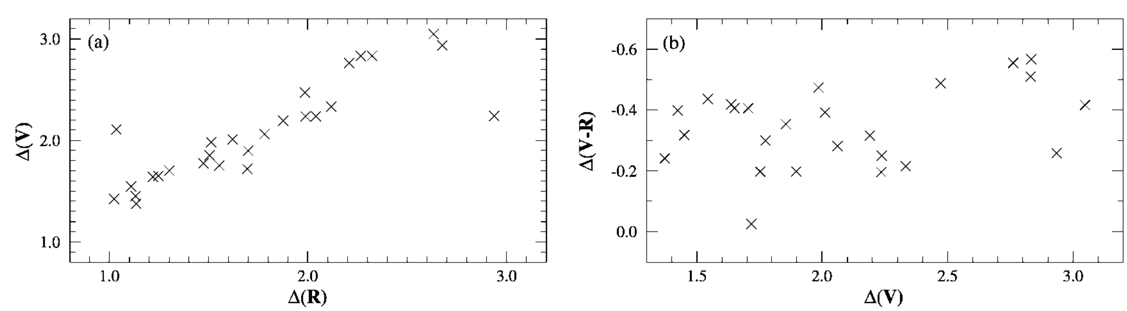

Fig. 2.— (*a*) Maximum outburst amplitude in MACHO *V* and *R* bands for dwarf nova grade-A candidates. (*b*) Color index variation between the outburst maximum and quiescence for grade-A dwarf nova candidates. The color amplitude is shown as a function of outburst maximum amplitude in the *V* band.

TABLE 3
SU UMa Dwarf Nova Candidates

MACHO Identification	$\Delta(V)$[c]	Length[d]	N[e]	Recurrence[f]
101.20784.2398	~2	~15–20	13	~100–120
104.20129.2662[a]	~3.2	~15–20	>9	~150–200
113.19455.4698	>3	>20	>4	?
118.19052.2032	~2.7	~20–30	>6	>200
159.26395.2298	~2	~20–25	>3	?
17.2832.2606[b]	>2.5	~50–60	>7	>200

[a] Known object ≡ V5099 Sgr.
[b] See comments in the text.
[c] Estimated superoutburst amplitude.
[d] Estimated superoutburst length (days).
[e] Observed number of superoutbursts events.
[f] Estimated superoutburst recurrence time (days).

for complete dwarf novae cycles is still sparse in the literature. However, it is clear that most dwarf novae at maximum are redder in $U-B$ and possibly slightly bluer in $B-V$ when compared to quiescence (Warner 1995). Our sample of dwarf novae shows significantly bluer $V-R$ color indices at maximum, with Δmag ranging from −0.2 to −0.5 mag, while no clear trend in outburst amplitude could be found. The bluer $V-R$ indices at maximum confirm our first selection method for the outburst data points. The MACHO *V* filter runs from 450 to 630 nm, being slightly bluer than the standard *V* band. The *R* filter covers from 630 to 760 nm, i.e., slightly redder than the standard Kron-Cousins *R* band (Alcock et al. 1999). These color variations may suggest that the maximum rise of the continuum is less pronounced in the red and also in the UV.

3.2. Identification of SU UMa Dwarf Nova Candidates

Considering observations of dwarf novae with the same quiescent magnitudes, the identification of members of the SU UMa subclass is favored by the longer duration and large amplitude of the superoutbursts, as well by the more frequent occurrence of normal eruptions. By inspecting the light curves shown in Figure 1, we can distinguish some dwarf novae with eruptive characteristics suggesting a SU UMa subtype. The strongest candidates found in our sample include the objects 101.20784.2398, 104.20129.2662, 113.19455.4698, 118.19052.2032, 159.26395.2298, and 17.2832.2606 (this last system shows a very long decay time, making its classification as a CV uncertain). Some photometric properties of their superoutburst events are shown in Table 3, which gives the estimated values of the number of the observed superoutbursts, the amplitude and length of the eruption, as well the probable recurrence time interval. We would like to mention that the presented values might not always reflect the real ones, since there are "gaps" in time coverage, the frequency of measurements is not uniform, and the weakness of the objects make the task of estimating such parameters difficult.

In a previous search using OGLE data (Paper I), two new SU UMa were identified, totalling seven new candidates in such surveys (one of them, 104.20129.2662, is already known as V5099 Sgr). This represents 6% of the sample of confirmed SU UMa members (~120 objects; Downes et al. 2003). Four less-probable candidates for this subclass were also found in the selected MACHO data. The correct classification of the later systems will only be possible with more observations.

4. SUMMARY

We have carried out a survey of the MACHO light-curve data from the Magellanic Clouds and Galactic bulge in order to find new CVs. The objects (about 3720) were selected using the amplitude of brightness variation and color indices as criteria. The individual light curves were visually inspected for typical CV outbursts, providing 28 new dwarf nova candidates. In a previous search using the OGLE-II database (Paper I), we found 33 new dwarf nova candidates. The number of dwarf novae found in these two surveys (61 members) is roughly 15% of the known sample of dwarf novae in the Galaxy, proving the potential contribution from deeper systematic photometric surveys to the CV population studies. Most of the dwarf novae systems found are probably members of the Galactic disk. Synoptic monitoring of the Galactic bulge with better time resolution may not only find new CVs, but may also estimate many orbital periods by observing eclipses and orbital modulations.

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