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ARE MICROLENSING EVENTS CONTAMINATED BY DWARF NOVA ERUPTIONS?

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ABSTRACT

We present a simple test that can distinguish between the light curves of candidate microlensing events and those of some dwarf nova eruptions that have a similar morphology. We find that the distribution of the amplitudes versus durations of ordinary dwarf nova eruptions is significantly different from that exhibited by the main body of 53 microlensing candidates discovered by the MACHO and OGLE collaborations. The most serious source of potential contamination may be due to old novae that exhibit dwarf nova outbursts. By adopting the current estimates for the space density of such old novae, we find that a significant fraction of the microlensing candidates could be cataclysmic variables.

Subject headings: binaries: close — gravitational lensing — novae, cataclysmic variables

1. INTRODUCTION

Inspired by the seminal paper of Paczyński (1986), a number of long-term projects were started to search for microlensing events toward the LMC (Alcock et al. 1993; Aubourg et al. 1993) and toward the Galactic bulge (Alcock et al. 1995; Udalski et al. 1994). Because of the fact that the line of sight to the Galactic bulge lies close to the Galactic plane, a considerable number of lensing events due to low-luminosity disk stars (Griest et al. 1991; Paczyński 1991) are presently available (Bennett et al. 1995). This number significantly exceeds the expected one (e.g., Gould 1995 and references therein). Thus, it is important to examine the possibility that the number of detections has been artificially inflated by some source of contamination (Ansari et al. 1995). Among the known classes of variable stars, the best candidates for mimicking microlensing events are cataclysmic variables (CVs). In particular, it has been recently pointed out (Della Valle 1994; Mao 1995) that some light curves of known dwarf novae (DNs) and of DN eruptions observed in old novae could mimic the photometric signatures of MACHOs. As an example for this possibility, we show in Figure 1 (*filled circles*) a DN-like eruption exhibited by V841 Oph (Nova Oph 1848) during quiescence. The solid line in the figure represents a microlensing event corresponding to an impact parameter of 0.55. These DN-like eruptions can be separated by long periods of quiescence ($\approx 150^{d}$), and therefore they can be (in principle at least) misidentified with microlensing events. A complementary valuable tool that can ascertain whether a candidate event is a CV rather than a MACHO is that of obtaining spectrograms of the sources after (Della Valle 1994; Beaulieu et al. 1995) or, better yet, during the event (Benetti, Pasquini, & West 1995). However, this is not always feasible, because of telescope scheduling problems.

In the present Letter, we would like first to estimate the expected number of DN events in the MACHO experiment. Unfortunately, the space density of DNs is rather poorly known (see, e.g., Warner 1995 for a review of the issue) because of incompleteness of surveys and selection effects. Estimates range from about $N_{DN} = 3 \times 10^{-7}$ pc^{-3} (Patterson 1984) to $N_{DN} = 10^{-4}$ pc^{-3} (Shara et al. 1993). Probably the most reliable value at present comes from identification of *Einstein* sources, and it gives $N_{DN} = 2–3 \times 10^{-5}$ pc^{-3} (Hertz et al. 1990). The space density of novae is also very uncertain, with quoted values in the range $N_{CN} = 1.5 \times 10^{-7}$ pc^{-3} to $N_{CN} = 3 \times 10^{-5}$ pc^{-3} (e.g., Duerbeck 1984; Downes 1986; Della Valle & Duerbeck 1993). An inspection of the light curves of the small sample of old novae given in Table 1 (which gives the duration of the luminosity increase, Δt, and the brightness ratio between the peak and quiescence, A) finds, on the basis of a rather sparse monitoring at quiescence, that at least two objects (i.e., V841 Oph and Q Cyg 1872) show dwarf nova eruptions with symmetric light curves. On the other hand, the light curves of ordinary DNs show both types of maxima (symmetric and asymmetric) in an unpredictable way (Petit 1987). A clear example of this behavior is shown by VY Aqr. A collection of observations of the six outbursts exhibited by this system between 1983 and 1990 (Della Valle & Augusteijn 1990) shows that two of them were symmetric and short (duration about 5 days). Taking these figures at face value, one could infer that about 30% of the outbursts exhibited by VY Aqr are symmetric. However, we note that a 5 day outburst can be easily missed, and therefore, the fraction of symmetric outbursts could be higher. Consequently, 30% may represent only a lower limit. We therefore estimate that about 20%–40% of the outbursts undergone by old novae and dwarf novae are symmetric. Thus, we obtain a space density for such objects between $N_{sym} = 3 \times 10^{-8}$ and 1.2×10^{-5} pc^{-3}.

Old novae, with the exception of only a handful of objects like V1500 Cyg and CP Pup 1942, have an absolute magnitude at minimum spanning the range between $V = +1$ and $+5$ (Della Valle & Duerbeck 1993, their Figs. 2 and 3). At 8 kpc, this range results in an interval of apparent magnitudes of +15.5 to +19.5. The absorption along the Galactic plane is normally high, about 0.8 mag per kpc (Allen 1978), but in the direction of Baade's window, in which the MACHO searches are mainly carried out, it might be considerably lower, of the order of $A_V = 1.5$ (Paczyński et al. 1994). After considering the fact that the limiting magnitude of the OGLE and MACHO surveys is $V = 21.5–22$ (Paczyński et al. 1994; Alcock et al. 1995), we are in a position to estimate upper and lower limits to the number of expected detections of DN events in the MACHO survey. The patrolled field by the MACHO collaboration is 43×43 arcmin^2; at 8 kpc this projected area gives a

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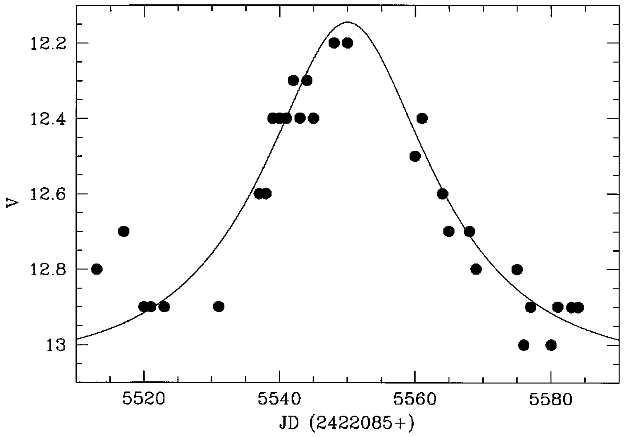

FIG. 1.—A DN-like eruption exhibited by V841 Oph (Nova Oph 1848) during quiescence. The solid line represent a microlensing event corresponding to an impact parameter of 0.55.

volume, within the solid angle, of 2.7×10^7 pc^3. If we assume that most old novae are still observable at a distance of 8 kpc, we obtain from the spatial density of old novae undergoing symmetric outbursts an upper limit of 1–240 objects. If we make the conservative assumption that an absorption of 0.8 mag kpc^{-1} dims the brightness of old novae along the line of sight toward the Galactic bulge, we find that only old novae within 5 kpc from the Sun can contaminate the MACHO surveys, at a limiting magnitude $V = 21.5$. In this case, the number of old novae within the solid angle of the surveyed field is reduced to 0.3–60. On the average, DNs with relatively infrequent, large-amplitude eruptions (which are relevant for the present study) have at maximum a brightness that is comparable to that of old novae (Warner 1995).

By monitoring 4.3×10^5 stars toward the Galactic bulge, the MACHO team was able to detect four microlensing events (Alcock et al. 1995). In view of the figures obtained above, we cannot exclude a priori the possibility that the light curves of some MACHO events could have been misidentified with those of some CVs.

2. THE AMPLITUDE VERSUS DURATION FOR MICROLENSING EVENTS AND DWARF NOVAE

We propose to investigate the intrinsic nature of MACHO and DN events by studying the distribution of the duration of the luminosity increase against the amplitude of the brightening. The physical basis for such an approach lies in the fact that DN eruptions are caused by an accretion disk instability, and thus the amplitude and duration are determined by the global energetics and the nature of the accretion process (see, e.g., review by Livio 1993), whereas the timescales of the MACHOs and their amplification peaks ought to be uncorrelated (Paczyński 1986).

The analysis presented here is based on the candidate microlensing events discovered toward the Galactic bulge by the MACHO and OGLE teams (Bennet et al. 1995; Udalski et al. 1994). The data are presented in Table 2, which gives the identification number (col. [1]), the duration (col. [2]), and the amplification (col. [3]). These data are presented in Figure 2 by the filled circles (MACHO) and filled squares (OGLE). For

TABLE 1

DATA FOR OLD NOVAE

Nova	log Δt (days)	A
V841 Oph	1.71	2.1
Q Cyg..............	1.78	1.9
IV Cep.............	2.44	2.3
V603 Aql	1.86	1.5
V446 Her...........	1.85	6.3
HR Lyr	2.03	2.5
DN Gem............	1.97	1.9
DI Lac..............	1.83	1.3

TABLE 2

DATA FOR MACHOS

MACHO (1)	log Δt (days) (2)	A (3)
121026...........	1.471	4.841
108017...........	1.694	1.76
106024...........	1.63	2.9
104037...........	1.648	2.068
111029...........	1.045	2.325
111039...........	2.093	2.517
128027...........	1.215	7.115
128055...........	1.487	2.184
159043...........	1.341	1.61
121040...........	1.215	3.233
159053...........	1.824	8.571
162006...........	1.34	2.383
162032...........	1.56	2.093
OGLE 1..........	1.71	2.7
OGLE 2..........	1.95	6.5
OGLE 3..........	1.03	1.26
OGLE 4..........	1.45	5.8
OGLE 5..........	1.39	11.5
OGLE 6..........	1.23	6.9
OGLE 7..........	2.2	9.5
OGLE 8..........	2.0	1.9
OGLE 9..........	1.54	1.7
OGLE 10	2.09	1.1
OGLE 11	1.38	1.3
OGLE 12	1.62	2.0

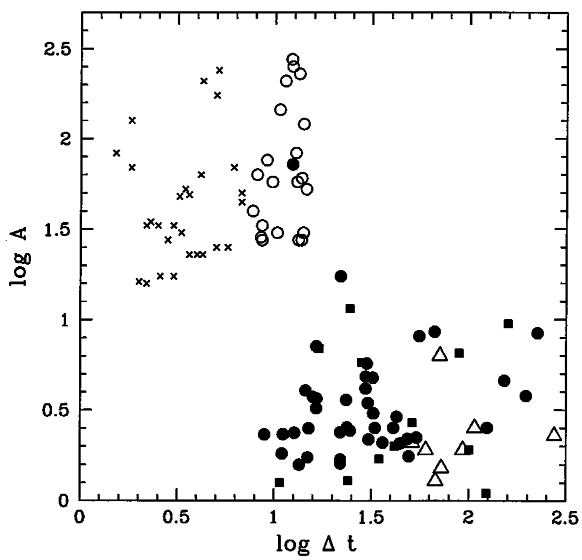

FIG. 2.—Distribution of MACHO (*filled circles*) and OGLE (*filled squares*) events in the amplitude-duration plane. Also shown are long-outburst (*open circles*) and short- and faint-outburst (*crosses*) DNs (see text) and DN eruptions exhibited by old nova systems (*open triangles*).

the data on DNs, we used the compilation by Petit (1987). DNs undergo three major types of outburst: long, short, and faint (see also Warner 1995). Petit (1987) has shown that if $E_{\rm long}$ is the average energy emitted (in the optical range) in long outbursts and $E_{\rm short}$ is the average energy in short outbursts, then $E_{\rm short}/E_{\rm long} = 0.35$. Similarly, the ratio between the average energy in a long outburst and a faint one is $E_{\rm faint}/E_{\rm long} = 0.13$. Concerning the durations of the outbursts, we obtain from Petit's (1987) data the following average ratios: $D_{\rm short}/D_{\rm long} = 0.42$ and $D_{\rm faint}/D_{\rm long} = 0.22$.

The data on both the amplitude and the duration is known for all the long outbursts; this is shown in Figure 2 by the open circles. For the short and faint outbursts, we have used for the amplitudes the above ratios. The data for the short and faint outbursts are presented in Figure 2 by the crosses. As is clearly seen in the figure, the microlensing candidates generally occupy a very different region of the diagram than that of the normal DN events. Notable exceptions are the two most spectacular events, 101046 and 108054. A different picture emerges from the DN eruptions exhibited by old nova systems (e.g., V841 Oph [Nova Oph 1848] and Q Cyg [Nova Cyg 1872]). These systems occupy a similar region in the diagram (Fig. 2, *open triangles*) as the candidate microlensing events.

The best-fit regression on the MACHO data points (without the two large amplitude candidates) shows that the amplitude of the MACHOs is not significantly correlated with the duration (correlation index $r = 0.26$, significance $\approx 90\%$). The slight apparent trend of amplitude with duration is probably the result of an observational bias, since the discovery of short and small amplification events is favored over the small amplitude and long events when the length of the observational run (about $180^{\rm d}$) becomes comparable to the timescale of the candidate microlensing event (about $200^{\rm d}$).

3. DISCUSSION AND CONCLUSIONS

We find that the distribution in the amplitude-duration plane of the brightenings for MACHOs and for normal dwarf novae are significantly different. While the distribution of neither class shows a statistically significant correlation between the amplitude and duration (see also Warner 1995), the two classes of objects occupy very different regions in the A-Δt plane. The situation is different, however, for DN-type eruptions exhibited by old nova systems. In particular, such events can contaminate small-amplitude microlensing candidates with durations longer than 40–50 days. It should be noted that one of the criteria adopted for identifying microlensing events is the achromaticity of the brightening. While no data are available on the colors of the DN eruptions observed in old novae, it is known that the outbursts of normal DNs can be achromatic (e.g., case B type; Warner 1995) to within the existing photometric accuracy. These results enable us to draw the following conclusions: (1) The bulk of the microlensing candidates discovered toward the Galactic bulge is not significantly contaminated by normal dwarf novae; if we apply the Kukarkin-Parenago relationship (Warner 1995) to the largest amplitude objects, namely 101046 and 108054, we find that the average interval between two outbursts, if these were normal DN eruptions, is not compatible with the criteria adopted by the teams to select the candidates (a single event in $\approx$0.5 yr). Nevertheless, an accurate spectroscopic investigation of these two events is highly desirable. (2) The most serious potential source of contamination for MACHO events could be due to DN-type eruptions of old nova systems. The frequency of these events is such (e.g., V841 Oph) that they would have passed the selection criteria of MACHO and OGLE teams. Given the current uncertainties in the space density of CVs, it is difficult to estimate reliably the contaminated fraction; however, the usually quoted values for the space density of CVs indicate that the contamination could be significant.

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