Light Curve Analysis of Be Star Candidates in the Small Magellanic Cloud

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Abstract. The recent discovery, based on a search of public OGLE data, of Be star candidates in the Small Magellanic Cloud showing spectacular photometric variations (Mennickent et al. 2002), has motivated further analysis of their light curves. Here we report the results of a statistical study of the light curves of Type-1, Type-2 and Type-3 stars. Type-3 stars show a bimodal period distribution, with a main, broad peak, between 20 and 130 days, and a narrower, secondary peak, between 140 and 210 days. We also find that, among Type-3 stars, the maximum amplitude of oscillation correlates with the system luminosity, in the sense that only low luminosity systems show large amplitude oscillations. In general, the amplitude of these oscillations tends to increase with the photometric period. A parametric study shows no correlation between the amplitude, duration and asymmetry of Type-1 outbursts, and amplitude of Type-2 jumps, with the available stellar photometric parameters.

1. Introduction

Detailed studies of Be stars in the Small Magellanic Cloud (SMC) have been performed only in recent years, being especially confined to open clusters like NGC 330 (e.g. Keller, Wood and Bessell 1999). These studies show the importance of studying Be stars in the low metallicity environment of the SMC since they serve as probes to test for the mechanisms of disk formation and of global disk oscillations (Baade et al. 2001, Hummel et al. 1999).

Recently, Mennickent et al. (2002, hereafter M02), based on a search of public OGLE data, reported the discovery of about 1000 Be star candidates in the SMC showing spectacular light curve variations. M02 classified their sample in Type-1 stars (showing outbursts), Type-2 stars (showing sudden luminosity jumps), Type-3 stars (showing periodic or near-periodic variations) and Type-4 stars (showing similar light curves that Galactic Be stars). M02 present examples of light curves for each one of these groups, giving some basic statistical information about colours and periodicities. Here we pursue this analysis, with a more detailed statistical study of the photometric properties of each group.

2. Results
2.1. Type-1 Stars

We have investigated the (I-band) outburst properties of a sample of these stars (the first 40 stars in the RA ordered list, corresponding to 30% of the total), measuring the amplitude $A$, duration $\Delta T$ and asymmetry $\delta$, of all detected outbursts, amounting to 105, according to the definitions shown in Fig. 1. The $A$ distribution reveals a strong, broad peak with a maximum around 0.1 mag (Fig. 2). The $\Delta T$ distribution shows a maximum around 25 d, with a steep decrease toward shorter periods and a much flatter decrease towards longer periods. The $\delta$ distribution reveals that about 30% of the outbursts have $\delta < 1$, the rest shows rapid rises and slower declines.

2.2. Type-2 Stars

We measured the amplitude of the photometric jumps in the I-band for these stars. Few objects showed two or even three (generally low amplitude) jumps during the observing period, the more prominent jump was used for the statistics in these cases. The histogram of amplitudes in Fig. 3 shows a prominent concentration around 0.15–0.25 mag. There is no correlation between the jump amplitude and the stellar magnitude, $B - V$ or $V - I$ color.

2.3. Type-3 Stars

Some information about the variability of these stars is already given in M02. Here we focus on the amplitudes of these variables, the morphology of their I-band light curves and the overall period distribution. Accordingly to Table-5 of M02, Type-3 stars could be classified as follows: those showing a possible period change (2 cases), those showing eclipses (5 cases), those whose periodicity appears after removing a long-term tendency (17 cases), and those showing rather clear oscillations, although usually of variable amplitude (54 cases). We fit the phase curves of the two later groups (obtained using residuals when necessary) with a simple sine function, obtaining the amplitudes for the oscillations. The period distribution for Type-3 stars shown in Fig. 4. suggests the existence of a bimodal distribution. We observe a broad concentration of stars with periods between 20 and 130 days and a narrower concentration with periods between 140 and 210 days. There is no privileged location for the different Type-3 classes in the above diagram (neither in the diagrams shown later in this section). Both bright and faint stars are found inside the two peaks of the period distribution. Surprisingly, we find that all stars in the secondary peak show rather “clean” light curves; for these stars it was not necessary to remove a a long-term trend in order to find the period, as occurred for 17 Type-3 stars (M02). Some phase curves of Type-3 stars with periods in the range of 140 to 210 days are shown in Fig. 5. Another interesting result is that large amplitude oscillations are only observed in low luminosity systems (Fig. 6). On the other hand, the amplitude—period diagram (Fig. 6) shows that, in general, the oscillation amplitude tends to increase with the period. It is worthy to mention that inclination effects are not included in Fig. 7, and they could be responsible for the large scatter shown by the data.
3. Discussion

The first impression, after the visual inspection of Type-1 light curves, was that the outbursts were divided in hump-like and sharp outbursts. However, a clear separation between these groups is not confirmed by the distributions of the parameters $A$, $\Delta T$ and $\delta$, which instead suggest smooth transitions between one outburst type and the other. The above results do not help to discriminate between the possible hypotheses for these outbursts raised by M02, viz. thermal instabilities in circumstellar discs or accretion by an unseen white dwarf.

The discovery of a bimodal period distribution in Type-3 stars is surprising and deserves further study. At present, we do not have an explanation for this finding, but we expect to make a deeper analysis of these stars incorporating spectroscopic data at the end of this year.

The fact that only Type-3 systems with faint absolute magnitude show large amplitude oscillations could be the clue to understand the underlying cause of this phenomenon. M02 suggested that Type-3 variability could be due to some kind of oscillation in a circumstellar envelope. More massive envelopes could trigger larger amplitude oscillations. Perhaps low luminosity stars can host massive envelopes, whereas the higher radiation pressure of higher luminosity stars conspires against the formation and maintenance of massive envelopes. This could explain the absence of large amplitude variations in high luminosity systems.

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4. References

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Figure Captions

Fig.1: Definition of amplitude ($A$), duration ($\Delta T$) and asymmetry ($\delta$) for Type-1 star outbursts.
Fig.2: Distributions for the parameters $A$, $\Delta T$ and $\delta$.
Fig.3: The distribution of amplitudes for Type-2 star jumps.
Fig.4: The period histogram for Type-3 stars. Note the bimodal distribution.
Fig.5: Examples of phase curves for Type-3 stars with periods between 140 and 210 days.
Fig.6: The amplitude–magnitude diagram for Type-3 stars. Error bars are plotted when available.
Fig.7: The amplitude–period diagram for Type-3 stars.
$A = y_4 - y_2$

$\Delta T = x_3 - x_1$

$\delta = (x_3 - x_2)/(x_2 - x_1)$
