The short-period end of the contact binary period distribution based on the All-Sky Automated Survey

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ABSTRACT

The search volume-corrected period distribution of contact binaries of the W UMa type appears to reflect primarily the constant number ratio of \( \simeq 1/500 \) to the number of stars along the main sequence; there exist no evidence for angular momentum evolution. The maximum in contact binary numbers is located at shorter periods than estimated before, \( P \simeq 0.27 \) d. The drop in numbers towards the cut-off at \( P \simeq 0.215–0.22 \) d still suffers from the small number statistics while the cut-off itself remains unexplained. Only one out of seven short-period All-Sky Automated Survey variables with \( P < 0.22 \) d have been retained in the sample considered here within \( 8 < V < 13 \); this short-period field-sky record holder at \( P = 0.2178 \) d should be studied.

Key words: binaries: eclipsing – binaries: general – stars: evolution.

1 INTRODUCTION

For main-sequence (MS) binary stars, the orbital period (\( P \)) distribution tells us primarily about the binary formation processes and the angular momentum (\( H \)) distribution among the pre-stellar fragments. These processes appear to produce a featureless (almost) scale-free distribution \( n(P)dP \propto (1/P)dP \) with a very mild maximum at \( \simeq 180 \) yr (Duquennoy & Mayor 1991, hereafter DM91). The dominance of the underlying logarithmic distribution was particularly stressed by Heacox (2000); in fact, sometimes in theoretical simulations, a flat distribution \( n(\log P)d\log P = \) constant is assumed.

Contact binaries of the W UMa type do not obey the flat logarithmic period distribution: not only a very sharp edge to the distribution appears at about \( 0.215–0.22 \) d, but also a strong maximum in the period distribution is present very close to the cut-off at very short periods. This is illustrated in Fig. 1 showing data for the best observed 352 short-period (\( P < 1 \) d) binary systems from the catalogue of Pribulla, Kreiner & Tremko (2003). The sharp edge is particularly well defined in the \( n(P)dP \) distribution (left-hand panel), but – in view of what has been said above – a better way to analyse the numbers may be to use \( \log P \) units (right-hand panel). Although the short-period cut-off is then less sharp, a well-defined maximum is still there. However, the catalogue data may be affected by several selection effects. First of all, the very steep period – luminosity relation (see below) results in a strong dependence of the search volume on the period. In addition, random discovery conditions and preferential attention of variable star observers produce additional, totally uncharacterized selection effects. The period range of 6–12 h, exactly the region of interest here, is particularly prone to various subjective preferences.

An attempt was made by Rucinski (1992) to explain the period cut-off as a ‘full convection limit’ for low-mass stars. Although this gave some insight into the physics of the least massive contact binaries, it failed to explain the existence of the cut-off. Because the W UMa type contact binaries are very magnetically active, an explanation for the cut-off may be related to their activity, but it is not clear how. Following the pioneering work of Vilhu (1982) and several observational evidences of ‘saturated’ magnetic (coronal, chromospheric) activity at very short rotation periods, Stepień (2006) attempted to explain the period cut-off by the magnetic-wind driven angular momentum loss (AML), operating in such a saturated regime. He found that at the shortest periods, the AML rate depends primarily on the binary moment of inertia (which can vary in contact binaries due to possibility of the mass transfer between components). This results in a progressive decay of the AML rate with the shortening of the period so that the period evolution takes progressively longer time. The period cut-off would be then due to the finite age of the binary population of several Gyr. Note that the tendency of \( \Delta H/H \simeq \) constant would produce a logarithmically flat distribution of periods, \( \Delta P/P \simeq \) constant, while a decreasing \( \Delta H/H \) would lead to a pile-up at short periods.

In this paper, we analyse the shape of the period distribution close to the period cut-off. To avoid the most obvious selection effects, the uniform and well-characterized All-Sky Automated Survey (ASAS) sample (Pojmański & Maciejewski 2005; Paczyński et al. 2006) is used, the same as in Rucinski (2006, hereafter Paper I ) where it was used to estimate the local fractional number density of W UMa systems at \( \simeq 1/500 \) of the FGK spectral type dwarfs. The same
approximately (3 \pm 1) times (Paper I).

The ASAS photometric data are in only one band. For that reason, the \( M_V = M_V(\log P, B - V) \) calibration of Rucinski & Duerbeck (1997) could not be used for distance estimates. This forced utilization of a subsample of 3374 shortest period binaries where a simplified period – absolute magnitude calibration period could be taken into account. The period dependence in the calibration is very steep, \( M_V = -1.5 - 12 \times \log P \); it certainly does not apply to \( \log P > -0.25 \) (or \( P > 0.562 \) d) where the luminosity is seen to depend on both the period and the colour index.

The selection of the ASAS sample used in Paper I was not altered in any way except for a particular attention to existence of contact binaries at \( P < 0.22 \) d. The online version of the ASAS database was carefully scrutinized (Appendix A) and – indeed – from seven systems previously included in Paper I, only one has remained as a genuine contact binary (083128+1953.1, \( P = 0.217 811 \) d); this is currently the shortest period record holder among Galactic field W UMa binaries.

### Table 1. The volume-corrected period distribution \( D_P \) derived from the ASAS sample and expressed as number of contact systems per interval \( \Delta \log P(d) = 0.025 \) in units of \( 10^{-15} \) stars \( \text{pc}^{-3} \). \( n \) is the number of binaries per interval; it can be used to derive the Poisson uncertainty of \( D_P \). The first column gives the low edge of each bin.

| \( \log P \) | \( r_1 \) (pc) | \( r_2 \) (pc) | \( n \) | \( D_P \) |
|-------------|-------------|-------------|-----|------|
| -0.675      | 21.88       | 190.55      | 3   | 0.423|
| -0.650      | 25.12       | 218.77      | 8   | 0.746|
| -0.625      | 28.84       | 251.19      | 12  | 0.739|
| -0.600      | 33.11       | 288.40      | 38  | 1.546|
| -0.575      | 38.02       | 331.13      | 74  | 1.989|
| -0.550      | 43.65       | 380.19      | 92  | 1.634|
| -0.525      | 50.12       | 436.52      | 130 | 1.525|
| -0.500      | 57.54       | 501.19      | 155 | 1.202|
| -0.475      | 66.07       | 575.44      | 233 | 1.193|
| -0.450      | 75.86       | 660.69      | 260 | 0.880|
| -0.425      | 87.10       | 758.58      | 279 | 0.624|
| -0.400      | 100.00      | 870.96      | 312 | 0.461|
| -0.375      | 114.82      | 1000.00     | 247 | 0.241|
| -0.350      | 131.83      | 1148.15     | 234 | 0.151|
| -0.325      | 151.36      | 1318.26     | 184 | 0.078|
| -0.300      | 173.78      | 1513.56     | 161 | 0.045|
| -0.275      | 199.53      | 1737.80     | 167 | 0.031|

The selection of the ASAS sample in Paper I was utilized there so that the reader is referred to previous paper for details.

## 2 THE ASAS SAMPLE

The material for this study is the ASAS sample discussed in Paper I, consisting of 5381 binaries and apparently uniform in terms of detection selection effects within the range \( 8 < V < 13 \). Although many small amplitude binaries are included in the sample, down to amplitudes of \( \approx 0.05 \) mag, the amplitude detection threshold for completeness is relatively high for this sample at about 0.4 mag, necessitating a correction for missed low-amplitude binaries of approximately (3 \pm 1) times (Paper I).

The ASAS photometric data are in only one band. For that reason, the \( M_V = M_V(\log P, B - V) \) calibration of Rucinski & Duerbeck (1997) could not be used for distance estimates. This forced utilization of a subsample of 3374 shortest period binaries where a simplified period – absolute magnitude calibration appears to be valid (Paper I). This way the dominant selection effect of the search volume being directly dependent on the binary period could be taken into account. The period dependence in the calibration is very steep, \( M_V = -1.5 - 12 \times \log P \); it certainly does not apply to \( \log P > -0.25 \) (or \( P > 0.562 \) d) where the luminosity is seen to depend on both the period and the colour index.

The selection of the ASAS sample used in Paper I was not altered in any way except for a particular attention to existence of contact binaries at \( P < 0.22 \) d. The online version of the ASAS database was carefully scrutinized (Appendix A) and – indeed – from seven systems previously included in Paper I, only one has remained as a genuine contact binary (083128+1953.1, \( P = 0.217 811 \) d); this is currently the shortest period record holder among Galactic field W UMa binaries.

## 3 THE MAIN RESULTS

In Paper I, the period distribution for all contact binaries of the ASAS was shown (fig. 3 in that paper). It contained the strong period–distance selection effect which we now attempt to eliminate. For each binary of known \( P \) and \( V \), the simplified calibration \( M_V = -1.5 - 12 \times \log P \) was used to derive \( M_V \) and then the distance \( r \) (in pc) from \( V - M_V = 5 \log r - 5 \). Then, the numbers of binaries, \( n \), in intervals of \( \Delta \log P \) were counted within the limits of \( 8 < V < 13 \) corresponding to the respective distance limits \( r_1 \) and \( r_2 \) (Table 1). By dividing the numbers \( n \) by the volume of the corresponding shells defined by \( r_1 \) and \( r_2 \), and taking into account the sky coverage of the ASAS sample (73.5 per cent) and the amplitude-related undercounting by a factor of 3 \( \times \), we could derive the volume-corrected period distribution \( D_P \). This quantity was called a ‘period function’ in the analysis of the OGLE sample in Rucinski (1998), see fig. 3 there. \( D_P \) is expressed in numbers of stars per counting interval \( \Delta \log P \) and per unit of volume in \( \text{pc}^3 \). This is basically the same approach at that used in Paper I for derivation of the luminosity function. Even fig. 4 of Paper I can be of interest here if its horizontal axis with \( M_V \) units is converted into the \( \log P \) units (note e.g. the vertical strip of missing systems with \( P \approx 0.5 \) d at \( M_V \approx +2.1 \), an effect most likely caused by the sparse and somewhat regular data taking of typically two to five observations per night and by associated difficulties with detection of periods commensurable with one day). The results for the counting interval of \( \Delta \log P(d) = 0.025 \) are shown in Fig. 2.

The period distribution in Fig. 2 shows a very strong peak at about \( \log P \approx -0.57 \) or \( 0.27 \) d. Thus, the maximum appears at periods shorter than for the catalogue data (Fig. 1) which directly shows the systematic effects of the sampling volume being dependent on the period. One also sees a drop in numbers shortwards of the maximum, but the Poisson uncertainty there is large. Even with the search limits extending beyond \( V = 13 \), the ASAS has small number of systems with \( P \leq 0.27 \) d. An artificial gap at 0.25 d, similar to that definitely present at 0.5 d, may additionally depress the distribution at very short periods.

## 4 COMPARISON WITH THE DETACHED MAIN-SEQUENCE BINARIES

The volume-corrected period distribution for contact binaries derived above, \( D_P \), can be compared with an extension of the MS period distribution for detached binary stars of DM91. This involves a rather extensive and perhaps risky extrapolation into the domain of \( P < 1 \) d where the DM91 survey contains only one object. The MS binary distribution has the shape \( D_{MS} \propto \exp[-(\log P - \log P_0)^2/(2 \sigma_P^2)] \) with \( \log P_0 = 4.8 \) and \( \sigma_P = 2.3 \), where the period unit is one day. After normalization of this distribution to the
integral of unity, the distribution was multiplied by 0.53 to represent the binary fraction among MS stars (DM91). Such a normalized distribution must be further adjusted for a direct comparison with the contact binary distribution. Integration of $D_P$ (as in Fig. 2) over the whole range of periods, after accounting for the contact binary occurrence fraction of $1/500$ gives the total number density of the MS stars in the ASAS volume considered here of $6750$ stars/(10$^6$ pc$^3$); this was the multiplier used to derive the line shown in Fig. 2 to represent the expected MS binary frequency. An entirely independent estimate of the multiplier based on the local luminosity function (Wielen, Jahreiss & Krüger 1983) gives 9350 stars/(10$^6$ pc$^3$). The $\pm1/3$ discrepancy in these numbers is a fair representation of the uncertainty inherent here.

As discussed in Section 1, the expected MS period distribution $D_{ASAS}$, as shown in Fig. 2, is almost flat within the contact binary range. It is drastically different from what we see for contact binaries. Apparently, contact binaries are very common and dominate in numbers in the period range of $0.25 < P < 0.35$ d, but are relatively infrequent for longer periods. Presumably, other binaries are common there, but any quantitative studies of this would have to address the very different discovery selection effects for contact, semidetached and detached short-period binaries. We note that Lucy (1976) bravely attempted to use the general catalogue of variable stars to address exactly the same point, but his data were very poor at this. Surveys such as ASAS or many planned ones can be used to study the metamorphoses of short-period binaries as they evolve into contact; here, we only point interesting potential for research.

Figure 2. The volume-corrected period distribution based on the ASAS data, taking into account the distance selection effects. The error bars are derived from the Poisson statistics uncertainties based on the number of objects, as given in Table 1. The broken line gives the DM91 distribution scaled with the assumption of the relative frequency of occurrence of one W UMa binary per 500 FGK dwarfs.

Table 2. The volume-corrected period distribution $D'_P$ derived from the ASAS sample and expressed as number of contact systems per interval $\Delta P(d) = 0.025$ in units of 10$^{-6}$ stars pc$^{-3}$. $n$ is the number of binaries per interval. The first column gives the low edge of each bin.

Figure 3. The volume-corrected period distribution based on the ASAS data, taking into account the distance selection effects. This is the same diagram as in Fig. 2, but in linear units of the period. The error bars are derived from the Poisson statistics uncertainties, as in Table 2. Note that there are only three systems in the first bin of $0.200 < P < 0.225$ d.

5 CONCLUSIONS

We find that the search volume-corrected period distribution for W UMa binaries is a direct result of their luminosity function following the MS luminosity function over the range of $1.5 < M_V < 5.5$. The maximum of the period distribution occurs at periods close to 0.27 d ($M_V \approx 5$), at the point where the W UMa luminosity function has a point of inflection and stops following the MS numbers. The maximum is located at shorter periods than estimated previously from the catalogue data (Lucy 1976; Rucinski 1992) at about 0.35 d; see also Section 1. The new determination based on the ASAS and based on 3374 objects is clearly superior to the one based on 98 objects of the
OGLE survey (Rucinski 1998). The OGLE sample analysis appears to have suffered from an unaccounted image blending which led to erroneous depth limits and, in consequence, to an exaggerated frequency of occurrence of W UMa binaries of ≃ 1/130 in place of ≃ 1/500. But the shape of the period distribution was probably unaffected.

The statistics at shorter periods beyond the maximum is still very poor. Apparently, even a survey such as ASAS with the coverage of almost 3/4 of the sky and extending to V ≃ 13 still has too few objects to establish the statistics at short periods; deeper all-sky surveys are needed. Nevertheless, the ASAS data have improved our knowledge of the short-period end of the distribution and of its maximum. The shortest period known field system, ASAS 083128+1953.1, with P = 0.2178 d needs investigation; other ASAS variables with P < 0.22 d which were previously considered in this context are either not contact binaries or have poor light curves at their brightness levels beyond the V = 13 limit.

The use of the n(log P) d log P or n(P) dP forms of the period distribution does not seem to make such an important distinction for contact binaries as for MS stars of same mass. The strong maximum in numbers appears at short periods in both of these forms and is mostly related to the stellar mass distribution along the MS. It should be noted that – unlike detached binaries – contact binaries can respond to the angular momentum loss by an internal mass transfer towards more dissimilar masses (i.e. a decrease in the mass ratio) with the associated lengthening of the period. However, this is not directly visible in the ASAS period distribution at the present level of the statistical accuracy.

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APPENDIX A: CONTACT BINARIES WITH PERIODS SHORTER THAN 0.22 D IN THE ASAS
The seven systems of the ASAS sample with P < 0.22 d (Table 3) were checked, if they are genuinely contact binaries. The online version of the ASAS-3 catalogue was consulted for updates and the Tycho-2 catalogue (Hög et al. 2000) was used as a source of B – V colour index data.

It appears that the system 042606+0126.5 has been re-classified in the ASAS catalogue to a δ Sct pulsating star with the period two times shorter than estimated before. Also, the ASAS tables give V = 12.6 for 174930−3355.4 while its rather poor light curve clearly shows V = 13.8; thus, the star is fainter than the adopted completeness limit of V = 13. Two more stars are fainter than this limit and also have poor light curves, 071829−0336.7 and 113031−0101.9.

Short-period contact binaries must be red because they consist of mid-K dwarfs. Thus, a colour index which is not sufficiently red (B – V > 0.8) can be used to reject δ Sct and β Cep pulsating stars. This criterion was used to eliminate 162155−2128.7 and 201354−4633.4.

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Table 3. Systems with periods < 0.22 d.

| ASAS | P(d)   | V    | B − V | Comment |
|------|--------|------|-------|---------|
| 042606+0126.5 | 0.148860 | 12.4 | 0.27 | δ Sct, 0.074430 d |
| 071829−0336.7 | 0.211249 | 13.8 | ?   | >13 mag, poor l.c. |
| 083128+1953.1 | 0.217811 | 10.3 | 1.03 | genuine W UMa |
| 113031−0101.9 | 0.213135 | 13.4 | ?   | >13 mag, poor l.c. |
| 162155−2128.7 | 0.209918 | 10.1 | 0.47 | too blue, amplitude 0.06 |
| 174930−3355.4 | 0.186629 | 13.8 | ?   | >13 mag, poor l.c., new V |
| 201354−4633.4 | 0.147786 | 9.6  | 0.17 | too blue, amplitude 0.08 |

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