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STATISTICS OF THE LARGEST SAMPLE OF LATE-TYPE CONTACT BINARIES STUDIED SO FAR

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Abstract. Late-type contact binaries, also known as W UMa stars, are intriguing objects whose present-day properties, evolutionary history and membership in multiple stellar systems are still not fully understood despite decades of dedicated research. At the same time, they are a favorite target for observations with relatively small, ground-based telescopes because of their short periods, so an entire light curve can often be recorded in a few nights. The last decade has seen a considerable rise in both the number and quality of studies of W UMa stars, and the establishment of de-facto standards in their analysis that help aggregate the results. We have collected new and updated solutions of light curves for 688 W UMa stars, more than half of which have been studied for the first time in the last few years. This is the largest catalog of its sort published to date and it provides ample material for various statistics. We showcase and discuss the most interesting findings.

1. INTRODUCTION

W UMa binaries are the most common class of eclipsing binaries and they account for about 0.2% of all solar-type stars in the Solar system neighborhood (Rucinski 2002). The majority of variable stars in the Catalina Real-Time Transient Survey (CRTS) Variable Star Catalog (Drake et al. 2014) are W UMa binaries.

From the observational standpoint, they are characterized by continuous changes in brightness with periods typically shorter than half a day. Their light curves have minima of similar depth and no clear transitions between eclipse and out-of-eclipse phases, suggesting gravitationally distorted components of nearly equal effective temperatures. At the same time, one star is usually twice or more as massive as the other. This paradoxical property is explained in terms of mass and energy exchange between the components through a co-rotating common envelope (Lucy 1968).

Although W UMa binaries have been studied for decades, our understanding of their evolutionary history and present-day characteristics is still incomplete (see e.g. Webbink 2003). Much of our current knowledge comes from analyzing ensembles of well-studied individual objects (see e.g. Yakut & Eggleton 2005). Yet, to our knowledge, the latest effort to aggregate the results for individual stars from the literature into a comprehensive catalog dates back almost two decades (Pribulla et al. 2003).

We have made such an effort now and compiled the orbital and stellar parameters of 688 W UMa stars by reviewing around 420 relevant papers. Two thirds of this sample (478 stars) are "new" in the sense that they have not been considered in any previous statistical studies. Our catalog is not only the largest to date, but also the most complete in terms of cataloged quantities. Special care was taken to homogenize the results of modeling with different tools; missing quantities were calculated where possible; and additional measurements were included by cross-referencing the Gaia (Gaia Collaboration 2016, 2018) and LAMOST (Qian et al. 2017) archives.

We conducted various analyses of the collected data; the results of this research are being prepared for publication. Here we give a preview of our methods, findings and conclusions.

2. COMPARATIVE STATISTICS

Among the cataloged quantities characterizing W UMa stars, some of the most important ones are categorical rather than numerical. For example: the type of eclipse (partial or total), the A or W subtype (Binnendijk 1979), the presence or absence of spots and third light in the light curve model, the method for finding the mass ratio (photometric or spectroscopic) and so on. To explore and compare the properties of cataloged stars when the full sample is divided according to such groups, we use split violin plots (Figs. 1 and 2).

The split violin plot shows the distribution of a numerical quantity (i.e., the orbital period) when the sample is split according to a categorical quantity (i.e. the A/W subtypes). The distribution is plotted vertically with a split between the groups, making the similarities or differences obvious at a glance. Summary statistics such as mean and median values or the interquartile range can also be included to make the plot more informative. For simplicity, we only include the median, represented by the horizontal line in each distribution.

2. 1. ECLIPSE TYPES AND DETERMINATION OF THE MASS RATIO

Typically, the mass ratio is measured from the radial velocity curves, which are in turn derived from spectroscopic time series. Such observations are difficult to come by, especially for faint targets, and binaries with these measurements are relatively rare (only about 20% of objects in our catalog). However, in contact binaries it is also possible to measure the so-called photometric mass ratio from the light curve alone. Because the components share a common envelope described by the same equipotential surface, their mass ratio is proportional to their size ratio via the relation $R_2/R_1 \approx (M_2/M_1)^{0.46}$ (Kuiper 1941). As the size ratio is readily determined from light curve modeling, so is, in principle, the mass ratio.

This method of measurement is known to be robust when the system is totally eclipsing. But what of partially eclipsing stars with no spectroscopic measurements? In Fig 1 we compare the properties of totally and partially eclipsing stars (panel a), and of those with spectroscopic and photometric mass ratios (panel b). Objects with partial eclipses have slightly shorter periods, smaller fillouts and lower temperatures than those with total eclipses; most notably, their mass ratios are spread evenly over the range from 0 to 1, whereas the totally eclipsing stars have mass ratios in a much smaller range that tappers off near $q = 0.5$. Stars with photometric and spectroscopic mass ratios have similarly disparate distributions, with more pronounced differences in periods and temperatures, but essentially the same issue with mass ratios.

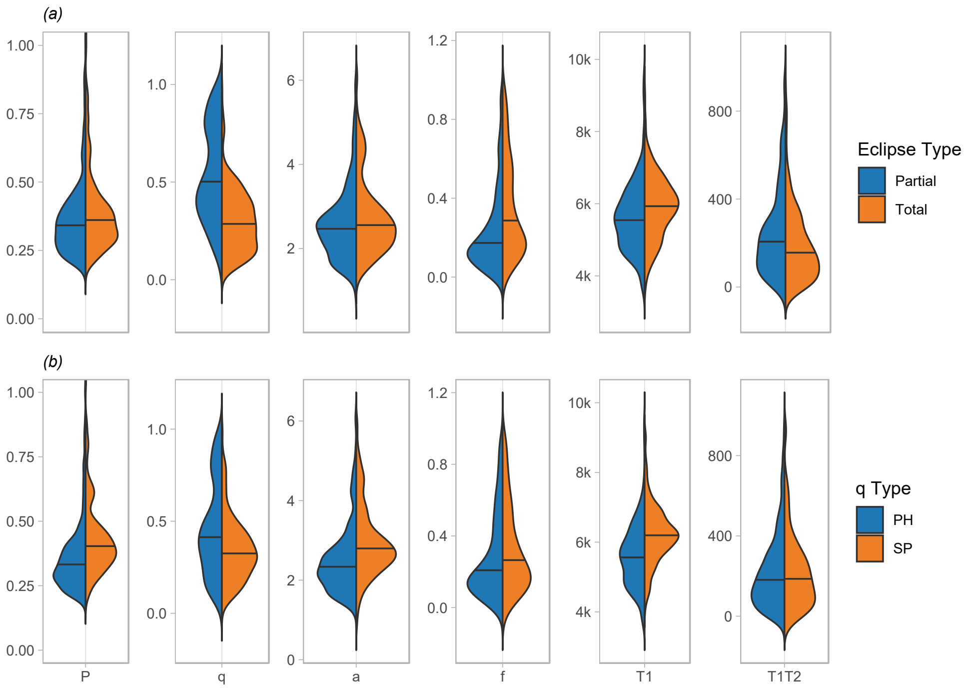

Figure 1: Comparative distributions of selected quantities (from left to right: orbital period, mass ratio, orbital separation, fillout, primary temperature and the temperature difference between the components) for stars with total and partial eclipses (panel a) and with mass ratios determined from spectroscopy (SP) and photometry (PH) (panel b).

By combining the totally eclipsing systems and those with spectroscopic mass ratios into a "reliable" sample, and the rest into the "unreliable" sample, we could confirm that mass ratios and other parameters obtained from light curve modeling of partially eclipsing W UMa stars without the support of spectroscopic measurements are tentative at best.

2. 2. THE A AND W SUBTYPES AND SPOTS

W UMa binaries are traditionally divided into the A and W subtypes. The original definition came from Binnendijk (1970), who made the classification according to whether the deeper light curve minimum is caused by a transit or an occultation. This translates to a simple criterion by model parameters: in A types, the bigger, more massive star is hotter, and in W types, it is cooler than the companion. Early statistical analyses (see e.g. Maceroni & van't Veer, 1996) showed that members of these two groups have different properties. The A-type systems have longer periods, higher temperatures and larger fillouts.

During data collection, we noticed that many authors use these secondary characteristics for classification of systems under study. As many as 10% of the stars in our sample have subtypes in source publications that conflict with the original definition.

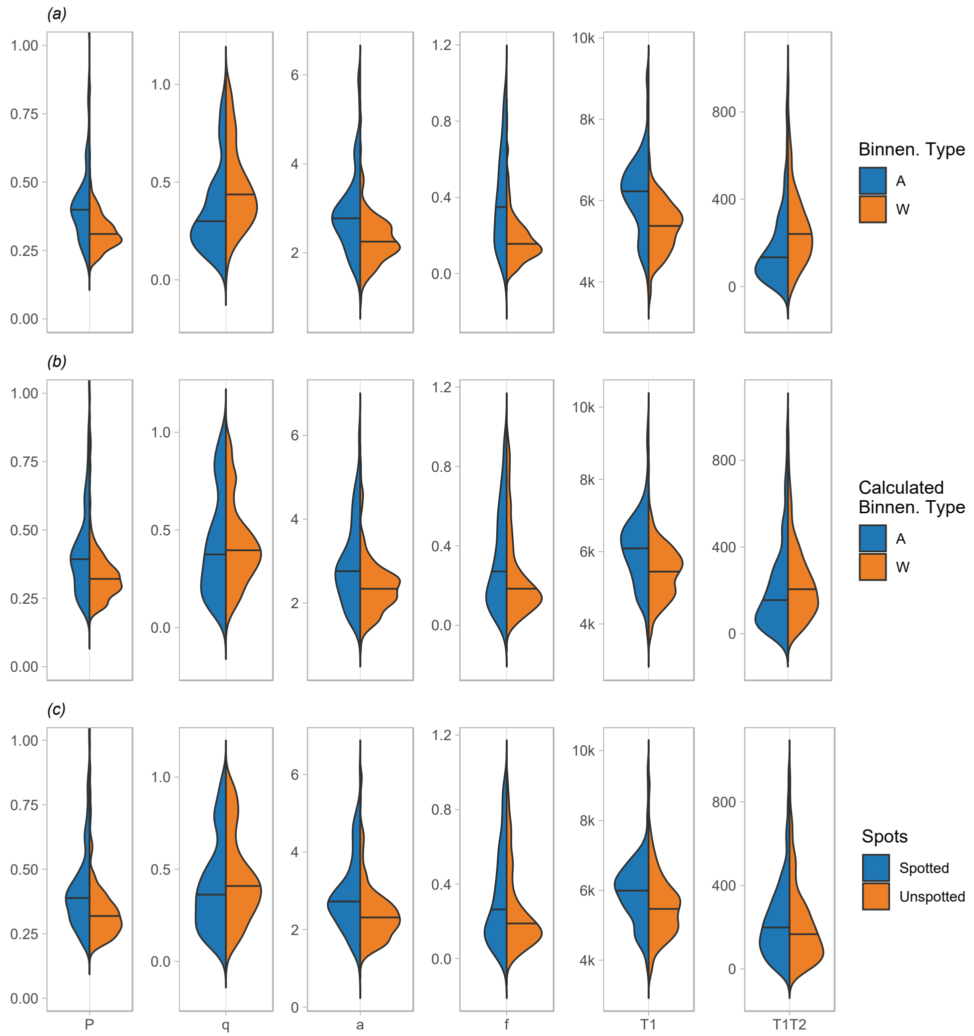

Figure 2: Same as in Fig. 1, but for Binnendijk's A and W types from source publications (panel *a*), those calculated from the original definition (panel *b*), and presence or absence of spots (panel *c*).

Fig. 2 shows the comparative distributions of A and W stars with types adopted from the source papers (panel *a*) and assigned using Binnendijk's definition (panel *b*). We see that the differences in periods, fillouts and temperatures are much less dramatic in the latter case, and the difference in the mass ratios disappears altogether. In a sort of circular argument, the deviations from the definition in the literature have artificially boosted the differences between the subtypes.

This is important because the nature of these subtypes is one of the open questions about W UMa stars. In the most widely accepted evolutionary scenario, they enter contact while still on the main sequence as the orbit shrinks due to the loss of angular momentum via magnetized winds (Stępień 2011). But that scenario cannot explain the higher temperature of the smaller, less massive components in the W types. It has been suggested that the apparently lower temperature of the larger, more massive companion is the result of spot coverage (Yakut & Eggleton 2005).

Comparing the parameter distributions of the subtypes (Fig. 2*b*) and spotted and unspotted stars in our sample (Fig. 2*c*) shows that indeed, the A-type sample resembles the spotted sample, and the W-type the unspotted. However, when the presence of spots is examined by subtype, it turns out that there are as many spotted as unspotted systems among both the A and W stars, indicating that these groupings are not correlated.

3. SUMMARY

We collected stellar and orbital parameters for 688 late-type contact binaries and conducted a comparative statistical analysis of various groupings within this sample. Among other findings, we show that: 1) parameters derived from light curves with partial eclipses without spectroscopic support should be considered unreliable; and 2) despite markedly similar parameter distributions, there is no correlation between the A/W subtypes and the presence or absence of spots. Other results of our study, including the modeling of parameter distributions and their relationships, are expected to appear in press in 2021.

Acknowledgments

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