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Area of Ignorance in Astro-160: Contact Binaries (Common Envelopes and Subtypes)

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ABSTRACT

Contact stellar binaries are defined by their shared Common Envelope (CE) and their filled Roche Lobes. Of particular interest in stellar astrophysics today is the W-phenomenon. W subtype contact binary systems exhibit peculiar behavior contrary to the expected of a positive correlation between the mass of a star and its effective temperature. Where instead W sub-types exhibit the inverse behavior, with the secondary star appearing much more luminous than the primary star. The A sub-type contact binaries are still unknown if to be an evolutionary companion to W subtypes, or a separate phenomenon all on its own. This paper will discuss the connection between binary subtypes to the common envelope model as well as examine the relationships and findings across different datasets when comparing astrometric properties of contact binaries. There is very strong evidence for a clear connection between W and A subtypes when viewing through the lens of the velocity of contraction through changing gravitational potential between stars.

Keywords: (stars: binaries, common envelope, w-phenomenon)

1. INTRODUCTION

Contact stellar binaries still remain an area of great exploratory and theoretical interest. Contact binaries have periods on the order of less than one day due to the close proximity of each star to one another. The surface temperatures of each star appear equal upon observation but can have varying luminosities. This is primarily in part due to their shared common envelope (CE) creating a shared plasma for free mass and energy transfer (Qian et al. 2020).

A common envelope is formed through the gravitational pull of the secondary star on the less dense, outer gaseous layers of the more-massive primary star. This is most common with a red giant and main sequence star system (Izzard et al. 2012). The primary star, when in close enough proximity, will accrete matter onto the secondary star on the dynamical time scale. This accreted matter will form the filled Roche Lobe of the primary star. Once the accreted matter passes the proximity limit set by the inner Lagrangian point of the secondary star, it is now gravitationally bound to the secondary star. This accretion continues while the secondary star fills its Roche lobe, physically considering the stars to be in close contact (Izzard et al. 2012).

It is known that a developed contact binary in complete contact will exhibit EW type light curves. These light curves have virtually indistinguishable secondary and primary eclipses with a continuous sinusoidal increase and decrease in luminosity over its period. These orbits occur on the order of less than half a day for binaries in close contact (Qian et al. 2020).

Exploring the dynamics of contact binaries opens the door to understanding systems such as star mergers, origins of red supernova bursts, and formations of stars that are rapidly rotating (Qian et al. 2020). As astrophysics as a discipline unlocks more hidden information in these topics, there is no telling what physical phenomenon we have yet to consider through contact binary research.

Through this research paper, we will discuss the current improvements in the astrophysics community focusing on our current knowledge concerning the Common Envelope Model (Izzard et al. 2012), the classification of contact binary subtypes (Qian et al. 2020) (Csizmadia & Klagyivik 2004), as well as the correlations between period length and effective temperature (Qian et al. 2020) (Pawlak 2016).

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2. DISCUSSION

2.1. *State of the art*

The evolution of contact binary systems is clearly defined as having multiple stages, stemming first from the stage of Pre-contact Binaries to the final stage of Deep Low-Mass Ratio Contact Binaries (DLMCB). It is expected that as the system evolves, a merging event of both stars into one star of greater luminosity and angular momentum is formed. It is also well known that contact binaries exhibit EW light curve shapes, have well-defined bounds on their mass ratios, a minimum and maximum period, and poses filled Roche Lobes (RLs) and a shared Common Envelope (CE) Qian et al. (2020).

However, there are still many unanswered questions as to where these precise boundaries lie. It is widely agreed that the orbital period for a contact binary system is strictly less than one day, but where this value is constrained to is highly debated. Whether the minimum period is constrained to 0.14 days or 0.22 days is still undecided. The maximum period of a contact binary is more closely constrained to lie between 0.34 and 0.37 days. This is due in part to the period-color relation that shows a direct linear correlation between a contact binary's period and its luminosity (color) (Wadhwa et al. 2023). Since those with longer periods are more luminous and thus data collection has a minimized error in comparison to their dimmer counterparts.

The correlation between effective temperature and period is also highly correlated. There are clear constraints that follow a linear model of two equations that set natural limitations on normal contact binaries. These equations were derived empirically through observations and statistical reasoning (Qian et al. 2020).

$$T = 4000 + 7500P \tag{1}$$

$$T = 2450 + 7500P \tag{2}$$

Where T is the effective temperature of the system and P is the period.

When empirically observed contact binaries were plotted against the above equations, as seen in figure 2.1, it was found that the vast majority of EW contact binaries fall within the region of the two equations, with the binaries on the outside right side are marginal contact binaries, and those on the far left are deep contact binaries (Qian et al. 2020). The correlation equations are to identify the regions of the majority of contact binaries. There is clear discrepancies between the two data sets, however, it is more favorable to follow the LAMOST analysis of (Qian et al. 2020) as the analysis process had greater amount of data and time to work with as compared to our own fitted model using the 2015 contact binary data set from Kepler telescope.

This relationship is a spot of further research in the field of stellar astronomy as to if these binaries evolve on this diagram in time, moving from right to left, or if their evolution is stopped in place before their expected merging events. The current research findings lean towards there being an evolutionary tie, with contact binaries moving from right to left in the direction of decreasing orbital period.

It is evident to see that the number of observations plays an important role in determining the correlation between period and temperature. With 1 and 2 having variations as compared to the correlations found through our analysis of the Kepler Eclipsing Binaries survey of 2015. Our correlation equations are listed below:

$$T = 3750 + 6800P \tag{3}$$

$$T = 2750 + 6800P \tag{4}$$

Where T is the effective temperature of the system and P is the period.

There are still thousands of contact binaries that fall outside of these constraints, and the exact reasoning for these deviations remain mostly unknown with speculations of internal dynamical variations playing a key role in these variations. However, there seems to be a correlation between where the binary system is in its evolution and where it falls on the period-temperature relation. Those binaries that lie to the rightmost side of this graphed comparison (shown in figure 2.1) are believed to be marginal contact binaries, whereas those on the left side are predicted to be primarily DLMCBs. (Qian et al. 2020).

The W-phenomenon exhibited as the contradicting behavior of the secondary star to be hotter than the primary in some contact binary systems, has been a source of question for many years. There is a solution provided by (Wang 1994) that models a sufficiently large mass transfer from the primary to secondary, such that thermal equilibrium cannot be maintained in the secondary star, resulting in a larger amount of radiation being released compared to the primary star.

The physical basis behind this model is to solve for the contracting velocity β as a function of time in the secondary star. This will provide us with the ability to distinguish between stages of contraction or expansion in the secondary star. This led to the discovery that during contact binary orbits, the stars can come in and out of contact periodically, known as thermal relaxation oscillation stats (TROs) (Wang 1994). It was then discovered that when defining a value γ that is in terms of

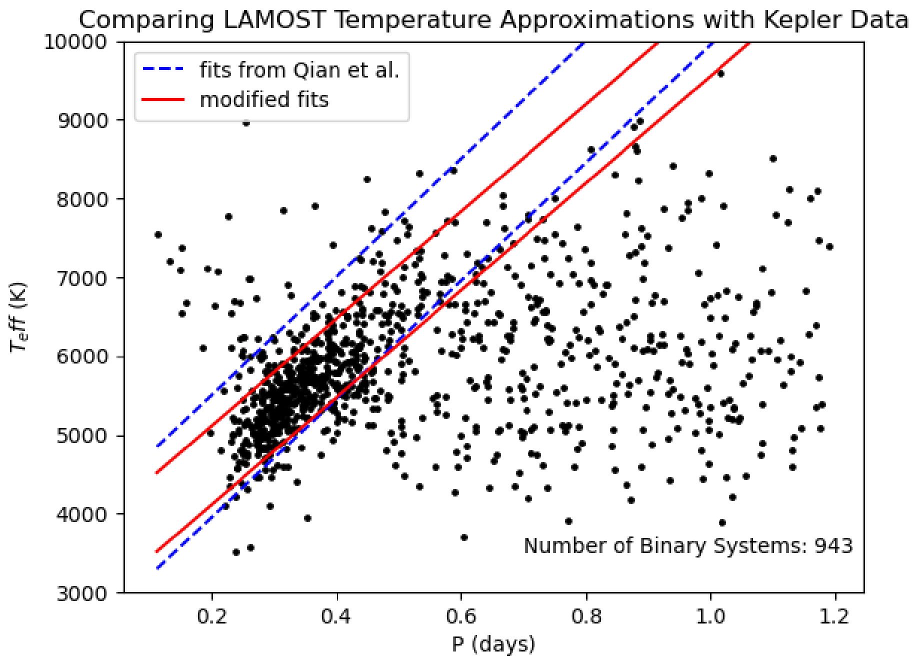

Figure 1. Temperature Approximation Differences The number of observations affects the temperature correlation with period length. The LAMOST Low Resolution Survey provided over 8,000 contact binaries to collect astrometric data from, which led to the correlation limits found in 1 and 2. However, when consulting the Kepler Eclipsing Binaries Library from December 2015, only 943 binary systems had sufficient information to create a similar plot seen with LAMOST. This leads to differences between correlation values. While the Kepler data set boasts low errors, of only ± 0.002 days for period length, there is still a discrepancy of 9.3% between the correlation values for temperatures and period lengths between the two sets of correlation equations.

the contracting velocity, γ is always negative for W sub-types and positive for A sub-types (Wang 1994). This positive value is an indication of a higher rate of release of gravitational energy, which explains the higher luminosities.

2.2. *The way forward*

Through the improvement of observational abilities of the Large Sky Area Multi-Object Fiber Spectroscopic Telescope (LAMOST) survey of Low-resolution to medium-resolution observational data, there have been massive improvements to the quality of data and the sheer order of observations collected, with the low-resolution survey observing 10,809,336 total spectra to 19,450,119 total spectra for the medium-resolution survey Qian et al. (2020).

One major limiting factor in our knowledge of contact binaries is lack of sufficient data to make meaningful conclusions about the behavior of certain aspects of stellar evolution. There is much progress to be made in the overarching knowledge regarding this stellar phenomenon.

For future steps in this field of study, one interesting discovery would be the relationship between W-sub type and A-sub type contact binaries. It has been explored that these two subtypes are connected in time via natural evolution, but no such relationship has been proven at this point. These two sub types are determined via their light curves and their secondary star's contraction velocity (Wang 1994). There has been speculation that these opposite relationships could be due in part to different thicknesses of Common Envelopes (Qian et al. 2020).

3. CONCLUSIONS

Contact binaries are a difficult binary system to study due to their short orbital periods and unique evolutionary stages. Through analysis of several papers across two decades, there have been many improvements to our knowledge of contact binary dynamics and evolution. These include the relationship between period length and effective temperature, improved physical interpretation of the differences between W and A sub-type binaries, physical interpretation of the TROs, and more bounded limitations on physical parameters such as the mass ratio and period length.

The W-phenomenon, long perceived as a mystery in its paradoxical nature, has been successfully interpreted through physical means, and allows us to attribute simple stellar models and principles to complex topics involving changing mass flow rates and angular momentum. The connection and leading causes to the differences between A and W sub-type contact binaries is still an area of unknown.

There are still many things left to learn about and delve deeper into. This is including but not limited to:

- the connection between A and W subtypes (Csizmadia & Klagyivik 2004)
- the evolution of the common envelope (Izzard et al. 2012)
- dynamics of mass transfer between companions (Qian et al. 2020)
- minimum mass ratio only determined through observation. A mathematical representation is still being researched (Qian et al. 2020)
- behavior of stars directly before a merger event remain heavily unknown in their physical interpretations (Qian et al. 2020)
- what occurs directly after a core merger occurs also remains heavily unknown (Qian et al. 2020)

Through improvements to telescopes and quality of surveys, the missing link to exploring the dynamics of contact binaries – our lack of quality data – will open doors for deeper understanding of these undeniably interesting stellar systems.

Facilities: LAMOST, Kepler Space Telescope

Software: matplotlib (Hunter 2007), pandas (pandas development team 2020), numpy (Harris et al. 2020)

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