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W Ursae Majoris Variable Stars

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ABSTRACT

W Ursae Majoris (W UMa) variable stars are a class of main-sequence binary stars with short periods of less than a day. These stars are also known as contact binaries, as their component stars are so close they are in contact with each other. The component stars share a common gas envelope and have a characteristic light curve. The study of W UMa stars is essential as they provide important clues about the nature of binary star systems. A vast body of research covers these over-contacting stars; they are well characterized but lack a complete model of their stellar evolution. This paper will surmise what is currently known about W UMa stars and what is now under investigation.[a)]

1. INTRODUCTION AND BACKGROUND

Like many classifications in astronomy, W UMa stars are named after the celestial object which originally required a new classification. W Ursae Majoris is an over-contacting star in the constellation Ursae Majoris; it is a pair of G2V stars with an orbital period of ≈ 8 hours (Hill et al. 1975). W Ursae Majoris varies by 0.73 magnitudes during its entire period. Recent studies have characterized its components as $1.14M_{\odot}$ and $0.55M_{\odot}$, giving it a mass ratio of $q = 0.48$ (Gazeas et al. 2021). These relationships, the low magnitude variation, low orbital period, high mass ratio, nearly constant color due to the shared gas membrane, and nearly equal eclipse minima, would become the basis for the W UMa class of stars. Though initially weary, the W UMa classification was solidified when two new stars fitting this description were discovered in 1926, 23 years after the original W UMa publication (Schilt 1926). Since then, many W UMa stars have been discovered and characterized; W UMa stars now outnumber all other types of variable stars, and an under-detection issue is still under discussion (Rucinski 2002)[1].

1.1. *W-Type Stars*

The W- and A-Type classifications were present at the conception of the W UMa stellar classification. W-Type W UMa stars are low-mass systems with spectral types of G or K and lower-end periods as low as 6 hours. These stars have very low variance in surface temperature due to the shared gas membrane. As the name "W-Type" implies, W Ursae Majoris is a W-Type W UMa star (Gazeas & Niarchos (2006); Jiang et al. (2009)).

1.2. *A-Type Stars*

A-Type W UMa stars are high-mass systems with spectral types F or A and high-end periods up to 16 hours. Like W-Types, these stars have low surface temperature variance due to the shared gas membrane. A-Type W UMa stars are of particular interest as candidates for modeling. Unlike W-Type stars, A-Type stars are thought to be in near equilibrium such that they could be treated as single stars (Wilson 1978) This is not true for other W UMa stars, like W-Types, which exhibit more erratic changes. Some believe that W-Types oscillate between being in thermal contact and being thermally disconnected with very long periods (Robertson & Eggleton 1977).

1.3. *B-Type Stars*

In 1978 B-Type W UMa stars were introduced and are often referred to as poor thermal contact systems. While some believe W-Type stars oscillate about being in thermal contact, B-Type stars are definitively not in thermal

[a)] I did not realize how different the length of this paper would be without being double-spaced. I hope this format is acceptable, I have been trying to learn LaTeX this quarter and when I learned there was an AAS standard I figured I had to try. When pasted into *Word*, and re-formatted, this paper exceeds 4 pages without the References section.

[1] The certainty of this view is a relatively recent advancement. W UMa stars were not always considered numerous, and I missed more recent data when researching for my presentation. From 1960 to 1990, various published estimates predicted anywhere between 10^{-6}%, or up to 1% of all stars being W UMa stars. Rucinski discusses that W UMa stars are not uniformly distributed in Rucinski (2002), which explains some prediction discrepancies.

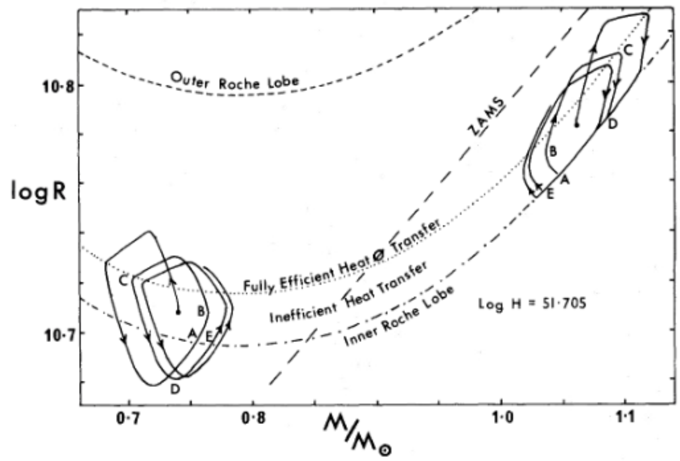

Figure 1. Two initial massed contact binary systems cyclic evolution of being in close thermal contact and not in thermal contact. Figure 3 from Robertson & Eggleton (1977).

contact. These stars exhibit significant differences in surface temperature (Rucinski & Duerbeck 1997). Though these stars lack a very important characteristic, they are referenced in literature less often than others. Figure 1 shows how contact binary systems may oscillate between being in or out of thermal contact. This cycle indicates that B-Type stars are a stage of a regular W-Type W UMa stars life (Robertson & Eggleton (1977)).

1.4. *H-Type Stars*

The most recent addition to W UMa sub-classification is the H-Type stars. These W UMa stars are characterized as having high mass ratios: $q > 0.72$ (Csizmadia & Klagyivik 2004). The H-Type classification is often appended to the A- or W-Type classification to indicate HA- or HW-Type W UMa stars.

2. THE LIGHT CURVE

W UMa stars have a characteristic light curve that differentiates them from other eclipsing binary systems.

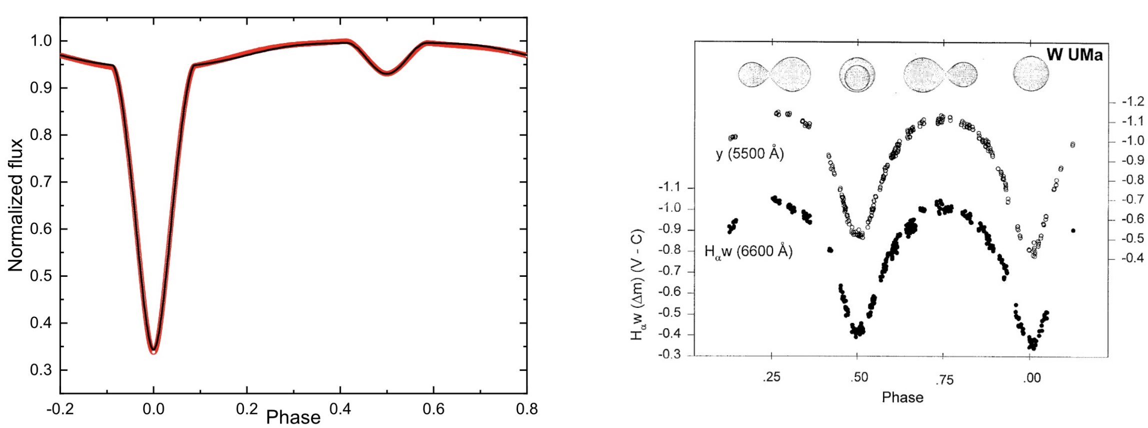

Figure 2. Left: The light curve of UZ Lyr. Observations are red dots with a solid line representing a model fit. Figure 3 from Roobiat & Pazhouhesh (2022). Right: The light curve of W Ursae Majoris in two filters. Shown at the top of the W Ursae Majoris light curve are the orientations of the two bodies from the observer's perspective. Figure 1 from Morgan et al. (1997). The maximum flux has been normalized to 1 for both plots.

Figure 2 Left shows the light curve of a disconnected eclipsing binary UZ Lyr. Though not perfectly continuous, UZ Lyr's light curve can be approximated as having a constant maximum flux broken by two sudden decreases in brightness. The first decrease moving left to the right is from the larger star, the primary, passing in front of the smaller star, the secondary; this event is called the primary eclipse. The second decrease moving left to right is from the second passing in front of the primary: secondary eclipse. Figure 2 Right shows the light curve of W Ursae Majoris, a W UMa type star. Instead of the nearly constant maximum flux, W Ursae Majoris shows a nearly continuous flux. Also shown in Figure 2 Right are diagrams depicting the configuration of W Ursae Majoris as seen from the observer. The location of the primary and secondary eclipse is flipped from Figure 2 Left; secondary eclipse occurs first with the secondary star passing in front of the primary, and primary eclipse occurs second.

Differences in this light curve can differentiate W UMa stars from other eclipsing binary stars. In a W UMa star, the magnitude difference between primary and secondary eclipse is minimal compared to other eclipsing binary stars. The W UMa star light curve is nearly continuously variable while other eclipsing binary stars have periods of relative consistency in their light curves.

3. FORMATION

One of the most significant research areas in contact binaries is their formation. On the topic of contact binary formation, the most popular model is the detached-binary channel. The detached-binary channel model proposes that a disconnected binary system might become a contact binary system through angular momentum loss.[2] Some proposed mechanisms of angular momentum loss include expanding binary components, magnetic breaking, or losing to a third stellar component. The most recent paper on the subject carries out a population analysis finding a higher birth rate for disconnected binaries and estimating a formation time scale between 1 Myr and 15 Gyr. Observational evidence indicates that some detached binary systems evolve toward shorter orbital periods indicating angular momentum loss and a shorter orbital radius (Jiang et al. 2014). The detached-binary channel is currently the most investigated W UMa star formation mechanism for these reasons. Most calculations from observations find that detached-binary systems would take too long to form contact binaries except in the oldest clusters (Jiang et al. (2014); Li et al. (2007)). Recent research takes this data to indicate that there must exist multiple mechanisms for contact binary formation (Bilir et al. 2005). The model for contact binary formation is very sought after in modern astrophysics and is poised to answer many important questions about binary star systems.

4. EVOLUTION

W UMa stars exhibit many characteristics and unique behaviors during their life as contact binary stars. Like many binary systems, W UMa stars exhibit a slight period decay (Li et al. 2008). This decay is often described as gravitational wave radiation, magnetic braking, interactions with a third body, or mass transfer (Gazeas & Niarchos (2006); Li et al. (2007); Bilir et al. (2005)). Of particular interest to mass transfer models is an apparent discrepancy in A-Type and W-Type stars. Theory predicts that A-Type stars, with more over-contact, have a higher mass transfer rate than W-Type stars. Observations, however, indicate that W-Type stars have more mass transfer than A-Type stars Csizmadia & Klagyivik (2004).

Recent research has also indicated that A-Type systems may evolve into W-Type systems through mass transfer (Gazeas & Niarchos 2006).

W UMa evolution is governed primarily by this mass transfer mechanism which has broad impacts on the lifespan, luminosity and observed characteristics of the W UMa star. The mass transfer mechanism is under intense investigation. While many models and observations exist, and many rules or equations are proposed, no one mechanism or explanation exists.

5. DEATH

The recently observed merger of the contact binary V1309 Sco demonstrates, for the first time, that contact binary systems may evolve towards mergers (Tylenda et al. 2011). However, the V1309 Sco merger was not the first of its kind. Before V1309 Sco, similar mergers had been observed and categorized as V383 Mon-type eruptions. Observing a contact binary evolving into a merger of pre-characterized types demonstrates that these eruptions may also have been contact binary systems before exhibiting their current behavior (Mason et al. (2010); Tylenda et al. (2011)). Further analysis of these candidate merger events may indicate upper bounds on the lifetime of W UMa stars and further motivate evolutionary models. It is also hypothesized that W UMa stars may be progenitors to other celestial objects (Jiang et al. 2014).

[2] Once again I have found research which very obviously contradicts part of what I said during my presentation. I remain by my point that the oval common envelope is an unstable stage of stellar evolution and collapses rather quickly. It seems, however, that the collapse does not always end with a merger event but may collapse into a stable contact binary. Recent research indicates that these common envelope events are observable and essential for explaining close contact binary stars (Ivanova et al. 2013).

6. CONCLUSION

W Ursae Majoris type stars are the main sequence binary stars encompassed by a common gaseous envelope. Their formation mechanisms remain unknown but are likely to answer many questions in astrophysics when discovered. Their evolutionary mechanisms are well observed but still in question. Their deaths have only just been confirmed but have likely been observed before revealing a significant amount of never before considered data. Despite these stars' prevalence throughout the universe, not much is known about them, but they seem to hold many secrets.

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