

THE EVOLUTION OF PRE-MAIN SEQUENCE CLOSE BINARIES

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1. INTRODUCTION

Conventional computer models of close binary star systems usually start with at least one component on the main sequence. Models of pre-main sequence binaries have been computed to study mass transfer (Yamasaki 1971). However no pre-main sequence computations have been published that follow the evolutionary tracks of a binary system onto the main sequence, even though some observed systems appear to be pre-main sequence (Field 1969). The main purpose of this investigation is the evaluation of individual close binaries with a pre-main sequence model. The evaluation will be accomplished by comparing the positions of the observed binary on the Hertzsprung-Russell diagram with the evolutionary tracks generated by the pre-main sequence model. If both components appear to have the same age and fall near the tracks of the model, then the system is possibly pre-main sequence. Eleven semi-detached binaries were considered, each with a total mass between 2.5 and 6 solar masses and with a period between 0.9 and 3.4 days.

2. MODEL AND RESULTS

The stellar structure is represented by a polytrope of index $n = 3$ for the radiative solution. A polytrope of index $n = 1.5$ is used for the Hayashi solution (Hayashi 1961). The initial configuration introduced is constrained by the Roche lobe. This limits the radius of each component of the binary system. The basic assumptions are as follows: 1) Mass and energy are conserved both for the individual components and the binary system as a whole; 2) the binary system obeys conservation of angular momentum, and circular orbits are assumed; 3) the stars are spherically symmetric; 4) the stars are in quasi-hydrostatic equilibrium; and 5) the chemical composition of Population I is chosen to be the same for each star ($X:Y:Z = 0.750:0.224:0.026$).

With the masses of each component and their periods being free parameters, a computer program calculated the sequence of contraction

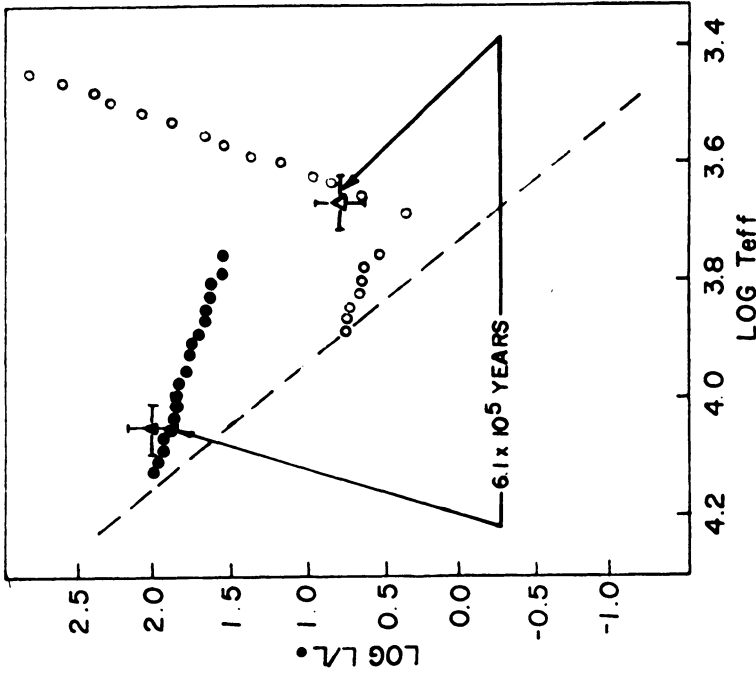


Fig. 2. U CEPHEI ($\Delta = 3.19 M_{\odot}$, $\Delta = 1.53 M_{\odot}$). The evolutionary tracks of the pre-main-sequence binary model is represented by the circles (primary \bullet , secondary \circ).

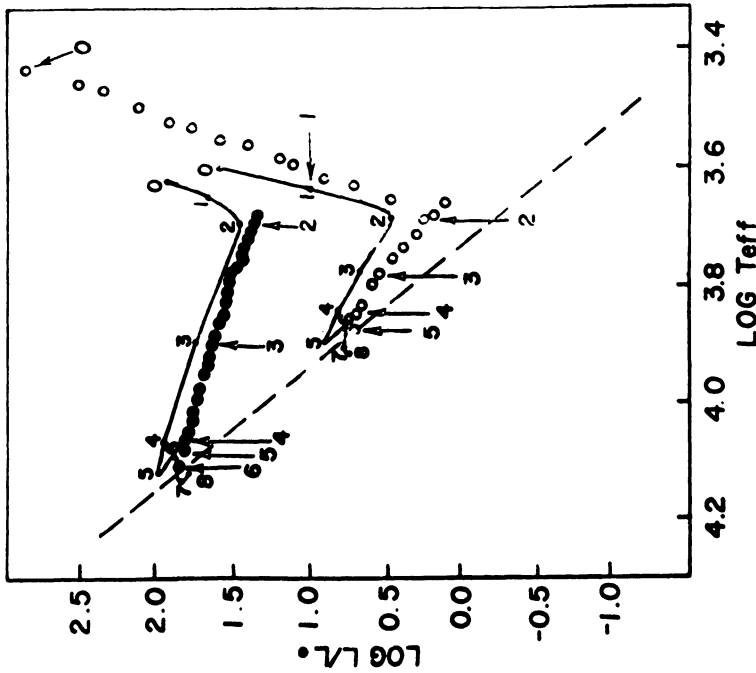


Fig. 1. Evolutionary tracks of a pre-main-sequence model for a binary ($\bullet = 3 M_{\odot}$, $\circ = 5 M_{\odot}$) and the evolutionary tracks for single stars published by Iben (1965).

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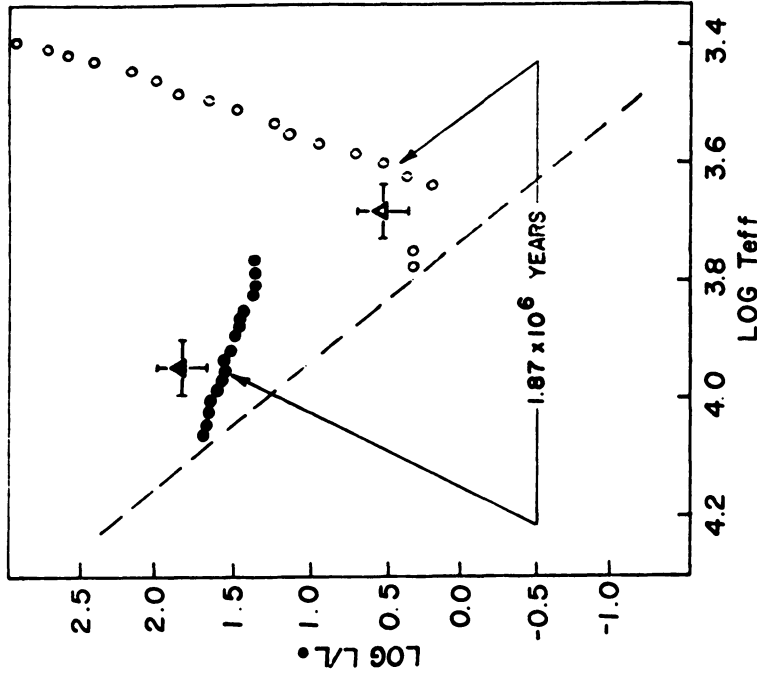


Fig. 4. W URSAE MINORIS ($\Delta = 2.68 M_{\odot}$, $\Delta = 1.19 M_{\odot}$). The evolutionary tracks of the pre-main-sequence binary model is represented by the circles (primary \bullet , secondary \circ).

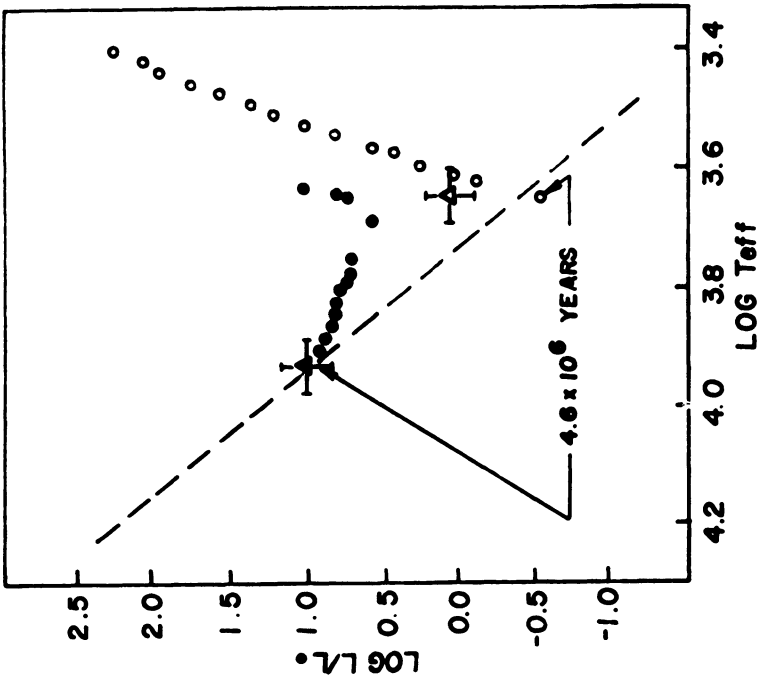


Fig. 3. X TRIANGULI ($\Delta = 1.72 M_{\odot}$, $\Delta = 1.00 M_{\odot}$). The evolutionary tracks of the pre-main-sequence binary model is represented by the circles (primary \bullet , secondary \circ).

models. It calculated both sequences simultaneously which allowed comparison of the age and structure of each component. A test model is compared with the evolutionary tracks published by Iben (1965). The primary for the test model is 3 solar masses, the secondary is 1.5 solar masses, and the period is 3 days. Initially both test stars are filling their Roche lobes and are on the Hayashi Track. Figure 1 shows the plots of the test model and Iben's pre-main sequence tracks for single stars on the Hertzsprung-Russell diagram. The initial point for Iben's models is labeled "0". The points 1 through 5 can be used for age comparison with the test model. The same numbering is used for the test model. The following table shows the ages (10^6 years) at these points for each star.

		Primary = $3 M_{\odot}$		Secondary = $1.5 M_{\odot}$	
<u>Age Point</u>	<u>Iben</u>	<u>Test Model</u>	<u>Iben</u>	<u>Test Model</u>	
1	0.034	---	0.23	0.205	
2	0.208	0.06	2.36	1.391	
3	0.763	0.747	5.80	3.483	
4	1.135	1.202	7.58	4.962	
5	1.250	1.351	8.62	5.949	
6	1.465	1.432	10.43	---	
7	1.741	---	13.39	---	
8	2.514	---	18.21	---	

The absolute dimensions of the eleven systems are published by Giannone and Giannuzzi (1974). Figures 2, 3, and 4 show the three systems found to fit the pre-main sequence model best: U Cephei (6.1×10^7 years), X Trianguli (4.6×10^6 years), and W Ursae Minoris (1.87×10^6 years). Four systems are found not to fit the pre-main sequence model: TV Cassiopeia, AI Draconis, β Persei, and TX Ursae Majoris. Finally, four systems could fit the pre-main sequence model with modifications: IM Aurigae (3.5×10^5 years), δ Librae (8.2×10^5 years), U Sagittae (3.78×10^5 years), and V505 Sagittarii (1.89×10^6 years). These modifications would require differing chemical compositions for each component of a binary. This investigation shows that it is possible to represent some semi-detached close binaries by a pre-main sequence model. More detailed study of individual systems is needed in order to adapt any model to the observed data and inferences therefrom.

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DISCUSSION FOLLOWING WEST AND CHEN

Anderson: How accurately determined are the observed masses, which you assume for your theoretical models? In many of these systems, they must be exceedingly uncertain.

West: These data were taken from Giannone and Giannuzzi (1974). The error bars shown were calculated from their paper. They estimated the maximum errors caused by inaccuracy in the mass determination.

Zuiderwijk: Do you have a physical reason for starting your computations with two Roche lobe filling stellar models?

West: Typically, pre-main sequence models published by Yamasaki (1971) terminated at the end of the mass transfer phase in a few hundred years. Therefore, this assumption is good. Also, starting at this point fills a theoretical gap between conventional post-main sequence binary evolution (which typically starts with a binary on the main sequence), and the work of Yamasaki.

Shu: Do any of the systems you discuss exhibit the characteristics of T Tauri stars which might indicate that they are young?

West: For the cases which fit the pre-main sequence model, we would expect T Tauri type spectra. However, the luminosity of the primary would make these characteristics.

Whelan: Are you really saying that U Cep is a pre-main sequence object? It is known as a classical post-main sequence one.

West: It appears to fit this model well.

Wilson: Are there not too many of these binaries for them to be pre-main sequence objects? Why should the low mass components accurately fill the Roche lobes so often, and where are the intermediaries between lobe-filling cases and fully contracted cases?

West: The model fits three of these eleven close binary systems. It is not a thorough survey.

Smak: I am old enough to make two historical remarks. First, it was in the 30s that Kurt Walter originally suggested that the secondaries of Algols would be in the contraction phase. And secondly, it was in the 50s, when--mostly due to the work of Otto Struve and Su-Shu Huang--this hypothesis was found incompatible with the observational data. Namely, it was found that the secondaries are greatly overluminous for their masses, etc., etc.

West: This is what the pre-main sequence model shows. Only three systems, selected for their mass range, appear to fit this pre-main sequence contraction model. All other Algol-type systems evaluated show secondaries too over-luminous to be pre-main sequence.