PHOTOMETRIC AND SPECTROSCOPIC ANALYSIS OF ECLIPSING BINARY TY TAU. J. L. Wojno[12] and C. H. S. Lacy[13], [1]Arkansas Center for Space and Planetary Sciences, University of Arkansas, Fayetteville, AR 72701, [2]Department of Physics & Astronomy, 102 Natural Science Building, University of Louisville, Louisville, KY 40292, [3]Department of Physics, University of Arkansas, clacy@uark.edu.

Introduction: An eclipsing binary system is a system in which two stars are orbiting a common center of mass, with the plane of their orbit along our line of site. In this type of system, the stars appear to pass in front of each other at regular intervals, which is known as the period of the system. When the hotter star is eclipsed, this is known as the primary eclipse, and when the companion star is eclipsed, the secondary eclipse. By analyzing observational photometric and spectroscopic data, certain properties and information about the system can be determined. Binary star systems such as these can provide critical comparisons with models of stellar evolution, as they are relatively easy to measure and analyze.

Methods: *Light curve*. To construct a light curve for TY Tau, photometric observations collected from November 2000 to December 2010 were used. These observations were taken using the URSA telescope, a 10" Meade Schmidt-Cassegrain telescope located on top of Kimpel Hall at the University of Arkansas, and recorded using an SBIG ST-8 CCD camera with a field of approximately 20' by 30'. Thousands of collected photos were then processed using *Multi-Measure* 2.11 [1]. *Multi-Measure* measures the magnitude of the variable (binary), comparison, and check stars for each separate observation using a user-defined pattern.

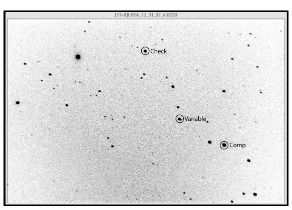
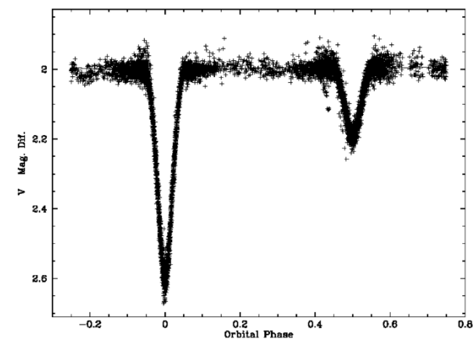


Fig. 1 (left): An example of a user-defined pattern used by *Multi-Measure.* The variable star is TY Tau, and the comp and check stars were used as comparisons. This method of using nearby comparison and check stars to accurately measure the magnitude of the variable star is called differential photometry.

These measurements are then compiled in *Multi-Minima* 2.2 [1]. By combining the observations of the variable star over a long period of time, a light curve is constructed. A light curve (Fig. 2) shows the change in magnitude of the variable star versus the orbital phase. For a system with a perfectly circular orbit, the primary eclipse will occur at phase 0, and the secondary eclipse at 0.5.

For each full eclipse that was measured, the date at the minimum was measured. These dates of minima were collected in a separate file, and analyzed in the program *Dates of Minima* [1]. This program gives an estimate for the period of the eclipsing binary system, for both primary and secondary eclipses. The average of these two was used as the final adopted period. To complete the ephemeris, an accurately measured date of primary eclipse was used.

Fig. 2: Light curve for TY Tau. The period was determined to be 1.0773629, with a full ephemeris of HJD Min I = 1.0773629n + 54307.3175.



Radial Velocity Curve. In addition to a light curve, a radial velocity curve was also constructed, using data provided by G. Torres [2]. Using the program *GLSPL*[3], these data were used to fit a radial velocity curve using a general least squares method. A radial velocity curve provides certain information about the system such as the velocity of each star, eccentricity of the orbit, and the combined radial velocity of the system.

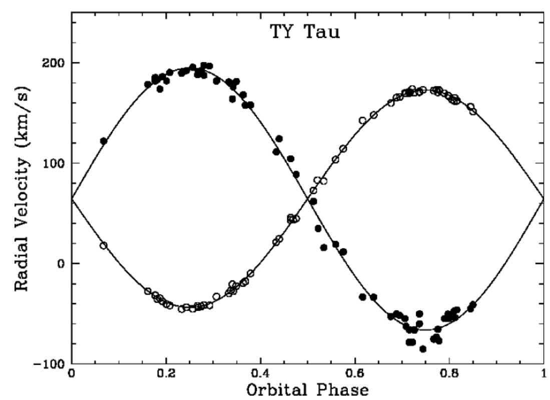


Fig. 3: Radial velocity curve for TY Tau. From the shape of the curve, the orbits of the stars are very circular.

Modeling: The program *JKTEBOP*[4][5] was used to fit a theoretical curve to the light curve constructed from observational data. Although vital information about the system such as period, ephemeris, and eccentricity had been attained by other methods, other parameters of the system had to be estimated. The limb darkening coefficients were estimated using data from Díaz-Cordoves et al. [5] , and gravity darkening coefficients estimated using Claret [6]. By systematically changing which variables stayed fixed, relatively accurate values for properties of the system could be determined. For this set of data, the application *NightShift* 2.4 [1] was also used to eliminate most of the night to night differences, resulting in a more accurate final photometric orbit.

JKTEBOP can be used to gain valuable insight into the binary system. From the light curve fit, the relative radii, mass, and luminosities of the stars in the system can be found. In addition, other information such as third light, which is the theoretical amount of light coming from a third star in the system, if there is one, can be found. Because certain values, such as mass and radius, are only given as ratios, another program must be used to convert these ratios into physical values.

MRLCALC (Mass, Radius, Luminosity Calculator) [1] was used to model the system in a different way, by producing physical values relative to our sun. To use *MRLCALC*, the temperature of the stars had to be computed, as they were not directly modeled by *JKTEBOP*. Data from Popper [7] was used in conjunction with the value for the visual surface brightness from *JKTEBOP* to determine the temperature of each star. In calculating the temperature, interstellar reddening was suspected, and the Q-method [8][9] was used to obtain the intrinsic color indices. Using these corrected indices, the correct values for the temperature of each star was determined. These values were then used in *MRLCALC*, and the results can be found below.

Finally, modeling the system using a YY-model[10] was attempted. However, due to the fact that the stars in TY Tau are low-mass (below 1 solar mass) from *JKTEBOP* and *MRLCALC* results, they do not fit well with the YY-model. Without a fit, it is difficult to determine the age for this system.

Results and Discussion:

Properties	Primary	Secondary
Mass ($M_\odot$)	0.846± 0.016	0.701± 0.008
Radius ($R_\odot$)	0.802± 0.008	0.864± 0.007
Log G	4.557± 0.008	4.411± 0.008
Log L	-0.132± 0.075	-0.391± 0.050
Visual Magnitude	5.07± 0.020	5.94± 0.20
Temperature (K)	5971± 281	4958± 150

Table 1: Physical properties of TY Tau

There are a few points of interest in regards to the results and data. First, from the light curve of TY Tau (Fig. 2) it is clear that there is some magnitude variance outside of eclipse, which has been determined to not be caused by night-to-night differences. In small, relatively cool stars such as these, it is possible that these changes in magnitude may be due to star spots, much like those our Sun has.

Second, from JKTEBOP results it is unclear whether or not a third star is present in the system. In the final adopted fit for the light curve, a third light of approximately 16% produced by the model. However, this is not conclusive evidence to a third body in the system, as extra light may have entered the view from another, unrelated source.

In addition, JKTEBOP produces unexpected results in regards to the relative radii of the stars. For low-mass, main sequence stars such as these, it is assumed that the primary star, being hotter and more luminous, will have a larger radius. From the theoretical fit by JKTEBOP, however, this is not the case, as shown in Table 1.

For future research, additional spectroscopic data may be used to produce more thorough and accurate results.

References:

[1] Lacy, C. H. S. (2011) [2] Torres, G. (2011) Private communication [3] Daniels, W. E. (1966) University of Maryland, Physics and Astronomy Technology, Report No. 579 [4] Southworth et al. (2004MNRAS.351. 1277S) [5] Diaz-Cordoves J., Claret, A., and Gimenez A. (1995) *Astron. Astrophys. Suppl. Ser.* 110, 329-350 [6] Claret, A. (1998) *Astron. Astrophys. Suppl. Ser.* 131, 395 [7] Popper, D. M. (1980) *Ann. Rev. Astron. Astrophys.,* 18, 115. [8] Johnson, H. L. and Morgan, W. W. (1953) *ApJ,* 117, 313 [9] Deutschman, W. A. et al. (1976), *ApJS,* 30, 97-225 [10] Yi, Demarque, Kim, Lee, Ree, Lejeune, & Barnes 2001, ApJS, 136, 417