A PHOTOMETRIC STUDY OF ALGOL TYPE ECLIPSING BINARY LV HER. C. Gong[12] and C. H. S. Lacy[13], [1]Arkansas Center for Space and Planetary Sciences, University of Arkansas, Fayetteville, Arkansas 72701, [2]Ohio Wesleyan University, Delaware OH 43015, ccgong@owu.edu, [3]Department of Physics, University of Arkansas, clacy@uark.edu.

Introduction: Analyzing eclipsing binary stars' photometric data is the only way that enables astronomers to accurately calculate fundamental properties of stars such as mass and size, which can be tested against current stellar evolutionary theory. The eclipsing binary occurs under the condition that we see its orbital plane almost edge-on, but eclipsing binaries are not rare phenomenon due to the high frequency of the binary stars. In Solar neighborhood, with the advantage of close proximity, Latham et. al. [1] concluded the frequency of spectroscopic binaries is more than 50%. By comparison, single stars like the Sun are minority with around 30% frequency.

Since LV Her as an eclipsing binary was discovered in 1939, efforts have been made to determine its orbital period. Torres in 2001 determined it to be about 18.4 days, much longer than what used to be 2.6 days determined by Zessewitch half a century ago. Intriguing properties such as the long period, old age along with high eccentricity make LV Her an interesting analysis.

Observation: Photometric data (light curve) was obtained using the 10 inch URSA telescope, equipped with ST-8 CCD camera and V filter. It has observed the variation of light intensity of LV Her from Feb. 2001 to May 2009. The telescope was stationed on Kimpel Hall at University of Arkansas. Sky flats (frames exposed to a uniform light source) were taken every month to minimize the distortion of the CCD sensor. G. Torres provided the radial velocity data in 2007 (priv. comm.).

Modeling: By recognizing the pre-determined pattern on each image (Fig.1), application *Multimeasure* measures the magnitudes of the comparison and variable stars on approximately 7,000 images regardless of the change in stars' position throughout the seasons.

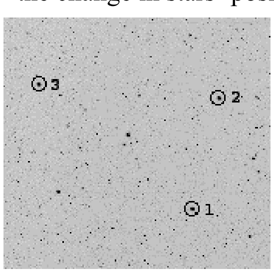


Fig.1: Light source 1 is LV Her, 2 and 3 are two comparison stars. Two comparison stars are used to accurately measure the light variation of a dim star like LV Her. This method is called differential photometry. The difference between the magnitudes of the comparison stars and the magnitude of LV Her is plotted against orbital phase. This results in a plot called the light curve. (Fig.2)

Applications *Multiminima* and *Dates of Minima* determine the orbital period to be 18.43595 days. *Multiminima* finds the center of symmetry in order to determine the minima of the light intensity and the corresponding times of minima (Kwee and van Woerden [2]). Two secondary minima and four primary minima are obtained. With other primary minima obtained by Hubscher[3] and Brat[4], *Dates of Minima* is able to determine the period by exploiting the fact that any harmonics (2, 3, 4, etc.) of the true orbital period will appear to fit the differences between each of the six dates of primary minima.

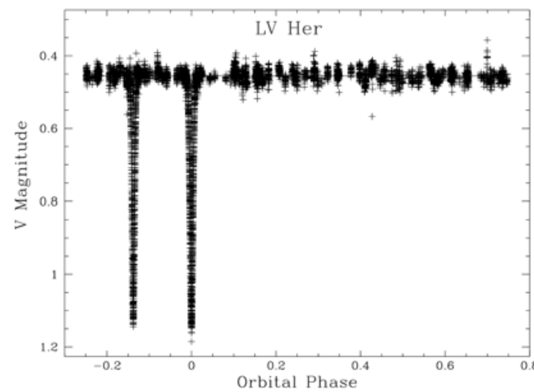


Fig.2: Light Curve of LV Her. Secondary Minima is around phase -0.14 due to high orbit eccentricity.

Application *GLSPL* uses general least square method to fit the radial velocity curve to the spectroscopic data. Using the fitting results such as the eccentricity and longitude of periastron, we proceed to fit the light curve to the photometric data using *EBOP* (Nelson and Davis [5]). The gravitational darkening coefficient used in the fit is obtained from Claret [6]. The final calculation of the absolute dimensions is carried out by application *MRLCALC.* The distance of LV Her to the Sun, calculated using the absolute magnitude (see Result section) and the apparent magnitude [7], is 1147.14 light-years (with 5% uncertainty).

In the first attempt of determining temperature, we use the Strömgren color obtained by Hilditch and Hill [8], confirmed later by Popper's spectral analysis [9] that LV Her should be between spectral class F8 and G0. According to Popper's relation [10] between spectral class and temperature, we calculate the temperature for F9. However, since the uncertainty was taken as the temperature difference between F9 and the adjacent types F8 and G0, which is very big, the prediction on the age of LV Her based on the stellar evolutionary model was very crude (Fig.3). Also, after realizing that for the stars a thousand light-year away from us, the interstellar reddening will have visible effect on the observed magnitudes, we wished to refine the temperatures of LV Her accordingly. This motivates us to use color indices directly in our second attempt, with data obtained from three recent surveys: the Amateur Sky Survey (TASS), the Two Micron All Sky Survey (2MASS) and the Hipparchos Catalogue (TYCHO). To implement these data we first convert color systems Tycho [11] and Strömgren [12] used in TYCHO and Hilditch&Hill data to Johnson system (BVRIJHK), then we "guess" a reddening for the B-V color, and use the reddening relations [13] to adjust other filters (R-I, J-H, J-K) to corresponding magnitudes, until our guess can line up all the colors to those predicted by the model atmosphere study of Bessell and Kurucz [14]. To obtain a more accurate temperature, we interpolate between colors of 6000K and 6250K, the color table of which has been modified to match the corresponding surface gravities (Table.1) of the two stars.

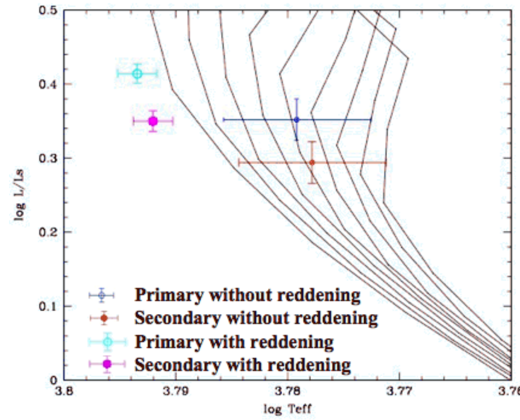
Results and Discussion: The temperature for primary is 6214.89K and secondary 6195.13K, each with an uncertainty of 25K

Parameters	Prim.	σ	Sec.	σ
Mass (M☉)	1.191	0.015	1.165	0.011
Radius (R☉)	1.388	0.018	1.298	0.018
Log L	0.414	0.013	0.358	0.014
Abs. Mag. (M)	3.84	0.08	4.01	0.08
Log g	4.229	0.011	4.277	0.012

Table 1. The absolute dimensions of LV Her

With known luminosity, we are able to plot the two stars on an H-R diagram, and compare them to Y2 Isochrones [14], a current stellar evolutionary model with α-element enhancement in the stellar model and convective core overshoot treatment. Since components of the binary system must be born at the same time, we expect that a successful stellar evolutionary model should predict two stars of LV Her to have the same age, i.e. that they should overlay on top of the same isochrone(s)/track(s). Isochrones are plots of on the H-R diagram at constant time across all masses. Y2 Isochrones also features a FORTRAN interpolator, which enables us to use SM (Super Mongo) to plot and visualize our results. We first estimate the age of LV Her using Claret's evolutionary model [16] based on the temperatures obtained from spectral class, to be around 3 to 4 billion years old. However, after the adjustment due to interstellar reddening, the intrinsic color of the stars should be bluer than what is observed, i.e. the intrinsic temperature of LV Her should be higher. This results in a large shift of about a billion years younger. (Fig. 3, 4). As a conclusion, within the observational uncertainties, we are unable to reject the Isochrones theory using LV Her's data.

Fig.3 The positions of the stars on the H-R diagram



Y2 before and after interstellar reddening is considered. The tracks (isochrones) from right to left are of 4.52, 4.32, 4.12, 3.92, 3.72, 3.52, 3.32, 3.12, 2.92 billion years. Both stars are near the 3.72Ga track.

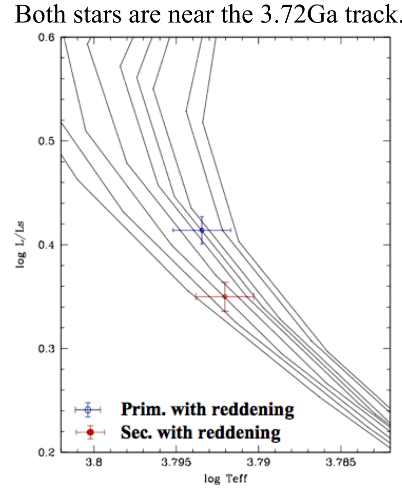


Fig.4 The tracks from right to left are of 2.87, 2.82, 2.72, 2.67, 2.62, 2.52, 2.42, 2.32, 2.22 billion years, with primary on the 2.67Ga track, and secondary on the 2.42Ga track.

References: [1] Latham, D. W.; Mazeh, T.; Stefanik, H. P.; Davis, R. J.; Carney, B. W.; Torres, G.; Laird, J. B., (1992) *Spectroscopic Binaries in the Halo,* in Vol. 32, *Complementary Approaches to Double and Multiple Star Research, IAU Colloquium* p.135 [2] 1956BAN....12..327K[3]2005IBVS.5643....1H[4] 2007OEJV...74....1B [5] 1972ApJ...174..617N [6] Claret, A. (1998) A&AS, **131**, 395 [7] 1971GCVS3.C......0K [8]1975MmRAS..79..101H [9] 1996ApJS..106..133P [10] Popper, D. (1980), Annual Reviews of Astronomy &Astrophysics, **18**, [11] 1151985ApJ…288..618R [12] 2006AJ....131.2360M [13] 1990PASP..102.1331T [14] 1998A&AS...333..231B [15] Demarque, Woo, Kim, & Yi 2004, ApJS, **155**, 667 [16]1992A&AS...96..255C