Single Channel UBV and JH Band Photometry of Epsilon Aurigae

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Abstract

Epsilon Aurigae is the longest known eclipsing binary star system, with a 27.1 year period. The next eclipse begins in 2009. While many observatories make observations during the eclipse, few have maintained an observing program between eclipses. As seen with the last eclipse, there are some very interesting pre and post eclipse light variations. There is evidence for periodic variations between eclipses, possibly pulsations of the primary F star. The Hopkins Phoenix Observatory made single channel UBV photon counting observations during the last eclipse and for several years thereafter. In 2003 a concentrated observing effort was resumed and recently infrared bands J and H have been added. The intent of these observations is to provide out-of-eclipse data on the system in preparation for the 2009 - 2011 eclipse. This paper will summarize current activity, present out-of-eclipse data and provide analysis of the data.

Introduction

The Hopkins Phoenix Observatory has been observing epsilon Aurigae in the UBV bands since early 1982 including detailed coverage during the 1982-1984 eclipse[1]. Observations continued through 1988 and resumed in the fall of 2003[2]. At the end of 2005 infrared bands JH were added to the observing program. This work complements new spectroscopy and space infrared observations now underway, to be reported elsewhere.

Epsilon Aurigae (HR1605)

Epsilon Aurigae (Vmax = 2.99) is the longest period eclipsing binary known with a period of 27.1 years. The next eclipse is due in 2009. The exact nature of this system is still not fully resolved. With such a long period the actual eclipse would be expected to be short, but is just the opposite – lasting nearly 2 years. This means the eclipsing body is gigantic - by some estimates over 2,000 solar radii making it a contender for the largest object known. What is even more intriguing is that during the middle of the eclipse there is an eclipse brightening. There appears to be a hole in the center of this object. To add to the mystery the secondary object does not appear to have a spectrum of its own. Only the primary star's spectrum can be seen. During the eclipse the system's light is reduced the same at all wavelengths. It is as if there is a giant neutral density filter with a hole in the middle is passing in front of the primary star.

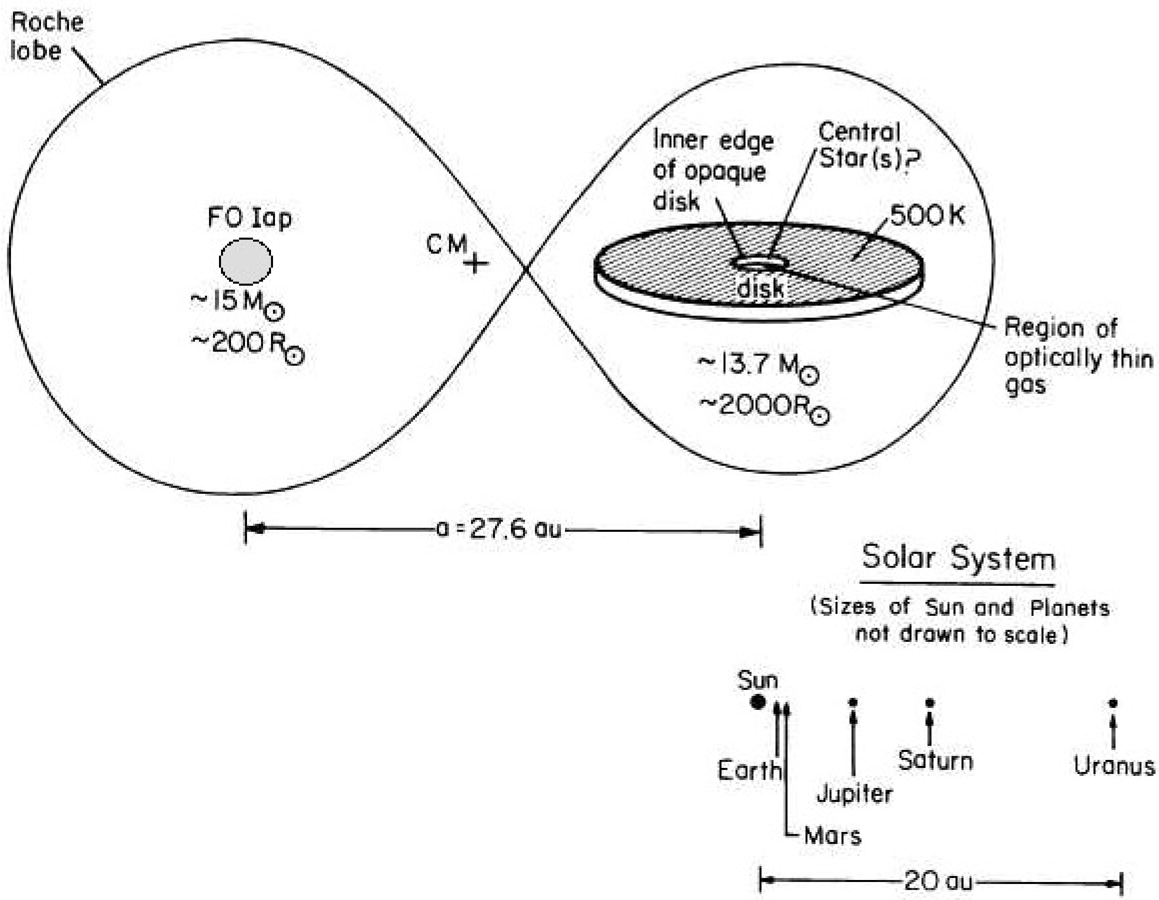

Figure 1 Epsilon Aurigae System Schematic (Carroll et. al.1991 Ap. J. 367: 278)

Hopkins Phoenix Observatory Photometry Equipment

UBV Photometry Equipment

The UBV photometry used an HPO photon counting photometer with a 1P21 photomultiplier tube with standard filters and 8" Celestron Schmidt Cassegrain C-8 telescope. For improved tracking the C-8 has been adapted to a Meade LX-90 fork mount. In the fall of 2004 a Meade 8" LX-90 was to replace the C-8. It was discovered that the LX-90 OTA produced 50% fewer counts in the U band than the C-8. Since the C-8 OTA is fine, it was decided to just adapt it to the newer LX-90 mount. The system has been calibrated using standard stars.

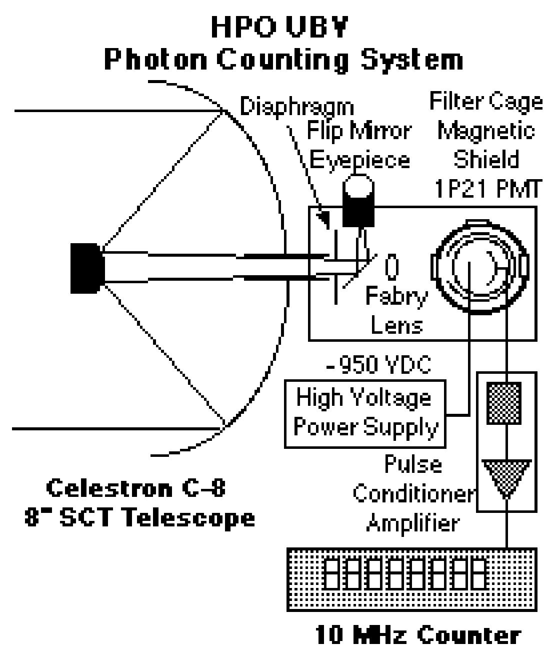

Figure 2
HPO UBV Photon Counting System

Figure 3
HPO UBV Equipment

Figure 4
UBV Equipment Detail

JH Photometry Equipment:

JH photometry was done using an Optec SSP-4 (see Figure 5) solid state photometer with a 0.3 mm InGaAs 2-stage thermoelectric cooled photodiode detector. Normal operating temperature for the detector is -40 degrees. The photometer is mounted on a Meade 12" LX200GPS telescope (see Figure 6). The system is auto guided with an Orion 80 mm f/11.4 guide telescope attached to the LX200 and uses a Meade Deep Sky Imager Pro CCD camera and AutoStar software for the guiding. Because of the small detector area, precise centering of the star is essential for consistent readings. It was found near impossible to do without the auto guiding. If continued observational data do not provide a better data spread, the 0.3 mm detector may need to be replaced with the large 1.0 mm detector.

Filter Specifications:
J Band - Central Wavelength 1250 nm
FWHM 200 nm
H Band - Central Wavelength 1650 nm
FWHM 300 nm

Photodiode Specification:
Hamamatsu G5851-203 PIN Diode
Active area 0.3 mm with two-stage thermoelectric cooler (maximum cooling to -40 degrees F)
Spectral sensitivity: 1000 nm to 2100 nm, peaking at about 1900 nm.

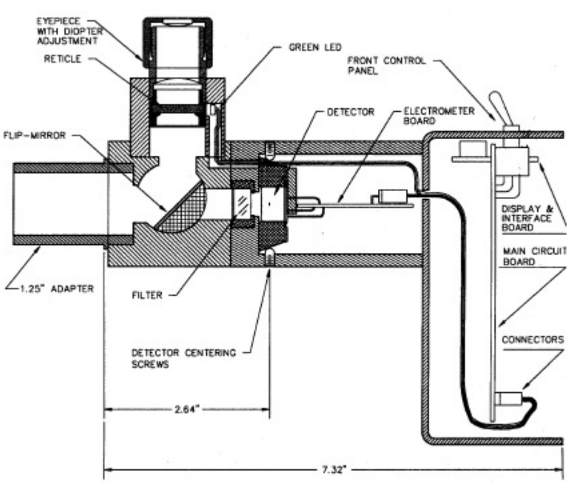

Figure 5 SSP-4 Cross-sectional View

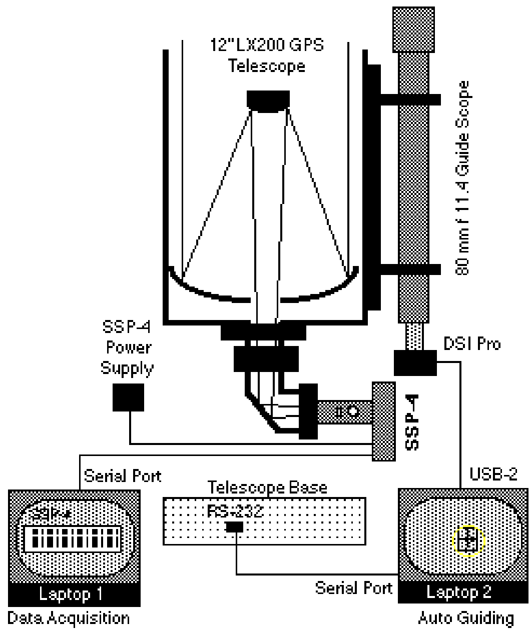

Figure 6
HPO JH Band Photometry System Block Diagram

Figure 7
HPO JH Equipment

Figure 8

Hopkins Phoenix Observatory Observations

While the Hopkins Phoenix Observatory has been observing epsilon Aurigae in the UBV bands since the early 1980's including through the last eclipse. Infrared J and H band observations have recently been added to the program due to the availability of the Optec SSP-4.

Typical observations, which include both the UBV and JH band observations, of a star consisted of 3-10 second readings of each star (star + sky) in each band followed by 1-10 second reading of the sky adjacent to the star in each band. Because of the poor signal-to-noise ratio in the JH bands, 3-10 second readings of the sky in each filter were done instead of the single sky reading as with the UBV photometry. A gain of 100 was used for the JH readings.

All observations were made using differential photometry with the sequence of comparison, program, comparison, program, comparison, program and comparison star as the last star measured. Initial data reduction adjusted for dead time for the photon counting data, for counts per second and adjusted to unity gain for the J and H band data.

A database program developed with FileMaker Pro was used to reduce and archive the data.

Data reduction procedure consisted of:

Three consecutive 10 second star observations for each band entered.
Corresponding sky data entered.
Data averaged.
Sky readings subtracted.
This constitutes one set of readings for each star.
Comparison star has 4 sets.
Program star has 3 sets.
Air mass of each the observations was calculated.
The air mass for the middle observation was used as the air mass for the final data point.

Data were then transferred into another part of the database program, converted to magnitude data and adjusted for extinction and color coefficients.

Three differential readings were then calculated referenced to the comparison star.

Three resulting values for each band were then averaged and a standard deviation determined as an indication of the data spread.

The results were then normalized to the comparison star's published value. The resulting reduced data were then archived.

Typical UBV data have standard deviations of better than 0.01 magnitudes and often approach 0.001 magnitudes or better. The J and H band data have a less favorable signal to noise ratio and typical standard deviations are 0.2 magnitudes.

Observing seasons for epsilon Aurigae at the latitude of the Hopkins Phoenix Observatory (33 degrees north) begins late summer and runs through April. However, because of the weather extreme in the summer in Phoenix, Arizona, summer observations are limited due both to seasonal storm activity and observatory temperatures that can exceed 100 degrees F at midnight.

Sample Data

A complete set of UBV data from the fall of 2003 through the current season as well as 1980's data is available from HPO. Recent JH infrared and corresponding temporal UBV data for 2006 are shown in Tables 1 and 2.

The comparison star used for both UBV and JH data was lambda Aurigae (HR1729). Lambda Aurigae magnitudes used

U = 5.46
B = 5.34
V = 4.71
J = 3.62
H = 3.33

HPO JH Infrared Data

JD	X	J	#	SD	H	#	SD	(J - H)
March 2006								
2453811.66	1.3489	1.777	3	0.040	1.525	3	0.139	0.253
2453808.62	1.1519	1.728	3	0.044	1.403	3	0.055	0.325
2453807.62	1.1626	1.921	2	0.074	1.524	2	0.140	0.397
2453802.59	1.0394	1.830	3	0.267	1.399	3	0.502	0.430
2453799.59	1.0339	1.695	3	0.234	1.279	3	0.345	0.416
2453798.61	1.0479	1.909	3	0.204	1.601	3	0.347	0.307
2453797.59	1.0314	1.858	3	0.169	1.222	3	0.289	0.636
February 2006								
2453790.59	1.0189	1.719	3	0.145	1.301	3	0.225	0.418
2453788.59	1.0171	1.824	3	0.099	1.572	3	0.120	0.251
2453786.59	1.0167	1.826	3	0.010	1.420	3	0.086	0.406
2453784.65	1.0574	1.895	3	0.032	1.597	3	0.139	0.297
2453781.62	1.0218	1.632	3	0.103	1.109	3	0.051	0.523
2453780.58	1.0217	1.983	3	0.352	1.790	3	0.033	0.193
2453779.62	1.0196	1.886	3	0.012	1.762	3	0.108	0.124
2453777.62	1.0189	1.740	3	0.375	1.432	3	0.921	0.307
January 2006								
2453767.68	1.0327	1.850	3	0.023	1.565	3	0.042	0.285
2453766.65	1.0168	1.770	3	0.140	1.356	3	0.253	0.414
2453763.67	1.0243	1.832	3	0.122	1.483	3	0.156	0.349
2453759.63	1.0288	1.853	3	0.021	1.409	3	0.095	0.443
2453758.67	1.0187	1.883	3	0.093	1.615	3	0.155	0.238
2453756.68	1.0193	1.783	3	0.024	1.443	3	0.097	0.340
2453742.70	1.0202	1.705	1		1.476	1		0.228
2453741.70	1.0173	1.843	3	0.377	1.526	3	0.737	0.317
December 2005								
2453734.60	1.2297	1.760	3	.062	1.483	3	0.286	0.277

Table 1 Epsilon Aurigae JH Band Photometric Data

HPO UBV Data

JD	X	V	#	SD	B	#	SD	U	#	SD`	B - V	U - B
March 2006												
2453818.63	1.2055	3.011	3	.004	3.590	3	.007	3.712	3	.007	.579	.122
2453815.61	1.1206	3.009	3	.002	3.581	3	.002	3.697	3	.005	.572	.116
2453813.61	1.1026	3.013	3	.001	3.582	3	.002	3.700	3	.005	.570	.118
2453812.62	1.1059	3.005	3	.005	3.575	3	.002	3.693	3	.004	.570	.118
2453811.63	1.1376	3.005	3	.004	3.572	3	.005	3.692	3	.004	.566	.121
2453810.72	1.6232	3.004	3	.002	3.588	3	.005	3.662	3	.010	.584	.075
2453808.61	1.0665	3.014	3	.003	3.588	3	.005	3.705	3	.003	.575	.116
2453807.60	1.0579	3.015	3	.003	3.579	3	.004	3.701	3	.007	.565	.122
2453802.64	1.1006	3.025	3	.003	3.587	3	.007	3.703	3	.006	.562	.116
2453799.65	1.1156	3.023	3	.004	3.596	3	.003	3.717	3	.001	.574	.121
2453798.65	1.1026	3.029	3	.004	3.609	3	.012	3.720	3	.008	.579	.111
2453797.64	1.0811	3.026	3	.016	3.595	3	.021	3.691	3	.049	.569	.097
February 2006												
2453791.68	1.1289	3.045	3	.003	3.638	3	.004	3.748	3	.010	.583	.120
2453790.64	1.0511	3.047	3	.008	3.618	3	.005	3.757	3	.009	.571	.139
2453788.63	1.0331	3.060	3	.003	3.633	3	.005	3.763	3	.005	.573	.130
2453786.63	1.0232	3.067	3	.002	3.647	3	.001	3.786	3	.004	.580	.139
2453784.71	1.1682	3.077	3	.007	3.651	3	.001	3.784	3	.005	.575	.133
2453781.67	1.0536	3.089	3	.001	3.669	3	.005	3.812	3	.007	.580	.143
2453780.63	1.0196	3.083	3	.006	3.653	3	.009	3.801	3	.010	.570	.148
2453779.68	1.0578	3.092	3	.007	3.670	3	.004	3.810	3	.006	.578	.140
2453777.69	1.0644	3.061	3	.002	3.672	3	.004	3.798	3	.009	.581	.126
January 2006												
2453767.66	1.0165	3.086	3	.002	3.658	3	.003	3.788	3	.004	.572	.130
2453766.72	1.0760	3.082	3	.004	3.652	3	.011	3.778	3	.003	.570	.126
2453763.72	1.0568	3.061	3	.005	3.603	3	.006	3.743	3	.013	.542	.140
2453758.73	1.0433	3.057	3	.002	3.611	3	.003	3.729	3	.003	.554	.118
2453759.68	1.0167	3.070	3	.014	3.624	3	.012	3.745	3	.014	.554	.121
2453757.72	1.0358	3.060	3	.007	3.617	3	.006	3.725	3	.003	.557	.108
2453756.74	1.0553	3.043	3	.005	3.598	3	.008	3.707	3	.001	.555	.109
2453752.71	1.0205	3.033	3	.003	3.581	3	.001	3.691	3	.009	.548	.110
2453751.73	1.0276	3.020	3	.006	3.567	3	.010	3.673	3	.010	.547	.106
2453746.72	1.0172	3.017	3	.010	3.567	3	.003	3.673	3	.005	.550	.106
2453745.72	1.0171	3.011	3	.003	3.558	3	.007	3.657	3	.008	.547	.099
2453744.73	1.0175	3.009	3	.005	3.554	3	.009	3.666	3	.007	.545	.112
2453742.74	1.0214	3.018	3	.002	3.560	3	.002	3.662	3	.005	.542	.102
2453741.69	1.0354	3.020	3	.006	3.567	3	.006	3.670	3	.006	.547	.103
2453740.73	1.0166	3.021	3	.002	3.568	3	.010	3.661	3	.003	.547	.093
December 2005												
2453734.73	1.0200	3.022	3	.005	3.587	3	.006	3.705	3	.000	.565	.008

Table 2 Epsilon Aurigae UBV Band Photometric Data

Data Plots

Plots of V data for the 2004/2005 and 2005/2006 observing seasons are shown in Figures 9 and 10 respective.

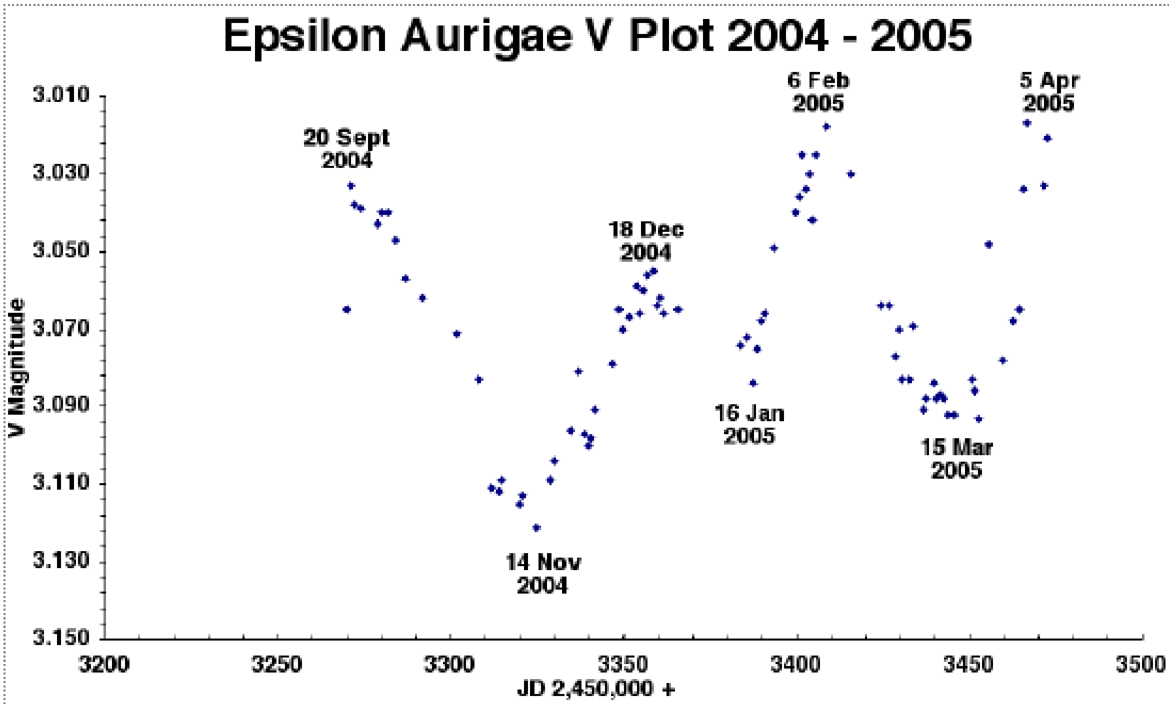

Figure 9 V Band Data Plot for the 2004 - 2005 Observing Season

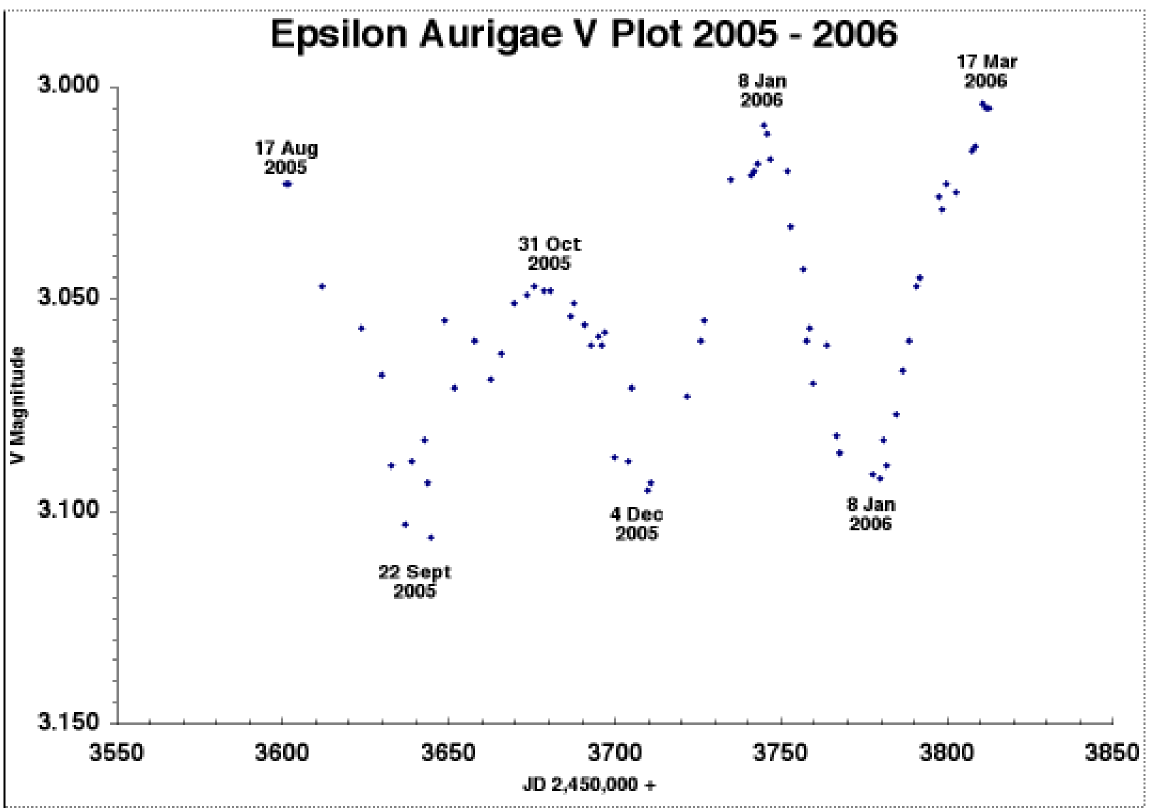

Figure 10 V Band Data Plot for the 2005 - 2006 Observing Season

A set detailed plots for V and B - V data that correspond to the recent JH data acquisition are shown in Figures 11 and 12. This covers the period JD 2,453734 through 2,453818.

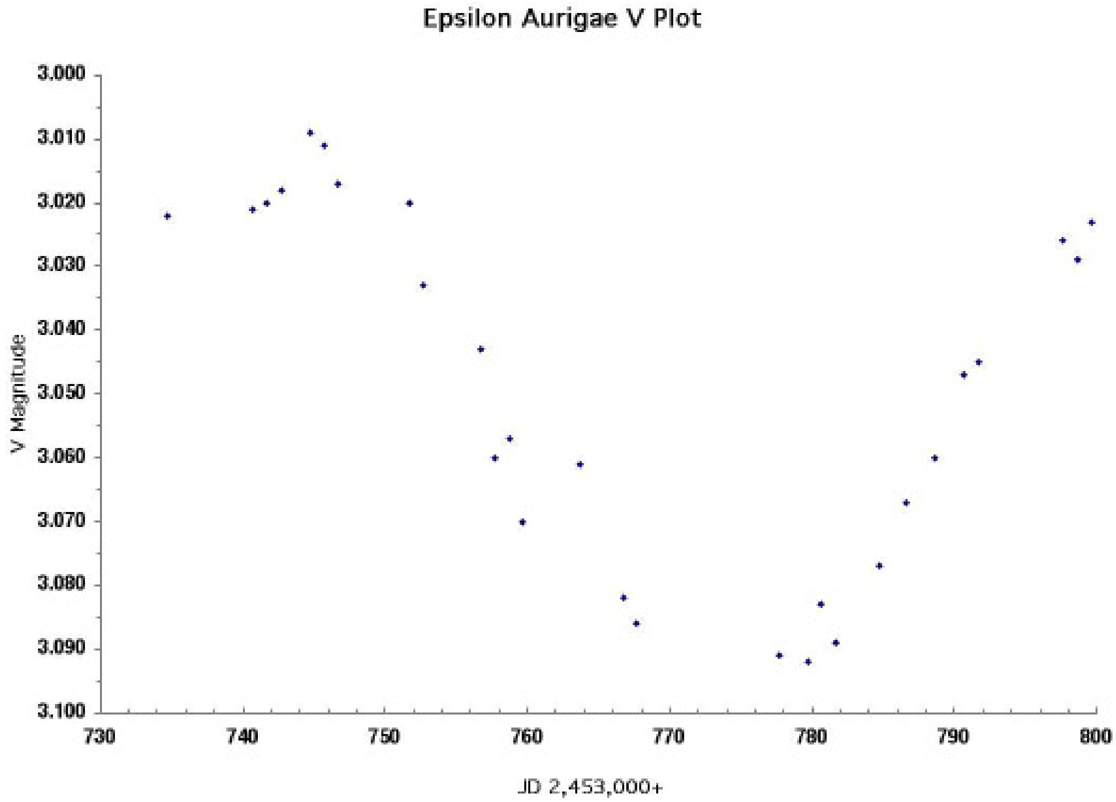

Figure 11 V Band Data Plot

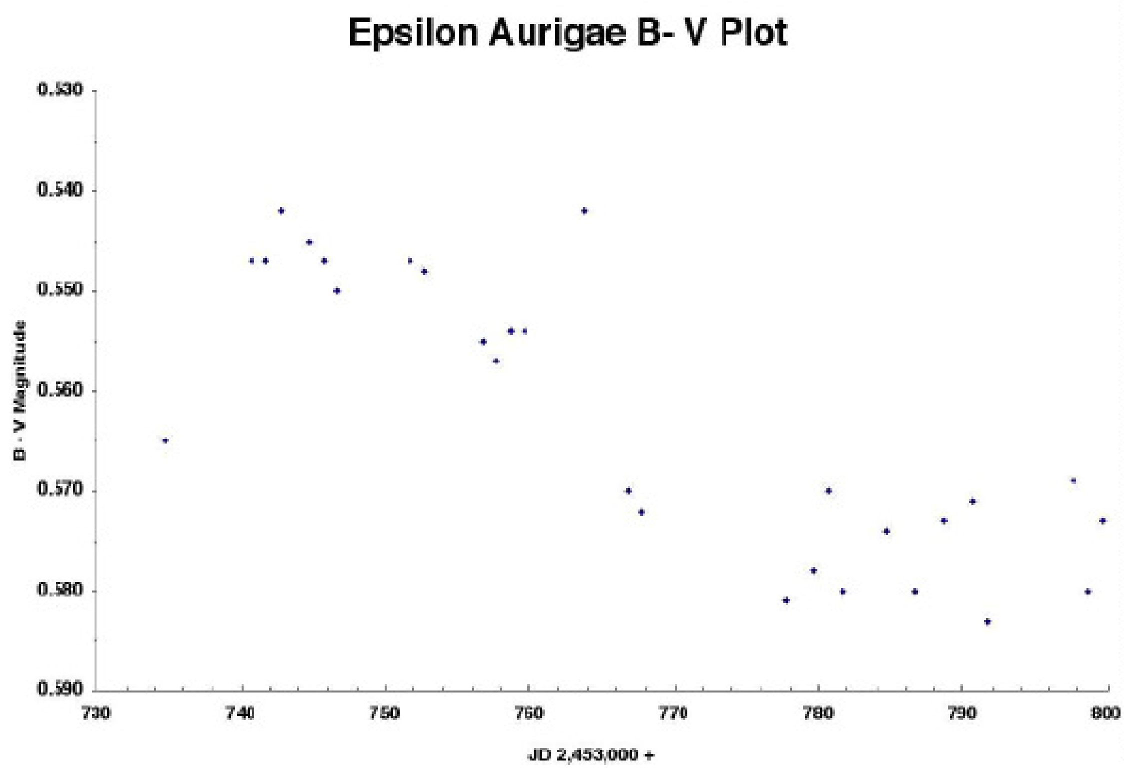

Figure 12 B- V Data Plot

A set detailed plots for JH data t shown in Figures 13 and 14. This covers the period JD 2,453734 through 2,453811.

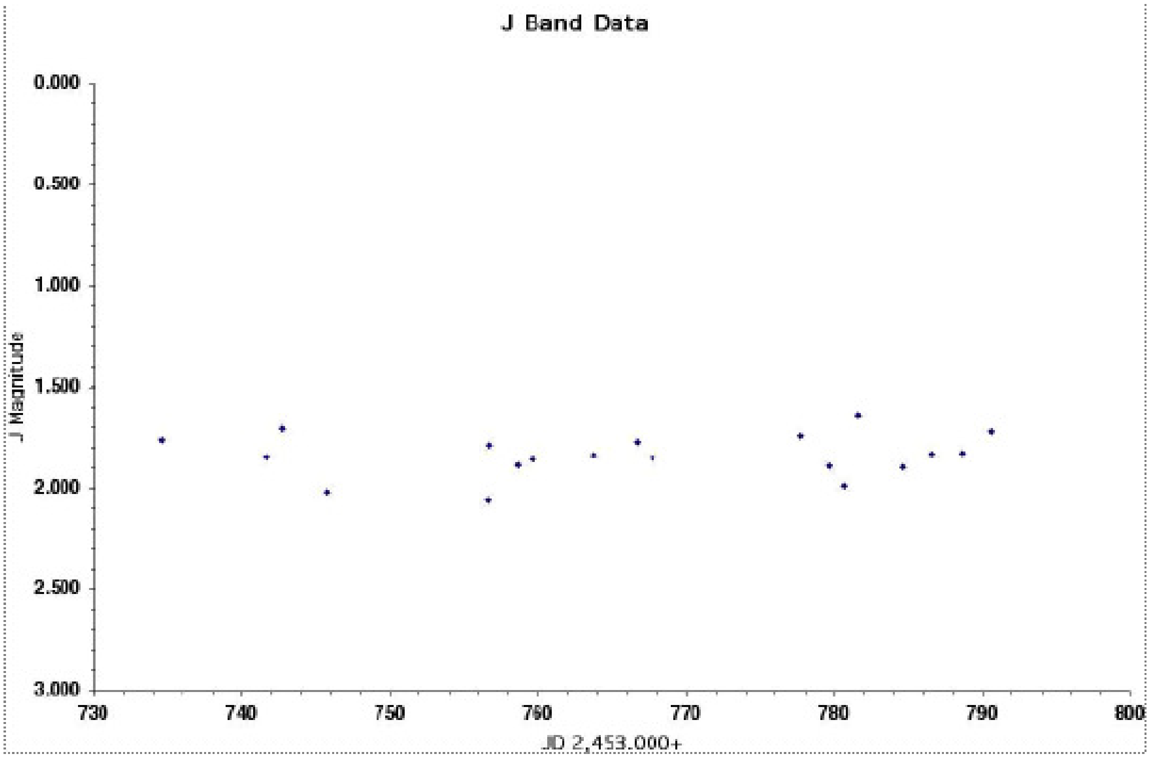

Figure 13 J Band Data Plot

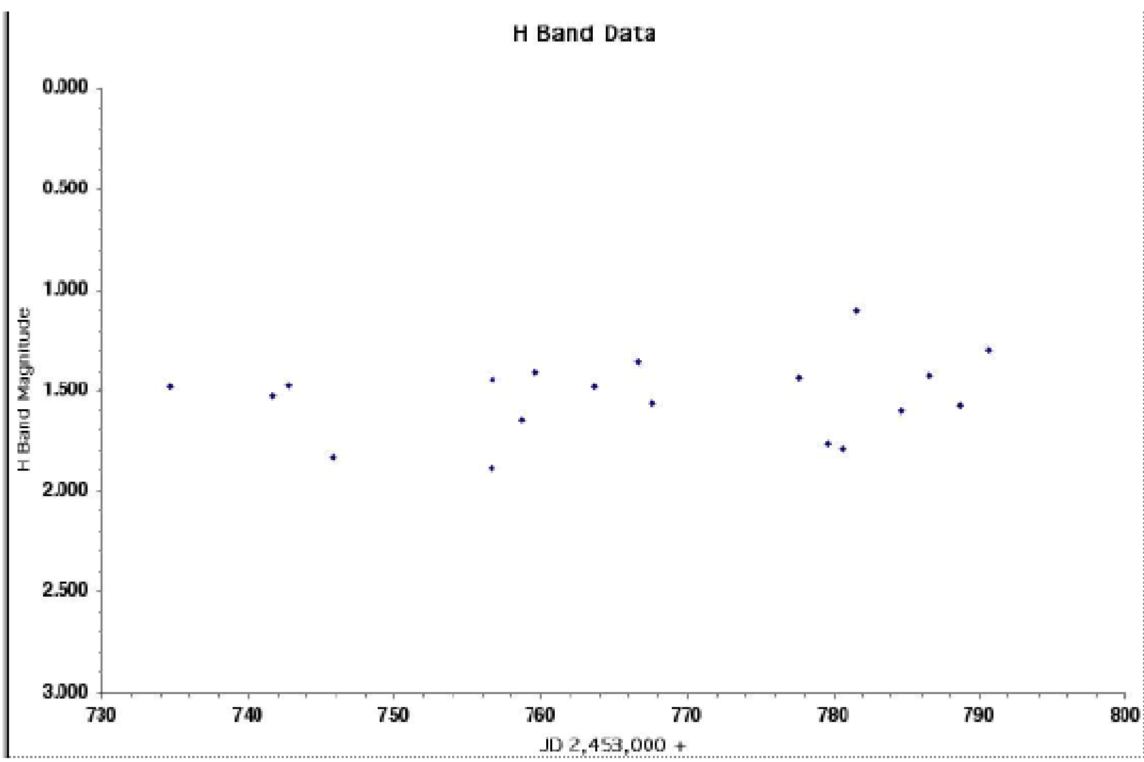

Figure 14 H Band Data Plot

A frequency domain plot is shown in Figure 15 using V data from the year 2003 - 2006 (as of April 2006). The plots were generated using Persano Light Curve and Period Analysis Software[4]. A major period is shown at 66.2006 days.

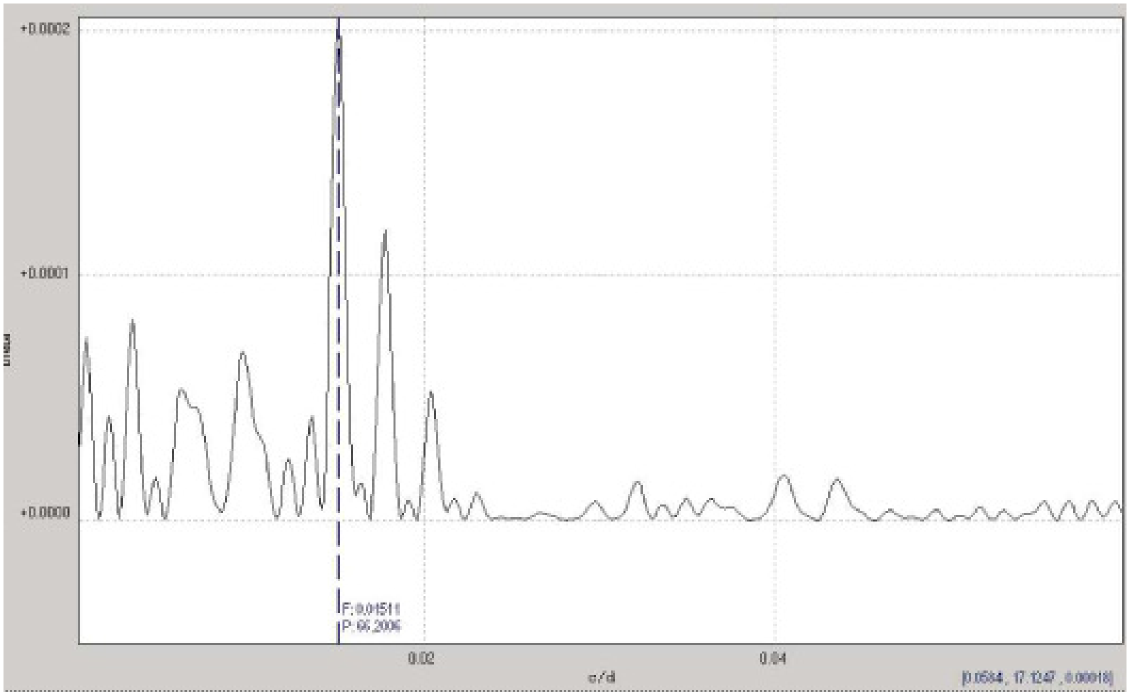

Figure 15 A Frequency Domain Plot of the V data for 2003 - 2006 * Cursor is at 66.2006 days

Analysis

From the photometry presented here, we can provide the following statements. The mean V magnitude was 3.05 with a variation range of 0.132 magnitude and a basic period of 66.2 days (see Figure 15). The pulsations appear to show a step like action starting lower, the next step higher and finally a highest step (see Figures 9, 10 and 11). A couple of more season of observations should show this in better detail.

Mean B magnitude is 3.625 with a variation of 0.175 magnitude and similar period (see Figure 12). Mean U band is 3.725 with a variation of 0.35 magnitude and similar period (see Figure 13). The B-V and U-B colors range from 0.54 to 0.58 magnitude and 0.10 to 0.14 magnitude respectively, corresponding to F8 supergiant colors[3] (see Figures 14 and 15). These colors are significantly redder than the canonical F0 I spectral type assigned epsilon Aurigae[5] and may represent spectral evolution during the 20th century. For comparison, see the Hopkins web report for post-eclipse UBV and color values [1986-88][6].

We are fortunate to be receiving contributed data from observers following the optical spectrum [especially H-alpha, L. Schanne and D. Mais], the near infrared spectrum [MIMIR, D. Clemens and R. Stencel] and far infrared data [Spitzer infrared space telescope, R. Stencel et al]. Correlations of the strength of the hydrogen recombination emission lines, seen in these spectra, with the optical variation will be closely studied.

Conclusions

Photometry will continue in the UBV bands with IR bands to be added. Data in the JH bands will also continue with hopes of being able to get more consistent data using a larger detector with the SSP-4. Partners in monitoring the coming eclipse are welcome to join in [see next paper by Lucas et al].

Acknowledgments

The Hopkins Phoenix Observatory wishes to thank Dr. Stencel for his help and encouragement for this project. This research also was supported in part by an astronomy bequest from William Herschel Womble to the University of Denver.

References

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4. http://users.skynet.be/fa079980/peranso/index.htm

5. Carroll et al. 1991 Astrophys. J. 367: 278.

6. http://www.hposoft.com/Astro/PEP/EAur82-88.html