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PHOTOMETRY OF ALPHA Ori (BETELGEUSE), GAMMA Ori, AND PHI-2 Ori

We present photometry of Betelgeuse with respect to two comparison stars, Gamma Ori (V=1.64, B-V=-0.22) and Phi-2 Ori (V=4.09, B-V=0.95, Johnson et al. 1966, Table 9). Previous data has been published by Krisciunas (1986, and references therein). For V-band data reduction we adopted B-V=1.84 for Betelgeuse, as given by Johnson et al.

Data by Fisher, given in Table I, was obtained at Berwick, Ontario, Canada, using a 20 cm Celestron reflector and an Optec SSP-3 solid state photometer. Transformatiom to the UBV system (determining ϵ_V) was accomplished by differential measurements of 28 and 27 LMi (for which ΔV=0.378, Δ(B-V)=-1.03, Hall 1983). Differential magnitudes with respect to Phi-2 Ori were then added to the known V magnitude of Phi-2 Ori to obtain the V magnitude of Betelgeuse. Fisher's ϵ_V was typically -0.01. A value of V-band extinction of 0.30 mag/air mass was used in the data reduction.

Data by Krisciunas, given in Tables II and III, was obtained at the 2800 m level of Mauna Kea on the island of Hawaii. Krisciunas used a 15 cm f/5.82 Newtonian reflector, an uncooled RCA 931A photomultiplier tube, operated at -1050 V, and UBV filters by Estafilter. His transformation coefficients ϵ_V and μ were obtained from all - sky measurements of UBV standards, typically 9 observations on a given night, but on one occasion 26 observations of 15 stars. Typically ϵ_V ranged from -0.04 to -0.06 but on JD 7205 and 7222 ϵ_V was -0.092 and -0.081, respectively. The average value of μ was 0.940.

On JD 7242 Krisciunas found ϵ_V =-0.060 +/-0.004 from observations of 8 standards. That was followed by 10 differential measurements of 27 vs. 28 LMi, for which ϵ_V =-0.046 +/-0.006. From 6 differential measurements on the same pair on JD 7262 he found ϵ_V=-0.050 +/-0.007. On nights when ϵ_V and μ were not determined, recently determined values were adopted.

Krisciunas also measured the extinction and reddening as often as possible. From observations on 20 nights from September 1985 to April 1988 the median V-band extinction at the 2800-m level of Mauna Kea on nights without cirrus

Table I

Photometry of alpha Ori by Fisher (comp star phi-2 Ori)

Date	Julian Date	V
5/6 Jan 1986	2446436.54	0.666
13/14 Jan 1986	6444.69	0.610
12/13 Feb 1986	6474.54	0.442
29/30 Nov 1986	6764.62	0.542
30 Nov/1 Dec 1986	6765.65	0.539
6/7 Dec 1986	6771.64	0.555
16/17 Jan 1987	6812.60	0.536
25/26 Jan 1987	6821.55	0.531
4/5 Feb 1987	6831.63	0.491
9/10 Feb 1987	6836.61	0.446
14/15 Feb 1987	6841.54	0.465
24/25 Feb 1987	6851.55	0.466

Table II

Photometry of alpha Ori by Krisciunas (comp star gamma Ori)

Date	<UT>	Julian Date	V		B-V		η_V	η_{bv}
11/12 Oct 1986	1158	2446716.00	0.435	± 0.020			3	
29/30 Nov 1986	1047	6764.95	0.544	0.020			3	
21/22 Dec 1986	0839	6786.86	0.531	0.014			4	
27/28 Dec 1986	0830	6792.87	0.543	0.007			4	
21/22 Jan 1987	0932	6817.90	0.562	0.007	1.797	± 0.004	3	3
8/9 Feb 1987	0716	6835.80	0.523	0.014	1.795	0.017	3	3
29/30 Mar 1987	0707	6884.80	0.383	0.024	1.958	0.033	3	3
5/6 Apr 1987	0548	6891.74	0.428	0.011			5	
16/17 Apr 1987	0619	6902.76	0.451	0.010			2	
24/25 Oct 1987	1041	7093.95	0.555	0.005	1.923		3	1
12/13 Nov 1987	0929	7112.90	0.538	0.009	1.857		3	1
27/28 Dec 1987	0829	7157.85	0.610	0.007	1.857		3	1
23/24 Jan 1988	0708	7184.80	0.602	0.005	1.819	0.010	4	2
13/14 Feb 1988	0839	7205.86	0.478	0.021	1.809	0.025	3	3
1/2 Mar 1988	0710	7222.80	0.511	0.008	1.751		3	1
21/22 Mar 1988	0651	7242.79	0.402	0.010	1.869		3	1
10/11 Apr 1988	0614	7262.76	0.396	0.007			3	
16/17 Apr 1988	0625	7268.77	0.385	0.023			3	

Table III

Photometry of alpha Ori by Krisciunas (comp star phi-2 Ori)

Date	<UT>	Julian Date	V		B-V		n_v	n_{bv}
21/22 Dec 1986	0839	2446786.86	0.508 ±	0.008			4	
27/28 Dec 1986	0830	6792.87	0.487	0.007			4	
21/22 Jan 1987	0932	6817.90	0.535	0.017	1.858 ±	0.015	3	3
8/9 Feb 1987	0716	6835.80	0.443	0.005	1.871	0.009	3	3
29/30 Mar 1987	0707	6884.80	0.337	0.005	1.925	0.022	3	3
24/25 Oct 1987	1041	7093.95	0.505		1.989		1	1
12/13 Nov 1987	0929	7112.90	0.482		1.958		1	1
27/28 Dec 1987	0829	7157.85	0.609		1.853		1	1
23/24 Jan 1988	0708	7184.80	0.569	0.004	1.805	0.066	3	2
13/14 Feb 1988	0839	7205.86	0.488	0.009	1.856		3	1
1/2 Mar 1988	0710	7222.80	0.434	0.014	1.790		3	1
21/22 Mar 1988	0651	7242.79	0.408	0.013	1.822		2	1
10/11 Apr 1988	0614	7262.76	0.357	0.011			4	
16/17 Apr 1988	0625	7268.77	0.363	0.011			4	

Table IV

Differential photometry of gamma Ori vs. phi-2 Ori

Date	<UT>	Julian Date	ΔV		Δ(B-V)		n_v	n_{bv}
29/30 Nov 1986	0252	2446764.62	-2.519					
30 Nov/1 Dec 86	0336	6765.65	-2.475					
6/7 Dec 1986	0321	6771.64	-2.510					
Krisciunas data:								
21/22 Dec 1986	0841	6786.86	-2.486 ±	0.008			4	
27/28 Dec 1986	0832	6792.86	-2.513	0.011			4	
21/22 Jan 1987	0927	6817.89	-2.464	0.013	-1.111 ±	0.018	3	3
8/9 Feb 1987	0721	6835.81	-2.519	0.003	-1.097	0.010	3	3
29/30 Mar 1987	0712	6884.80	-2.516	0.016	-1.223	0.024	3	3
24/25 Oct 1987	1053	7093.95	-2.500		-1.109		1	1
12/13 Nov 1987	0943	7112.90	-2.520		-1.065		1	1
27/28 Dec 1987	0848	7157.87	-2.446		-1.173		1	1
23/24 Jan 1988	0723	7184.81	-2.470	0.011	-1.184	0.076	4	2
13/14 Feb 1988	0844	7205.86	-2.444	0.028	-1.092		3	1
1/2 Mar 1988	0710	7222.80	-2.505	0.023	-1.122		3	1
21/22 Mar 1988	0658	7242.79	-2.436	0.012	-1.239		2	1
10/11 Apr 1988	0612	7262.76	-2.484	0.009			3	
16/17 Apr 1988	0623	7268.77	-2.463	0.015			3	

Table V

Mean star color differences

Pair	<Δ(B-V)>		n_{bv}	Johnson et al. value
α Ori - γ Ori	2.061	± 0.016	19	2.06
α Ori - ϕ^2 Ori	0.923	0.015	17	0.89
γ Ori - ϕ^2 Ori	-1.139	0.015	17	-1.17

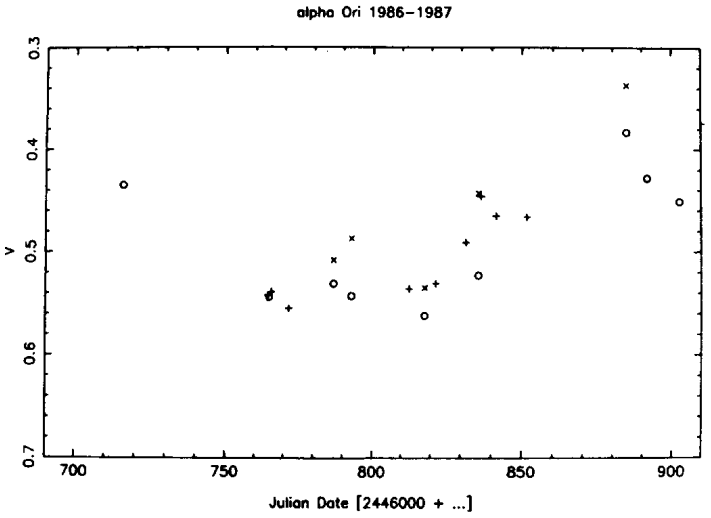

Figure 1. V magnitude of Alpha Ori vs. Julian Date for 1986-1987 observing season. Circles: Krisciunas data using Gamma Ori as comparison star. X's: Krisciunas data using Phi-2 Ori as comparison star. +'s: Fisher data using Phi-2 Ori as comparison star.

is 0.173 mag/air mass. It was assumed that $k''(v)$ was 0.00.

For the data presented here we used a value of $k(v)$ appropriate for the night. For all the B-V color determinations we used the mean coefficients of out-of-atmosphere reddening parameters of:

$k'(bv) = 0.10$;

$k''(bv) = -0.05$.

In Table II we give data on Betelgeuse by Krisciunas, reduced using Gamma Ori as comparison star. Given are the local date/UT date, the mean Universal Time, the geocentric Julian Date, the mean V magnitude, B-V color, and numbers of differential v and b-v observations made. Table III gives

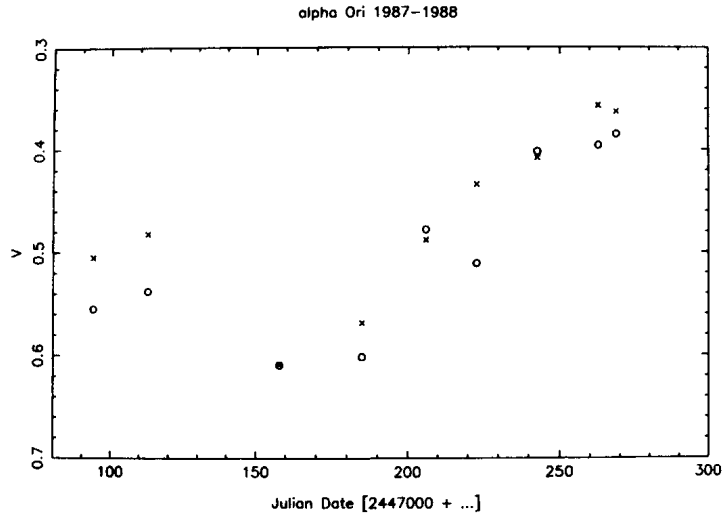

Figure 2: V magnitude of Alpha Ori vs. Julian Date for 1987-1988 observing season. Symbols same as in Figure 1.

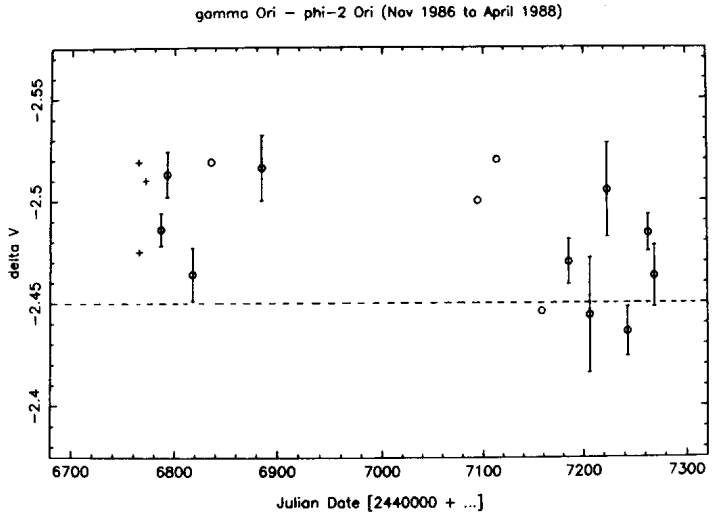

Figure 3: Differential V magnitude for Gamma Ori minus Phi-2 Ori, November 1986 to April 1988. +'s: Fisher data. Circles: Krisciunas data. The dotted line corresponds to data given by Johnson et al. (1966).

Betelgeuse data by Krisciunas, reduced using Phi-2 Orias comparison star. Table IV gives data by both authors on Gamma Ori minus Phi-2 Ori. In Tables II to V the errors quoted are the mean error of the mean, without the uncertainties of gain values, transformation coefficients, or atmospheric parameters folded (i.e., they are internal random errors).

Figure 1 is the V-band light curve of Betelgeuse in 1986-1987. Figure 2 is for Betelgeuse during 1987-1988. Figure 3 shows Gamma Ori minus Phi-2 Ori from November 1986 to April 1988.

Data obtained by Fisher in early 1986 for Betelgeuse is 0.153 magnitudes fainter than values interpolated from data previously published by Krisciunas. Fisher used Phi-2 Ori as the comp star, while Krisciunas used Gamma Ori. The most likely possible sources of error are:

1/ Saturation of Fisher's detector (he used the larger telescope).

2/ Systematic errors in the adopted values of ϵ_V.

3/ Wrong catalog value(s) for comparison star(s).

4/ Variability of comparison star(s).

5/ Systematic errors in adopted gain values for amplifier, given that observations by Krisciunas of Betelgeuse and comparison stars were made on different gains.

Krisciunas recalibrated his amplifier gain steps in the lab and double checked the values using observations of standard stars. If these same gain values were correct for the 1985-1986 observing season, that would make Krisciunas's previously published values from 1985-1986 fainter by 0.057 magnitudes.

We note that photometry of Alpha Ori vs. Phi-2 Ori by Fisher in January and February of 1987 is in excellent agreement with the two points of Krisciunas obtained in those months, using the same comparison star.

Consider the following facts:

1/ Alpha Ori vs. Phi-2 Ori in 1987-1988 shows a relatively smooth light curve.

2/ Alpha Ori vs. Gamma Ori in 1987-1988 shows a relatively ragged light curve.

3/ Gamma Ori vs. Phi-2 Ori from 1986-1988 is ragged.

4/ Other photometry by Stebbins (see Goldberg 1984) indicates that Alpha Ori usually varies smoothly.

This would seem to indicate that Gamma Ori is a "standard" star that is variable. Further, Krisciunas finds that all-sky photometry of Phi-2 Ori gives values

not statistically significantly different than V=4.09, while Gamma Ori has shown standardized values up to 0.07 brighter than its catalog value. (However, Gamma Ori is usually the bluest star observed, and it is assumed that the V-band transformation is linear.)

Given our list of 5 sources of error above, we feel that numbers 1, 2, and 5 are under control. Gamma Ori, of spectral type B3 III, could be a Beta Cephei star, and seems variable. Phi-2 Ori, of spectral type KO III, is not suspected to be variable.

Finally, a word about B-V colors. Table V gives mean color differences between pairs of stars, obtained from observations when the stars were high in the sky, so as to minimize the effect of the k" (bv) term. There is considerable scatter of the nightly means given in Tables II, III, and IV. We do not believe these variations are due to actual color variations versus time. The scatter comes from star centering, filter positioning, possible systematic errors in the adopted value of μ, and possible variations of $k'(bv)$ and $k''(bv)$.

KEVIN KRISCIUNAS

Joint Astronomy Centre
665 Komohana Street
Hilo, Hawaii 96720 USA

DAVID FISHER

Geophysics Institute
Haraldsgade 6
2200 Copenhagen N., Denmark

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