THE COLORS OF THE BETA CANIS MAJORIS STARS*

D. H. McNamara and A. D. Williams
Berkeley Astronomical Department, University of California
Received July 3, 1954

ABSTRACT

The colors of nine β Canis Majoris stars have been measured. A correlation between the periods and the colors of the stars is clearly indicated for stars with periods <5 hours. For stars with periods in the interval 5–6 hours the color appears to be constant.

I. INTRODUCTION

The β Canis Majoris or β Cephei variable stars form a very compact group with respect to spectral type. The ten stars that are known to belong to this class of variables have been assigned either to spectral type B1 or B2. In spite of the small range in spectral type, McNamara (1953*a*) has presented evidence that indicates the existence of a period-spectrum relationship for this group of stars. The present investigation was undertaken for the purpose of supplementing our knowledge of this relationship with accurate photometric color data. The recent Q method, developed by Johnson and Morgan (1953) from their three-color photometry, provides us with a unique method of overcoming the difficulties of interstellar reddening inherent in the determination of the intrinsic colors of early-type stars. Fortunately, the β Canis Majoris stars fall in the spectral type range in which the Q method is valid. The present discussion is based on colors determined by this method.

II. PHOTOELECTRIC OBSERVATIONS

The photoelectric observations of the β Canis Majoris stars were made on the nights of December 20/21 and December 21/22, 1953, with the Crossley reflector of the Lick Observatory. A description of an amplifier similar to the one used here is given elsewhere (Kron 1952). A 1P21 photomultiplier was used as the light-sensitive unit. The observations were made through three filter combinations; a Corning 9863 (ultraviolet), a Corning 3060 + Schott BG 12 (blue), and a Schott GG 14 (yellow). The effective wave lengths of the photomultiplier-filter combinations are approximately 3550, 4400, and 5420 A. The observations were recorded by means of a Brown recording potentiometer and were corrected for the sky background admitted through the diaphragm (diameter = 40 seconds of arc). The extinction reductions were made by making use of the condition that the colors of the extinction stars must be the same on both nights. The stars selected for extinction standards were: μ Eri, ι CMa, π^4 Ori, γ Peg, β Ari, and 10 Lac. These stars were selected because they are located close to the β Canis Majoris stars and, with the exception of β Ari, have colors almost identical to the variable stars. Although γ Peg is itself a β Canis Majoris star, its use as an extinction star is justified, since color changes with phase are probably negligible as its light-amplitude is only 0.015 mag. (Williams 1954). Following the notation of Johnson and Morgan (1953), the observed colors reduced to outside the atmosphere are given by:

$$C_y = C_{y0} - K_y \sec Z ,$$

$$C_u = C_{u0} - K_u \sec Z .$$

* The observational material presented in this paper was obtained at the Lick Observatory.

No attempt was made to determine the variation of K_y with color, since the stars are very similar in color. The star β Ari, which differs by the greatest amount in color from the other stars, was reduced to no atmosphere with its own yellow color-extinction coefficient.

The internal probable errors for the instrumental colors were computed for the β Canis Majoris stars which were observed several times, and were found to be:

$$\left.\begin{aligned} C_y\text{:p.e.} &= \pm 0.006 \text{ mag.} \\ C_u\text{:p.e.} &= \pm 0.009 \text{ mag.} \end{aligned}\right\} \text{ for one observation.}$$

A single observation consists of two deflections on the recorder.

The observed colors C_y and C_u were related to the $B - V$ and $U - B$ system of Johnson and Morgan by the transformation equations

$$B - V = A_1 + A_2 C_y ,$$
$$U - B = A_3 + A_4 C_u .$$

The five standard stars used to determine the transformation coefficients are listed in Table 1. The stars were given equal weight, with the exception of 10 Lac, which was

TABLE 1

COLORS OF STANDARD STARS

Star	Sp.	C_y	C_u	$(B-V)_{J,M}$	$(B-V)_C$	$(U-B)_{J,M}$	$(U-B)_C$
ι CMa....	B3 II	−0.705	+0.046	−0.07	−0.075	−0.70	−0.703
π^4 Ori....	B2 III	− .790	− .055	− .17	− .162	−0.81	−0.804
10 Lac....	O9 V	− .832	− .304	− .200	− .205	−1.04	−1.051
ν And....	B5 V	− .769	+ .196	− .15	− .141	−0.57	−0.554
β Ari.....	A5 V	−0.495	+0.848	+0.14	+0.140	+0.10	+0.093

given double weight in the solution of the $B - V$ coefficients, since its $B - V$ color is given to three decimals by Johnson and Morgan. From least-square solutions the coefficients were found to be:

$$A_1 = +0.646 \pm 0.013 ,$$
$$A_2 = +1.023 \pm 0.017 ,$$
$$A_3 = -0.749 \pm 0.004 ,$$
$$A_4 = +0.993 \pm 0.010 .$$

The $B - V$ and $U - B$ values were then computed for the standard stars and the β Canis Majoris stars. A comparison between the computed standard star colors and those given by Johnson and Morgan is given in Table 1.

An attempt was made to observe the β Canis Majoris stars near the mean light-positions in their light-curves, since the colors are known to vary with phase in the case of the stars with the larger light-amplitudes (Nikonov and Nikonova 1952; Kraft 1953; de Jager 1953; Walker 1954). BW Vulpeculae was observed near the light-minimum on December 21/22; the observed colors were corrected by −0.015 mag. and −0.040 mag. in the C_y and C_u colors, respectively, to bring them to the mean light-colors. The other stars were observed near the mean light-phases, and therefore no corrections were necessary.

The final results of the observations of the β Canis Majoris stars are given in Table 2. The first column contains the star names, listed according to increasing period. The second column lists the spectral types assigned on the M.K.K. system. The third column contains spectral types assigned on the basis of the color of the stars from the calibration of Q with respect to spectral type, as given by Johnson and Morgan. The fourth and fifth columns contain the periods (in hours) and the observed $B - V$ colors. The sixth column lists the $B - V$ colors for four of the stars, observed by Stoy (1953). The seventh, eighth, and ninth columns contain the observed $U - B$ colors, the values of Q computed by the equation $Q = (U - B) - 0.72\,(B - V)$, and the color excess given by $E_y = (B - V) - 0.337Q + 0.009$ (Johnson and Morgan 1953). The tenth and eleventh columns list the intrinsic $(B - V)_I$ and $(U - B)_I$ colors determined from the Q values. The twelfth column gives the number of observations. The colors listed in Table 2 are given to the nearest 0.005 mag.

TABLE 2

SPECTRAL TYPES AND COLORS OF THE β CANIS MAJORIS STARS*

Star	Sp.†	Sp$_Q$	P	$B-V$	$(B-V)$‡	$U-B$	Q	E_y	$(B-V)_I$	$(U-B)_I$	No.
γ Peg.....	B2 IV	B2	3^{h}64	−0.215	.....	−0.840	−0.685	0.025	−0.240	−0.860	5
δ Cet.....	B2 IV	B2	3.87	− .210	−0.20	− .850	− .700	.035	− .245	−0.875	4
16 Lac.....	B2 IV	B1	4.06	− .145	.....	− .850	− .745	.115	− .260	−0.935	4
ν Eri.....	B2 III	B2	4.16	− .190	− .20	− .860	− .725	.065	− .255	−0.905	4
β Cep.....	B2 III	B1	4.57	− .225	.....	− .945	− .785	.050	− .275	−0.980	3
DD Lac...	B2 III	B1	4.63	− .135	.....	− .860	− .765	.130	− .265	−0.955	4
BW Vul...	B2 III	B1	4.82	− .130	.....	− .870	− .775	.140	− .270	−0.970	3
ξ_1 CMa....	B1 IV	B1	5.03	− .240	− .25	− .980	− .805	.040	− .280	−1.010	6
β CMa....	B1 II–III	B1	6.00	−0.235	−0.23	−0.970	−0.800	0.045	−0.280	−1.000	5

* The colors listed are given to the nearest 0.005 mag.

† M.K.K. spectral types. The spectral type of ξ' CMa was estimated by McNamara from Mills spectrograms on the basis of the classifications supplied by Morgan for the other stars listed.

‡ R. H. Stoy, *Cape Mimeogram*, No. 1, 1953.

III. DISCUSSION

The results given in Table 2 are depicted graphically in Figure 1. With the exception of σ Scorpii, all the known β Canis Majoris stars are shown in the figure. It is evident upon inspection of Figure 1 that there is a well-defined relation between the periods and the intrinsic colors of this group of variable stars. This is in agreement with the results announced earlier (McNamara 1953*a*). Figure 1 indicates that for stars with periods shorter than 5 hours the color is sensitive to the period. Excluding the star β Canis Majoris, we find from least-squares solutions that the colors can be represented by the regression lines

$$Q = -0.390 - 1.974\,P \text{ days},$$

$$(B - V)_I = -0.143 - 0.653\,P \text{ days}.$$

These straight lines are shown in the figure. If we use the first equation to compute the value of Q for β Canis Majoris, we find a value of $Q = -0.88$. Thus β Canis Majoris departs by a considerable margin from an extrapolation of this line to 6 hours. A Q value equal to -0.88 would require a spectral type near B0; β Canis Majoris is an M.K.K. standard of spectral type B1. A star of spectral type B1 should have a Q value near -0.78. Therefore, the observed Q value of -0.800 is in excellent agreement with the spectral type.

Although we have no color observations of σ Scorpii ($P = 5^h55^m$), its spectral type is identical to that of β Canis Majoris, and it would also probably fall off extrapolations

of the lines shown in Figure 1. Dr. A. R. Hogg of the Commonwealth Observatory, Mount Stromlo, has kindly supplied us with preliminary measures of the color of σ Scorpii. His results, which he stresses are subject to revision, indicate $Q = -0.76$; $(B - V)_I = -0.26$; and S_Q = B1. Since the period of σ Scorpii is $5^h.92$, Hogg's Q and $(B - V)_I$ are considerably smaller than would be indicated by an extrapolation of the period-color relationship for shorter-period members of the group. Examination of the spectra of ξ_1 CMa, σ Sco, and β CMa indicate that they are practically identical with regard to line intensities. This can be seen by an inspection of the Mills spectrograms (original dispersion 11 A/mm at $H\gamma$) reproduced in Figure 2. While there is a considerable change in the intensities of a number of lines as we proceed from ξ_1 CMa to a star like 16 Lac, there is little, if any, change between ξ_1 CMa and β CMa, in spite of an equivalent change in period. Thus the observational evidence indicates that the β Canis Majoris stars are restricted to spectral type B1 or later. This result should be accepted only tentatively, in view of the small sample of stars.

It is of interest to note that, for stars with a declination greater than $-40°$ and a magnitude brighter than 7.00, the B0 stars outnumber the B1 stars in the ratio of 2 to 1 (Stebbins, Huffer, and Whitford 1940). This suggests that if the β Canis Majoris stars

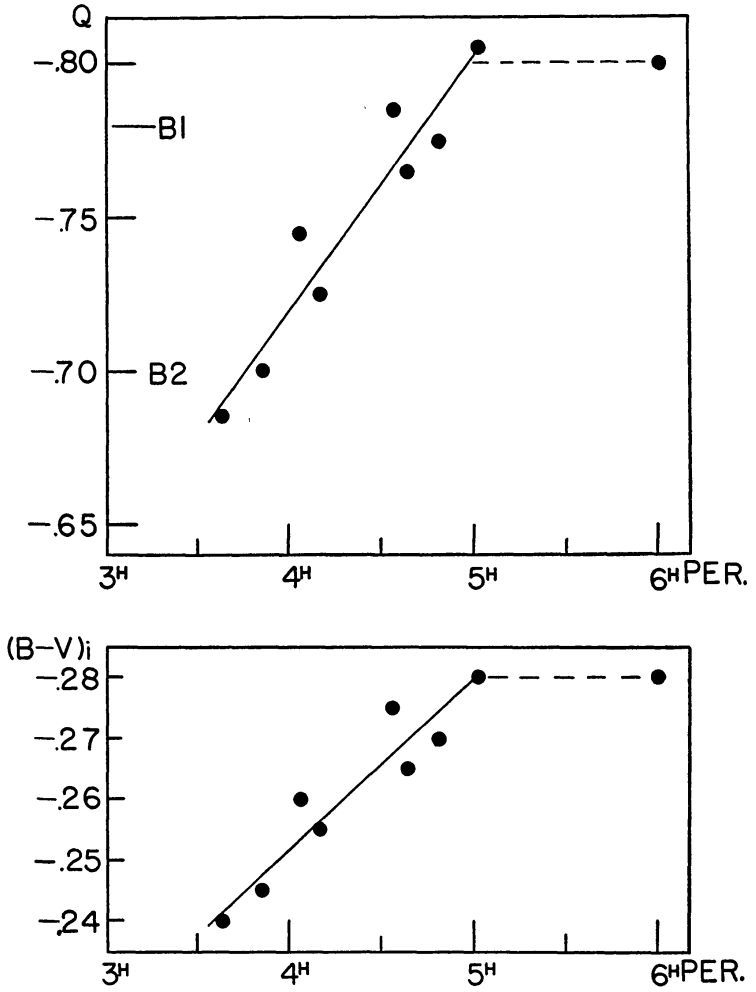

FIG. 1.—Color-period relationship of β Canis Majoris stars. *Upper*, the relationship between Q and period; *lower*, the relationship between the intrinsic $(B - V)_I$ color and the period.

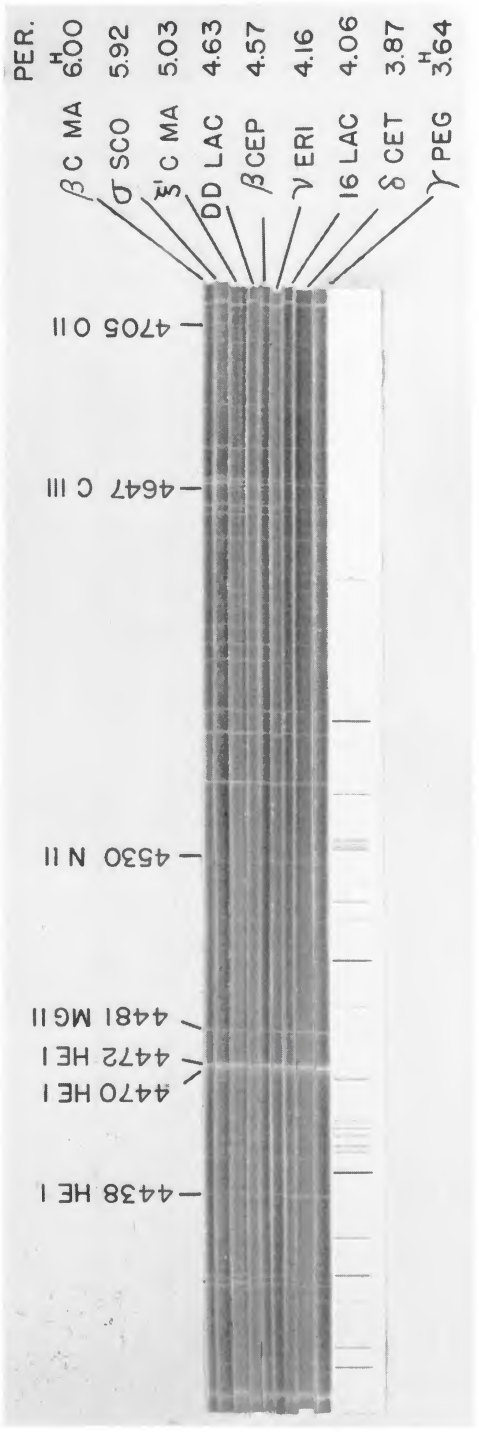

FIG. 2.—Spectra of the β Canis Majoris stars

are present among the B0 stars, it is with a lower frequency that their occurrence among the B1 stars.

This suggested cutoff at spectral type B1 raises some interesting questions regarding the position of the β Canis Majoris stars in the H-R diagram. Blaauw and Savedoff (1953) and also McNamara (1953*b*) have presented evidence favoring the existence of a period-luminosity relation for this group of stars. If the relation is valid through the interval of periods from 5 hours to 6 hours, the β Canis Majoris stars with periods longer than 5 hours would fall on a perpendicular sequence in the H-R diagram.

We wish to express our gratitude to Dr. G. E. Kron for the use of his photometer and for valuable suggestions.

REFERENCES

Blaauw, A., and Savedoff, M. P. 1953, *B.A.N.*, **12**, 69.
de Jager, C. 1953, *B.A.N.*, **12**, 81.
Johnson, H. L., and Morgan, W. W. 1953, *Ap. J.*, **117**, 313.
Kraft, R. P. 1953, *Pub. A.S.P.*, **65**, 45.
Kron, G. E. 1952, *Ap. J.*, **115**, 1.
McNamara, D. H. 1953*a*, *Pub. A.S.P.*, **65**, 155.
———. 1953*b*, *ibid.*, p. 286.
Nikonov, B. V., and Nikonova, E. K. 1952, *Izvestiia Krimskoi Astrophiizicheskoi Observatorii*, **9**, 135.
Stebbins, J. Huffer, C. M., and Whitford, A. E. 1940, *Ap. J.*, **91**, 20.
Stoy, R. H. 1953, *Cape Mimeogram*, No. 1.
Walker, M. F. 1954, *Ap. J.*, **119**, 631.
Williams, A. D. 1954, *Pub. A.S.P.*, **66**, 25.