THE ASTROPHYSICAL JOURNAL, 216:L31–L33, 1977 August 15

ON THE PERIOD AND LUMINOSITY STABILITY OF SIGMA ORIONIS E

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Received 1977 March 22

ABSTRACT

The highly enigmatic prototype He-rich B star σ Ori E has been observed continuously for 13 nights for a third consecutive season on the *uvbyβ* systems, and the results have been combined with reanalyzed data from earlier years. We find its period to be stable over the interval 1974 December–1977 February, allowing determination of an improved value: 1.19081 ± 0.00001 days. Features of the light curve reproduce very well season-to-season, and wavelength-dependent secular variations in excess of ~0.015 mag seem ruled out. These findings represent important constraints for any model of the system.

Subject headings: stars: early-type — stars: variables

I. INTRODUCTION

Sigma Orionis E, the prototype He-rich B star (Greenstein and Wallerstein 1958), manifests a perplexingly unique combination of phenomena, including an 1800 km s^{-1} wide Hα emission feature (Walborn 1974) that varies in intensity by nearly an order of magnitude with period $1^d.19$ and transitions on a time scale of minutes (Walborn and Hesser 1976); a double minimum light curve highly suggestive of an eclipsing binary system (Hesser, Walborn, and Ugarte 1976); an apparently constant radial velocity (Bolton 1974), implying that if the star is a binary its mass ratio could be $\gtrsim 80$, i.e., several times that of any other known binary; and equal $u - b$ minima with redder colors coinciding with Hα emission and He absorption minima. Other bases for the claim that σ Ori E is a unique object of considerable interest may be found in the above references and in Hunger (1974), Nissen (1974), Thomsen (1974), Shore and Bolton (1976), Pedersen and Thomsen (1977), and Groote and Hunger (1976, 1977). To date the attempts to model the observed phenomena have involved two versions of a mass-transfer binary system (one modeled after U Gem stars; and one suggesting stable L_4, L_5 point clouds) and oblique rotators.

In order to further constrain the models, data heretofore unavailable (such as the polarization measures of Kemp and Herman 1977) and a precise knowledge of the stability of the period and light curves are necessary. It is the purpose of this *Letter* to report results obtained during 1977 January–February, when we doubled the *uvbyβ* (Crawford and Barnes 1970; Crawford and Mander 1966) data available to us by continuously observing σ Ori E on 13 nights using a refrigerated RCA 4513 (S-11) photocell on the 0.4 m number 1 telescope at CTIO. Apart from the photocell, the equipment and observational and analytical procedures were identical to those used in 1975–1976 (Hesser, Walborn, and Ugarte 1976). In particular, the photometry was done differentially with respect to the *uvby* standard star HR 1861 which is 1° distant, and minimal time was spent off of σ Ori E in order to maximize our coverage of known and possible short-duration phenomena. We have also re-reduced the 1974 data in a manner that is as consistent as possible with that used for the data of subsequent years,[1] and we have combined the ~1000 observations from all seasons to produce improved light curves.

II. RESULTS

Upon combining data from three seasons covering a time span of 793 days, we find that a stable period of 1.19081 ± 0.00001 days fits all magnitudes and colors well, as may be seen in Figure 1. (We adopt the same time for primary minimum as Hesser, Walborn, and Ugarte 1976, but set its phase equal to 0.0 following

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[1] The 1974 data were observed against an all-sky network of standards, instead of differentially with respect to HR 1861. The original reductions presented in Walborn and Hesser (1976) used run mean values for extinction, whereas the more consistent and appropriate use of individual night values has been adopted here. In addition, improved values of high-air-mass 1975/1976 observations are used here.

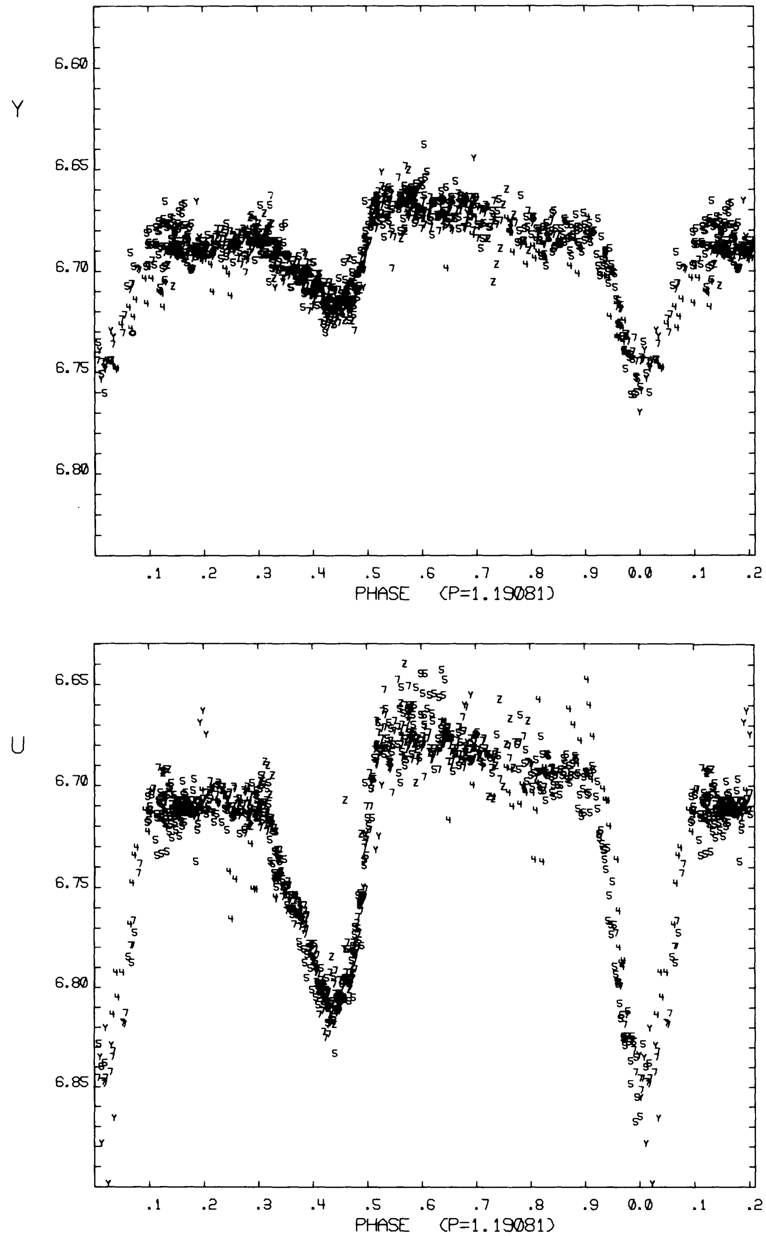

FIG. 1.—The y and u light curves for the 1974–1977 Tololo observations of σ Ori E phased with a period of $1^d.19081 \pm 0^d.00001$. Data from the 1974, 1975/1976, and 1977 seasons are plotted with a number (if the air mass was <2.0) or letter (if the air mass was $\geq$2.0) using the following conventions: 1974(4, X), 1975/76(5, Y) and 1977(7, Z). As discussed in the text, the 1977 data have been made fainter by 0.010 mag to approximately correct for the secular variation.

eclipsing binary convention.) Features of the 1977 light curves resemble very closely those of the 1975/1976 and 1974 ones, but superposition of data from each season reveals that the 1977 light curves are approximately 0.006–0.007, 0.011, 0.012, and 0.012 mag brighter in y, b, v, and u, respectively, relative to the 1974 and 1975–1976 data, i.e., a brightening that is essentially independent of wavelength. (The lack of wavelength dependence is also evident in the sensitive c_1 and $u - b$ color diagrams, where data from all seasons at a given phase coincide closely.) In order to define the repetitive features of the light curves as well as possible, we have added 0.010 mag to all 1977 magnitudes used in forming the light curves displayed here to approximately remove the effects of this small secular variation.

The secular variation could be due to three causes or combinations thereof: (i) a systematic error in the transformations of the two seasons; (ii) variation of σ

Ori E itself; or (iii) variation of the standard star. Explanation (i) seems highly unlikely, as the photocell used in 1977 has a 1P21-like response and all other factors in the differential photometry were identical. Explanation (iii) cannot be unequivocally ruled out. HR 1861 = HD 36591, a B1 V *UBV* and *uvby* standard star, was suspected of varying by ~0.06 mag during photoelectric observations by Wood (1946) in 1938–1939. Data in the Washington *UBV* catalog (Blanco *et al.* 1968) or Crawford and Barnes's (1970) and Eggen's (1976) *uvby* standard star lists seem to argue against such notable variability, at least in recent years. The differences (in the sense 1975/1976 − 1977) in the mean magnitudes of HR 1861 derived from comparison at the end of the night with, typically, six other *uvby* B-type standard stars for those nights with low, stable extinction are 0.003, 0.007, 0.004, and 0.029 mag in y, b, v, and u, respectively. Considering the precision inherent in transformations based on six stars observed only at the end of the night, these small differences are insignificantly different from zero, and they run contrary to the sense of the σ Ori E light curve differences. (*If* HR 1861 brightened by the indicated amounts in 1977 relative to 1975/1976, then the secular brightening of σ Ori E in 1977 inferred from the light-curve comparison would, of course, be an underestimate by the amount HR 1861 brightened. Also, the generally excellent agreement between measures of σ Ori E obtained on different nights within the same season suggests that any variability of HR 1861 is a longer-term phenomenon than the β Cephei one.)

In Figure 2 we present the normal points of our ~1000 observations in 1974–1977 averaged into 0.02 phase bins.[2] It is particularly interesting to note the clear double minimum variations discovered in the sensitive Hβ index, variations which are not detected spectroscopically due to their weakness. Curiously, the Hβ phase 0.45 minimum is slightly deeper than the primary (phase = 0.0); i.e., the reverse of the situation in the other magnitudes and colors. The Hβ emission maximum occurs ~0.2 phase units prior to the zero phase minimum, a result in agreement with our earlier spectrophotometric findings for Hα emission.

We conclude that modeling of the unique σ Ori E system may assume that over at least three observing seasons: (i) the period is stable to 10^{-5} days; (ii) the principal features of the light curves are stable to ~0.01 mag; and (iii) secular variations are $\lesssim$0.015 mag and are nearly wavelength independent in the $uvby\beta$ systems.

The stability of the light curve and the lack of nonrepetitive short-duration phenomena on the 28 nights we have observed (cf. Figs. 1 and 2) also suggest that the (highly desirable) inclusion of additional comparison stars in future photometric observations will not result in a high risk of missing transitory phenomena in σ Ori B itself.

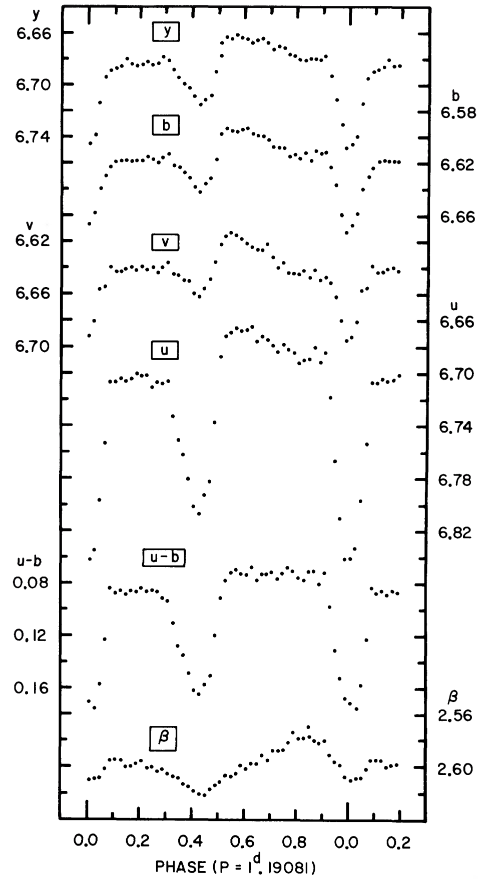

FIG. 2.—The normal curves for the 1974–1977 CTIO data based on ~1000 observations of σ Ori E made on 28 nights. The number of individual measures in a 0.02 wide phase bin ranges from 6 to 31 and the error of the normal points is typically about 0.003 mag.

[2] A detailed paper presenting the 1974–1977 observations will be prepared shortly; in the meantime, investigators wishing copies of the data may write directly to the first author.

We would like to thank M. Bitran, I. Matus, D. Ojeda, and M. Rubio, students of the University of Chile, for their considerable aid with the observing, and Dr. N. R. Walborn for his invaluable criticism.

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