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A *UBV* PHOTOMETRIC STUDY OF THE 5.2 HOUR X-RAY BINARY 4U 2129+47[1]

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ABSTRACT

We present results derived from *UBV* photometric observations of the 5.2 X-ray binary 4U 2129+47 which were made on 11 nights between 1978 October and 1979 August. The light curves observed during this period are relatively stable in shape and amplitude ($\Delta B \approx 1.5$ mag) and are a surprisingly close match to the time-averaged light curves observed for HZ Her. There is a significant asymmetry in their shape which is independent of color and varies in amplitude by a factor of ~ 2. The *UBV* colors at minimum light suggest a considerably earlier spectral type (G or earlier) than is inferred by assuming that the star fills its Roche lobe (late K or early M). We searched for broad-band optical pulsations and set a 3σ limit of 0.5% on the fraction of the flux which is pulsed for periods between 60 ms and 300 s. Assuming that the optical companion is a normal main-sequence star filling its Roche lobe, its mass is $\sim 0.65\ M_\odot$. Assuming also that the compact object has a mass $\sim 1.3\ M_\odot$ and that the orbital inclination of the system is $\sim 90°$, we find that the orbital separation is $\sim 1.9\ R_\odot$ and $K_{\rm opt}$ is ~ 300 km s^{-1}.

Subject headings: stars: individual — X-rays: binaries

I. INTRODUCTION

The large-amplitude ($\Delta B \approx 1.5$ mag) optical light curve of Hz Her/Her X-1 ($P = 1\overset{\mathrm{d}}{.}7$) has been scrutinized in more than 50 publications since its discovery (Forman, Jones, and Liller 1972; Davidsen *et al.* 1972; Bahcall and Bahcall 1972). For 8 yr the HZ Her light curve was unique; the amplitudes observed for ~ 20 other X-ray binaries were less than ~ 0.4 mag, a factor of ~ 4 less than for HZ Her. Recently, however, a second large-amplitude system, 4U 2129+47, was discovered and studied spectrophotometrically by Thorstensen *et al.* (1979).[3] Its amplitude is the same as HZ Her, $\Delta B \approx 1.5$ mag, but it is about 4 mag fainter. The orbital period is $5\overset{\mathrm{h}}{.}2$, which is short enough to allow continuous coverage of a complete orbital cycle. In 1978 October, shortly after the discovery of 4U 2129+47, we began the photometric study presented in this paper.

In the case of HZ Her, it is widely agreed that the large amplitude ($\Delta B \approx 1.5$ mag) and large color variations are due to optical radiation emitted from the X-ray–heated face of the optical star, which is modulated by changing aspect. However, such a simple heating model predicts that the light curve near minimum will have a flat bottom for the duration of X-ray eclipse ($0\overset{\mathrm{d}}{.}24$), whereas the minimum is observed to be V-shaped (Wilson 1973). This is most likely due to the gradual eclipse of an accretion disk, which is an important source of light near minimum, but contributes only a few percent of the total light near maximum (Strittmatter *et al.* 1973). Recently, Kippenhahn, Schmidt, and Thomas (1980) have presented evidence for a total optical eclipse which is about half as long as the X-ray eclipse. There are significant night-to-night variations in the shape of the light curve, much of it associated with the 35 day X-ray cycle (Gerend and Boyton 1976). Broad-band optical pulsations (~ 0.2% amplitude), which are driven by the $1\overset{\mathrm{s}}{.}24$ X-ray pulsations, are observed for well-defined values of the binary and 35 day phases (Middleditch and Nelson 1976).

II. OBSERVATIONS

On 11 nights between 1978 October and 1979 August we made photometric observations of 4U 2129+47. We have grouped the data into seven data sets (I–VII), each of which covers a complete orbital cycle. The *UBV* data (I–VI) are plotted in Figure 1, and the broad-band data (VII) are plotted in Figure 3. The data were obtained using the McGraw-Hill 1.3 m telescope, except for the 1979 July data (III) which were obtained using the KPNO 2.1 m telescope. Details of the observations are given in Table 1.

The highest quality *UBV* data were obtained on 4 nights (data sets II and IV–VI), during which the star was observed continuously for a full binary cycle. Throughout these observations seeing was 1″–2″, the sky was dark,

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[3] More recently the discovery of a third object, 4U 1822–37 ($\Delta B \approx 1$ mag), has been reported by Seitzer *et al.* (1979).

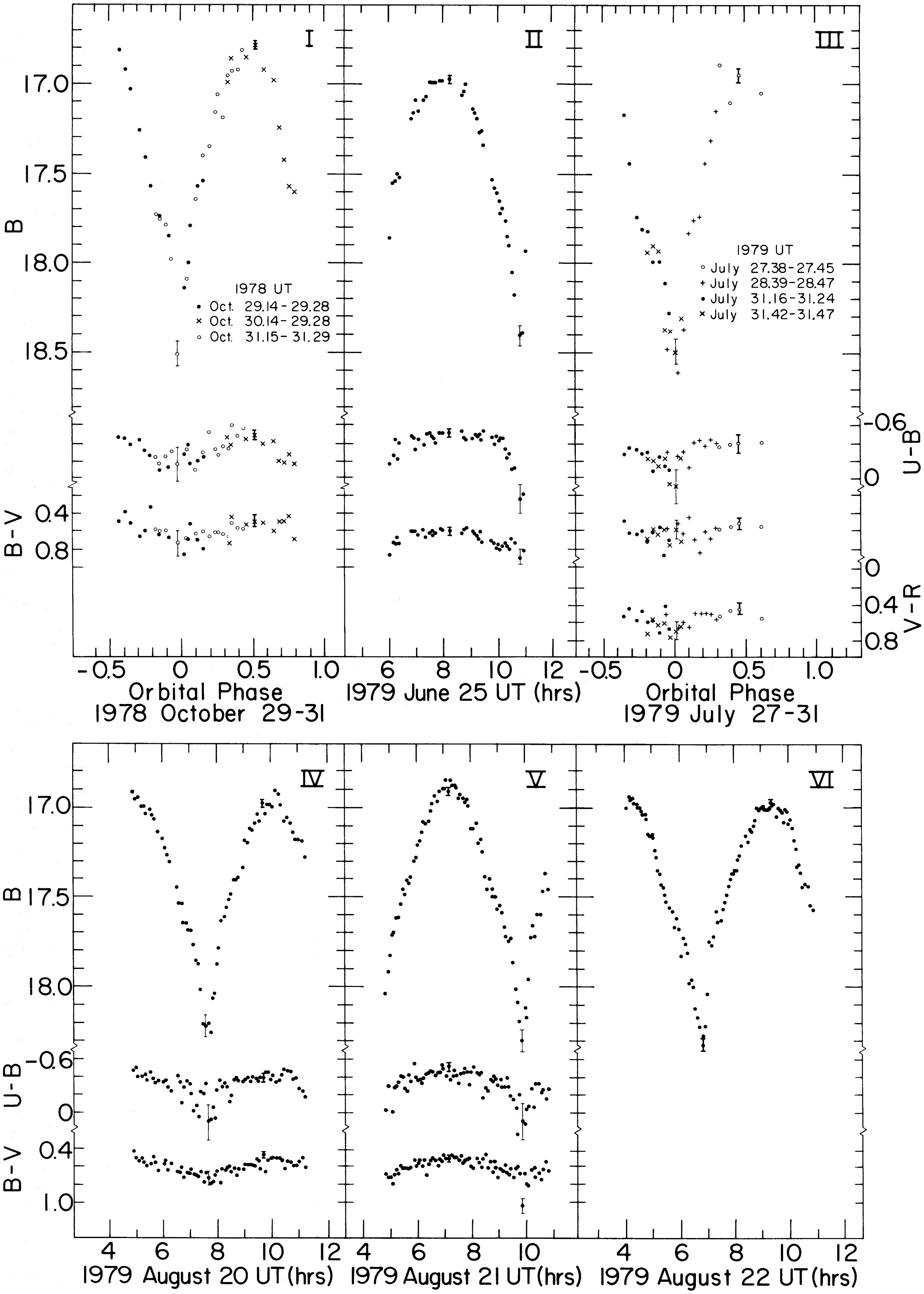

FIG. 1.—*B* magnitudes and *UBV* colors observed for 2129+47 grouped into six data sets, each covering a full $5^{\rm h}24$ orbital cycle of the system. Data sets (II) and (IV)–(VI) are continuous records, each of which was obtained on a single night; (I) and (III) are composites derived by folding data obtained on several nights. As shown in (III), *R* data were obtained in 1979 July. Only *B* data were recorded during 1979 August 22 (VI). One sigma uncertainties due to counting statics are indicated near maximum and minimum light.

TABLE 1

Journal of Observations

Data Set Number	Date (UT)[a]	Telescope	Observer(s)	Phototube	Passband(s)	Sky Conditions	Seeing (arc seconds)	Days from New Moon
I	1978 Oct. 29–31	McGraw-Hill 1.3 m	McClintock and Remillard	EMI 9789	*UBV*	poor (intermittent clouds)	3	−3 to −1
II	1979 June 25	McGraw-Hill 1.3 m	Remillard	VPM 159S	*UBV*	good (winds up to 40 mph)	2	+2
III	1979 July 27–31	KPNO 2.1 m	Margon	FW 130	*UBVR*	good	2	−6 to −3
IV	1979 Aug. 20	McGraw-Hill 1.3 m	McClintock and Armstrong	VPM 159S	*UBV*	excellent	1–2	−4
V	1979 Aug. 21	McGraw-Hill 1.3 m	McClintock and Armstrong	VPM 159S	*UBV*	excellent	1–2	−3
VI	1979 Aug. 22	McGraw-Hill 1.3 m	McClintock and Armstrong	VPM 159S	*B*	excellent	1–2	−2
VII	1979 Aug. 23	McGraw-Hill 1.3 m	McClintock and Armstrong	VPM 159S	3200–6500 Å	excellent	2	−1

[a] The precise observing intervals are given in Figures 1 and 3.

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and the air mass was less than ~ 1.5. We made alternate 30 s observations of 2129+47 and the sky background for each passband. The object was centered in a 9″ photometer aperture using a television guider. Every few cycles, one of two nearby companion stars was observed. The areas used for sky background measurements were selected carefully, since the sky count rate was several times the stellar count rate near minimum light. The data were obtained using a Varian VPM-159S photomultiplier tube with a GaAsP photocathode. It has a high quantum efficiency in the blue and a flat response which drops sharply at 6500 Å. We used the *UBV* filter set recommended by Bessell (1979) for GaAs phototubes and obtained good transformations to the *UBV* system based on our twice-nightly observations of about a dozen standard stars which covered a wide range of colors. Because of the faintness of the object, the uncertainties in our data are primarily due to counting statistics. The transformation to the *UBV* system, systematic uncertainties in the sky background, and other sources of uncertainty are of secondary importance. Consequently, $(N)^{1/2}$ uncertainties are given in Figure 1 and elsewhere. The approximate number of counts per 30 s observed for 2129+47 at maximum light, minimum light, and the sky background were $U(1550, 250, 1200)$, $B(5800, 1500, 3300)$, and $V(3300, 1200, 2400)$, respectively.

In a search for optical pulsations, we observed 2129+47 continuously for 5 hr at the McGraw-Hill Observatory on 1979 August 23 UT using a 9″ aperture and the VPM-159S phototube without filter (3200–6500 Å FWHM). The data in 30 ms time bins and the UT time (WWVB) were recorded on magnetic tape. These data have higher statistical precision and reveal the shape of the minimum better than the *UBV* data and are therefore shown plotted in Figure 3 in 15 s time bins.

III. RESULTS

a) *General Appearance of the Light Curves*

The *B* light curves shown in Figure 1 have a relatively narrow V-shaped minimum, a rounded or flat-topped maximum, and an amplitude of ≈ 1.5 mag. Although there is no gross variability apparent over this 10 month period, there is a night-to-night variability in the *B* magnitude at maximum light of ≈ 0.1 mag (cf. V and VI) and variability in the shape of the *B* light curve near maximum (cf. II and V).

b) *Ephemeris for Times of Minimum Light*

We determined the following photometric ephemeris using the times of the six minima shown in Figure 1 and the epoch of the minimum given by Thorstensen *et al.* (1979):

$$T_{\rm min} = 2{,}444{,}107.7852(\pm 0.0025) + 0.2182584(\pm 0.0000017)E\,,$$

where $T_{\rm min}$ is the heliocentric Julian date of minimum light. The period is uniquely determined by our data. The errors were computed using estimated uncertainties for the seven times of minimum which ranged from 2 to 8 minutes. These are conservative estimates since the rms of the observed times minus the calculated times of minimum light is 2.2 minutes per degree of freedom.

c) *The Folded Light Curve*

Using the ephemeris, we produced the composite folded light curves shown in Figure 2, which include all the data in Figure 1 except for the color data ($U - B$, $B - V$, and $V - R$) contained in data sets I and III. For the remaining color data (II and IV–VI), pairs of adjacent points were averaged in order to reduce the statistical scatter. The six plotting symbols used in Figure 2 correspond to the six data sets (see figure caption for key). An inspection of Figure 2 shows that the mean modulation is ~0.25 mag in $B - V$ and ~0.5 mag in $U - B$. The $U - B$ light curve is markedly more flat-topped than the *B* curve. The night-to-night variations in *B* near maximum light mentioned above are obvious, as well as significant variability near phase 0.7. Also, a large decrease (~ 0.3 mag in *B* near phases 0.2 and 0.8) was observed in 1979 July (data set III; square symbols) compared to the results obtained a month earlier and a month later.

d) *Asymmetry in the Light Curves*

The *B* light curve in Figure 1 (VI) is replotted twice in Figure 4, once with orbital phase increasing to the right (filled circles; bottom scale) and a second time with orbital phase increasing to the left (crosses; top scale). A comparison of the two curves shows that there is a significant asymmetry with respect to the time of minimum light. In particular, the system is ~ 0.15 mag brighter at phase 1.25 than it is near phase 0.75, and the decrease in intensity preceding minimum light is more gradual than the increase following the minimum.

In order to evaluate the stability and possible color dependence of the asymmetry feature, the data were converted from a logarithmic scale to a linear scale of relative fluxes, $F_{U,B,V} = 10^{-0.4(U,B,V)+8}$, and six of the light curves were fitted individually to a truncated Fourier series of the form

$$F(t) = a_0 + \sum_{n=1}^{3} a_n \cos\,[n\omega_{\rm orb}(t - T_{\rm min})] + \sum_{n=1}^{3} b_n \sin\,[n\omega_{\rm orb}(t - T_{\rm min})]\,,$$

where $\omega_{\rm orb} = 2\pi/0^{\rm d}.2182584$, and $T_{\rm min}$ is the predicted time of minimum light at the Earth. $T_{\rm min}$ was computed using the heliocentric ephemeris given above and corrected for light travel time to the location of the Earth. The data points were weighted using the uncertainties due to counting statistics. The results for data set VI are shown by the solid line in Figure 4. The fit is generally good, and the asymmetric shape of the light curve is accurately described by the seven Fourier terms. The poor fit near the V-shaped minimum is due to the lack of higher frequencies in the fitting function and is not important in

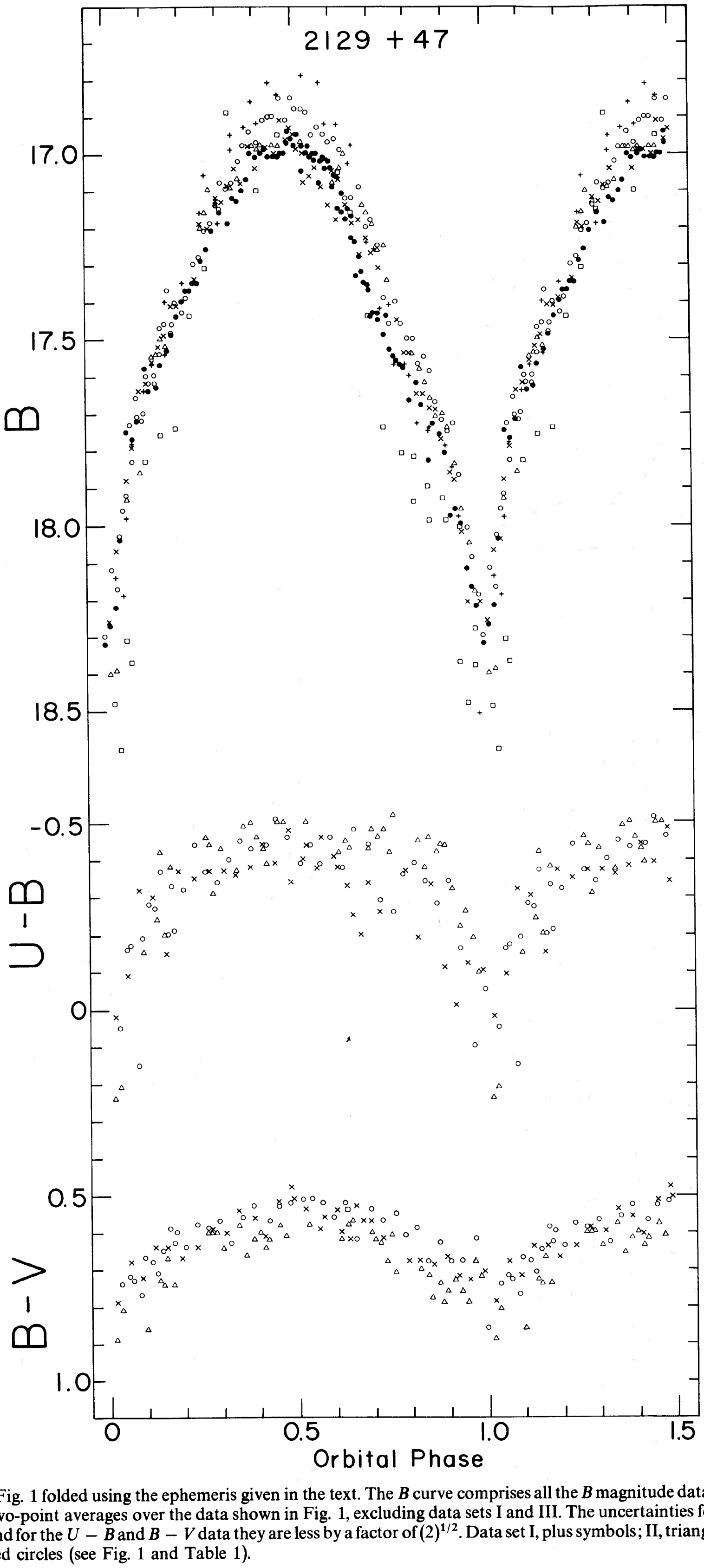

FIG. 2.—Data from Fig. 1 folded using the ephemeris given in the text. The *B* curve comprises all the *B* magnitude data shown in Fig. 1. The $U - B$ and $B - V$ curves are two-point averages over the data shown in Fig. 1, excluding data sets I and III. The uncertainties for the *B* data are the same as those shown in Fig. 1, and for the $U - B$ and $B - V$ data they are less by a factor of $(2)^{1/2}$. Data set I, plus symbols; II, triangles; III, squares; IV, crosses; V, open circles; VI, filled circles (see Fig. 1 and Table 1).

TABLE 2

ASYMMETRY IN THE LIGHT CURVES

UT Date (1979)	Data Set No.	Passband	a_0	a_1	a_2	a_3	b_1	b_2	b_3	Asymmetry Parameter $\lvert b_1/a_1 \rvert$ (percent)	Phase Angle $\tan^{-1} \lvert b_1/a_1 \rvert$ (degrees)
June 25	II	*B*	11.9	−5.16	−0.85	−0.42	0.82	+0.14	−0.14	15.9 ± 1.4	9.0
Aug. 20	IV	*B*	11.5	−4.89	−0.51	−0.44	0.55	−0.10	+0.12	11.2 ± 1.0	6.4
Aug. 21	V	*U*	17.0	−9.31	−0.18	−0.94	0.78	−0.09	+0.07	8.4 ± 1.8	4.8
Aug. 21	V	*B*	12.1	−5.43	−0.07	−0.05	0.42	+0.03	−0.00	7.7 ± 0.9	4.4
Aug. 21	V	*V*	20.8	−7.80	−0.22	−0.52	0.85	+0.01	+0.02	10.9 ± 2.2	6.2
Aug. 22	VI	*B*	11.1	−4.88	−0.01	−0.41	0.75	+0.19	−0.16	15.4 ± 0.8	8.7

TABLE 3

UBV DATA AT MINIMUM LIGHT

PARAMETER	OBSERVED $A_v = 0$	CORRECTED FOR REDDENING $A_v = 1.0$	$A_v = 1.5$	$A_v = 2.0$
V	17.42 ± 0.03	16.4	15.9	15.4
$B - V$	$+0.82 \pm 0.04$	+0.5	+0.4	+0.2
$U - B$	$+0.02 \pm 0.11$	−0.2	−0.3	−0.5
Spectral class[a]	late G	late F	early F	late A
Distance (kpc)	2.2	2.8	3.6	3.9

[a] Main-sequence spectral class based on $B - V$ color (Allen 1973).

the present discussion. The Fourier coefficients are tabulated in Table 2 for six of the highest quality U, B, and V light curves. Excluding a_0, the dominant coefficients are clearly the amplitudes of the fundamental cosine and sine terms, a_1 and b_1. The ratio b_1/a_1 is a good measure of the asymmetry and is given in Table 2 along with its uncertainty (1 σ) due to counting statistics. A phase angle is also given which can be interpreted as the phase lag of the overall light curve relative to the time of photometric minimum. From these limited data, we conclude that the asymmetry feature does not depend on color and that it is a relatively stable feature of the light curve. However, it may vary in amplitude by a factor of ~ 2 on a time scale as short as 1 day (cf. rows 4 and 6 of Table 2).

e) *UBV Colors at Minimum Light*

We determined the magnitude and colors of the system using data obtained within ±5 minutes of the predicted times of minimum light for the nights of August 20 and 21 UT (Fig. 1, IV and V). Changes in magnitude and color are negligible compared to statistical uncertainties during this time interval. The observed V magnitude and colors at minimum light are given in the first column of Table 3. The $B - V$ color corresponds to a late main-sequence G star (Allen 1973). The distance to such a star would be ~ 2.2 kpc. Thorstensen *et al.* (1979) report significant reddening (~ 1–2 mag) in the field of 2129+47 (see § IV). Therefore, in Table 3 we also give the results corrected for $A_v = 1.0$, 1.5, and 2.0. For each assumed value of the extinction, we give a spectral type based on the $B - V$ colors. In each case the $U - B$ color is too ultraviolet by ~ 0.3–0.6 mag to match the spectral type. It is therefore likely that a normal main-sequence star is not the sole source of light at minimum, and consequently the spectral types and distances given in Table 3 cannot be taken literally. The distances are probably conservative upper limits. Much of the ultraviolet excess (up to ~ 0.3 mag can be accounted for by assuming that the companion is a metal-poor, halo population star (Blaauw 1965; see discussion of HZ Her by Strittmatter *et al.* 1973). In any case, regardless of the assumed reddening, we deduce from the colors a considerably earlier spectral type (G or earlier) than that inferred in § IV and by Thorstensen *et al.* (1979) based on the assumption that the star fills its Roche lobe (late K or early M). We note that the earlier spectral type is consistent with the lack of strong λ4226 Ca I absorption in the spectra obtained by Thorstensen *et al.* (1979), which would be expected if the object is late K or early M.

f) *Search for Broad-Band Optical Pulsations*

We computed a coherent Fourier transform (2^{19} data bins) of the 5 hr of continuous data which were obtained on 1979 August 23 UT (Fig. 3). The data were recorded with a time resolution of 30 ms. To reduce the possible "smearing" effects due to high orbital velocities in the system ($K_{\text{opt}} \approx 300$ km s^{-1}, see Table 5), we also divided the data into four equal time intervals and Fourier analyzed them individually. No periodicities were detected. The upper limits are summarized in Table 4. They lie between the 0.2% pulsed fraction frequently observed for HZ Her (Middleditch and Nelson 1976) and the ~ 2% pulsed fraction observed for 4U 1626−67 (Ilovaisky, Motch, and Chevalier 1979; McClintock *et al.* 1980).

IV. DISCUSSION

As shown in Figure 5, the average light curves for 2129+47 and HZ Her are strikingly similar. The solid-line curves for 2129+47 are approximate averages over the data shown in Figure 2. They have been corrected for an interstellar extinction of $A_v = 1.5$ mag.[4] The dashed curves for HZ Her are approximate averages over several months of folded data published by Boynton *et al.* (1973). No reddening corrections are required for HZ Her, since recent *IUE* studies have shown that $A_v < 0.15$ mag (Gursky *et al.* 1980). The B light curves for 2129+47 and Hz Her have comparable broad maxima and nearly identical amplitudes. The V-shaped minimum for 2129+47 is somewhat narrower than for HZ Her. The amplitude of the $B - V$ curves for both objects is ~ 0.25 mag, and the $B - V$ colors are closely matched (assuming $A_v \approx 1.5$ mag). The $U - B$ curves show the greatest differences. The $U - B$ curve for 2129+47 is much broader, and its amplitude is about half as large. Nevertheless, the $U - B$ colors are well matched near maximum light (assuming $A_v \approx 1.5$ mag).

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[4] The extinction is uncertain and is based on the measurements of several field stars by Thorstensen *et al.* (1979). They estimate $A_v(D \approx 1.5$ kpc$) \approx 1.2$–1.6 mag, and $A_v(\infty) \lesssim 1.9$ mag.

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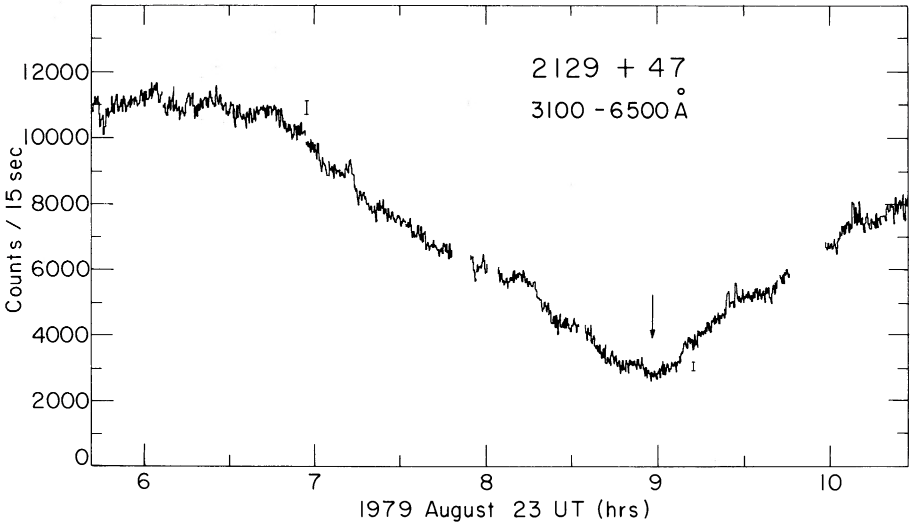

FIG. 3.—Broad-band data recorded with a time resolution of 30 ms and shown plotted here in 15 s time bins. Except during checks on the guiding and a few measurements of the background count rate, 2129+47 was observed continuously. An average background count rate of 9600 counts per 15 s has been subtracted. The detailed structure in the light curve may be due to 2129+47, but it may also be due to variability in the sky background or possibly due to an artifact of the observation. Representative error bars ($\pm 1\ \sigma$) are shown. The arrow marks the time of minimum light.

TABLE 4

UPPER LIMITS ON BROAD-BAND OPTICAL PULSATIONS[a]

1979 August 23 UT	Pulsed Fraction (percent) ($60\ \mathrm{ms} < P < 300\ \mathrm{s}$)	Comments (see Fig. 3)
$05^{\mathrm{h}}45^{\mathrm{m}}$–$10^{\mathrm{h}}07^{\mathrm{m}}$	<0.5	all data
05 45 –06 50	<0.7	maximum light
06 55 –08 00	<0.9	...
08 10 –09 15	<1.5	minimum light
09 30 –10 35	<1.0	...

[a] Ratio of pulsed flux to the total source flux in the 3200–6500 Å band. Upper limits correspond to the 3 σ level of confidence.

From the above discussion and by analogy to HZ Her, we adopt the model that the $5\overset{\mathrm{h}}{.}2$ optical modulation in the flux and temperature of 2129+47 is due to the changing aspect of a normal star with an X-ray–heated face (also see discussion by Thorstensen *et al.* 1979). Assuming that the optical star fills its Roche lobe and is a normal main-sequence star, we have the following relationships:

$$R_{\mathrm{opt}}/a = 0.46\left(\frac{M_{\mathrm{opt}}}{M_{\mathrm{opt}} + M_x}\right)^{1/3}, \quad \frac{M_{\mathrm{opt}}}{M_x} < 0.8 \qquad \text{(Paczyński 1971)}$$

$$R_{\mathrm{opt}} = 0.93 M_{\mathrm{opt}}, \qquad \text{(Robinson 1976)}$$

$$a^3 = 3.51(M_{\mathrm{opt}} + M_x)\,, \qquad \text{(Kepler's law)}$$

where a is the orbital separation, and all distances and masses are in units of $R_\odot$, and $M_\odot$, respectively. These relations uniquely define the radius and mass of the optical star:

$$R_{\mathrm{opt}} = 0.60\,,$$

$$M_{\mathrm{opt}} = 0.65\,.$$

An estimate of the uncertainties, which are primarily due to the uncertainties in the mass-radius relationship, is given by Thorstensen *et al.* (1979). A normal main-sequence star with this mass should be a late K star with $B - V \approx +1.4$ and $U - B \approx +1.2$ (Allen 1973). We adopt these values for the purpose of estimating other parameters of the system. We note that a main-sequence star is a reasonable candidate for the optical companion since, for example, a slightly evolved star such as HZ Her, $R \approx 3.5\,R_\odot$ (Middleditch and Nelson 1976), is ruled out by the $\sim 2\,R_\odot$ orbital separation set by Kepler's law. Similarly, giant companions of any spectral class are not allowed. A hydrogen white dwarf or a helium white dwarf is allowed, but it cannot be more massive than about $0.015\,M_\odot$ or $0.0025\,M_\odot$, respectively.

We make two final assumptions: (1) $M_x \approx 1.3$. This is consistent with our current empirical knowledge of neutron star masses (Rappaport 1979) and with theoretical scenarios for neutron star formation (cf. Iben 1974); and (2) the orbital inclination angle is $\sim 90°$. The large optical modulation suggests a large value for the inclination angle ($\gtrsim 60°$). Based on these assumptions, the estimated and observed dynamical parameters of the 2129+47 system are given in Table 5 and compared to those for the HZ Her system. The 2129+47 system has an 8 times shorter orbital period and is ~ 5 times smaller in linear scale than the HZ Her system (Table 5). Of greater interest, the radial velocity predicted for the 2129+47 optical companion, $K_{\mathrm{opt}} \approx 300\ \mathrm{km\ s^{-1}}$, is ~ 3 times the value observed for HZ Her. This may make a radial velocity study of 2129+47 feasible despite the star's faintness.

The maximum optical and 2–10 keV X-ray fluxes observed for 2129+47 are summarized in Table 6 and compared to those for HZ Her. The ultraviolet, soft

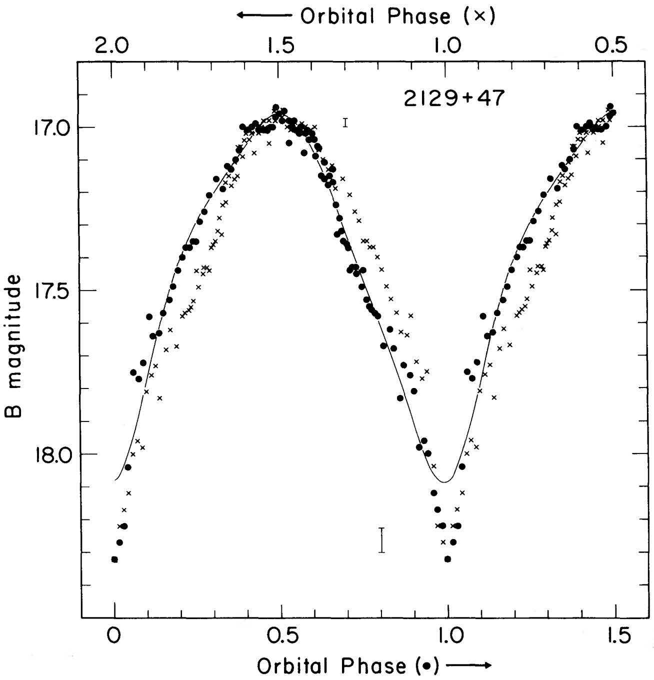

FIG. 4.—The *B* light curve shown in Fig. 1 (VI) replotted *vs.* orbital phase (*filled circles; lower scale*). A mirror image of the light curve about phase 1.0 is also shown (*crosses*). It was obtained by replotting the data with orbital phase increasing to the left (*upper scale*). The solid curve is a fit to the data using a seven-term Fourier series (see text).

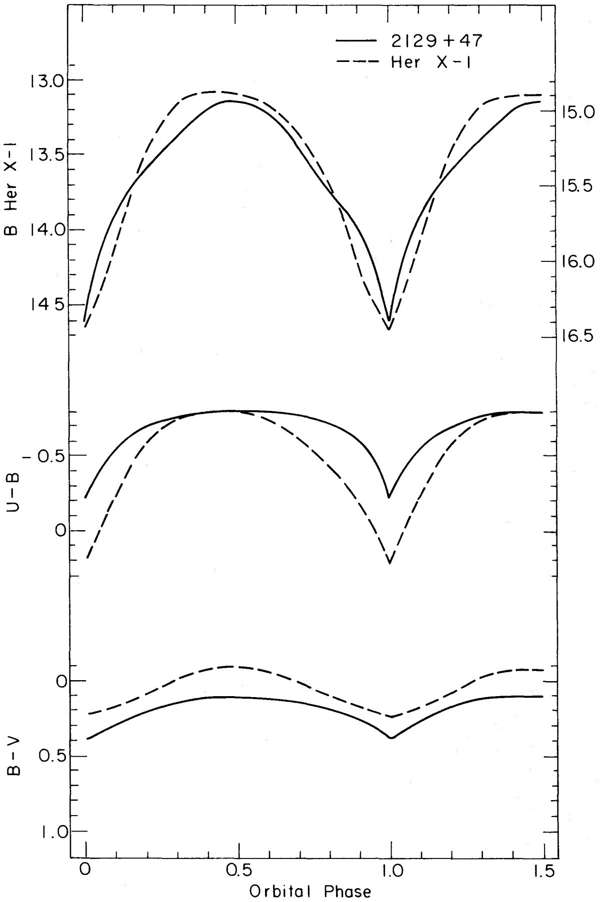

FIG. 5.—The solid curves for 2129+47 are approximate averages over the folded data shown in Fig. 2. They have been corrected for an estimated extinction of $A_v = 1^m.5$ ($A_B = 2^m.0$; $E_{B-V} = 0.45$; $E_{U-B} = 0.35$; Allen 1973). Similarly, the dashed curves are approximate averages over several months of folded data published by Boynton *et al.* (1973). No extinction correction is required for HZ Her ($A_v < 0^m.15$; Gursky *et al.* 1980).

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TABLE 5

DYNAMICAL PARAMETERS FOR 2129+47 AND HZ HERCULIS

Parameter	2129+47	HZ Herculis[a]
P_{orb}(hr)	5.24	40.8[b]
i	~60°–90°	87° ± 3°
X-ray eclipse duration	?[c]	51°[d]
$M_{\mathrm{opt}}(M_\odot)$	0.65	2.2
$R_{\mathrm{opt}}(R_\odot)$	0.60	3.4
$M_x(M_\odot)$	~1.3	1.3
$a(R_\odot)$	1.9	9.1
K_x(km s^{-1})	~145	169[b]
K_{opt}(km s^{-1})	~295	100

[a] We use the results of Middleditch and Nelson 1976, which are consistent with most other studies. See also Bahcall, Joss, and Avni 1974 for a review of earlier dynamical studies of HZ Her and a thorough discussion of uncertainties.

[b] Tananbaum *et al.* 1972.

[c] Ulmer *et al.* 1980 present weak evidence for the existence of an X-ray eclipse with a duration of ~36°–54°.

[d] Giaconni *et al.* 1973.

TABLE 6

OBSERVED OPTICAL AND X-RAY FLUXES FOR 2129+47 AND HZ HERCULIS NEAR PHASE 0.5

$f \leftrightarrow 10^{-10}$ ergs cm^{-2} s^{-1}	2129+47	HZ Herculis
f_{opt}(3000–6500 Å)	0.23[a]	0.66
f_{UV}(1150–3000 Å)	?	2.2[b]
f_{xm}(2–10 keV)	4.8[c]	24[c]
f_{xs}(0.16–0.28 keV)	?	8[d]
f_{xh}(> 10 keV)	?	34[e]

[a] Assuming $A_v = 1.5$ mag. If $A_v = 1.0$ mag, $f_{\mathrm{opt}} = 0.12$, and if $A_v = 2.0$ mag, $f_{\mathrm{opt}} = 0.43$.

[b] Gursky *et al.* 1980.

[c] Forman *et al.* 1978.

[d] The soft X-ray flux observed by Shulman *et al.* 1975 corrected by a factor of 2.7 for interstellar absorption corresponding to the maximum allowed hydrogen column density, $N_{\mathrm{H}} = 2.5 \times 10^{20}$ cm^{-2} (Gursky *et al.* 1980; Knapp and Kerr 1974). The value for the corrected flux quoted by Shulman *et al.* 1975, using a less reliable value for N_{H}, is a factor of 2.5 greater.

[e] Becker *et al.* 1977. The value given for f_{xh}(> 10 keV) is normalized to the 2–10 keV flux given in line 3.

X-ray, and hard X-ray fluxes observed for HZ Her are also given. We note that the ratio of 2–10 keV X-ray luminosity to 3000–6500 Å optical luminosity is comparable for the two systems: ~ 10–40 for 2129+47 (assuming 1 mag $\lesssim A_v \lesssim 2$ mag), and ~ 35 for HZ Her. However, the luminosity of the HZ Her system is almost certainly much greater. For 2129+47, using a Roche-lobe radius of ~ 0.6 $R_\odot$ and an empirical relationship between surface brightness and color, Thorstensen *et al.* (1979) find $D \approx 1.4$ kpc and $L_x \approx 6 \times 10^{34}$ ergs s^{-1}. The X-ray luminosity of Her X-1 is ~ 100 times as great, assuming $D \approx 5$ kpc (Bahcall, Joss, and Avni 1974). Using a distance of ~ 4 kpc for 2129+47, probably a very conservative upper limit (§ III*e* and Table 3), the luminosity of 2129+47 is still a factor of 15 less than for HZ Her.

We accept the model that 2129+47 is a bona fide X-ray binary containing a neutron star (see discussions of degenerate dwarf models by Thorstensen *et al.* 1979 and Ulmer *et al.* 1979). The binary 2129+47 is a Lilliput compared to HZ Her and is one of the least luminous of the compact galactic X-ray sources. However, it is an important object. It lies at the watershed between the massive OB star systems for which $L_x/L_{\mathrm{opt}} \lesssim 1$ and the low-mass systems, such as Sco X-1 and the burst sources, for which $L_x/L_{\mathrm{opt}} \approx 1000$. For the latter systems, normal stellar absorption lines are not observed, and, with few exceptions, their binary character must be inferred indirectly. For 2129+47, $L_x/L_{\mathrm{opt}} \approx 20$, photospheric absorption lines are observed (Thorstensen *et al.* 1979), and its binary nature could not be more obvious. Hopefully, 2129+47 will help us in unravelling the nature of the low-mass systems; however, an important first step will be to understand why this source is so different.

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