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LIGHT CURVE OF THE OPTICAL COUNTERPART OF 2A0311-227

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Visual and blue light curves are presented for the optical counterpart of the X-ray source 2A0311-227. This system, which is the newest member of the AM Herculis class of binaries, has an orbital period of 81 minutes which also modulates the visual light curve. A Fourier analysis of the data has revealed the presence of a 6-minute oscillation, at least in the visual light curve. Whether or not it is also present in the blue light curve is unclear.

Key words: X-ray sources—binaries—photometry

The binary star which is the optical counterpart of the X-ray source 2A0311-227 has recently been shown to be the newest member of the AM Herculis class of binaries, which also include AN Ursae Majoris and VV Puppis. These systems consist of a white dwarf of approximately one solar mass which is accreting matter from a lower main-sequence secondary. The characteristics of 2A0311-227 which signify it as a member of this class are X-ray emission (Cooke et al. 1978; Charles and Mason 1979); strong optical emission lines of H, He I, He II, and C III–N III λλ4640–50 (Griffiths et al. 1979); a short orbital period of 81.04 minutes (Hiltner et al. 1979); and strong and variable linear and circular optical polarization (Tapia 1979). In a previous paper (Williams et al. 1979) we discussed the binary nature of the optical counterpart and presented preliminary results of *V* and *B* photometry. In this paper we present that photometry along with a Fourier analysis of the light curves.

Shortly after the identification of the 81-minute orbital period in the optical counterpart of 2A0311-227, photometric observations were made of this object at the Carnegie Southern Observatory in Chile. Observations were obtained in *B* and *V* with emphasis on the latter. A nearby comparison star was used as a substandard to reduce the observations to the standard *UBV* system (Landolt 1973).

The reduced visual light curves obtained on 1979 February 17, 18, and 19 are shown in Figure 1. The orbital phase convention which we have used is defined in terms of the velocity curve of the Hβ emission line. We have taken the zero of orbital phase to be the instant when the radial velocity of the Hβ line shows the mean systemic velocity; changing from a negative to a positive radial velocity relative to the system. In this convention the orbital phase may be computed from HJD2443915.6300 + 0.05628*E*. Some authors prefer to express the orbital phase in terms of the linear polarization pulse which occurs at phase 0.742. Figure 2 shows the blue light curve obtained on 1979 February 20.

As can be seen from Figure 1, the visual light curve shows two maxima and two minima in each orbital cycle. The minima are of roughly equal depth at apparent visual magnitude 15.0; while the maxima differ by approximately 0.4 magnitude. The primary maximum, which occurs at phase 0.775, reaches an apparent visual magnitude of 13.6, for a total variation of 1.4 magnitudes. The secondary maximum occurred roughly one-half of a cycle earlier at phase 0.30. Superimposed on the general trend of the light curve are variations in brightness which seem to range from the integration time (8.5 seconds), with variations up to several hundredths of a magnitude, up to several minutes, and variations of up to 0.6 of a magnitude. Our suspicion is that these variations consist of both random and periodic components. Some sections of the visual light curve (e.g., the first primary maximum of February 18) are suggestive of a regular variation with a period of about six minutes and an amplitude of 0.3 to 0.4 magnitude. In other sections, however (e.g. the secondary maximum of February 19), this variation seems to be completely absent.

The blue light curve differs from the visual light curve in that it shows only one maximum and a broad minimum in each cycle. The total variation in the blue is only 0.7 magnitude, ranging from $B = 15^{\mathrm{m}}\!.3$ to $14^{\mathrm{m}}\!.6$. The maximum of the blue light curve corresponds in phase to the primary maximum of the visual light curve. As in the visual light curve, variations in brightness ranging from the integration time up to several minutes are apparent.

As one would expect from the differing light curves, the system shows a color variation over an orbital cycle. Figure 3 shows an approximate color curve for this system. This curve was obtained by separately folding all of the visual and blue data into one orbital cycle. To these light curves were fit cubic smoothing splines, which were then subtracted to give the approximate variation in the color index. It can be seen that the color index varies from $(B - V) = +0.2$ to $+1.0$; with the system reddest at the two maxima of the visual light curve.

To investigate the possibility that there is a periodic component in the light curves of about six minutes duration, we performed a Fourier analysis of each of the four

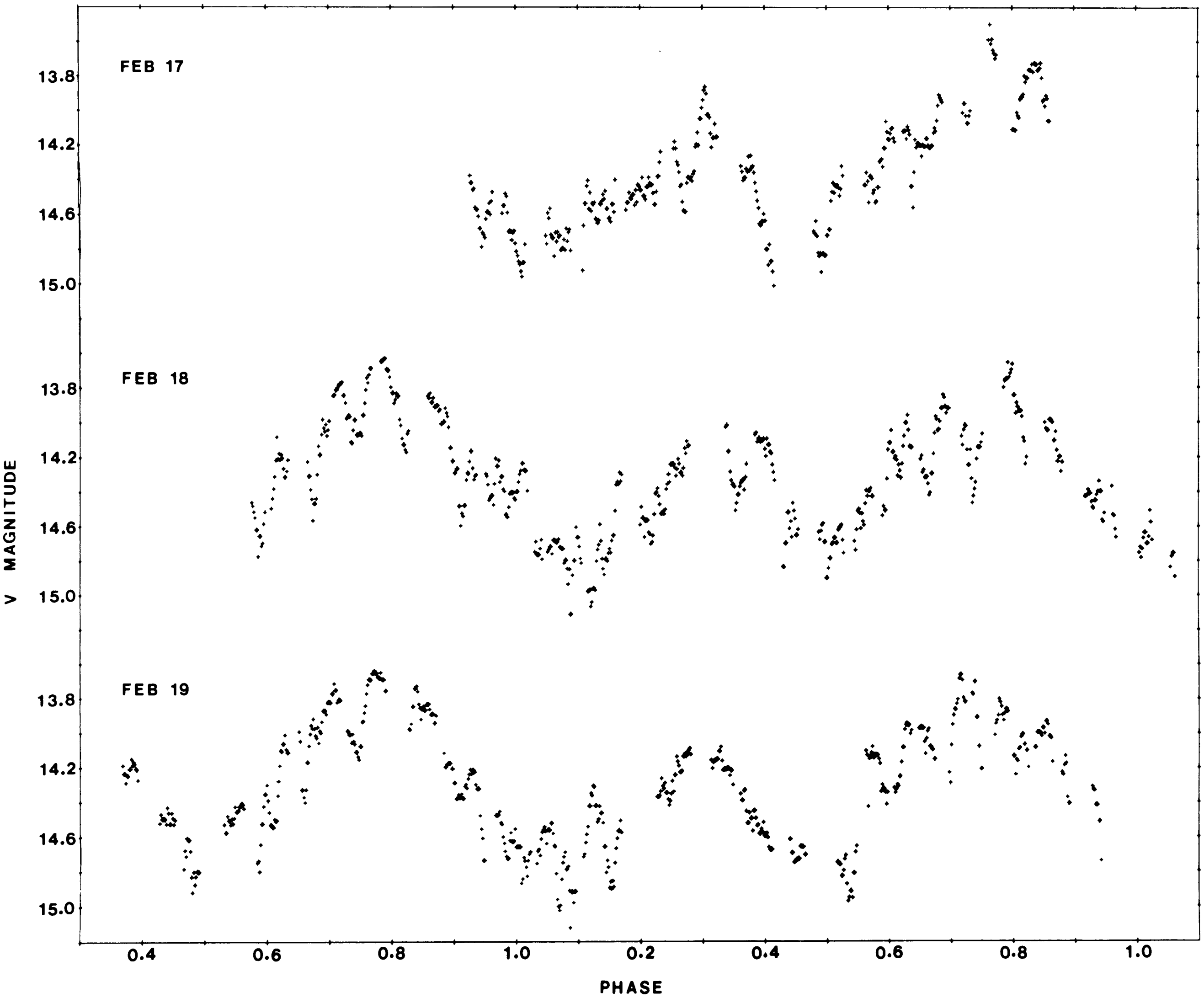

FIG. 1—Visual observations of 1979 February 17, 18, and 19.

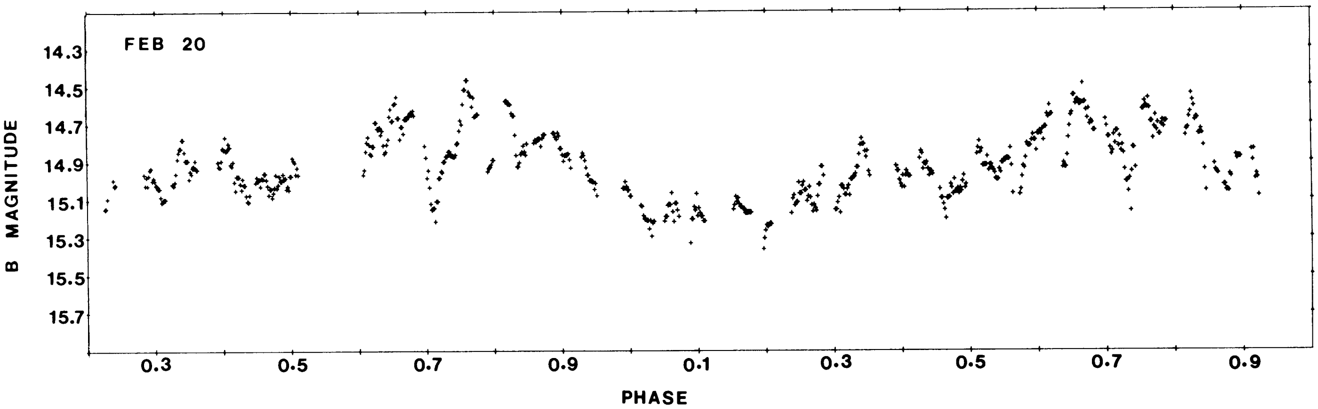

FIG. 2—Blue observations of 1979 February 20.

nights of visual and blue data. The first step in this analysis was to remove the overall variation of the light curves and reduce the data to a mean value of zero. This was done by fitting, to each night of data, the first five

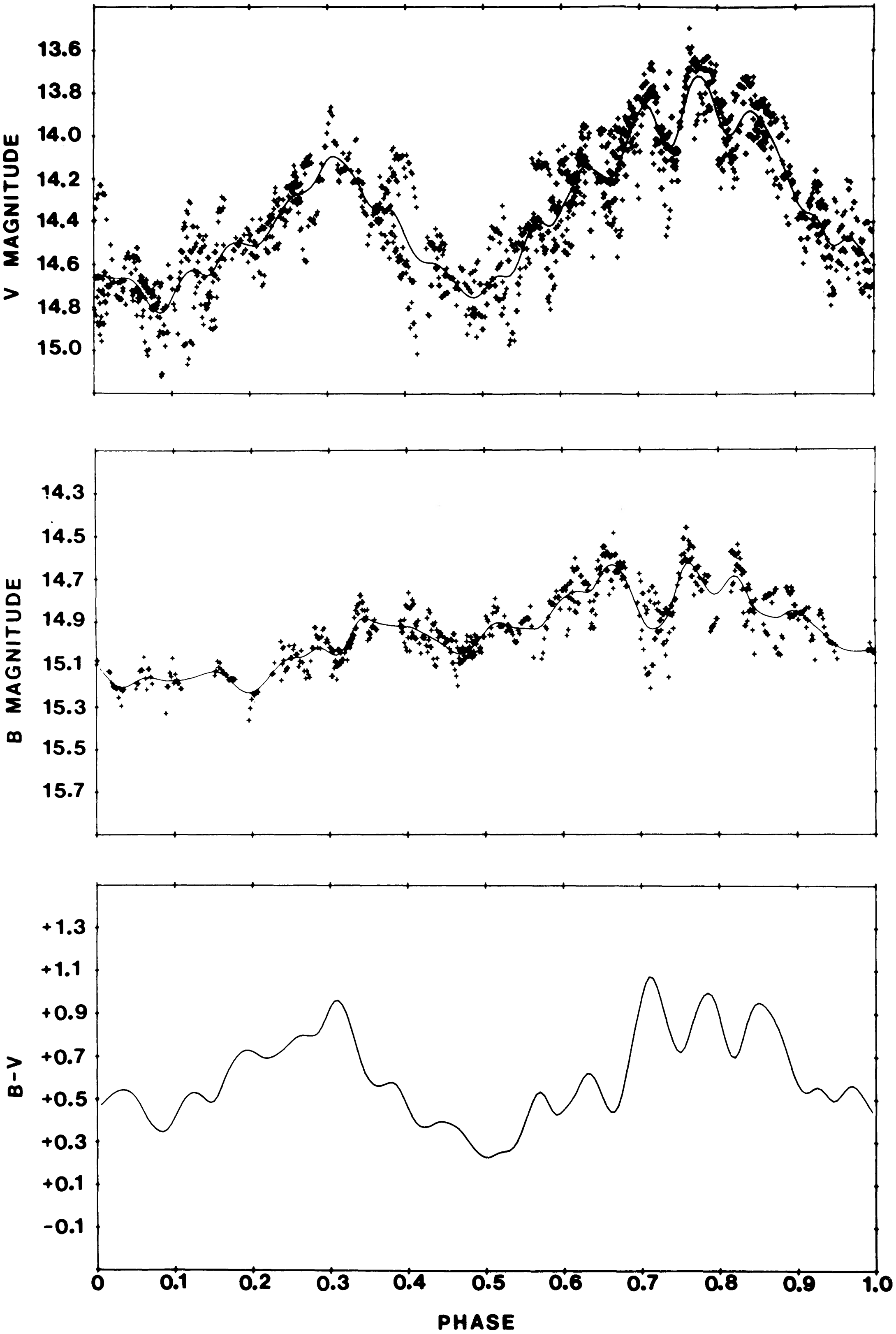

FIG. 3—Composites of all the visual and blue data folded by the orbital period. Cubic smoothing splines were fit to the light curves and then subtracted to give the approximate color curve for the system.

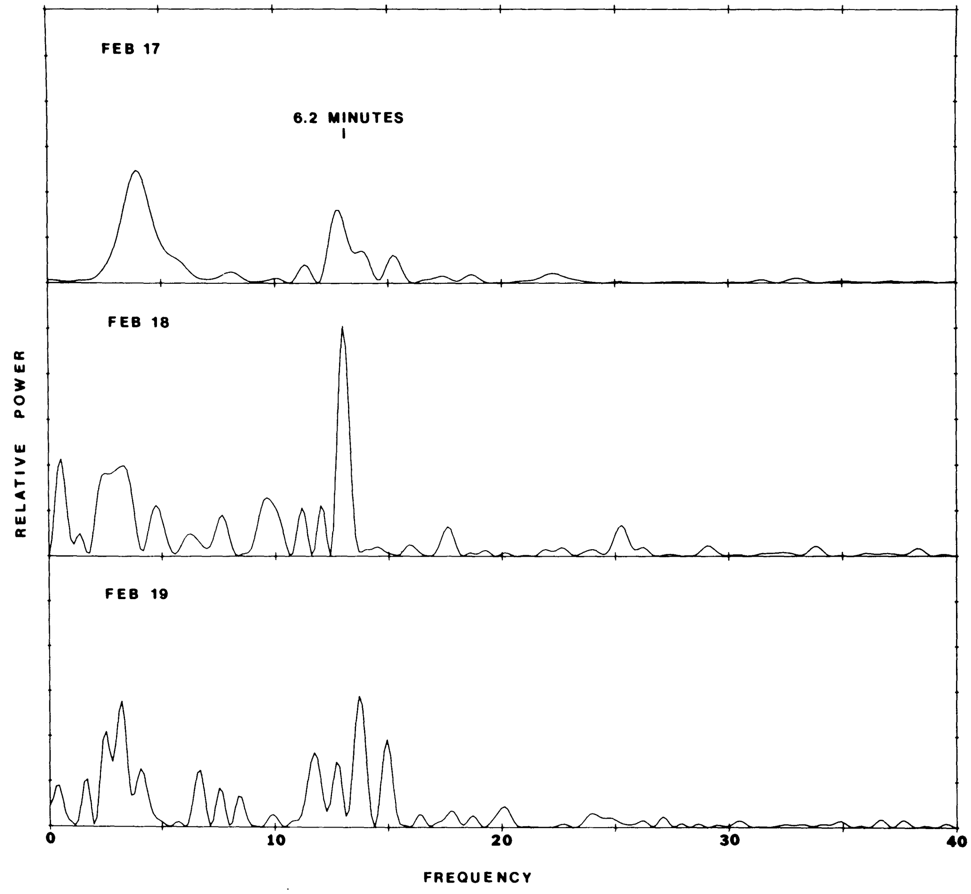

FIG. 4—Power spectra of the three nights of visual observations, after the removal of the fundamental and first harmonic of the orbital frequency, plotted against frequency in terms of the orbital frequency.

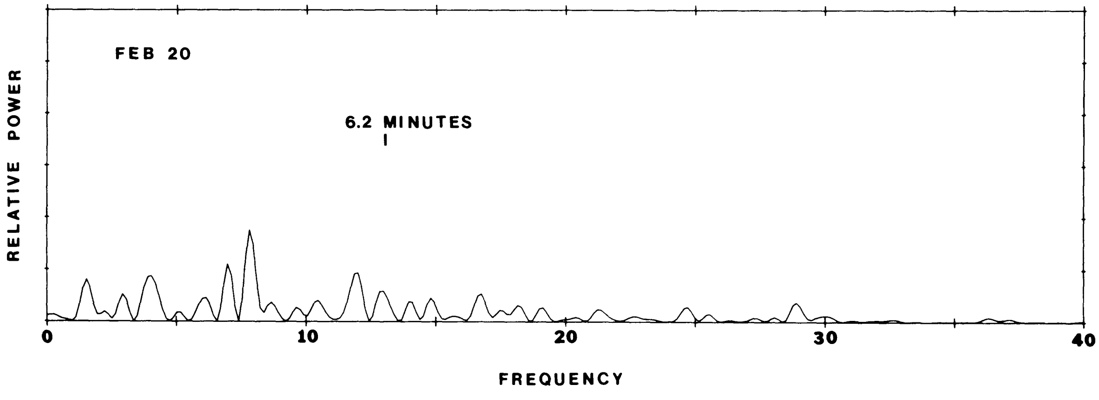

FIG. 5—Power spectrum of the one night of blue observations, after removal of the fundamental and first harmonic of the orbital frequency, plotted against the frequency in terms of the orbital frequency.

terms of a Fourier series,

$$A_1 + A_2 \sin \phi + A_3 \cos \phi + A_4 \sin 2\phi + A_5 \cos 2\phi$$

where ϕ represents the orbital phase in radians. The fit was achieved by an exact least-squares calculation. After the coefficients had been determined this function was subtracted from the original data. There were two reasons for wanting to remove the overall variation in the light curve and reduce the data to a mean value of zero. First it was desirable to perform the Fourier transform using a 1024-data-point, fast-Fourier-transform routine. Since each night of observations would consist of less than 1024 data points, the ends of the data array were filled with zeroes. Reducing the data to a mean value of zero removed any problems which might have arisen from a discontinuous jump in the data. Second, since the orbital frequency would, in general, not be an integral multiple of the fundamental frequency of the transform, removing the overall variation in the light curve prevented "spectral leakage" of power from the orbital frequency to higher frequencies.

The second step in the analysis was to bin the observations by 34 seconds before they were inserted in the data array. This made the length of the data array 580 minutes, or 7.16 orbital cycles, and increased the spectral resolution at low frequencies. A linear interpolation was used as an approximation to the light curve across breaks in the data that occurred due to observations of sky or a standard star.

The results of the Fourier analysis are shown in Figures 4 and 5 for the visual and blue light curves, respectively. The relative power of each Fourier coefficient has been plotted against frequency in terms of the orbital frequency. The results do indicate that a six-minute oscillation is present, at least in the visual light curve. Whether or not it is also present in the blue light curve is difficult to determine from the present data. From the three nights of visual data we might conclude that the six-minute oscillation probably varies in amplitude and may vary slightly in frequency. The coherence of the oscillation over many orbital cycles is unclear. This analysis did not show the presence of any higher frequency oscillations in either the visual or blue light curves.

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