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THE NATURE OF AM HERCULIS

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ABSTRACT

The light curve of AM Herculis shows irregular variation in intensity of as much as 0.2 mag on time scales of minutes. No stable pulsations seem to exist, although quasi-periodic oscillations are evident in the light curves. We suggest that AM Her is a cataclysmic variable; while the evidence is not overwhelming, we favor the Z Camelopardalis subclassification. A possible identification of AM Her as the optical counterpart of a weak unidentified X-ray source is indicated.

Subject headings: stars: individual — stars: U Geminorum

I. INTRODUCTION

Recent observational studies of high-frequency variability in stars have revealed several new luminosity-variable white-dwarf stars (Landolt 1968; Lasker and Hesser 1971; McGraw and Robinson 1975*b*, and references therein) and have elucidated the nature of the variability of the binary cataclysmic variables (Robinson 1973; Arnold, Berg, and Duthie 1976), which contain degenerate stars as one of the components. In this paper we describe our observations of another high-frequency variable star, AM Herculis, and suggest that its variability is similar to that of the cataclysmic variables. These observations are part of our continuing program of monitoring these stars and variable white-dwarf stars in two colors to clarify their photometric properties on both long and short time scales.

II. BACKGROUND

AM Her ($\alpha_{1975} = 18^h13^m.7$, $\delta_{1975} = +49°51'.3$) is categorized as an RW Aurigae variable in the variable star catalog (Kukarkin *et al.* 1969). Photographic archives show the star brightness to be variable over long time intervals. Two series of plates, from 1934 to 1939 and between 1940 and 1960, taken at the Sonnenberg Observatory, show the star to be "very irregular" and "in part semiregular" (Meinunger 1960). The variations are of the order of two magnitudes, and the time scale of the variability from these observations is between 130 and 176 days.

A single, 240 Å mm^{-1} spectrogram of AM Her has been taken and analyzed by Bond and Tifft (1974). They report a very blue continuum with sharp hydrogen and calcium K emission lines and no definite absorption lines. In this respect, AM Her is similar to the U Gem cataclysmic variables at minimum light (Kraft 1962); and Bond suggested that in fact AM Her had been wrongly classified. At the time of the spectroscopic observations, AM Her was estimated to be near 15th magnitude.

III. OBSERVATIONS

Our observations were obtained at the Cassegrain focus of the No. 2 91 cm telescope at Kitt Peak National Observatory, using a Kitt Peak two-color photometer and the University of Rochester data-recording system. On four of the five nights of observations, a nearby reference star was simultaneously monitored with a third photometer, to allow us to monitor short-term variations in the extinction. Our data-recording system allows simultaneous recording of the photometer pulse output in all three channels. Successive 1 s integrations are stored on magnetic tape without interruption for extended periods. Table 1 shows our journal of observations for the six runs.

Figure 1 is the light and color curve of AM Her during run 4. The data have been corrected for extinction. The light curve has the distinctive saw-toothed character of cataclysmic variables (cf. Robinson 1973), with rapid linear increases and decreases in luminosity on time scales of a few hundred seconds. Even more rapid variations of a few tens of seconds are seen. The variations are present in both red and blue colors. On each night this saw-toothed variability has characteristic rise and fall times which

TABLE 1
JOURNAL OF OBSERVATIONS

Run	Date UT	Start UT	No. Bins	Mean Counts s^{-1} Red	Mean Counts s^{-1} Blue
1.......	1975 May 9	08:25	3600	3840	1810
2.......	1975 May 9	09:50	2400	3420	1890
3.......	1975 Oct. 9	03:12	3600	3650	1110
4.......	1975 Oct. 10	02:56	3600	3410	1140
5.......	1975 Oct. 11	02:52	3600	3180	1060
6.......	1975 Oct. 12	02:36	3600	3720	1150

* Visiting Astronomers, Kitt Peak National Observatory, which is operated by AURA, Inc., under contract with the NSF.

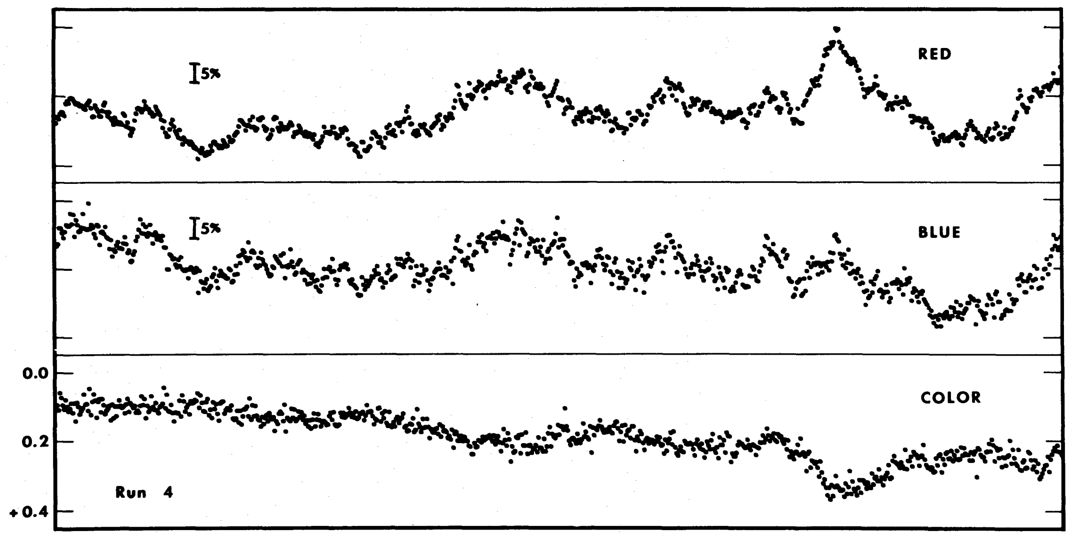

FIG. 1.—The light and color curve for run 4. Each plotted point is the average of five 1 s integrations. The data have been corrected for extinction but remain on the instrumental system. The brackets indicate the scale of a 5% variation. The total duration of data shown spans 1 hour.

persist throughout the run. The characteristic slopes are different from night to night. No systematics to this variability have been found other than that steeper rise times are found on nights with more frequent flickering activity. The observation of flickering variability supports Bond's suggestion that AM Her is a nova-like object. The bottom curve of Figure 1 shows the color variation of AM Her. The overall color variation is about 0.3 mag. There is a periodic ripple in the color curve and an "event" near the end of this run. The periodic ripple was not always present on other nights.

Figure 2 shows the light variations during observing runs 1 and 2. Run 2 follows 25 minutes after the end of run 1. During this interval, standard stars were observed. Runs 1 and 2 have been photometrically reduced and the color curve is transformed to the *UBV* system. The average apparent visual magnitude, as derived from the red measurements, is 12.8 in the first run and 13.0 in the second. The flickering is clearly evident on this night. In many of the cataclysmic variables, for example in U Geminorum itself, there is a gradual increase in intensity near the time of conjunction and an eclipse feature on the descending shoulder of the light curve. In Figure 2, AM Her displays a gradual rise in intensity followed by a decline; but we have detected no eclipses and have not recognized a recurrence of this phenomenon. Our extended observations show that there is no indication of binary behavior. At the bottom of the figure we show the color variations during these observations. Over the two-hour span the $B - V$ color changes from +0.29 to 0.00. There are quasi-periodic color variations during the first run that are completely absent during the second.

The light curves in each color, as well as the color curves, were separately analyzed, using a fast Fourier transform algorithm. Figure 3 shows the power spectra for observing run 1, which had a duration of 60 minutes. The large peaks marked with asterisks are powers of an injected sine curve having an amplitude of 1% of the mean stellar intensity. In addition to providing a power calibration, this allows us to estimate the resolution of the computed spectrum.

There is considerably more power at low frequencies than at high frequencies. This is typical of all cataclysmic variables and also of our observations of AM Her. The spectrum is clearly not that of white noise. Consequently, conventional analysis such as that of Groth (1975) is not correctly applicable, especially at low frequencies. At frequencies greater than $N_Q/10$, where N_Q is the Nyquist frequency, our spectra are essentially flat. To estimate the statistical significance of the calibration signal, we have used the mean power above $N_Q/10$ as an estimate of the variance, σ, of the power spectrum. To estimate the significance of the peak power we compare it with the variance. The power seen at the injected sine curve frequency (Fig. 3) is 7.5 σ above the mean in the red and 5.5 σ above the mean in the blue.

Dominant peaks are identified subjectively as those features in the spectra that appear to be at least as strong with respect to their "local baselines" as the injected sine curve peak is to its baseline. In Figure 3 the three largest peaks occur in both colors at periods of 328, 145, and 62 s. Figure 4 shows similar spectra for the 40 minute run 2. There are five peaks above the 6 σ, 1% injected reference signal, with the three strongest corresponding to periods of 446, 177, and 143 s.

Table 2 lists the dominant peaks in the power spectra of the light curves for each run. The frequency resolution is roughly 0.00004 Hz. We find many peaks on each night. The principal peaks occur at the low-frequency end of the spectrum. From about 0.05 Hz to the Nyquist frequency, the spectra are virtually

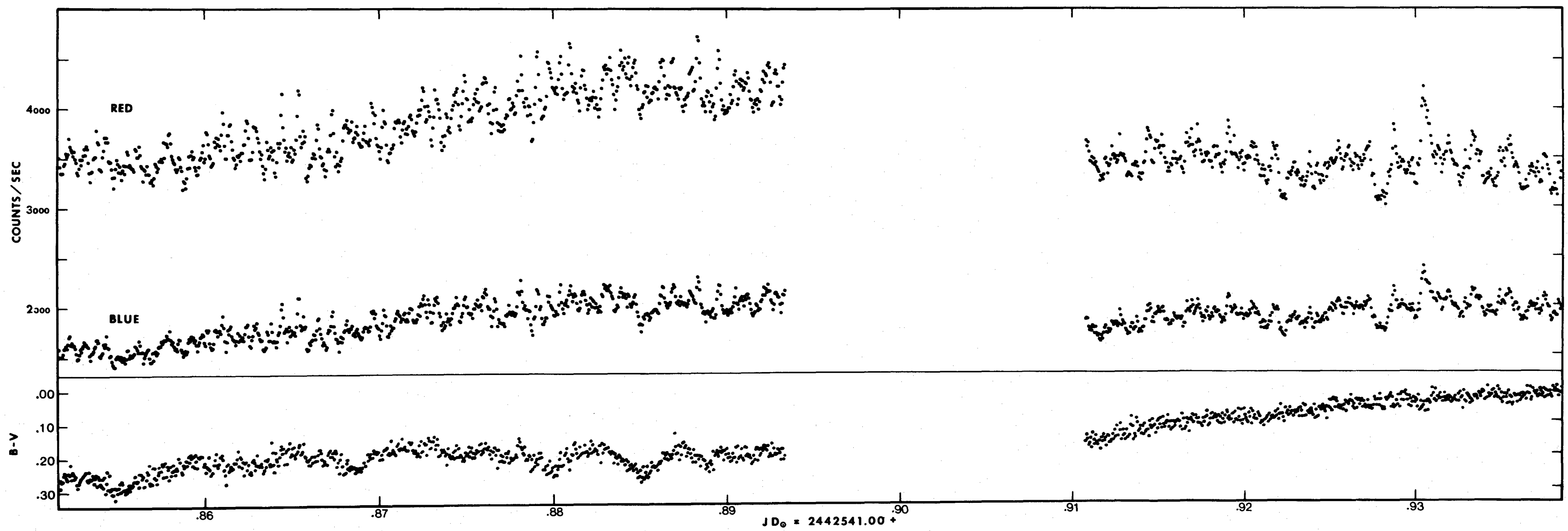

FIG. 2.—The light and color curves for runs 1 (*left*) and 2 (*right*). Each plotted point is the average of five 1 s integrations. The light curves are corrected for extinction; the color curve has been transformed to the *UBV* system.

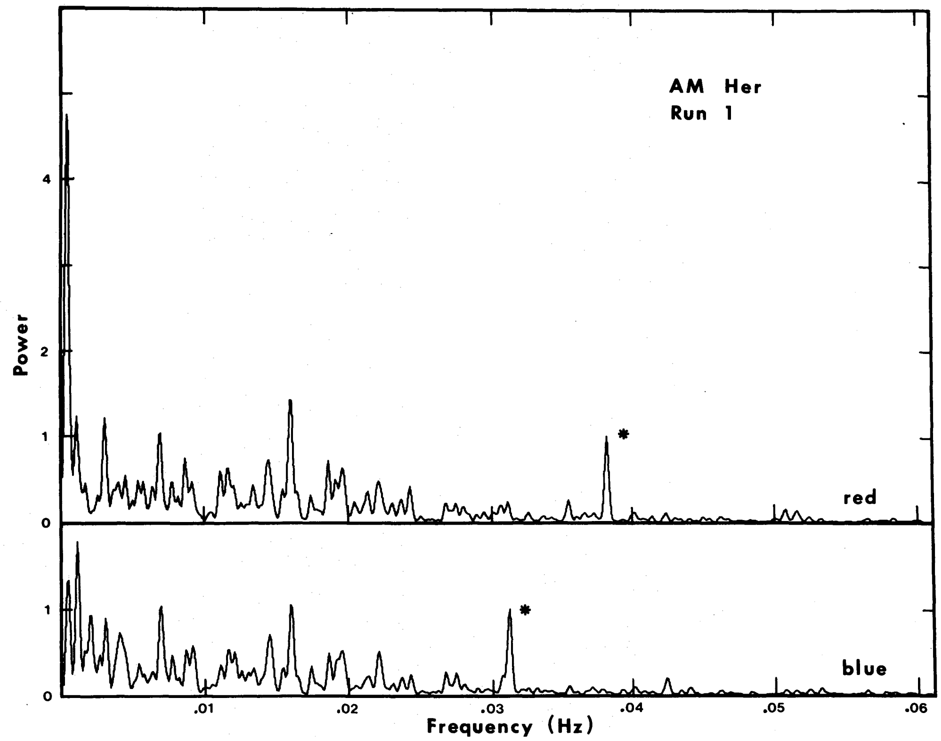

FIG. 3.—The power spectrum of AM Her, run 1, in red and blue light. The peaks marked with an asterisk are injected sinusoidal tracers at the 1% intensity level. The units of power are arbitrary.

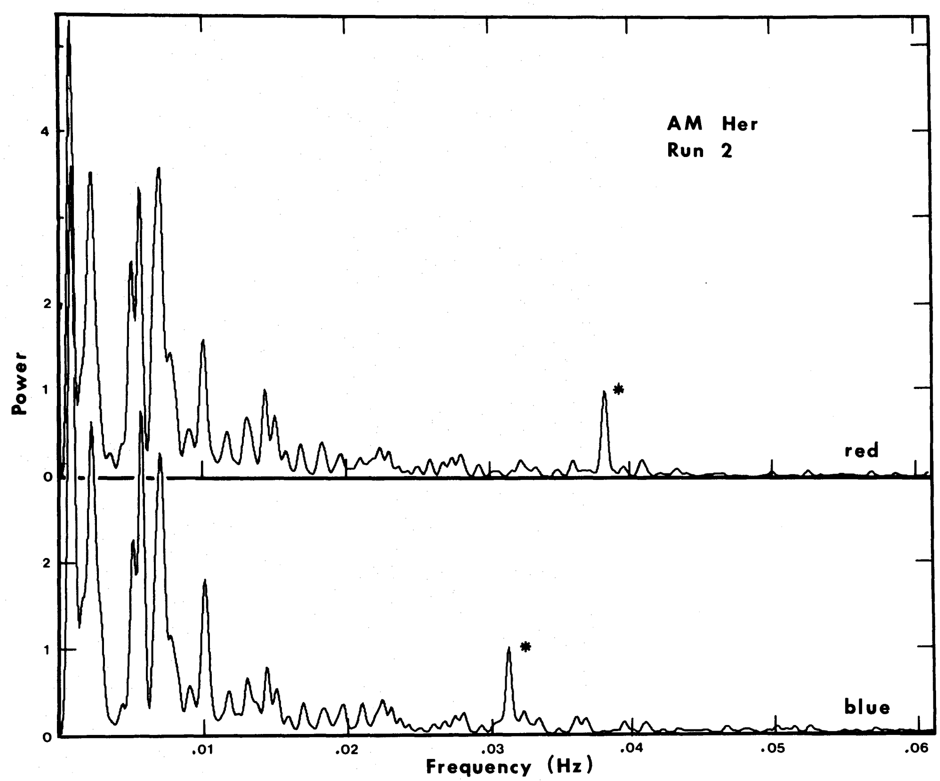

FIG. 4.—The power spectrum of AM Her, run 2, in red and blue light. The peaks marked with an asterisk are injected sinusoidal tracers at the 1% intensity level. The units are arbitrary.

TABLE 2

DOMINANT PEAKS IN POWER SPECTRA

Run	Color	ν (Hz)	Period (sec)
1	Red	0.00306	327.8
		0.00690	144.9
		0.01605	62.3
	Blue	0.00307	325.7
		0.00691	144.7
		0.01605	62.3
2	Red	0.00225	446
		0.00507	197.2
		0.00567	176.4
		0.00702	142.4
		0.01010	99.0
	Blue	0.00222	446
		0.00508	196.9
		0.00567	176.4
		0.00700	142.8
		0.01010	99.0
3	Red	0.00333	300.3
	Blue	0.00327	305.8
4	Red	0.00325	307.7
		0.00379	263.8
		0.00440	227.3
	Blue	0.00327	305.8
		0.00380	263.2
		0.00439	202.8
5	Red	0.00307	325.7
		0.00493	202.8
	Blue	0.00304	328.9
		0.00412	242.7
		0.00496	204.1
6	Red	0.00442	226.2
		0.00487	205.3
		0.00546	183.1
	Blue	0.00444	225.7

flat. There is no overwhelming evidence of reproducibility in the detailed structure in the power spectra from night to night, although with such complex power spectra some coincidences are to be expected. The low-frequency spectrum may best be described as complicated and variable. On some runs weak peaks occur at frequencies which are linear combinations of strong peak frequencies. Such effects are found in the variable DA white dwarfs R808 (McGraw and Robinson 1975*b*), HL Tau 76 (Fitch 1973; Page 1972), and G29-38 and G38-29 (McGraw and Robinson 1975*a*). The best example of this phenomenon in our observations of AM Her is in run 1, where the three most significant peaks are $f_0 = 0.01605$ Hz, $f_1 = 0.00306$ Hz, and $f_2 = f_0 - 3f_1 = 0.00690$ Hz. In the analysis of the color curves shown in Figure 5 for run 1, there are two well-established periodicities at 500 and 241 s. Both peaks are above the 8 σ level of the calibration peak. In run 2, the single significant peak is at 953 s, but this feature is at sufficiently low frequency that its validity is questionable. We note that the No. 2 91 cm telescope has a worm-wheel drive with a period of 120 s (Hoag 1976). Although we find no features at this period, the color variation at 241 s in run 1 may in some way be related to a systematic effect caused by the drive mechanism.

IV. DISCUSSION

Perry (1975) has obtained some Strömgren photometric data of AM Her simultaneous with our run 6. Table 3 lists his data for three observations over a period of seventeen minutes. His values of V and $b - y$ are consistent with those we derive from our own rapid photometry. The m_1 index varies from 0.18 to 0.33 over the span of the observations and is typical of DA white dwarfs. The c_1 index, however, is grossly different from the c_1 index of normal white dwarfs. Figure 6 shows a color-color diagram for white dwarfs (adapted from Graham 1972). The observations of AM Her are indicated on the diagram. The c_1 index [converted to $(u - b)$] places AM Her well above the DA white dwarfs and even above the DC white-dwarf positions on the blackbody curve. Mumford (1967) has shown that in the color-color plane the U Gem stars tend to fall above the blackbody curve.

We conclude that AM Her is a cataclysmic variable. The evidence includes: (1) Bond's observations of the emission features on the very blue continuum; (2) our observations of the light curves with the variability characteristic of other known cataclysmic variables; (3) the nonstationary complex structure in the power spectra; and (4) the position of the star in the color-color diagram above the blackbody curve. We are unable to distinguish between a U Gem or a Z Cam subtype for AM Her, but perhaps the latter is correct. Throughout our observations, AM Her remained closed to $V \approx 12.5$ mag, whereas Bond observed $V \approx 15.0$ mag. This may represent the standstill typical of the Z Cam variability.

At an apparent magnitude of 12.5 mag or greater, AM Her lies 25° above the galactic plane at $l^{\rm II} = 78°$, in an unobstructed region of the sky. The Palomar prints show no evidence of diffuse nebulosity around the star. Thomas (1975) at our request reviewed the Lowell Proper Motion survey plates and concluded that over a 25 year baseline there is no evidence for proper motion greater than 0".04 yr^{-1}. No radio

TABLE 3

STRÖMGREN PHOTOMETRY OF AM HERCULIS 1975 Oct. 12 UT

Magnitude or Color Index	T	$T + 9'$	$T + 17'$	rms Error
V	+12.56	+12.56	+12.59	±0.12
$b - y$	+0.13	+0.12	+0.07	±0.01
$(B - V)$	+0.23	+0.21	+0.13	...
m_1	+0.21	+0.18	+0.33	±0.02
c_1	−0.78	−0.70	−0.82	±0.02

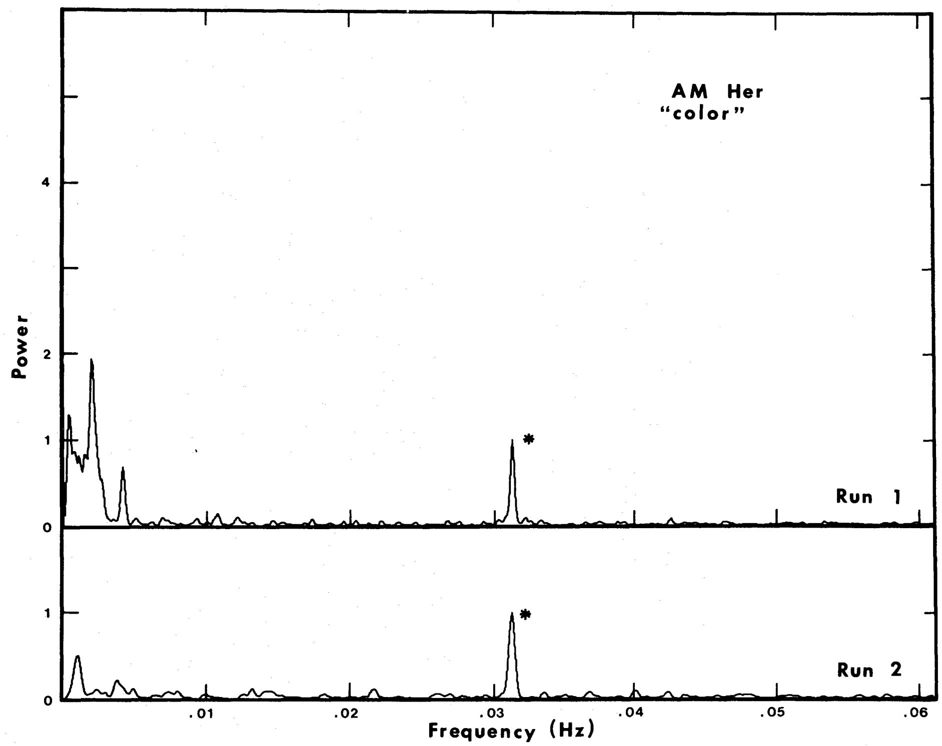

FIG. 5.—The power spectrum of the color of AM Her on runs 1 and 2

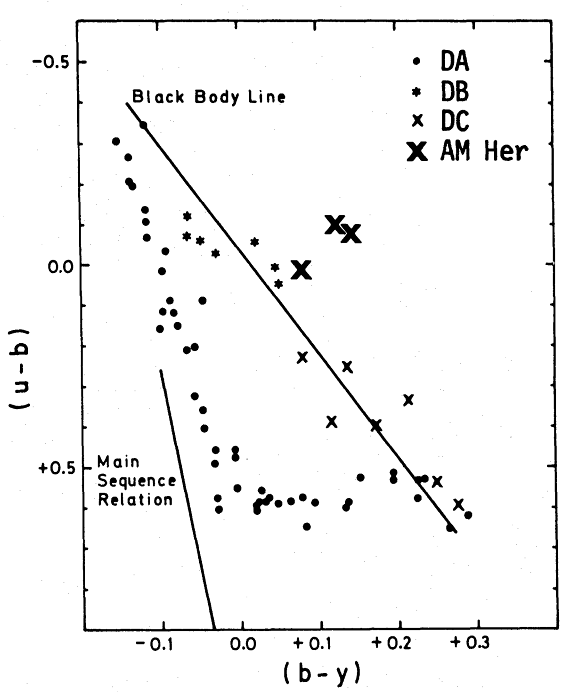

FIG. 6.—The color-color diagram for white dwarfs, after Graham 1972. To Graham's figure we have added his data for DB and DC white dwarfs and the observed data for AM Her.

sources or quasars are within three degrees of AM Herculis. The star lies just outside the 90% confidence error box for the weak X-ray source 3U 1809+50 on a line along the major axis of the error box. Recent SAS-C satellite observations by Hearn, Richardson, and Clark (1976) have indicated a source at a position in which AM Her is inside the 0.026

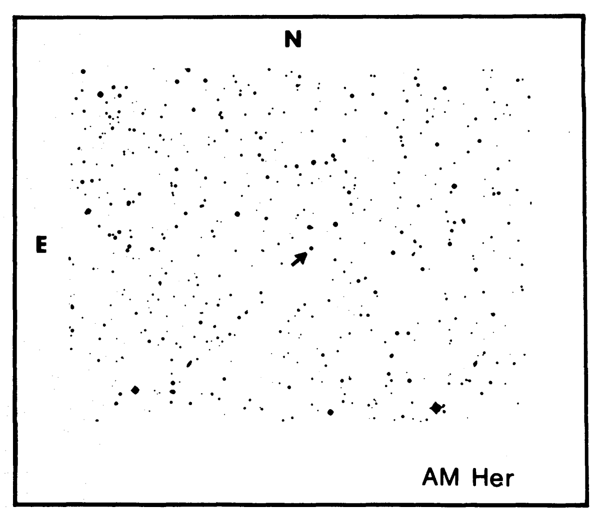

FIG. 7.—Finding chart for AM Her. The field is 20′ × 26′.

square degree 2 σ error box. The source has rapidly varying strong X-ray emission in the lowest energy channel, i.e., $< 1/4$ keV, roughly 0.2 the strength of HZ 43 at the same energy, and comparable in variability characteristics with the optical variability we see in AM Her. They are uncertain about the detection of higher energy radiation from this source. If the identification of AM Her with this source is confirmed, measurement of soft X-rays from this object will provide a measure of the distance to it. In Figure 7 we provide a finding chart for AM Herculis.

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