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ON VV PUPPIS

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ABSTRACT

Spectrophotometric observations of VV Puppis, a polarized AM Herculis–type binary, showed a dramatic change in the system's behavior between 1977 March 24 and April 12. In late March the object showed strong hydrogen and helium emission lines and varied from $m_v \approx 15.0$ to $m_v \approx 17.5$ within its 100 min period. Variations in the total emission-line flux independent of the continuum were noted. In April, however, the system remained at a steady $m_v \approx 17.8$ and the emission lines had disappeared. Subsequent observations in 1977 November and December showed the system again in a faint, inactive state. We report broad-band circular polarimetry during this time, and a peak value of only 7% compared with Tapia's bright-phase peak of 15%.

On the basis of these observations and the optical polarimetry properties reported by Tapia, it is clear that the standard dwarf nova model previously used to describe VV Pup is not correct. As with AM Her, accretion appears to take place directly onto the magnetic poles of a phase-locked magnetic white dwarf, without the formation of an accretion disk. However, VV Pup is strikingly different from AM Her in having (1) an eclipse-like light curve with more than half the period spent near minimum light, and (2) states of steady low light level almost free of emission lines, as reported here. We interpret this behavior in terms of emission from small accretion columns at the poles of an oblique dipole, which rotate in and out of view like sunspots. However, the rapid photometric eclipse shows that the "bright-phase" polarized emission region is only ~100 km in size. The emission lines must originate many radii away from the accreting degenerate in a high-density ($n_e \gtrsim 10^{12}$ cm^{-3}) region. Long-term light-curve variations suggest that both magnetic poles are generally active but at different accretion rates. However, it is argued that the steady low luminosity state observed in 1977 April and December was dominated by continua from the underlying stellar components. The red excess and structure in the energy distributions observed then may be attributable to a red secondary star: it appears to show TiO absorptions. A lower limit for the systemic distance of 80 pc and a model-dependent upper limit of 150 pc from the brightness-temperature constraint are deduced.

Subject headings: polarization — stars: accretion — stars: eclipsing binaries — stars: individual

I. INTRODUCTION

VV Puppis (1900: $8^h10^m38^s$, $-18°44.9'$) is now the third recognized AM Herculis–type system, a dwarf-nova–like binary with a magnetic degenerate primary. Known as a periodic variable since its discovery by Van Gent (1931), VV Pup was interpreted by Herbig (1960) as an eclipsing binary system with H and He II emission lines and a full radial velocity amplitude of 874 km s^{-1} over the 100 min period. The modern photometric studies of Walker (1965), Smak (1971), and Warner and Nather (1972, hereafter WN) have shown that the light curve is similar to that of U Geminorum. There is usually a rapid drop from maximum to minimum light, where the system remains for 58% of the period, followed by an irregular recovery. However, there are substantial variations in the light curve's shape in addition to the fast flickering. Long-term variations in minimum and maximum light levels have been documented. The photographic m_{min} was as bright as 14.4 several decades ago, but has not to our knowledge been reported brighter than 15.5 since 1960 (Smak 1971). Likewise, the Δm within a period has varied between zero and two magnitudes, though Smak was unable to establish a clear correlation between m_{min} and Δm. Thackeray, Wesselink, and Oosterhoff (1950) reported Δm near zero for brief periods during 1948–1949, with the system's light level at $m_{pg} = 16.8$–17.0.

Recently, Tapia (1977) reported the discovery of strong periodic circular and linear polarization for VV Pup, the key characteristic that previously distinguished AM Her and AN UMa from other short-period systems with various dwarf nova characteristics, and which is a sure indication of a very strong magnetic field. Strong positive circular polarization as high as 15% coincided with the brightening phase

TABLE 1

1977 OBSERVATIONAL LOG FOR VV PUPPIS

Date (UT)	Telescope (m)	Instrument	Comments
Mar 23........	2.3	Intensified reticon	Bright phases, flaring
Mar 24........	2.3	Intensified reticon	Bright phases, no flares
Apr 12.........	2.3	Prism scanner	Faint, $m_v \approx 17.8$
Apr 13.........	4	KPNO IDS	Faint, no strong emission
Apr 15.........	2.3	Intensified reticon	Faint, no strong emission
Nov 10........	2.3	Image-tube spectrograph	Faint, no strong emission
Dec 4..........	3	Lick IDS	Faint, no strong emission
Dec 4..........	3	Lick IDS	Faint, no strong emission
Dec 6..........	2.3	Polarimeter (broad-band)	$m_v \approx 17.6$, $\Delta m \approx 0.2$ Circular polarization $\lesssim 7\%$

of the period: near minimum light the circular polarization was found to be near zero or weakly negative. The linear polarization was essentially zero for most of the period, but jumped to $\sim 15\%$ briefly near the end of the system's bright phase. While these polarization properties are not dissimilar to those reported for AM Her and AN UMa, VV Pup differs in its eclipse-like photometric variations.

The discovery of polarization and the unique history of VV Pup led us to attempt spectrophotometric observations in 1977 March and April. While the two observing periods were separated by only 20 days, we were extremely fortunate to find that the source in early April had made a transition to an unusual state of steady low luminosity with no strong emission lines. These data and other more recent spectra are described in § II. Broad-band circular polarimetry measurements were added in 1977 December when the object was again found in an inactive state; these are discussed in § III. In § IV we show how the observed properties of VV Puppis can be accommodated by the magnetic-pole accretion model previously developed for AM Her (Stockman *et al.* 1977, hereafter Paper I). However, the differences between the two objects—the eclipse-like bright phase, the long-term variations, and states of steady low luminosity—give added information on these interesting systems. Preliminary reports of this work have been given in Woolf *et al.* (1977) and Liebert *et al.* (1977).

II. THE SPECTROPHOTOMETRY

In this section we describe spectrophotometry from several sources obtained over the period 1977 March–December. The different observations are listed in Table 1. VV Pup was observed for two hours each on 1977 March 23 and 24 and briefly again on April 15 with the Steward Observatory 2.3 m telescope and Cassegrain spectrograph. An intensified Reticon system behind an RCA two-stage image tube was used as the detector (Williams *et al.* 1978). In this early use of the instrument, only the central 512 channels of one array were operative, and we were unable to correct small-scale gain variations in the intensifier. Nonetheless, the observations showed behavior not previously observed for VV Pup and which was clearly intrinsic to the star. The resolution on March 23 and April 15 was 15 Å covering 3500–7000 Å, and for March 24 was 6 Å between 4000 and 5200 Å. Circular entrance apertures of 5″ and $3\frac{1}{2}$″ on the sky were used for the 15 Å and 6 Å resolution scans, respectively. Though the object was always low in the sky at hour angles ranging from 0^h to 2^h, color errors due to atmospheric dispersion should not be a serious effect for the 5″ aperture observations.

On March 23 and 24, the system exhibited an eclipse-like light curve, grossly similar to WN's Figure 3. A plot of the integrated signal at 5 min intervals on March 23 indicated $m_{\min} \approx 17.5$, $\Delta m \approx 2.5$. We also noted signal changes (i.e., flickers) on ~ 1 min time scales. There were two times on March 23 when the light level approximately doubled and then rapidly returned to its previous level. Light curves constructed from the integrated Reticon scans for this night are shown in Figure 1. The lower curve represents the continuum (points at 4000, 4500, and 5000 Å); the upper is a sum of Hβ, Hγ, and Hδ emission-line fluxes.

Two features stand out in these curves: (1) a sudden, fourfold increase in all emission-line strengths near phase 0.70, with the subsequent decline lasting $\sim 1/4$ period (emission-line flare); and (2) the maximum continuum emission about 1/3 period later, culminating in a very bright 1–2 min continuum flare noted in the real-time signal monitor and marked on Figure 1. On March 24 we detected no brightening of the emission lines as the continuum light rose. We thus conclude that the emission lines may brighten and dim independently of the main variations of continuous light and the continuum flickering. WN demonstrated flickering in their fast photometry of VV Pup, and various observers (e.g, Priedhorsky and Krzeminski 1978) have noted similar broad-band behavior in AM Her. However, we are unaware of any prior evidence for rapid variability in the line fluxes of any of these objects.

Three time spans indicated by letters on Figures 1 and 2 correspond to (*a*) the faint continuum, (*b*) the emission-line flare, and (*c*) the bright continuum phases of this March 23 period. In Figure 2 we show the composite spectra of these three phases, together with scans of the other objects similar to VV Pup—AM Her and AN UMa—obtained the same night. We

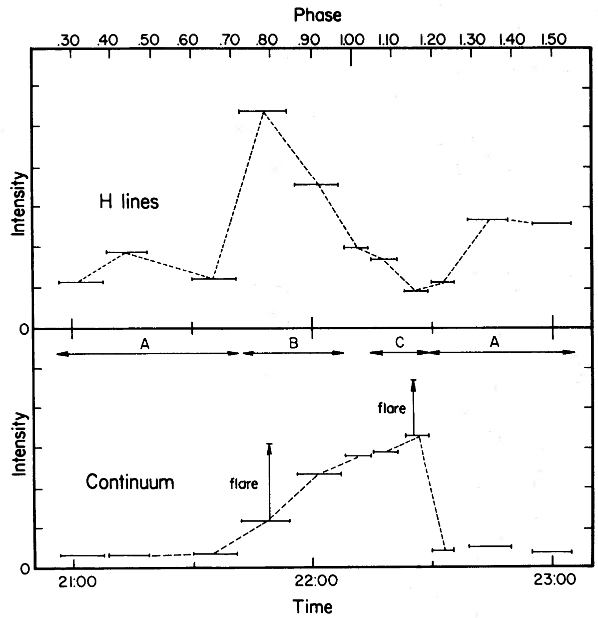

FIG. 1.—Light variations for VV Pup during one period on 1977 March 23 (UT) as determined from individual 5 min and 10 min Reticon integrations. The upper tracing is the sum of Hδ, Hγ, and Hβ measured manually from individual plots; the lower tracing is the sum of three continuum flux intervals near 4000 Å, 4500 Å, and 5000 Å where the signal-to-noise ratio was best. The continuum flares discussed in § II are indicated, as are three lettered time intervals from which the composite spectra of Fig. 2 were constructed. We believe that the continuum points are uncertain by $\sim 20\%$ due to guiding errors; line flux values are uncertain by approximately one of the arbitrary intensity units indicated by ordinate ticks. One can also judge by the Fig. 2 composites. Walker's ephemeris is used here and in Fig. 5; the zero point corresponds to the center of the photometric bright phase.

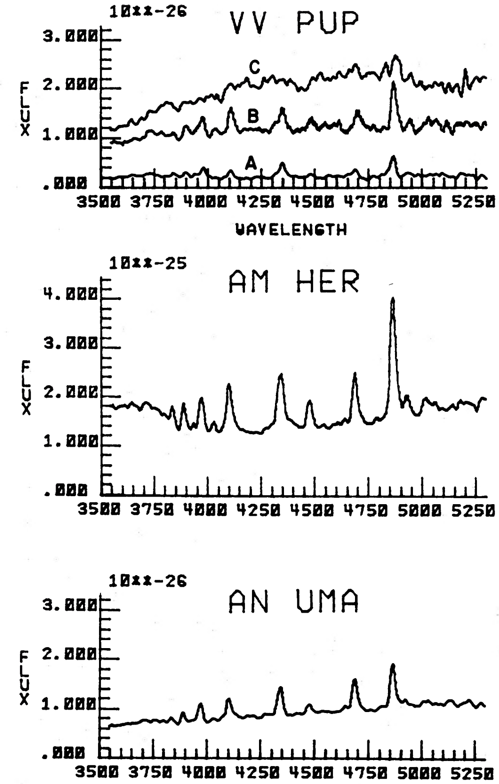

FIG. 2.—Steward 2.3 m Intensified Reticon spectrophotometry at 15 Å resolution on March 23. The intervals indicated in Fig. 1 were summed to produce composite VV Pup spectra of (*a*) the faint phase, (*b*) the line-emission flare, and (*c*) the bright phase. Also shown are spectra of Am Her and AN UMa obtained the same night with the same instrumental parameters.

note the appearance of weak He II $\lambda4686$ and He I $\lambda4471$, particularly in the emission-line flare. There appeared to be no substantial changes in the continuum color with time. We found that the color between 4000 Å and 5500 Å changed less than 0.1 mag from light minimum to light maximum.

The April 15 Reticon observing was limited by poor weather to one 15 min observation. However, two other types of data are available from the same week: (1) single-channel prism scans at Steward, and (2) a Kitt Peak 4 m intensified image-dissector scan (IDS) obtained by Hyron Spinrad and Harding E. Smith.

The prism scanner (Paper I) utilized an entrance slit aligned with the direction of atmospheric dispersion, permitting more accurate photometry over 3400–8200 Å. It became apparent during the 2 hr observations on April 12 that VV Pup was remaining quite faint, with variations of less than $\frac{1}{2}$ mag, and an average $m_{5500} = 17.8$, marginally fainter than the minimum light level in March. The composite energy distribution from this observation (Fig. 3) does not show any of the strong emission bumps or Balmer continuum seen in similar data on AM Her taken the same night. The April IDS scan (Fig. 4) and brief Reticon observations confirmed the low light level and demonstrated a lack of strong hydrogen emission lines. We estimate $F(\mathrm{H}\beta) \lesssim 2.0 \times 10^{-16}$ ergs cm^{-2} s^{-1} or 10% of the March average flux. A strong unidentified feature near 3470 Å is statistically significant in both scanner and IDS spectra. The scanner energy distribution covering 3500–7000 Å fits a 9000 K blackbody reasonably well, but the distribution appears to increase redward of this to the last data point past 8000 Å. IDS fluxes do not yield reliable colors because of strong atmospheric dispersion and seeing effects for this southern object ($\delta \approx -19°$).

Subsequent observations beginning with a photographic RCA image-tube spectrum on 1977 November 10 (UT) showed the system still in a faint state, lacking appreciable emission lines, although it had been reported to be active again in 1977 June by Bond (1977). The December 6 broad-band polarimetry measurements yielded the photometric result discussed in § III. Two Lick 3 m IDS observations were obtained on December 4. The IDS scans were each 16 min in duration and covered 3700–6000 Å and 5400–7500 Å, respectively, at 8 Å resolution. Due to the continued faintness of the object, these were of a noise level similar to that of Figure 4. We display flux points

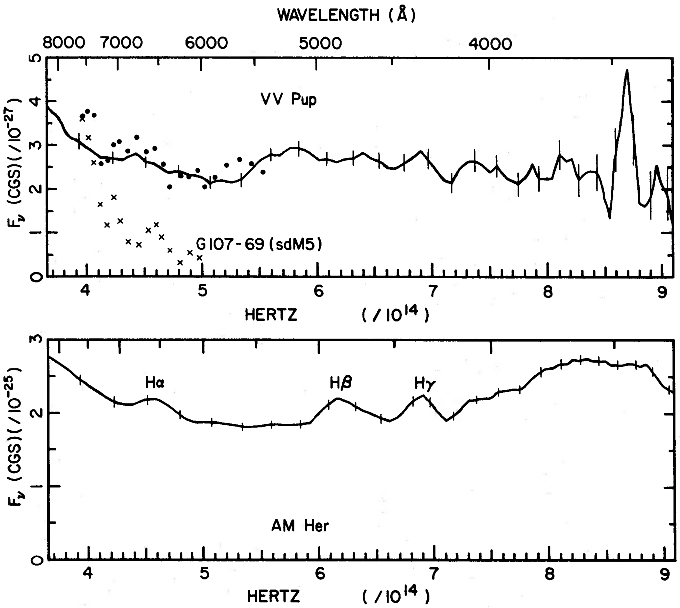

FIG. 3.—*Solid lines*, single-channel prism scans of VV Pup and AM Her, obtained on April 12. The horizontal bars, which are placed every smoothing width, indicate $\pm 1\ \sigma$ counting statistics. Note the red excess over the last $\sim$1000 Å. *Black dots*, the December 4 Lick IDS red observation, averaged in 100 Å intervals, with uncertainties of $\sim$20%. The IDS data are normalized to the scanner fluxes spanning 5400–6100 Å. *Crosses*, similarly compressed IDS observations of the sdM5 star G107−69.

averaged over 1000 Å intervals from the red IDS scan in Figure 3, greatly compressing the IDS information. A very late M star observed with the same system is shown for comparison. No emission lines were observed. A flat energy distribution consistent with the April measurements was found over 5000–6500 Å; for $\lambda \gtrsim 6500$ Å the general flux level rose, reaching a 50% excess over the 5000–6500 Å mean value at 7500 Å. The evidence for TiO absorption indicative of a cool secondary rests primarily on the expected broad dip at 7150–7300 Å and sharp rise in the continuum redward to $\sim$7500 Å. Possible TiO depressions near 6300 Å and 5900 Å are at the noise level. This evidence suggests that the scanner red excess

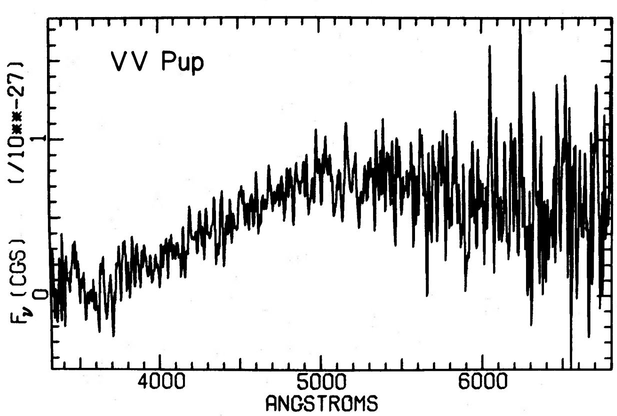

FIG. 4.—A 4 m IIDS scan of VV Pup on April 13, kindly made available by Drs. Hyron Spinrad and H. E. Smith, demonstrating the weakness or absence of hydrogen emission lines. The data have been smoothed to a resolution of $\sim$10 Å.

(Fig. 3) is due not to the polarized continuum as in AM Her (Paper I), but to an M dwarf companion not seen when VV Pup is bright. VV Pup would be the shortest period interacting binary system for which light from an apparent, mass-losing secondary is seen (see, e.g., Robinson 1976). See also the note added at the end of this paper.

III. BROAD-BAND CIRCULAR POLARIZATION MEASUREMENTS

VV Pup was observed on 1977 December 6 from 10.2 to 12.2 hours UT with the broad-band polarimeter described in Angel, Landstreet, and Martin (1978). A 4″ aperture was used, with the object at a mean airmass of 1.7. Since no filter was used, the spectral response of the instrument was approximately constant from the UV atmospheric cutoff ($\sim$3200 Å) to the red cutoff of the C31034A photomultipliers ($\sim$8600 Å). The measured efficiency for detecting circular polarization in this band was 81%.

In Figure 5 the time-resolved data corrected for night-sky background and instrument efficiency are displayed, with each point representing two minutes of integration and vertical error bars representing 1 σ counting statistics. Points are clumped in groups of four. Each point is free of sky polarization and corrected for dilution by the sky and instrumental efficiency. The time at which the circular polarization crosses zero from positive to (slightly) negative values corresponds approximately with Walker's phase 0.14, using his ephemeris in WN, and thus also coincides with the end of WN's photometric bright phase. A steady peak value of $\sim$7% was noted during the high-

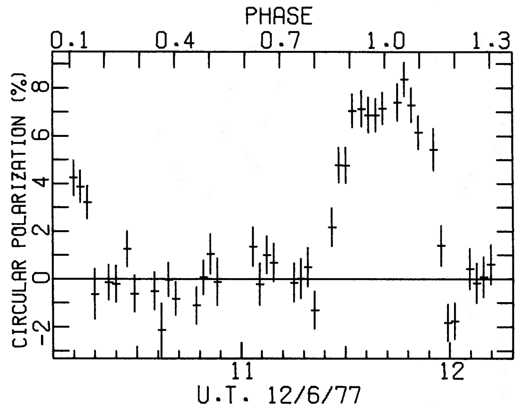

FIG. 5.—Broad-band (3200–8600 Å) circular polarization of VV Pup on 1977 December 6 (UT). Crosses indicate independent 2 min measurements. The vertical bars represent $\pm 1\ \sigma$ from the count statistics, while the horizontal bar spans the 2 min interval. The phase of positive polarization coincided with a modest ($\Delta m \approx 0.2$) photometric bright phase (see text).

polarization phase, a value substantially lower than Tapia's (1977) earlier result when the system was photometrically brighter. The brief period of negative polarization indicated by the two data points just past phase zero is also seen in Tapia's (1978, unpublished) data. The average value for the remainder of the low-polarization phase is $0.0 \pm 0.2\%$, though phase-dependent changes with amplitude as large as $\sim 1\%$ are not ruled out during the low state.

Broad-band apparent (visual) magnitudes of 17.5 and 17.7, corrected for extinction, were measured for the average high and low polarization phases; we estimate ± 0.2 mag absolute and ± 0.05 mag relative accuracies for these two numbers. Thus a modest photometric "bright" phase really occurred during this one period, though the object lacked detectable emission lines when observed during November and December (§ II).

IV. A MAGNETIC-POLE ACCRETION MODEL

Despite the similarities of its light and radial velocity curves to those of dwarf novae, previous investigators have encountered difficulties in fitting VV Pup with a conventional accretion-disk/hot-spot model. Smak and WN found it necessary to invoke a light-dominant spot where the incoming stream hits the accretion disk, rather than an extended luminous disk, to reconcile the light curve's striking "bright" phase, the Herbig velocity curve, and the absence of double-peaked emission lines. WN attributed the generally sharp drop from $m_{\max}$ to $m_{\min}$ to eclipse of the hot spot by the secondary star. However, the long eclipse duration ($\sim 60\%$ of the period) forced WN to extend the eclipse using the presumed dark, optically thick disk and/or stream of inflowing gas from the secondary. The initial secondary eclipse had to be a grazing one, and the hot spot's position was presumed to vary, since eclipse ingress is not always so sharp.

The association of high circular polarization with the bright-phase continuum light now provides conclusive evidence that this light is not emitted from a spot on an extended disk; rather, it must originate in a high-magnetic-field region ($B \gtrsim 10^8$ gauss) near or at the surface of a magnetic degenerate, presumably a white dwarf, as argued for AM Her in Paper I. In the remainder of this section, we show that the properties of VV Pup can be accommodated by the model for AM Her given in Paper I. A somewhat similar model for AM Her has been presented by Chanmugam and Wagner (1977).

The model assumes accretion directly onto a magnetic white dwarf rotating synchronously with the binary orbit. As depicted in Figures 6*a* and 6*b*, the magnetic field (here assumed to be a dipole) of the degenerate controls the accretion flow from the region of the mass-losing secondary to one or both of its magnetic poles. (One pole will generally be more active.) The angular momentum of the accreted material, which would tend to spin up the white dwarf, is balanced by either direct magnetic pressure on the secondary or by the sweeping of material out of the system. The polarized optical continuum is produced by optically thick cyclotron emission in the accretion column(s) at the magnetic pole(s)—see also Masters *et al.* (1977). For an oblique magnetic axis, the white dwarf's rotation produces variations in the observed optical flux and polarization. As with AM Her, it is clear that the normal photospheric radiation of both component stars is generally outshone by the bright accretion columns.

a) *The Emission Lines*

Since VV Pup's emission lines, present when the object is active, neither are eclipsed nor show obvious Zeeman splittings (see also Herbig 1960), they must originate at least a few radii from the accreting primary. However, the exact origin of the emission lines and the dynamics of the accretion flow for AM Herculis objects remain to be worked out, as is evident from the discussions of Crampton and Cowley (1977), Priedhorsky (1977), Greenstein *et al.* (1977), and Paper I. For VV Pup the only radial velocity data available are from Herbig (1960) at a time when the system was quite active. Since the accretion flow may be much more complicated when $m_{\min}$ and $m_{\max}$ are both bright (see § IV*c*), we don't attempt to include the Herbig radial velocity curve with the recent observations in the model.

We believe that the detailed line-velocity evidence available for AM Her suggests that broad line emission in these systems originates predominantly within the accretion stream (rather than at the secondary). We note a flat Balmer decrement in the VV Pup March data, similar to that reported for AM Her in Paper I. The same arguments of Paper I lead to a lower limit of $n_e = 10^{12}\ \mathrm{cm}^{-3}$ in the line-emitting region and the possibility of Stark broadening, as well as velocity effects, contributing to the observed line widths.

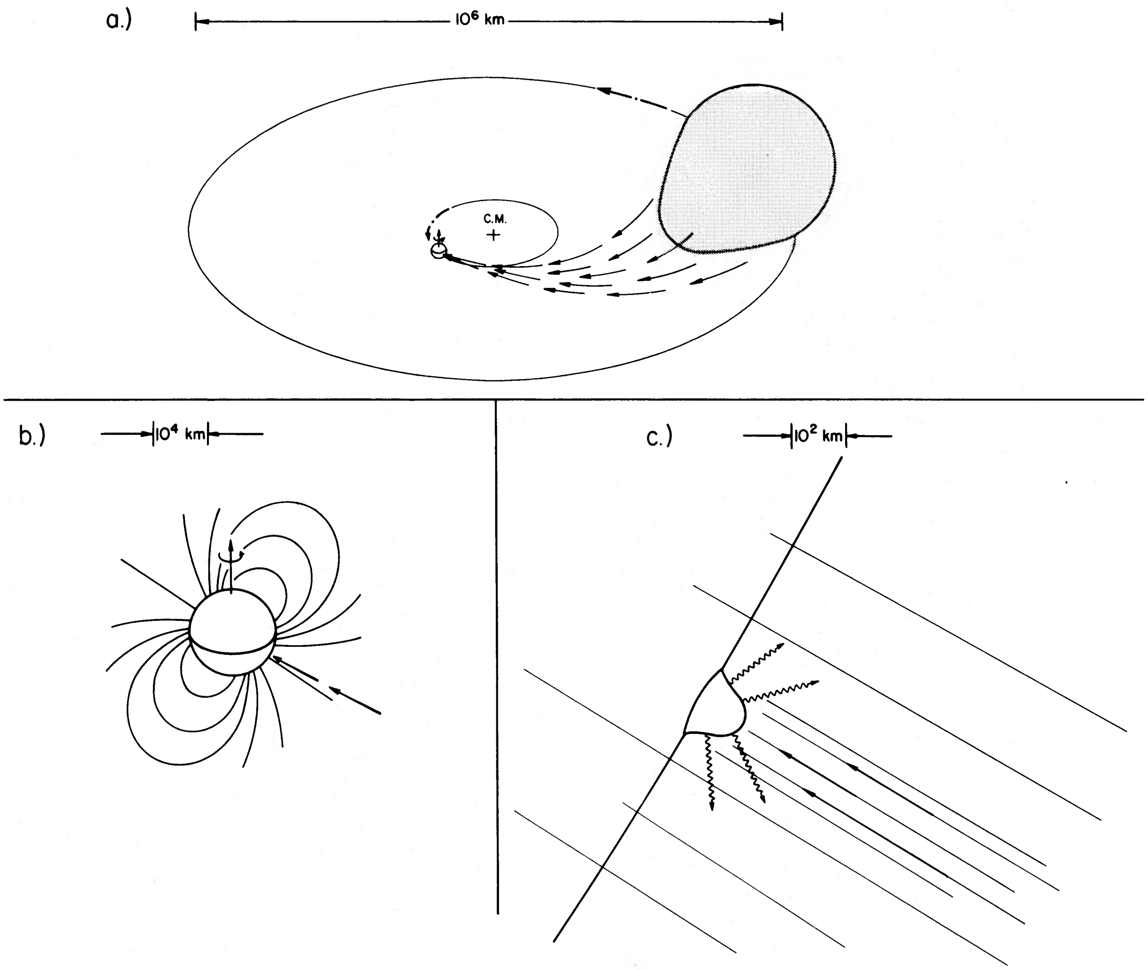

FIG. 6.—The three physical scales of VV Pup, each differing by two orders of magnitude in size, on which the mass flow must be discussed in our model. (*a*) The flow from the secondary into an active pole of the primary as it might be viewed from $\sim 30°$ orbital inclination at a time near the end of the photometric bright phase is indicated schematically. The direction of motion of the flow, position of the line emission, and mass ratio are uncertain. Usually both magnetic poles of the primary are accreting. (*b*) The primary white dwarf is depicted with a perfect dipole field, whose more actively accreting pole lies in the rotational hemisphere away from our line of sight. This allows a $\sim 60\%$ minimum light phase by self-eclipse. (*c*) The light-dominant hot spot located very near the magnetic pole at the surface of the degenerate. This region is constrained by the eclipse properties and the field lines to be so tiny (~ 100 km) that it must be shown on an enlargement of the white dwarf's polar region (see § IV*b*).

Flickers or flares in the observed emission lines, such as the March 23 flare discussed in § II, may be the effect of lumpiness in the flow of matter passing through the region of line emission. Likewise, bright-phase continuum flickering may be associated with the arrival of a lump of gas at the primary.

b) Short-Term Variations: the 100 min Light Curve

VV Pup differs from AM Her and AN UMa in having (usually) an eclipse-like light curve with more than half a period spent near minimum light. In our model the only reasonable explanation of this is a "self-eclipse"—i.e., the brighter accretion column rotating behind the white dwarf. The model allows no obscuring accretion disk, and the orbiting secondary cannot provide such a long eclipse duration. A self-eclipse, however, can provide an eclipse of more than 50% of a period if the emission region in the column is small and lies in the rotational hemisphere whose pole is hidden from our view. The observation of strong linear polarization at the end of the bright phase is also consistent with this picture and the polarization model presented by Stockman (1977), since the magnetic field in the emission region is then perpendicular to the line of sight (Figs. 6*b* and 6*c*). As the column continues to rotate behind the white dwarf but remains briefly in view, the circular polarization should change sign—as observed (§ III).

The rapid drop from maximum to minimum light and often rapid rise to maximum light (Walker 1960) indicates that the accretion-column emission region or polar "bright spot" is very small. The WN fast photometry shows these transitions occurring in

$\Delta P/P = 2$ min/100 min = 0.02. These rapid transitions place limits on both the height and width (in direction of rotation) of the emission region. Disregarding inclination effects, the restrictions on a column of height h and width w are given by

$$\frac{h}{R_{\rm wd}} \lesssim 1 - \cos(2\pi\Delta P/P) \quad \text{(optically thick or thin)}$$

and

$$\frac{w}{R_{\rm wd}} \lesssim 2\pi\Delta P/P \qquad \text{(optically thin)},$$

where $R_{\rm wd}$ is the radius of the white dwarf. For optically thick emission and $w > h$, the observed light curve will appear sinusoidal, with very gradual transitions into eclipse. Since the emission region is presumably optically thick, the rapid eclipse ingress and egress imply $w \lesssim h \lesssim 0.01 R_{\rm wd}$(100 km). The width of the accretion column at the bright spot also is determined by the number of field lines picking up inflowing matter, presumably near the secondary star. If the field lines come directly from a $\sim 10^5$ km secondary $\sim 10^6$ km away, then for a pure dipole field ($B \propto r^{-3}$), the column width at the white dwarf ($R_{\rm wd} \approx 10^4$ km) is $W \approx 10^2$ km, in order-of-magnitude agreement with the prior arguments. The complicated and variable bright-phase curve may be due to structure in the polar bright spot. Since the spot is thick in optical cyclotron absorption, the flux observed will depend on the spot's projected cross section and its temperature structure.

The spot is an extremely small region with an area $\sim 10^{-4}$ of the area of the white dwarf. Such small size, however, is not unreasonable if the accretion flow is everywhere controlled by the magnetic field and if cyclotron radiation is an efficient coolant. We can test the consistency of our model and indirectly gauge the cyclotron's efficiency by calculating a brightness temperature for the emission region (T_B) and comparing it to the maximum shock temperature ($T_{\rm max}$) expected for accretion onto a white dwarf. Using the flux at maximum light observed by WN and a distance of 100 pc, we obtain $T_B = 5 \times 10^8$ K (see Paper I for details), and $T_{\rm max} = 6 \times 10^8$ for a 1 $M_\odot$ white dwarf (Katz 1977). Although T_B is little better than an order-of-magnitude estimate, the consistency between T_B and $T_{\rm max}$ indicates that the polar "bright spot" spot model is physically reasonable at $d \approx 100$ pc.

We wish to make it clear that a similar analysis of the X-ray and optical-light curves for AM Her yields a very different picture. The X-rays (0.2–60 keV) have a rapid eclipse egress ($\sim$0.02 period for the soft X-rays [Tuohy, Lamb, and Garmire 1977]) and, therefore, they probably originate in a thin shock at the surface ($h \lesssim 0.01 R_{\rm wd}$, $w \lesssim 0.13 R_{\rm wd}$). The optical light, however, shows no eclipse-like feature, and the strong circular polarization changes sign throughout the time of X-ray minimum. We identify this light as coming from an extended region ($h \approx R_{\rm wd}$) above the accreting pole. In terms of the accretion models of Katz (1977), the size of the optical emission region is characteristic of a slow-settling solution (his regime III), while the temperature and size of the X-ray region are appropriate for a thin shock (regime II). Both regimes may exist in a cyclotron-cooled accretion column if gas enters the column with a temperature above $\sim 10^6$ K or is shocked to high temperatures during its infall (Paper I). This appears to be the situation for AM Her. For the cooler, steadier flows typifying low accretion rates, both optical and X-ray bremsstrahlung emission is confined to a hot, thin shock at the surface of the white dwarf (Masters *et al.* 1977). This latter picture best fits the optical properties of VV Puppis and the geometric model we have developed.

c) Long-Term Variations and the Origin of the Faint Phase Light

During self-eclipse ($m_{\rm min}$), VV Pup is generally brighter than the $m_{\rm min}$ observed during its extended low-luminosity state of 1977 April and subsequently WN also found that flickering continued during brighter $m_{\rm min}$ states as well. Thus the origin of minimum light when the system is active is either the less luminous accretion column or radiation from the primary bright spot on the back side being scattered into view. Since neither the stream of accreting material nor the secondary would subtend sufficient solid angle (< 1 steradian) for scattering, we favor the former explanation. The two-pole picture also provides a nice explanation of the brief dip below average $m_{\rm min}$ which is sometimes seen immediately after eclipse ingress (WN); such an effect would be expected if the two accreting poles are not diametrically opposite, and were for a brief period both out of view. Long-term variations in maximum light level should directly indicate changes in the accretion rate, while Δm gauges the balance in accretion between two active poles.

Small Δm values, however, seem to occur only when the system is at faint $m_{\rm min}$; i.e., is less active. We thus consider whether in this situation the light is still totally dominated by two nearly balanced but less active poles, or whether the thermal output of one or both stellar components is significant. The observational evidence presented in §§ II and III leads us to argue that the latter is the case. First, the observed lack of significant H and He emission with $m_{\rm min} \approx 18$ indicates a drastic curtailment of the mass flow. Second, apparently only the excess-light component observed in December (§ III), $\Delta m \approx 0.2$, showed substantial circular polarization; if its opposite pole dominated the OFF state light, strong polarization should have been seen with the opposite sense. We note that, if it is assumed that the underlying light is not strongly polarized, then the December excess-light component was circularly polarized at $\sim 40\%$. Tapia's (1977) higher circular polarization maximum of 17% thus could come from a brighter pole less diluted by other contributing radiation. Third, we found no evidence of substantial flickering in monitoring the light levels in April and December, though this included the polarized phase in December. Finally, we recall that both the April scanner and December Lick IDS red observations produced a distinct excess beyond ~ 6500 Å, with possible features indicative of a cool stellar component. Further observations to determine (1) whether the red light is less polarized and (2) the spectroscopic subtype of the presumed M dwarf can clinch this argument.

d) *A Distance Estimate*

If a bluish degenerate were dominating the April energy distribution shortward of 6500 Å (Fig. 3), the blackbody fit of $T_{bb} \approx 9000$ K corresponds to $M_{bol} \approx 13$ on the degenerate sequence. Thus a lower limit of 80 pc for a systemic distance is estimated. At *this* distance, the red excess corresponds to a late M dwarf at $M_v \approx 15$. W. J. Luyten (1977) has measured only a marginal proper motion for VV Pup of $\mu_\alpha = -0\farcs028 \pm 0.016$, $\mu_\beta = +0.001$; this would imply a tangential velocity of only 10 ± 6 km s^{-1} and suggests that the true distance is greater than 80 pc. The distance cannot be much greater than 150 pc in our model interpretation, since the required brightness temperature of the accretion columns would then be higher than 10^9 K and much greater than T_{max}. If VV Pup lies within these distance limits, the optical variations correspond to a range of $M_v = 8.5$–12.5 (± 0.5); when most active, it would therefore be about as luminous at optical wavelengths as typical dwarf novae (see, e.g., Robinson 1976).

e) *Predictions and Further Work*

The picture we have developed for VV Pup affords the following predictions. Soft and hard X-ray fluxes are likely to scale with the optical luminosity and are probably an order of magnitude less than those detected in AM Her (see Swank *et al.* 1977). Any detected hard X-rays will be strongly eclipsed with the "bright-phase" optical light and the same 100 min period. No periodic variations with $P < 100$ min should be present in any part of the spectrum. The model predicts that there should be marked changes in the circular and linear polarization properties when the system exhibits different combinations of m_{min} and Δm. The predicted parallax of $\sim 0\farcs01$ is deserving of a careful trigonometric measurement and is an important check of the model. In addition to important "faint-phase" observing tests mentioned in § IV*d*, simultaneous fast photometry of the lines and continuum during an active state is desirable to determine (among other things) a possible time-delayed correlation between line flares and continuum flickers.

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