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THE ENIGMATIC Hα LINE OF FK COMAE: LAST STAGES OF A COALESCING BINARY?[1]

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ABSTRACT

The apparently single, rapidly rotating G giant FK Comae displays an unusual Hα emission line which is very broad, strong, and variable. We present extensive high-resolution studies of this line with complete phase coverage. The Hα emission centroid shows a radial velocity modulation on the $2^{d}.4$ stellar rotation period with a semiamplitude identical to the photospheric rotational velocity. These data, when phased with optical photometry, indicate that the star has a bright, rather than dark, region on its surface and that the phase may have been stable for 7 years. We consider a qualitative model wherein the bright spot is caused by accretion from a low mass ($q < 0.1$) unseen companion onto the surface of the G giant. We find that such a model explains many of the observed characteristics of the stellar spectrum and Hα feature and conclude that FK Comae is not yet a single star, but is still evolving toward coalescence of the system.

Subject headings: stars: binaries — stars: emission-line — stars: individual

I. INTRODUCTION

FK Comae has been known for some time to be a peculiar star. Merrill (1948) noted its large projected rotational velocity, as well as the existence of a broad, variable Hα emission line. Bolton (1978) suggested, on the basis of its strong Ca II H and K emission cores, that this might be an RS CVn system. However, it shows two characteristics not seen in RS CVn systems: the lack of an observable radial velocity variation due to a binary nature, and a broad (20 Å FW) Hα emission line.

Herbig observed the Hα line spectroscopically and reported approximately a 5 day periodicity in the line profile (Chugainov 1966). Chugainov (1966) discovered a $2^{d}.41$ modulation in the optical light curve. Chugainov (1976) and Rucinski (1981) have confirmed the $2^{d}.40$ optical period, with apparently little drift in the phase of the minimum during the 5 years between observations. Bopp and Stencel (1981) have observed FK Comae and two similar systems with *IUE*, and found strong transition region emission lines. Walter (1981) reported on its detection with the *Einstein Observatory* as a strong X-ray source. Its X-ray surface flux is consistent with the rotation-activity relation proposed by Walter (1981). Ramsey, Nations, and Barden (1981), have reported on observations of the variability of the Hα emission profile, showing a $2^{d}.4$ periodicity in the V/R ratio.

Because of the lack of observed variation in the radial velocity (Bopp and Rucinski 1980), the star has been thought to be single. It is a rapidly rotating G giant with $V = 120 \pm 20$ km s^{-1} from the Mg II equivalent widths and $R \gtrsim 5\ R_{\odot}$ (Bopp and Stencel 1981). The evolutionary status is then peculiar: FK Comae would have had to evolve from a close binary, perhaps by coalescence of a W UMa system, as in the evolutionary models of Webbink (1976). Conservation of angular momentum in single star evolution indicates that the progenitor of FK Comae would have been rotating in excess of breakup velocity when on the main sequence.

In this paper, we report extensive observations of the Hα line of FK Comae obtained between 1981 February 5 and May 11 with the 40 inch (1 m) Nickel telescope at the Lick Observatory. We show that the Hα emission centroid exhibits a radial velocity variation with $2^{d}.4$ period at a 110 ± 10 km s^{-1} semiamplitude. By comparing these data with Rucinski's (1981) photometry, we conclude that one is likely to be dealing with a bright spot, not dark spots as in RS CVn systems (e.g., Eaton and Hall 1979). We propose a model requiring an evolving, mass transferring, but not yet coalesced close binary. The mass ratio is large and does not violate the limits on radial velocity variation. The unseen component loses mass through Roche lobe overflow; the Hα emission and a general brightening of the photosphere occur where the accretion stream heats the stellar surface.

II. OBSERVATIONS

All the observations presented here were obtained with the Image Dissector Scanner (Robinson and Wampler 1972) on the 40 inch Nickel telescope of the Lick Observatory. The observing log is presented in Table 1 to facilitate comparison by future observers. The blue scans were obtained in the third order, with

[1]Based in part on observations made at Lick Observatory.

TABLE 1

OBSERVING LOG

Date (UT) 1981	Number of Hα Observations	Phase Coverage
February 6	4	0.630–0.730
February 7	2	0.868–0.913
February 18	7	0.623–0.728
February 19	7	0.017–0.133
February 20	8	0.432–0.531
February 21	8	0.852–0.978
March 17	9	0.813–0.968
March 18	7	0.244–0.365
April 8	5	0.970–0.125
April 9	7	0.375–0.543
April 10	6	0.791–0.957
April 16	5	0.287–0.456
April 17	7	0.711–0.858
April 18	3	0.163–0.227
May 10	5	0.315–0.418
May 11	5	0.719–0.845

~1.5 Å resolution; the Hα data were taken in first and second order with resolutions of 5 and 2.5 Å, respectively. No smoothing has been applied. Integration times were 24^m in the blue and 16^m at Hα.

III. THE SPECTRAL TYPE OF FK COMAE

Published estimates of the spectral type of FK Comae range from G0pe III (Harlan 1974) to gG8pe (Bonsack and Greenstein 1960). We obtained spectra of this star in the blue with the 40 inch Nickel telescope in order to classify this star in the MK system (Morgan, Keenan, and Kellman 1943). The star is clearly a giant, on the basis of λ4077 Sr II (Fig. 1), in agreement with the 5–6 $R_\odot$ derived from $V \sin i$ and the rotational period. The spectral type cannot be later than G5, based upon the strengths of λ4226 Ca I and the G band. Because of variable filling in of the Hγ and Hδ absorption lines, perhaps by chromospheric emission, the ratios Hγ:λ4325 and Hδ:λ4045 vary; but when the hydrogen lines are deepest, a spectral type near G2 is indicated. We conclude that the spectral type is G2 III, with a certainty of ±1 subclass. This agrees with the G2 IIIap derived by Keenan and McNeil (1976).

Rucinski (1981) points out that the *UBVRI* colors are not consistent with any normal star. The $U-B$ and $B-V$ colors are consistent with a spectral type of G2 III. Approximately 30% of the ~0.1 mag $V-R$ excess can be accounted for by the Hα emission line; emission from possible circumstellar material (see below) may explain the rest of the $V-R$ and $R-I$ excesses.

IV. THE QUIESCENT Hα LINE

The Hα emission profile (Fig. 2) varies noticeably on time scales of a few hours. All the profiles obtained display a central absorption superposed upon a broad emission profile, giving a double peaked appearance. This is a true absorption, not a lack of emission, because the central absorption often dips below the continuum level. An acceptable description of the data is achieved by fitting the Hα profile as a broad Gaussian emission line plus a narrow absorption line. The fitting is accomplished using the Marquardt (1963) algorithm, with nine free parameters describing a quadratic background and two Gaussian lines. Radial velocities of Hα are measured with respect to the photospheric blend at ~λ6495. Basic line parameters are given in Table 2.

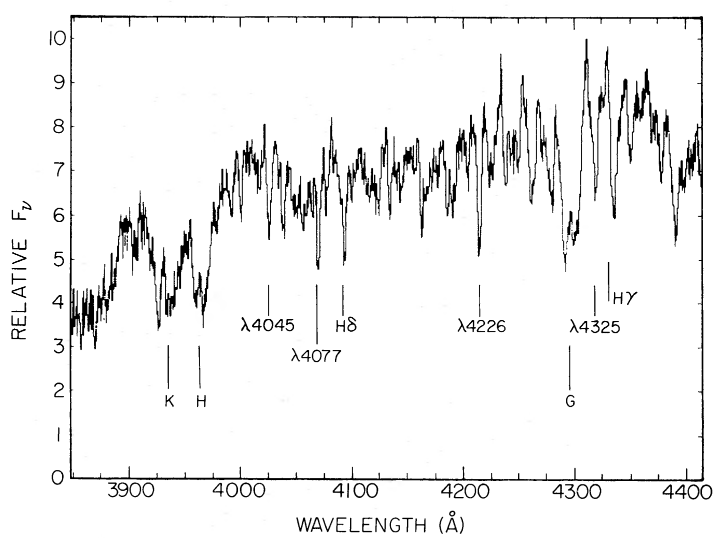

FIG. 1.—A fluxed spectrum of FK Comae taken in 3rd order with the 40 inch Nickel telescope. The resolution is 1.5 Å (5 channels); the data are unsmoothed. The spectral type is G2, the strength of Sr II λ4077 indicates luminosity class III. Note the strong Ca II H and K emission cores.

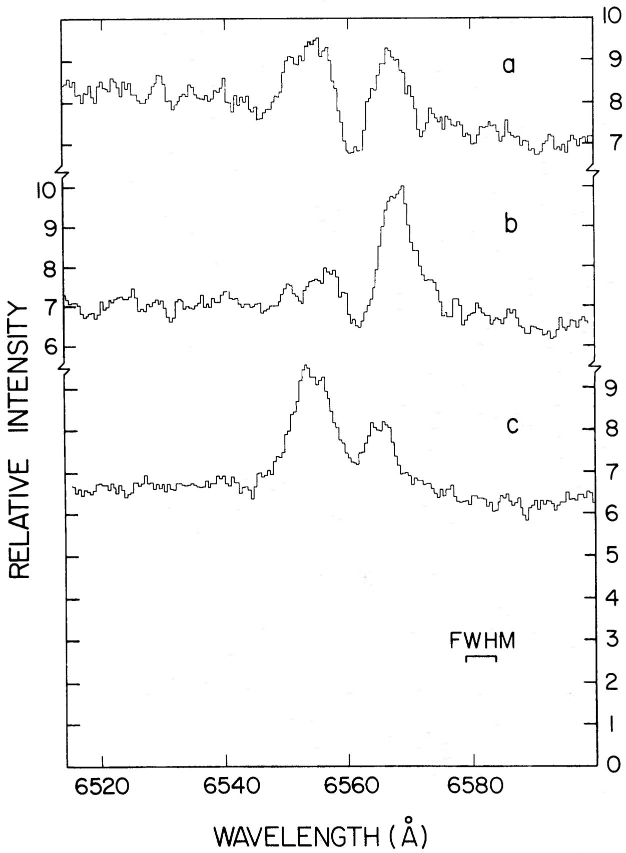

FIG. 2.—Three representative Hα profiles. The instrumental full width is indicated. The ordinate is in relative intensity (counts per second), uncorrected for the instrumental response. The profiles were obtained at the following times (JD−2,444,000.0): (*a*) 655.781; (*b*) 735.757; (*c*) 734.699.

The important fact to note is that almost everything varies. The wavelength of the central absorption is, within the uncertainties, usually at the Hα rest wavelength. The most pronounced motion of the absorption line, during a flare, will be discussed later. The emission centroid varies from the rest wavelength by up to +4.4 Å and −2.1 Å (+200, −100 km s^{-1}). The mean FWHM of the line corresponds to a velocity of some 400 km s^{-1}, and is unlikely to be due to Keplerian orbital velocities.

TABLE 2

QUIESCENT Hα LINE

Parameter	Mean	Extremes
FWHM (Å)	9	7, 18
Equivalent width (Å)	3.3	1.4, 10.3
Emission centered wavelength ...	λ6563	+4.4 Å, −3.7 Å
Absorption wavelength..........	λ6563	+0.5 Å, −1 Å

In Figure 3 we have plotted V/R (or, for symmetry, $2-R/V$ if $V/R>1$), the redshift of the emission profile, and the Hα equivalent width modulo the $2^{\rm d}.400$ rotation period. A clear sinusoidal variation is seen in the lower two panels. Data taken when the star was obviously flaring have been excluded.

The V/R data have been folded to search for the period, with a resultant period of $2^{\rm d}.397 \pm 0^{\rm d}.015$. There is evidence for random phase drifts of ~ 0.1 cycles, similar to those seen by Rucinski (1981), during these 100 days of observing, but the overall phase is quite stable. Using the period from Chugainov (1966), and reanalyzing the V light curve data from Chugainov (1976) and Rucinski (1981), the photometric period appears constant within the errors ($\dot{P}/P < 2\times 10^{-5}$) over the past 17 years. Because the minima of the latest two light curves agree, over a 5 year interval, we assume that there are no discontinuous phase changes, and that these 1981 Hα data can be compared in phase with Rucinski's photometry from 1979. This assumption is central to our analysis. It would obviously be very useful to obtain simultaneous Hα and photometric observations to confirm it.

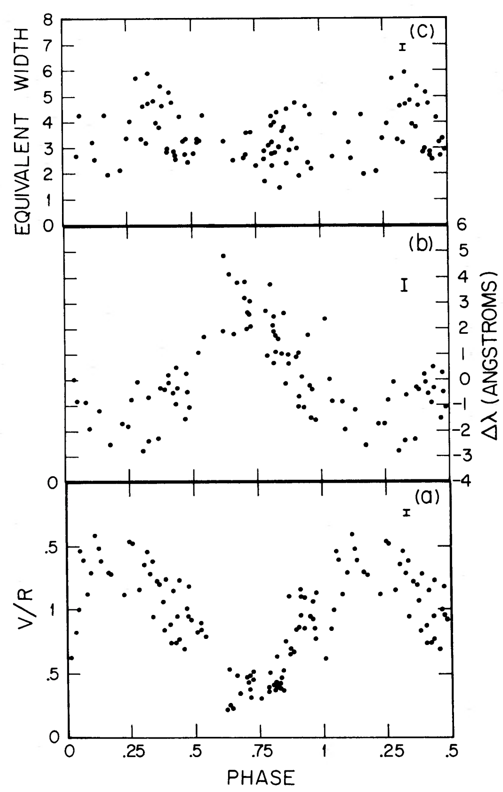

FIG. 3.—Properties of the Hα line as a function of rotational phase, relative to Chugainov's (1976) ephemeris. In the lower panel, V/R is the ratio of the intensity of the violet to the red peaks. For symmetry, when $V/R>1$, $2-R/V$ is plotted. Δλ is the difference between the wavelength of the Hα emission centroid and the Hα rest wavelength. For clarity, 1.5 cycles are plotted.

The redshift data show a similar sinusoidal character, as expected, since these and the V/R data measure different effects of the same line displacement for a line with a stationary central reversal. The best sinusoidal fit to these data, with the maximum fixed at $\phi = 0.70$, gives a projected radial velocity for the emission centroid of $104 \pm 10 \cos(\phi - 0.7)$ km s^{-1}. This circular velocity agrees well with estimates of $V \sin i$ of ~ 75 (Merrill 1948) and 120 ± 20 (Bopp and Stencel 1981), which implies that the bluk of the Hα emission arises on, or close to, the surface of the star. The emission region cannot be corotating at any significant distance above the stellar photosphere. However, inspection of Figure 3*b* shows that significant residuals occur at large $|\Delta\lambda|$. The residuals from the best fit curve for lower $|\Delta\lambda|$ are consistent with the measurement errors on the individual points; the residuals at large $|\Delta\lambda|$ are twice as great and indicate that on some occasions the bulk of the Hα emission may arise in a corotating region up to one stellar radius above the photosphere. The data with large residuals tend to be associated with unusually large emission lines (~ 7 Å EW) or flaring conditions: the "quiescent" Hα emission arises on or close to the photosphere.

The shape of the V/R and $\Delta\lambda$ curves is similar to that of the optical light curve (Rucinski 1981) in that the rise occupies some 0.6 cycles. However, the phasings of the Hα "spot" and the 1979 optical light curve are not as might be expected from a standard spot model (given our assumption of phase stability). The curves in Figure 3 are plotted according to Chugainov's (1976) ephemeris, with zero phase corresponding to minimum light. Maximum blueshift of the Hα emission centroid occurs at about phase 0.2, with maximum redshift at phase 0.7. The Hα emitting region is then facing the observer at phase ~ 0.5, or during maximum light. Hα emission in late-type stars is associated with chromospheric activity or circumstellar material. If we assume the former, it would be expected to be in phase with the light curve minimum if that were due to the passage of dark starspots. Such a correlation has been observed in UV chromospheric lines in λ And (Baliunas and Dupree 1982), although in general, perhaps because of flaring, Hα rarely shows phase-dependent variations in RS CVn systems. Our observations suggest the opposite (antiphase) correlation.

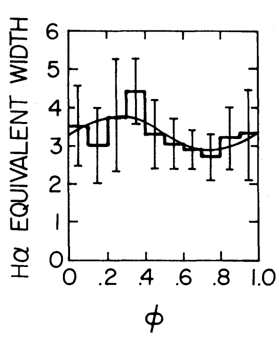

FIG. 4.—The equivalent width data from Fig. 3*c* binned in 0.1 phase bins. There is a slight suggestion of phase dependence with an amplitude of 30%. The error bars are determined from the rms scatter in each bin, and reflect activity related variations in the equivalent width from cycle to cycle.

The Hα equivalent width data show considerable scatter (Fig. 3*a*). Binning these data in 0.1 phase intervals (Fig. 4) leads to a slight suggestion of a maximum equivalent width at about phase 0.3–0.4 or close to the phase of maximum light, and a minimum near phase 0.8 or close to the phase of minimum light. Although this variation is only marginally significant, it is consistent with the hypothesis of increased Hα activity in a bright spot.

V. AN Hα FLARE

Figure 5 shows a progression of Hα profiles obtained on 1981 February 20 UT. A large flare occurred during the last 100 minutes of the night, with the Hα equivalent width increasing threefold to 10.3 Å with a 32 Å full linewidth.

In Figure 6 we plot the wavelength of the central absorption feature in Hα on this night. The absorption centroid is at the Hα rest wavelength on most occasions, but during the course of this night the absorption line showed a progressive blueward acceleration, with a final velocity of some 50 km s^{-1}. No such acceleration was observed in the emission centroid, which was, in fact, moving redward with the expected amplitude for this phase (0.3) as shown in Figure 3.

During the flare, only one spectrum was obtained because of the impending sunrise. The emission line is fitted acceptably as a Gaussian emission line with a velocity of -160 km s^{-1}, with a narrow absorption line still present at a velocity of -50 km s^{-1}. Assuming a distance of 250 pc, the flux in Hα above the continuum was 1.4×10^{32} ergs s^{-1} during this 16^{m} observation. This corresponds to an emission measure (Osterbrock 1974, case B) of some 4×10^{56} cm^{-3}.

The kinematics of the lines suggest a possible scenario for the flare. First, a cool shell is ejected and accelerated to a velocity of 50 km s^{-1} over a period of some 8 hours, by some unknown mechanism. Then, during the hour and a half between observations, a second shell is ejected with a velocity of 160 km s^{-1}. The two shells collide and shock about one hour later, with a 100 km s^{-1} relative velocity, at about 1 $R_\odot$ above the stellar surface. The energetics require some 10^{45} collisions during the 16^{m} the flare was observed; this gives a lower limit on the number of atoms in the shells. A crude upper limit on the gas density is given by $\rho = n^2 V/N < 2.5 \times 10^{11}$ cm^{-3}, and $V > 6 \times 10^{33}$ cm^3.

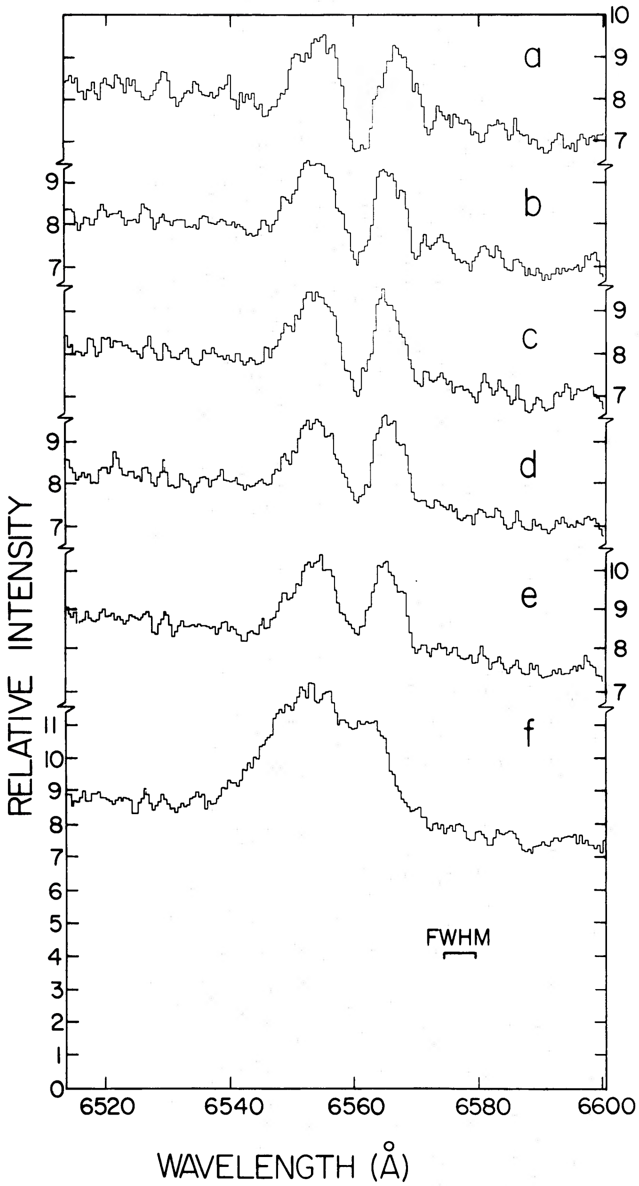

FIG. 5.—A progression of the profiles observed on 1981 February 20 UT, ending with a large Hα flare. Observation times were (JD+2,444,000.0): (*a*) 655.781; (*b*) 655.873; (*c*) 655.916; (*d*) 655.970; (*e*) 656.007; (*f*) 656.091.

Clearly this picture for the cause of the flare is simplistic, but only kinematic data are available. These flare events are not common, but apparently are not too rare either (Ramsey, Nations, and Barden 1981 show an Hα spectrum obtained during a large flare in June 1981), so an effort to obtain better observations may be worthwhile. Measurement of the Balmer decrement and the changes in other chromospheric lines could provide a far better basis for interpreting this and similar events. Yet, while the mechanism which ejects the shells is

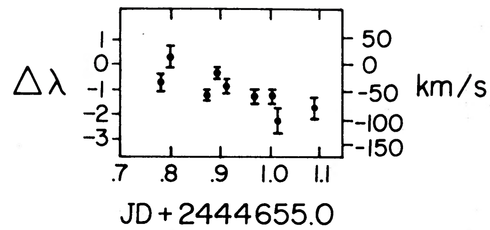

FIG. 6.—The wavelength displacement of the absorption component centroid on the night of Feb. 20 UT. There is an apparent trend to increasing blueshift (-50 km s^{-1}) as the night progresses. The error bars reflect the measurement uncertainty from counting errors.

somewhat mysterious, the appearance of the Hα line during flaring may be simply explicable.

V. DISCUSSION

The apparent phase stability of the bright region in FK Comae over a 5 year period implies that the Hα emission comes from the bright side of the star—from a hot spot and not a dark, spotted hemisphere as seen in many active stars. The Hα radial velocity curve indicates that the bulk of the emission comes from close to the photosphere, and not from a distance of a few stellar radii. The variation in V/R, and in the radial velocity, indicates that the Hα emission must be maximized on the bright hemisphere, but the lack of strong equivalent width modulation shows that there is also considerable emission extending over most of the stellar surface. The asymmetry of the Hα radial velocity and V/R curves, and the asymmetry of the V light curve (Rucinski 1981), suggest that the bright spot cannot be symmetric in longitude but must have a sharper trailing edge than leading edge.

Figure 7 shows the results of a simple model prediction of the Hα radial velocity curve. We have assumed that the Hα emission intensity is maximum at a particular longitude, and falls off linearly in both equatorial directions, with the distances over which the emission extends as free parameters. The Hα emission is assumed to come only from the equatorial region of the star (see below for justification). The radial velocity curve is an intensity weighted mean of the stellar equatorial velocity integrated over the visible hemisphere. No limb darkening is applied; to account for emission with a scale height larger than the photospheric radius the integration can be extended over the limb. We generated a series of these curves; the one plotted in Figure 7 best reproduces Rucinski's (1981) light curve and the plotted radial velocity data. The emission in the leading direction falls off over $\sim 180°$ of longitude; the decline is more rapid in the trailing direction, with a 90° extent. The emission comes from a radius of $\lesssim 0.15$ stellar radii. The predicted Hα equivalent width modulation is $\sim 50\%$, compared with the $\lesssim 30\%$ observed.

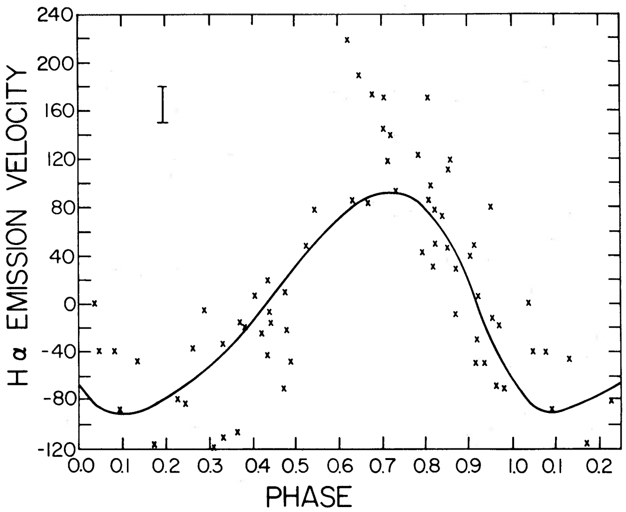

FIG. 7.—The radial velocity data from Fig. 3*b* for the Hα emission centroid are plotted with the best model prediction (*solid line*). The model velocity (see text) is an intensity weighted mean of the integrated Hα radial velocity. The Hα emission extends 180° in the leading direction and 90° in the trailing direction.

The success of this simple model shows that the bright spot hypothesis is tenable. The V light curve shows $\sim$10% modulation, which could be caused by a 2% ($\sim$100 K) temperature variation over the entire hemisphere, or more if the bright spot is smaller. The $B-V$ light curve of Rucinski (1981), although showing a considerable scatter and poor coverage at minimum light, seems to indicate bluer colors near maximum light. In our blue spectra, the Hγ and Hδ lines are filled in by $\sim$20% more at the same phases, relative to the strengths at minimum light.

The existence of a hot spot with good phase stability in this system suggests a binary model involving mass transfer. X-ray heating of the G giant, or ellipsoidal light variations, can be ruled out as a cause of the photospheric light curve on the basis of the X-ray observations and the limits to the stellar radial velocity variation. In the following we develop a qualitative model incorporating a low-mass secondary losing mass via Roche lobe overflow to the primary. We assume that the $2^{d}4$ stellar rotation is identical to the orbital period.

The limit on the radial velocity variation puts strong constraints on any possible binary configuration. We assume that $\sin i = 1$ since $V \sin i$ is already so large for a G giant. Thus $R_* = 5.2\ R_\odot$ is a lower limit on the semimajor axis a. From the radial velocity limit, $aq < 0.47$ if $m_2 \ll m_1$, where q is the mass ratio m_2/m_1 ($a\sqrt{q}$ is the Roche radius of the unseen component m_2 for $m_2 \ll m_1$), and $q < 0.09$. The radial velocity variation also implies limits on the mass of FK Comae as a function of a:

$$\frac{a^3}{1+0.47/a} < 424 m_1 < a^3,$$

where m and a are in solar units.

Upper limits on a and m_1 can be computed by assuming that the unseen component is less massive than a main sequence star of the Roche radius 2.0 $R_\odot$. We find $a < 22.1\ R_\odot$ and $m_1 < 25.5\ M_\odot$. These limits are summarized in Table 3. If the Hα velocity width ($\sim$400 km s^{-1}) is indicative of the escape velocity, then $m_1 = 2.2\ M_\odot$, $a \sim 9.7\ R_\odot$, and $q < .05$. Webbink's (1976) case III binary system, with the massive star at the base of the giant branch, has $m_1 = 1.7$, $a = 9.3$, and $q = 0.09$ (with the radius of the secondary exceeding its Roche lobe). Such a system has tidal circularization and synchronization time scales of $\lesssim 10^4$ years (Scharlemann 1981), so the primary should be in synchronous rotation. Any ellipsoidal light variation should have an amplitude of $\lesssim 0.01$ mag (Bochkarev, Kavitskaya, and Shakura 1979). We propose that the less massive Roche lobe filling component is losing mass through Roche lobe overflow. No accretion disk can form because of the size of the primary (Lubow and Shu 1975). The accretion stream intercepts the surface of the primary at an angle of $\sim$50° to the normal, subtending some 30° of the surface. The terminal accretion velocity of the gas, equal to the escape velocity of the primary, is assumed to be the explanation for the velocity width of the Hα emission centroid. Gas accreting at these velocities will cause the formation of a shock in the G giant atmosphere; gas hitting the shock at a large angle of incidence at the escape velocity may well splash to considerable distances about the star, generally in the equatorial plane. A similar model was suggested by Bolton and Zubrod (1980) to explain the Hα streaming in Algol. Because the gas would tend to splash forward, the accreted material should be distributed asymmetrically, with more

TABLE 3

LIMITS ON ORBITAL PARAMETERS

Parameter	Range	Best Estimate	Webbink's Case III
Mass of primary ($M_\odot$) ...	$0.34 \leq m_1 \lesssim 25.5$	2.2	1.7
Semimajor axis ($R_\odot$)	$5.2 \leq a \lesssim 22.1$	9.7	9.3
Mass ratio m_2/m_1	$0 < q \leq 0.09$	< 0.05	0.09

material, and hence more heating, in the leading direction. This material should form a warm, extended, asymmetric halo at temperatures of a few hundred thousand to a million Kelvins. This halo will occupy that region of the stellar atmosphere not occupied by closed magnetic flux tubes. The photosphere is then back heated by this warm halo, producing the visual light variations.

We have constructed some crude atmospheric models to see if the Hα emission could be explained instead by normal but enhanced chromospheric activity. These show that the breadth of the Hα emission (± 10 Å) would require that the chromosphere extend to deep within the stellar photosphere, in which case all the other strong photospheric lines, including the higher Balmer lines, would also be driven into emission; this is the case in the most extreme T Tauri stars like RW Aur, but is clearly not observed here (Fig. 1).

We have adopted the view that the Ca II and Mg II resonance line emission fluxes represent the true chromosphere. In this case the upper atmosphere more closely resembles that of an RS CVn system. The Hα chromospheric emission nearly fills in the photospheric absorption line, indicating that the emission profile is almost entirely due to some other mechanism. The central absorption feature could have a photospheric contribution, since it is stationary at the Hα rest wavelength; there might also be a contribution from cool material in orbit outside the accretion stream. The Hβ line is filled in but does not exhibit emission; this is plausibly explained if the density in the Hα emitting region is sufficiently low (cf. Kuan 1975).

With an active chromosphere underlying the Hα emitting region, one might reasonably expect that the star should have dark spots on its surface as seen in RS CVn systems (or perhaps even bright spots as inferred in BY Dra [e.g., Vogt 1975]). We argue from the appearance of Hα that in FK Comae the bright hemisphere is an accretion-induced phenomenon, unrelated to the "normal" chromospheric and coronal activity presumably generated by the rapid stellar rotation. The currently available photometry of FK Comae is insufficient to search for the signature of photospheric spots above the variation due to the bright hemisphere.

While the phase stability of the bright hemisphere alone does not justify our interpretations, it is good supporting evidence. Photospheric features in many active stars do not show phase stability, although some of the RS CVn systems do exhibit constant migration rates over long periods which, in the absence of a binary period, could be interpreted as a constant rotational period. Recently, Noyes (1981) has shown evidence for phase stability in active regions in some G dwarfs over intervals up to a decade. However, in units of stellar rotations, the phase of the bright spot in FK Comae has remained stable for nearly an order of magnitude longer. Although the case is by no means closed, all the data together indicate that the Hα emission line and the bright hemisphere are phenomena distinct from the true stellar activity, and that the existence of photospheric spots is likely but currently undetected.

The Hα emission likely originates in the warm halo, perhaps due to the recombination of the hydrogen ionized by the impact of accreting gas at a few hundred km s^{-1}. That the Hα emission line is present at all phases is due to the large extent of the heated region, but the motions of the emission centroid show that the distribution of the heating is indeed peaked (probably at the terminus of the accretion stream).

Rucinski (1981) reported the existence of some apparently random phase jitter of ~ 0.1 cycle in his photometric data. Similar jitter is evident in our Hα radial velocity and V/R data, with the same 0.1 cycles spread. This can be readily understood in terms of the accretion model. The average light curve or V/R curve is due to the mean accretion rate. For an enhanced accretion rate, the heating rate will be increased, leading to an increase in the visual magnitude (mimicking a decrease in the phase) and an enhancement of the Hα emission intensity at the terminus of the accretion stream (which will lead to apparent phase changes in the V/R and radial velocity rates). Decreased accretion rates lead to the same effects, in the opposite sense. Hence, unless the accretion is perfectly steady, such phase jitter is to be expected.

The accretion velocities are insufficient to account for the 2 keV temperature of the coronal X-ray emission (Walter 1981); rather, it is likely that it arises as a natural consequence of the rapid rotation in a convective star. Bopp and Stencel (1981) find that the ultraviolet emission line fluxes are stronger than seen in RS CVn systems; the accretion heating could easily augment the transition region fluxes, both through the back heating and by increasing the particle densities at transition region temperatures. They suggest that the X-ray surface flux may be low by a factor of 100 relative to the UV surface fluxes, compared to other examples, perhaps through soft X-ray absorption. There is no evidence for significant absorption in the X-ray spectrum. Indeed, the X-ray surface flux is consistent with that expected from a G star with a 2^{d} rotation period (Walter 1981).

If the 10% visual modulation is due to accretion heating, then at a distance of 250 pc a mass transfer rate of $\sim 10^{-8}$ $M_{\odot}$ yr^{-1} is required. For heating efficiencies of less than 100% the mass transfer must be occurring on thermal time scales. The low-mass secondary is likely to be close to becoming a naked stellar core. The primary is likely to be ascending the giant branch, with its evolution possibly accelerated by the doubling of its mass over the past 10^{7} years.

Ramsey, Nations, and Barden (1981), have proposed a model for this system involving a single star with an asymmetric excretion disk. The phase stability of the V/R curve is maintained by magnetic flux tubes tying the gas to the surface. They argue that the Hα profile of the disk (obtained by subtracting a G8 III spectrum) is a broad stationary emission line plus emission from density enhancements in the disk which produce the V/R variation. Our chromospheric models show that the observed Hα emission profile is likely to be entirely due to the emitting region, since the photospheric absorption is likely to be nearly filled in by normal chromospheric emission. Subtraction of a standard G8 profile will thus yield an artificially large inferred flux near line center for the emitting region. Our fitting of the Hα emission profile indicates as well that the entire broad Hα profile partakes of the ± 100 km s^{-1} velocity variation, not just a density enhancement in the disk profile. Finally, if the excretion disk rotates synchronously with the photosphere at a few stellar radii, the velocity variation should be 200–300 km s^{-1}, rather than the 100 km s^{-1} variation observed (which is virtually identical to the photospheric $V \sin i$). We conclude that their model, requiring enormous, stable magnetic flux tubes, is not reasonable in view of all the data.

Bopp and Stencel (1981) argue that FK Comae is the prototype of a class of rapidly rotating G–K giants with no evidence for duplicity. In light of our model, FK Comae may not even belong to this class. FK Comae exhibits Hα emission far broader than that seen in the other two members of the class, UZ Lib and HD 199178. It may be possible to explain those two in terms of rapidly rotating single stars with highly active chromospheres which have evolved by the Bopp and Stencel scenario of coalescing W UMa stars. There are two other good scenarios for generating rapidly rotating giants: tidal synchronization in a close binary or normal evolution from a rapidly rotating upper main sequence star (as in the case of the rapidly rotating F9 III secondary of Capella [Ayres and Linsky 1980]). FK Comae appears to fall in the former category. As the primary evolves further, it may well swallow up the secondary and become a rapidly rotating single giant, as in Webbink's (1976) scenario; perhaps then it would look like the other two class members. However, at this epoch FK Comae has apparently not yet become single. That the other rapidly rotating, likely single giants look similar (except at Hα) argues for the importance of rotation in determining stellar activity (Walter 1981; Walter and Bowyer 1981), irrespective of other parameters.

In the past FK Comae could have been either an Algol system or an RS CVn system; with $k^2 = 0.1$ (Webbink 1976) the angular momentum per unit mass is $\sim 1.5 \times 10^{18}$ cm^2 s^{-1}. Invoking conservative mass transfer, FK Comae could have evolved from a W UMa system with $\Pi^2 p = 0.83$, where Π is the system mass and p is the original orbital period (Mochnacki 1981). For nonconservative mass transfer, 0.8 is a lower limit on $\Pi^2 p$. It is hard to see how the period could have become so long compared to W UMa stars, however. A typical RS CVn system with a 4^d orbital period has some 3 times the specific angular momentum of FK Comae.

VI. SUMMARY

We conclude that FK Comae may be an example of an evolving, mass transferring, low-mass semidetached binary. At the present epoch it has a large mass ratio, making it look like a single, rapidly rotating giant. The optical and Hα phasing show both long term phase stability (indicative of a binary system) and imply that the emission activity is associated with a bright hemisphere, rather than the spotted darker hemisphere assumed in RS CVn systems. A simple accretion heating scenario invoking Roche lobe mass loss from an unseen secondary impacting on the G giant might explain most of the properties of the Hα emission and activity phase behavior. We find that the system parameters suggested by this model are quite reasonable, given theoretical expectations for coalescing binaries. FK Comae may be the best example of the short-lived final stages in the death of very close binary systems. As such, it may provide an interesting testing ground for more detailed theoretical treatments of accretion flow and its observational consequences in a novel setting.

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