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THE HIGH-STATE/LOW-STATE TRANSITION IN V794 AQUILAE

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ABSTRACT

We present a V-magnitude light curve of the cataclysmic binary V794 Aquilae covering an 800 day time span. The system shows variations of up to 3 mag. In particular, there are two dips of ~ 1 mag which last for about 50 days, and are followed by a rapid recovery to the original brightness, and a third dip of ~ 3 mag lasting about 100 days. These fluctuations are thought to be caused by the response of the accretion disk in the system to the cessation of mass transfer from the mass-losing secondary star. We present computations using a time-dependent accretion disk code to delineate a range of allowed behavior for the accretion disk. To model the observed light curve, we require that the model parameters $\alpha_{\rm cold}$ and $\alpha_{\rm hot}$, which characterize the degree of coupling of the viscous dissipation to the orbital shear in the low and high states of the accretion disk, be smaller than they have been inferred to be in the dwarf novae, and that the ratio $\alpha_{\rm hot}/\alpha_{\rm cold}$ also be smaller. The fact that α seems to vary with the rate of mass transfer may provide support for the model of Vishniac and Diamond, in which the impact of the mass transfer stream onto the outer edge of the accretion disk excites internal waves which transport angular momentum outward and provide the viscous dissipation.

Subject headings: accretion, accretion disks — novae, cataclysmic variables — stars: individual (V794 Aquilae)

1. INTRODUCTION

V794 Aquilae is a cataclysmic variable (CV) which is known to have prominent high-state/low-state behavior. The long-term photometric characteristics of V794 Aql were established photographically by Meinunger (1979) and Petrochenko & Shugarov (1982). In this and other published data, the star is seen to vary erratically between magnitude ~ 14 and ~ 17 on timescales of days to years, but in general the transitions have been unresolved. Szkody et al. (1981) reported a transition from ~ 14 to >17.5 mag which was unresolved at a data spacing of 3 days. This was followed by a recovery to ~ 14, unresolved at a 1 day data spacing. Honeycutt & Schlegel (1985) caught the star on one occasion at $B = 19$–20.

There are only a few reported spectra of V794 Aql. Some spectra are in the high state (Bond 1978; Szkody et al. 1981; Mukai et al. 1990), others in the low state (Honeycutt & Schlegel 1985; Szkody, Downes, & Mateo 1988). These spectra and the photometric behavior are consistent with V794 Aql being a member of the VY Sculptoris class of nova-like CVs (Robinson et al. 1981; Shafter et al. 1985). The VY Scl stars are apparently all disk systems with negligible accretion via magnetic poles. The magnetic CV subclasses, consisting of the AM Her stars or polars (high magnetic field with accretion via magnetic poles) and the DQ Her systems (intermediate magnetic fields with both accretion poles and accretion disks) also display high-state/low-state behavior.

Observationally, VY Scl stars all fall above the period gap, in the range 3–4 hr. A well-determined period for V794 Aql is not available, but a preliminary determination from a radial velocity study (Shafter 1983) gives 4–5 hr. The absence of any contribution from the secondary star to the blue-visual spectrum of V794 Aql argues for a period less than 6 hr, using Warner's (1976) general period/luminosity relationship for CVs. The mass transfer modulation that leads to the alternating accretion luminosity in VY Scl systems is thought to be related to the evolution of the secondary star (Spruit & Ritter 1983), and the high-state/low-state phenomenon may be closely related to the period gap between 2 and 3 hr that exists among CVs (Shafter 1992, and references therein).

During 1990–1992, V794 Aql was monitored photometrically and found to exhibit an unusual type of light curve, shown in Figure 1. The three transitions from high to low state are quite similar. Each rather uniform decline is interrupted by an abrupt return to the high state, giving a distinctive sawtooth appearance to the light curve. As far as we know, this is a previously unreported type of photometric variation in CVs. In this paper, we examine this behavior in the light of earlier photometry of this star, in comparison to the light curves of other VY Scl stars and in comparison to accretion disk models which are subjected to extreme mass transfer modulations.

2. OBSERVATIONS

V-band CCD photometry of V794 Aql and the surrounding field was obtained on 115 nights during the interval 1990 November–1992 October with the Indiana Automated CCD Photometric Telescope. This 16 inch telescope is equipped for unattended differential stellar photometry. Exposures with the instrument are scheduled, executed, and reduced in an automated, unattended fashion. A full description of the system has yet to appear, but some components of the operation of the observatory can be found in Honeycutt et al. (1990) and Honeycutt & Turner (1992).

A total of 131 usable 4 minute exposures of V794 Aql were obtained. All 131 exposures were reduced in single ensemble reduction using the technique of inhomogeneous ensemble photometry (Honeycutt 1992). This method incorporates as comparison objects all the constant stars observed in each exposure, even though the number and identity of the comparison stars vary from exposure to exposure due to changes in sky transparency and in telescope pointing. This particular ensemble solution used 165 comparison stars.

Figure 1 shows the light curve of V794 Aql from this photometry. The error bars are established from the inhomogeneous

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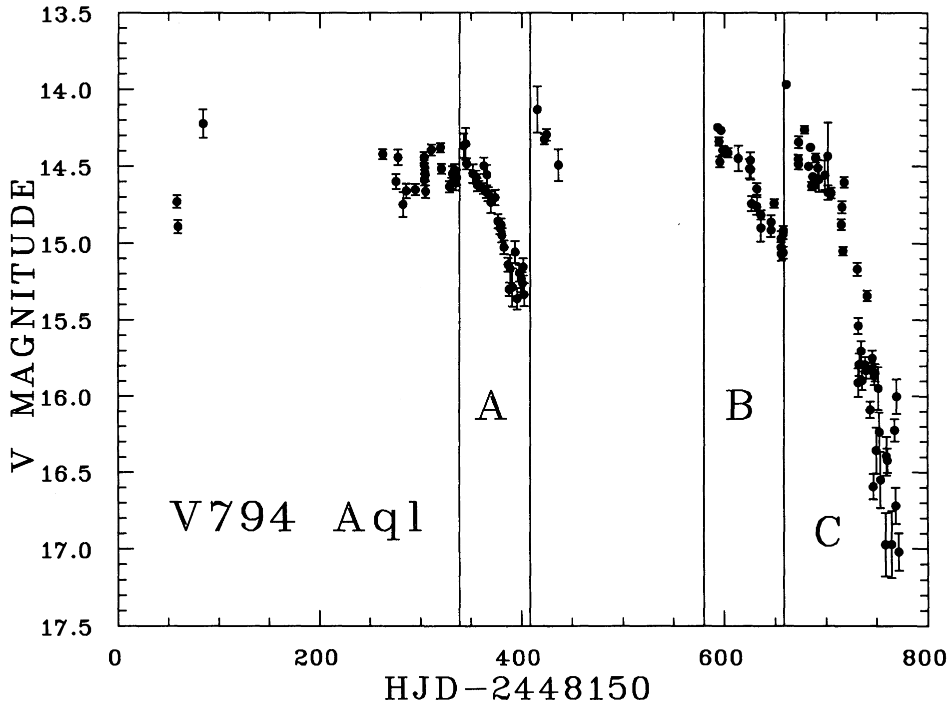

FIG. 1.—Photometry of V794 Aql during 1990–1992. Sequences A, B, and C as defined in this plot are shown on an expanded timescale in Figs. 2–4

ensemble solution. The errors are calculated in the ensemble solution from the dispersion of the individual magnitudes of the constant stars from their mean magnitude and are therefore quite reliable. The errors range from ~0.02 mag, when the system is bright and the sky transparency is good, to ~0.15 when the system is faint and/or the sky is poor. The errors are for magnitudes on the instrumental system, whose zero-point is peculiar to each particular ensemble reduction. The photometry was placed on a rough standard system using exposures of standard star fields which are obtained each night. These standard star fields are exposed for the purpose of monitoring overall system performance and are, in general, unsuited for all sky photometry. However, using V794 Aql and standard star field exposures from clear nights, it was possible to establish the zero-point of the ensemble solution to a precision of ± 0.2 mag. The magnitude scales in Figures 1, 2, 3, and 4 are there-

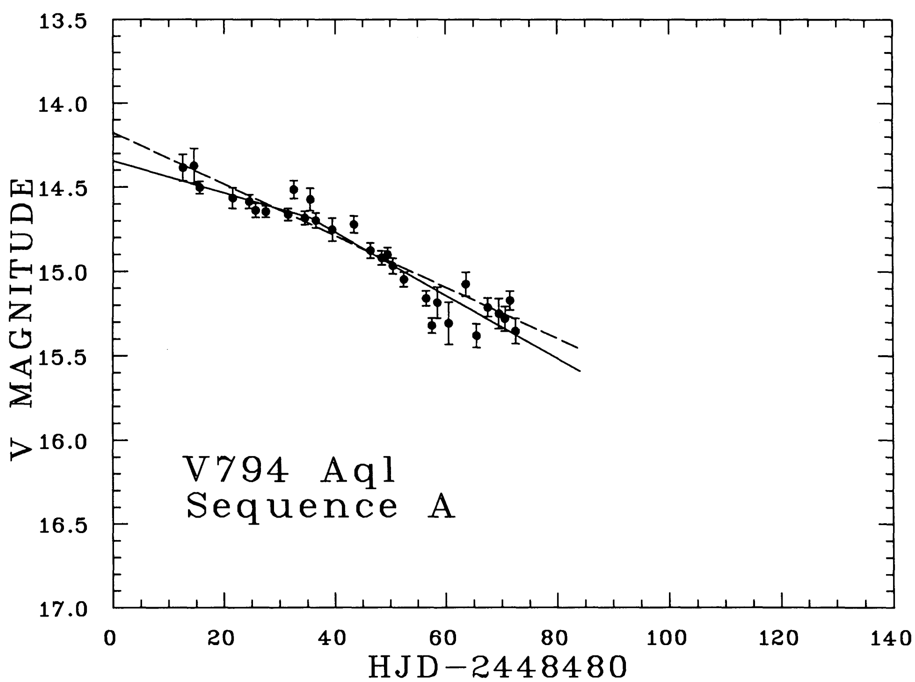

FIG. 2.—Photometric sequence A with the straight line fits shown in Table 1

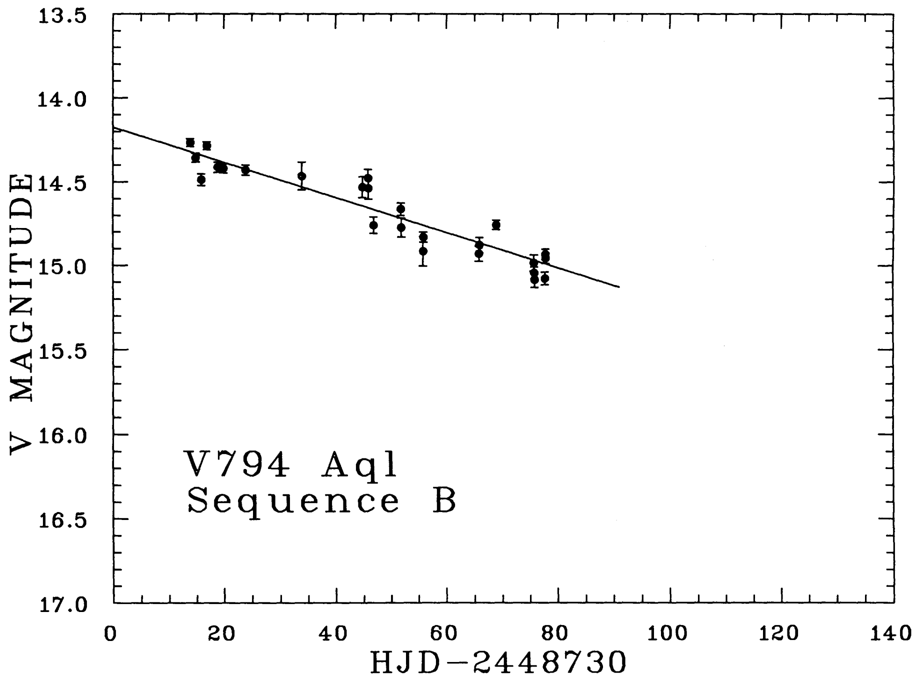

FIG. 3.—Photometric sequence B with the straight line fit shown in Table 1

fore uncertain in zero-point by 0.2 mag, while the internal accuracy of the light curves is typically 5–10 times better, as represented by the error bars.

The data in Figure 1 show V794 Aql falling on several occasions from a high state. In each case the decline is rather slow and regular, followed by an abrupt recovery to the original level. In order to examine the systematics of this behavior, we define sequences A, B, and C in Figure 1, encompassing the three best-defined declines. Sequence A is composed of 30 points on 30 nights over a 61 day interval, 1991 August 24 (UT)–1991 October 22. Sequence B consists of 25 points on 17 nights over a 65 day interval, 1992 May 1–1992 July 4. Sequence C comprises 48 points on 44 nights over a 112 day interval, 1992 July 7–1992 October 26. The recovery from declines A and B are unresolved. The recovery from decline A is <13 days, and the recovery from decline B is <3 days. Declines A and C both appear to have an inflection, becoming steeper part of the way down the decline.

The character of any photometric modulation on the orbital period is, unfortunately, unknown. A periodogram of the data of Figure 1 (with the slow declines removed) showed no significant peaks. If the power in the declines is included, then a

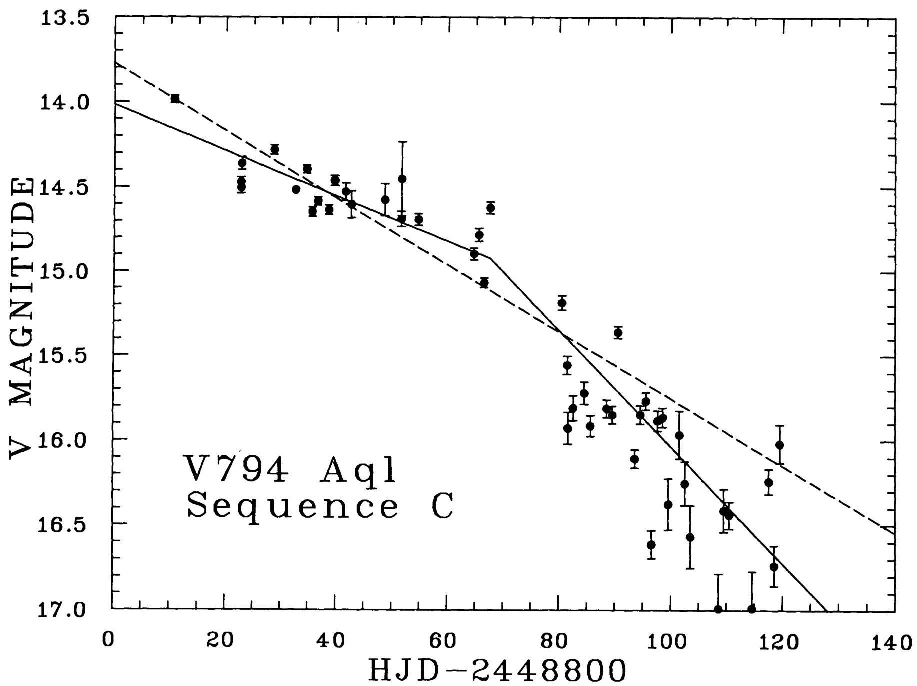

FIG. 4.—Photometric sequence C with the straight line fits shown in Table 1

TABLE 1

STRAIGHT LINE FITS TO THE DECLINES

Sequence (1)	Number of Points (2)	Number of Lines (3)	χ^2 (4)	τ (days) (5)	Length (days) (6)
A	30	1	86	70 (3)	61
	...	2a	76	104 (20)	25:
	...	2b	...	61 (4)	36:
B	25	1	1323	102 (3)	65
C	48	1	1220	52 (1)	>112
		2a	819	77 (5)	57
		2b		32 (1)	>55

strong peak very near 1 day appears. This is a natural consequence of the average 1 day data sampling of the deep, smooth, long-term decline of sequence C. Our real-time scheduler is effective in preventing a star from being observed at the same time each night, but the *mean* 1 day interval must, by necessity, remain. We therefore cannot conclusively rule out that the decline seen in sequence C is due to a 2.5 mag deep eclipse with a period within 0.5% of 1 day. We think, however, this is quite unlikely for several reasons: 1) a period of 1 day is much too long for an expected CV orbital period, 2) a period so near 1 day would be an unexpected coincidence, and 3) when the data are folded on a period near 1 day, the declines of sequences A and B do not coincide in phase with the decline of sequence C. For the remainder of the discussion, we will therefore assume that the declines in Figure 1 are real long-term variations.

Figures 2, 3, and 4 present the light curves for these three sequences on an expanded (and common) timescale. In order to characterize these declines quantitatively, we fitted a straight line to each decline. For sequences A and C (Figs. 2 and 4) we also fitted two straight lines to each decline to characterize the apparent inflections. Table 1 summarizes the slopes of these fits as an *e*-folding time in days. Column (3) denotes whether 1 or 2 lines are fitted. Column (4) gives χ^2 for the fit. These χ^2 values considerably exceed the expectation value ($n - 2$ for one straight line, $n - 4$ for two straight lines), presumably because of superposed intrinsic variations due to flickering and/or orbital variations. The relative values of χ^2 are nevertheless a useful guide to the quality of the fit. Column (5) gives the *e*-folding time, which is calculated as 1.086/(decline rate in magnitudes per day). Column (6) is the duration of the decline.

The reality of the inflection in sequence C is supported by the substantial reduction in χ^2 in going from 1 to 2 straight lines. The same is not true for sequence A, though we note that the apparent inflection in sequence A is in the same sense as the stronger inflection in sequence C. The following summarizes the overall behavior. The decays last from $\sim$60 to $\gtrsim$110 days, with initial *e*-folding times ranging from 70–100 days. There is a moderate tendency for the decline to steepen as the event progresses, with the latter part of some declines having *e*-folding times as short as 30–35 days. The rapid return to the high state is unresolved but is less than 3 and 13 days, respectively, for two of the declines.

3. DISCUSSION OF OBSERVATIONS

The data in Figure 1 represent only $\sim$2 yr sample of the photometric behavior in V794 Aql. It is of interest to know if this recent light curve of V794 Aql is representative of the long-term variations, or instead is a new kind of behavior for this star. Meinunger (1979) presented photographic photometry of V794 Aql from 1932–1972 ($\sim$112 data points), and Petrochenko & Shugarov (1982) added 32 points over 43 days in 1981 and 8 points over 28 days in 1982. Unfortunately, these photographic data are not easily compared to our data because the time resolution and/or photometric accuracy in Figure 1 are significantly superior. The Petrochenko and Shugarov photometry shows variations in the range $B \approx 14$–17, but without any well-defined regular declines in brightness. The variation is instead mostly stochastic; whatever systematic trends might be present have the character of poorly defined outbursts. The Meinunger data set does show a few regular declines, particularly near JD = 2430260, 2440450, and 2440770. However, these three declines are defined by only 5 data points each, and the decline timescales (insofar as they can be characterized by an *e*-folding time) are 30–40 days, about a factor of 2 faster than the declines in Figure 1. The rest of the Meinunger data is mostly too poorly sampled to test whether declines of the type reported here were a common occurrence for V794 Aql during 1932–1972.

The Meinunger photometry and the Petrochenko and Shugarov photometry strongly suggest that V794 Aql can, at least on some occasions, display photometric variations quite *unlike* those in Figure 1. This suggestion is reinforced by the description in Szkody et al. (1981) of a fall from $V = 14.5$ to $V > 17.5$ in <3 days. Szkody et al. suggested that this event (which was followed by an even faster [<1 day] rise back to the high state) might be due to an eclipse. However, Warner (1982) observed V794 Aql continuously on two nights for 2.0 and 3.2 hr, respectively, without seeing an eclipse, and there is no evidence for an eclipse in the high-state behavior in Figure 1. It therefore seems likely that the Szkody et al. event represented a rapid transition from the high state to the low state, a type of behavior that is not present in Figure 1.

It is also of interest to examine whether any other CVs exhibit the systematic slow declines and rapid rises seen here in V794 Aql. There have been a number of studies of high-state/low-state CV behavior using photographic archives. For some of these studies, the transition between states is in fact resolved (but not to the extent of our V794 Aql data). Examples include Garnavich & Szkody (1988) for three AM Her stars and two nova-like CVs; Hudec, Huth & Fuhrmann (1984) for TT Ari; and Kraicheva & Genkov (1992) and Rosino, Romano, & Marziani (1993) for MV Lyr. Examination of these light curves (and others cited in the references above) leads to the conclusion that some published transitions do resemble those of V794 Aql, but most do not. The most useful comparison might be expected to be to the other CVs regularly observed by the automated telescope. However, the time base of about 2.5 yr is considerably shorter than most of the photographic studies, and most of our program stars have not yet been observed to undergo a strong transition. Of the 43 nova-like CVs with good coverage over 2.5 yr, only 10–15 (depending on the criteria adopted) have been seen to change state. Of those systems with state changes, four of the stars (including V794 Aql) are seen to display multiple cycles of slow declines and unresolved rises. Our conclusion is that this behavior is a relatively common (but not necessarily dominant) kind of behavior in nova-like variables and represents a systematic CV property worthy of further study.

The cause of the state transitions in VY Scl stars is poorly understood but is thought to be due to a cessation and resumption of the mass transfer. High state/low state behavior is seen in both disk systems and in the AM Her stars where the strong magnetic field of the white dwarf prevents disk formation. While this result strongly argues that the fundamental mechanism for the state change does not lie in the disk, the character of the *response* of the system to mass transfer changes might well be due to disk properties in those systems possessing disks.

There is no direct evidence for a disk in V794 Aql (such as double-peaked emission lines or a rotational disturbance in the emission lines during an eclipse). V794 Aql is nevertheless generally grouped among the nova-like disk systems (Garnavich & Szkody 1988). Szkody et al. (1981) argue that V794 Aql is not a magnetic system because, compared to AM Her stars, the ratio of He II 4686 to Hβ is quite small, and the X-ray hardness ratio is more like that of disk systems. Furthermore the preliminary orbital period of 5–6 hr is evidence in favor of a disk system, since AM Her stars fall predominantly below the period gap. For the remainder of the discussion we will assume that V794 Aql has an accretion disk, though we admittedly know little about the disk properties in this system.

4. THEORY

The current understanding of the different classes of cataclysmic variables is based on the accretion disk limit cycle mechanism. (See Cannizzo 1993a for a recent review.) The basic theory is as follows. By considering the vertical structure of the disk in a given annulus, one finds a hysteretic relationship between the effective temperature (or the local rate of mass accretion) and the surface density $\Sigma(r)$. Time-dependent computations have shown that this hysteresis causes the entire disk to go through a limit cycle process for systems in which the rate of mass transfer $\dot{M}_T$ from the secondary star to the outer edge of the accretion disk is less than some critical value $\dot{M}_{\rm crit}$. Material accumulates in the accretion disk during a low state and accretes onto the WD during outburst. In the low state the disk is highly non–steady. Most of the matter piles up at large radii, and the rate of radial mass inflow at small radii in the disk is negligible. In outburst, the disk is close to steady state, and the rate of accretion onto the WD exceeds the mean mass transfer rate $\dot{M}_T$ from the secondary. The transition between the high and low states is carried out by transition fronts which either heat the disk or cool it. The fronts are triggered whenever the local surface density $\Sigma(r)$ crosses either the local maximum or minimum in the surface density relation found from the vertical structure computations. We use $\Sigma_{\rm max}$ to denote the local maximum in Σ, and we use $\Sigma_{\rm min}$ to denote the local minimum in Σ. Both $\Sigma_{\rm max}$ and $\Sigma_{\rm min}$ increase with radius, and in the outburst disk, $\Sigma(r)$ is a decreasing function of radius. By necessity the cooling front must therefore always begin at the outer edge of the disk (Cannizzo, Shafter, & Wheeler 1988). In the low state, however, $\Sigma(r)$ generally increases with radius and is bounded by $\Sigma_{\rm min}$ and $\Sigma_{\rm max}$. Therefore, the heating transition can begin at any radius. The only requirement is that Σ exceed $\Sigma_{\rm max}$ at some radius.

Within this framework, the dwarf novae are understood as systems in which $\dot{M}_T < \dot{M}_{\rm crit}$. For the nova-like class of CVs, we infer that $\dot{M}_T > \dot{M}_{\rm crit}$ so that the accretion disk is always in the hot, totally ionized state. The VY Scl stars, of which V794 Aql is a member, are thought to be systems which are basically nova-likes, but in which $\dot{M}_T$ occasionally dips below $\dot{M}_{\rm crit}$ so that the disk can periodically be subject to cooling transition fronts.

The light curves of V794 Aql presented earlier may fit into this picture. The "sawtooth" light curve covering sequences B and C, in particular, provides evidence for the presence of transition fronts in the disk. If $\dot{M}_T$ had exceeded $\dot{M}_{\rm crit}$ prior to the time shown in Figure 1, and if, for some reason, $\dot{M}_T$ had been reduced so that $\dot{M}_T < \dot{M}_{\rm crit}$, then a cooling transition front would begin to move from the outer edge of the accretion disk toward the inner edge. If the cooling front were to stall at some $r < r_{\rm outer}$ and be reflected as a heating front, that could give rise to the abrupt increase in flux seen between sequences B and C. This type of reflection can occur in models with $\alpha_{\rm hot}/\alpha_{\rm cold}$ near unity, where $\alpha_{\rm cold}$ and $\alpha_{\rm hot}$ are the accretion disk viscosity parameters in the cold and hot states, respectively.

To explore this possibility, we now present the results of time-dependent computations of the accretion disk. The code we use is described in detail by Cannizzo (1993b). Earlier descriptions were given by Cannizzo, Wheeler, & Polidan (1986) and Cannizzo & Kenyon (1987). The code uses scalings of the vertical structure adapted from the steady state computations of Cannizzo & Wheeler (1984) in a one-dimensional hydrodynamical treatment which follows the evolution of surface density $\Sigma(r, t)$ and midplane temperature $T(r, t)$ in a self-consistent fashion. In particular, the heating and cooling functions are evaluated separately. Thus, we do not impose either steady state or thermal equilibrium conditions. The orbital period of V794 Aql is unknown, but it is thought to lie somewhere above the period gap. The input parameters we take are appropriate for such a system: $r_{\rm outer} = 4 \times 10^{10}$ cm, $r_{\rm add} = 0.875 r_{\rm outer}$, $r_{\rm FWHM} = 10^9$ cm, $r_{\rm inner} = 5 \times 10^8$ cm, and $M_{\rm WD} = 1\ M_\odot$, where $r_{\rm outer}$ is the outer disk radius, $r_{\rm add}$ is the radius at which matter is added, $r_{\rm FWHM}$ is the full width at half-maximum of the Gaussian profile which characterizes the mass addition, $r_{\rm inner}$ is the inner disk radius, and $M_{\rm WD}$ is the mass of the accreting WD star, respectively. Our radial grid contains 100 points equispaced in $\sqrt{r}$. The accretion disk model is based on the so-called α prescription (Shakura & Sunyaev 1973). To compute the light curve we assume a face-on disk at a distance of 100 pc, and we take Planckian flux distributions for each annulus in the disk.

The light from the accretion disk can decay either because 1) mass is being drained away onto the central WD faster than it is being added at the outer edge, or because 2) a cooling transition front is transforming the disk from the hot state to the cool state. These two physical processes are depicted in Figure 5. For this run, we place the disk in the high state and set the disk mass to a large value so that significant mass loss from the disk onto the WD must occur before the cooling wave can form. Initially, Σ is large everywhere in the disk. The cooling front cannot begin at large radii because $\Sigma(r_{\rm outer}) > \Sigma_{\rm min}$ there. For the parameters we have chosen, the disk must drain onto the WD for about 46 days until $\Sigma(r_{\rm outer}) = \Sigma_{\rm min}(r_{\rm outer})$. The cooling front then begins at the outer edge and starts to move inward. The final curve shows the time step at which the entire disk has returned to the cool and relatively inviscid low state. It would appear that fluctuations in the mass transfer would not be able directly to affect the light curve. Some time is required for the disk to respond to changes in $\dot{M}_T$, and thus the brightening and fading shown in Figure 1 would be difficult to account for by changes in $\dot{M}_T$.

Figures 6 and 7 show a series of light curves from runs in which the mass transfer $\dot{M}_T = 0$, and for which the disk is started with a steady state profile $\Sigma(r) = \Sigma_{\rm min}(r_{\rm outer})(r/r_{\rm outer})^{-3/4}$. Each panel actually contains two runs; the dotted curves show

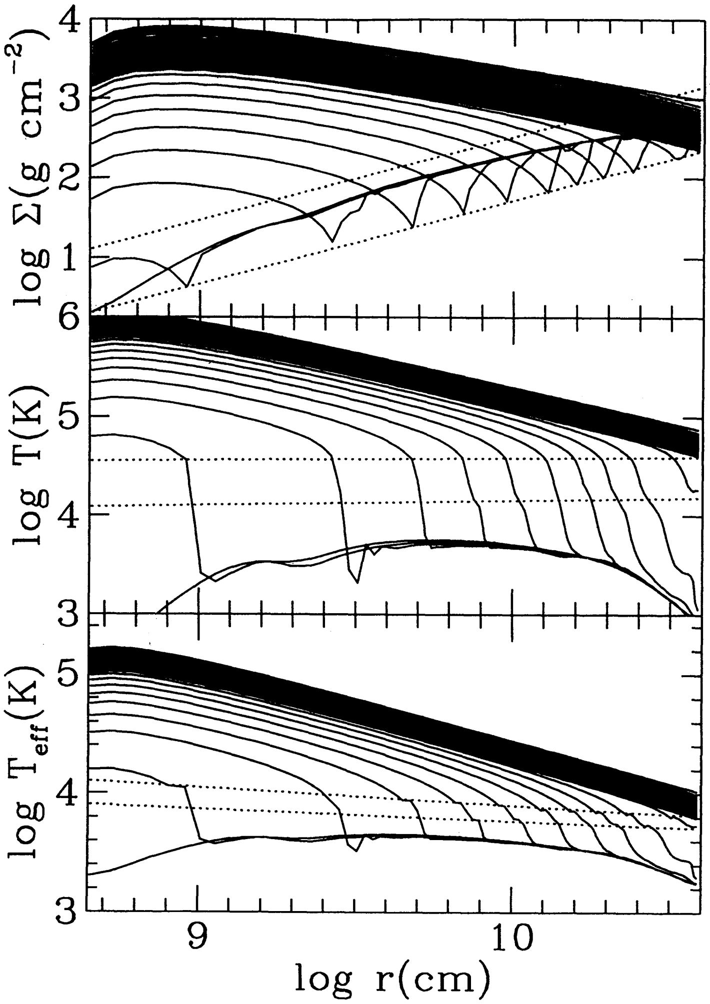

FIG. 5.—Evolution of surface density, midplane temperature, and effective temperature in space and time for a 70 day run with $\Sigma(r, t = 0) = 5\Sigma_{min}(r_{outer})(r/r_{outer})^{-3/4}$, $\dot{M}_T = 0$, $\alpha_{cold} = 0.02$, and $\alpha_{hot} = 0.1$. Each curve shows the state of the disk at 2 day intervals. The dashed curves in each panel show values corresponding to Σ_{max} and Σ_{min}, the critical surface densities which instigate heating and cooling transitions. For the first ~46 days of evolution, the entire disk decays self-similarly as it accretes onto the WD. At the end of this time $\Sigma(r_{outer})$ is low enough that the cooling front can begin to propagate inward and cause the disk to revert from the high state to the low state. This leads to a period of much more rapid decay of the visual light curve.

the light curves for models in which the mass transfer is turned back on at t(days) = 250, to a level $\dot{M}_T = 10^{-8}\ M_\odot\ \mathrm{yr}^{-1}$. The fact that $\Sigma(r_{outer}) = \Sigma_{min}(r_{outer})$ initially means that the cooling front can start immediately. Each panel shows 500 days of evolution for various combinations of α_{cold} and α_{hot}. It may seem paradoxical that outbursts can occur even with no fresh supply of material at the outer disk. The triggering of the outbursts shown in these figures is all at small radii, and during the complete cycle of quiescence and outburst the matter merely shifts back and forth in the disk. Little accretion onto the WD occurs in these computations. In accord with previous workers, we find that well separated outbursts cannot occur until $\alpha_{hot}/\alpha_{cold}$ is greater than about 3. The best agreement with the light curve shown in Figure 1 seems to be for parameters in the range of the first two panels in Figure 6—i.e., $\alpha_{cold} \simeq 0.005$ and $\alpha_{hot} \simeq 0.005$ to 0.01. These values are smaller than those generally inferred for dwarf nova outbursts, and also $\alpha_{hot}/\alpha_{cold}$ is smaller. For these runs there is a decrease of between about 1 and 2 mag over 50 to 100 days, followed in each instance by an increase covering about 10–20 days. As noted earlier, the recovery time scale after a period of slow fading is always rapid. This fits in with the theoretical picture in which the cooling front which brings about the fading of light travels slower than the heating front which brightens the system.

The dotted light curves shown in Figures 6 and 7 show the slow response time of the disk to a resumption of the mass transfer. The mass transfer is turned on halfway through the runs, but the entire disk does not immediately return to the high state. For our best-fit models, shown in the top two panels of Figure 6, for example, the disk responds about 50 days after mass transfer resumes. It would be difficult to account for the dips and subsequent rises seen in Figure 1 by invoking resumption of mass transfer: if the branch of declining light in V794 Aql were caused by a cooling front, the resumption of mass transfer would have to be pretimed so that ~50 days after resumption occurred, the cooling front would just be reaching an intermediate radius in the disk. On the other hand, if α were much larger than what we have been assuming, i.e., $\gtrsim 0.1$, then the response time of the disk would be faster, and it would be possible for variations in $\dot{M}_T$ to be mirrored directly in the light from the disk. The disk would, however, have to be always in the high state. This would be difficult to manage, especially with the requisite large α values, because there would be a natural tendency for the cooling transition front to begin once Σ drops below Σ_{min} at the outer edge. In order to avoid this, one would have to postulate a monotonic relationship between the local mass flow rate and surface density, rather than a hysteretic relationship. It would seem arbitrary that VY Scl stars should contain disks with this physics, while the dwarf novae have disks with the usual S-curve physics. It seems more natural to explain the declines and rises in V794 Aql purely in terms of cooling and heating fronts.

5. DISCUSSION

What are the implications of the constraints we place on the disk instability model? Why should α be smaller for a system like V794 Aql than it is for dwarf novae? The main difference between the dwarf novae and the VY Scl stars is thought to be that $\dot{M}_T$ is highly variable in the latter group—in particular, that it occasionally goes to zero (or at least to some small value). Cannizzo (1993b) modeled the long-term light curve of SS Cygni using the same disk instability model employed in this work. By attempting to match observed correlations seen in SS Cyg between various properties associated with the outbursts, Cannizzo concluded that it was unlikely that α could be a function of $\dot{M}_T$. In SS Cyg, however, the inferred fluctuations in $\dot{M}_T$ are small (less than about 20%). It may be that much greater fluctuations in $\dot{M}_T$ could have an effect on α. In the model of Vishniac & Diamond (1989, 1992), for instance, internal waves excited by the impact of the mass stream from the secondary star on the outer rim of the accretion disk transport angular momentum outward and generate viscous dissipation, thereby providing the physical basis for "α." In this model, it would seem plausible that the strength of the waves generated would depend on the magnitude of $\dot{M}_T$. Therefore, if $\dot{M}_T$ were suddenly to become small, this could also lower α_{cold} and α_{hot}. In order to get the sawtooth pattern of decay followed by rapid recovery which we see in V794 Aql, we also require that $\alpha_{hot}/\alpha_{cold}$ be of order unity, so that we do not obtain well separated outbursts. This would imply that one of the α's is

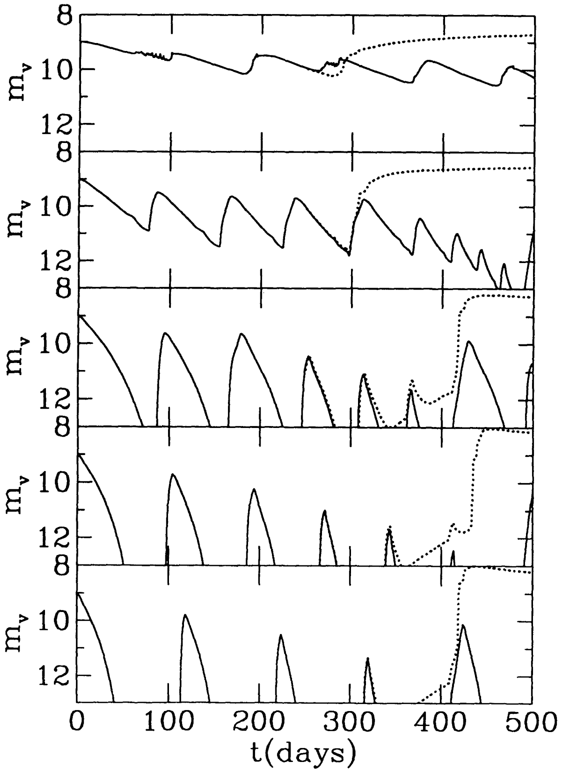

FIG. 6.—A series of five runs in which $\dot{M}_T = 0$, $\alpha_{cold} = 0.005$, and $\alpha_{hot} = 0.005$, 0.01, 0.015, 0.02, and 0.025, respectively. Initially, $\Sigma(r) = \Sigma_{min}(r_{outer})(r/r_{outer})^{-3/4}$. For the light curves shown by the dotted lines, the mass transfer is turned on at $t = 250$ days, to $10^{-8}\ M_\odot\ \mathrm{yr}^{-1}$.

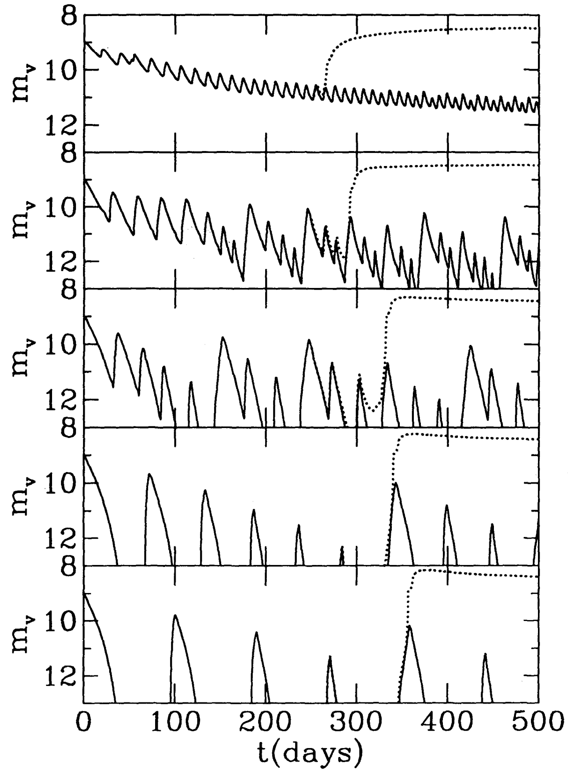

FIG. 7.—A series of five runs in which $\dot{M}_T = 0$, $\alpha_{hot} = 0.03$, and $\alpha_{cold} = 0.03$, 0.015, 0.01, 0.0075, and 0.006, respectively. Initially, $\Sigma(r) = \Sigma_{min}(r_{outer})(r/r_{outer})^{-3/4}$. For the light curves shown by the dotted lines, the mass transfer is turned on at $t = 250$ days, to $10^{-8}\ M_\odot\ \mathrm{yr}^{-1}$.

more sensitive to $\dot{M}_T$ than the other. Sequence B in Figure 1 shows a ~ 1 mag decrease, followed immediately after a short recovery period to maximum light by a ~ 3 mag decrease. This indicates that the cooling front associated with the first decline is reflected at a larger radius than the cooling front associated with the second decline. From Figure 6, this can be accomplished in the model by having $\alpha_{hot}/\alpha_{cold}$ vary or by having enough accretion onto the WD during the first decline so that the surface density in the disk is reduced somewhat, and on its second passage the cooling front can penetrate to a smaller radius. It may be that the turning off of $\dot{M}_T$ is not abrupt but stochastic, so that both α_{hot} and α_{cold} are fluctuating significantly.

Rosino et al. (1993) have shown that MV Lyr, another VY Scl star, can have very extended periods of low accretion. We have shown that there is a natural tendency in the model for outbursts to continue long after the mass transfer has turned off. This tendency is, however, mediated by α_{cold}. If α_{cold} were to become extremely small, then 1) the viscous drift time for the low-state disk would become very long, and 2) Σ_{max} which triggers the outbursts would increase greatly. These effects would effectively prevent further outbursts from occurring. This constraint provides strong qualitative support for models of the type discussed by Vishniac and Diamond to the extent that α_{cold} must become very small when $\dot{M}_T$ becomes small. Furthermore, $\dot{M}_T$ must not only decrease below $\dot{M}_{crit}$ so that the disk ceases steady state accretion from a permanent high state; it must also drop significantly below the range of mass transfer rates which standard dwarf novae possess, or the system would simply revert to exhibiting dwarf nova outbursts.

Additional support for the idea that α_{cold} may decrease when $\dot{M}_T$ becomes very small is provided by the shortest orbital period SU UMa systems, especially WZ Sge. Smak (1993) shows that, to reproduce the ~ 33 yr outburst recurrence time for this system, α_{cold} must be $\sim 10^{-4}$, assuming a mass transfer rate $\dot{M}_T \sim 3 \times 10^{-11}\ M_\odot\ \mathrm{yr}^{-1}$.

6. CONCLUSION

We have presented a long light curve of the cataclysmic variable V794 Aql and shown that there is a tendency for the system to decline in brightness by about 1 to 3 mag over periods of 50 to 100 days, after which it brightens to its original level over <3 to <13 days. This behavior can be explained by the accretion disk limit cycle theory using models in which we set the mass transfer rate to zero, and the accretion disk supports cooling and heating transition fronts which propagate back and forth in the disk. The fact that the observed decay is slower than the recovery in V794 Aql would be a consequence of the fact that the cooling front is slower than the heating front. In addition, the values of the viscosity parameter α which we infer for V794 Aql are significantly smaller than those inferred from dwarf novae. This may indicate that the accretion disk viscosity is mediated by changes in $\dot{M}_T$. Reducing $\dot{M}_T$ would appear to lower α.

V794 Aql has not been observed long enough to see if it enters into prolonged periods of low light as does MV Lyr. Robinson et al. (1981) theorized that the VY Scl stars represent an evolutionary stage for CVs that are just beginning to enter the upper edge of the period gap, where mass transfer is thought to turn off. In this scenario, it may be that a system like MV Lyr has advanced a little further in its evolution than V794 Aql—i.e., the reduction in mass transfer for systems entering the gap is not abrupt but proceeds in stages, turning off and on many times before it finally turns off permanently, with the fraction of time spent in the off state increasing with time. Given the sawtooth nature of the light curve for V794 Aql, the mass transfer may only be off for brief periods—i.e., there would be no extended low state. For MV Lyr, however, the system does spend many years in the low state, during which time one sees occasional brightening. Thus, the mass transfer has not completely turned off even during these times. The intermediacy in $\dot{M}_T$ in going from systems like MV Lyr to V794 Aql, to SS Cyg, would then also translate into an intermediacy in terms of α. Thus, the result of a more complete cessation of mass transfer in MV Lyr versus V794 Aql would be that the smallest α values (leading to outburst recurrence times so long that no true outbursts are seen) would be found in the accretion disks in systems like MV Lyr, larger α values would be characteristic of V794 Aql-like disks, and the dwarf novae and true nova-like CVs would possess the disks with the largest α's.

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