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Orbital Light Curves of UU Aquarii in Stunted Outburst

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Abstract

Stunted outbursts are $\sim 0^{\mathrm{m}}.6$ eruptions, typically lasting 5–10 days, which are found in some novalike cataclysmic variables, including UU Aqr. The mechanism responsible for stunted outbursts is uncertain but is likely related to an accretion disk instability or to variations in the mass transfer rate. A campaign to monitor the eclipse light curves in UU Aqr has been conducted in order to detect any light curve distortions due to the appearance of a hot spot on the disk at the location of the impact point of the accretion stream. If stunted outbursts are due to a temporary mass transfer enhancement, then predictable deformations of the orbital light curve are expected to occur during such outbursts. This study used 156 eclipses on 135 nights during the years 2000–2012. During this interval, random samples found the system to be in stunted outbursts 4%–5% of the time, yielding ~7 eclipses obtained during some stage of stunted outburst. About half of the eclipses obtained during stunted outbursts showed clear evidence for hot spot enhancement, providing strong evidence that the stunted outbursts in UU Aqr are associated with mass transfer variations. The other half of the eclipses during stunted outburst showed little or no evidence for hot spot enhancement. Furthermore, there were no systematic changes in the hot spot signature as stunted outbursts progressed. Therefore, we have tentatively attributed the changes in hot spot visibility during stunted outburst to random blobby accretion, which likely further modulates the strength of the accretion stream on orbital timescales.

Key words: novae, cataclysmic variables – stars: individual (UU Aqr)

1. Introduction

Cataclysmic variable stars (CVs; Warner 1995; Hellier 2001) consist of a donor star that is transferring gas to a companion white dwarf, usually forming an accretion disk (AD). Some CVs are dwarf novae (DN), having semi-regular outbursts (outbursts) of the AD. Others, such as novalike (NL) CVs, have stable non-outbursting disks. UU Aqr is a well-studied (e.g., Baptista et al. 1996; Baptista et al. 2000) NL, having an orbital period of 3.9 hr and displaying superhumps at times (Patterson et al. 2005). The system also shows occasional stunted outbursts. Stunted outbursts have amplitudes of $\sim 0^{\mathrm{m}}.6$, durations of 5–10 days, and the spacings are often similar to that of DN outbursts (but with considerably smaller amplitudes, hence "stunted"). The mechanism for stunted outbursts remains uncertain. There is evidence that stunted outbursts are due to mass transfer events (Honeycutt et al. 1998; Baptista et al. 2011) and also evidence that they are due to disk instabilities occurring under unusual circumstances (Honeycutt 2001). Stunted outbursts have also been reported in *Kepler* photometry (e.g., Gies et al. 2013 for KIC 9406652, Mason & Howell 2016 for V523 Lyr, Ramsay et al. 2016 for KIC 9202990; Schlegel & Honeycutt 2017 for AC Cnc).

The stunted outbursts in UU Aqr are not regular in time and are sometimes even missing for a year or more. In some other novalikes, the stunted outbursts can be more frequent and reliable than in UU Aqr. However, UU Aqr has a $\sim 1^{\mathrm{m}}.6$ deep eclipse of the AD, providing an opportunity to study the relationship of the AD hot spot to stunted outbursts. In this paper, we compare the properties of orbital light curves of UU Aqr obtained both during and outside of stunted outbursts. Because the UU Aqr outbursts mostly occur at random intervals, an extensive observing campaign is required to obtain a few eclipses during any stunted outbursts. We report here on 135 nights of monitoring, resulting in 156 eclipse curves, several of which were obtained during stunted outburst. These data are used to help distinguish accretion disk instabilities (ADIs) from mass transfer events.

Due to the orbital motion of the binary and Coriolis effect, the accretion stream in a CV curves to the leading side of the line-of-centers as it falls to its impact point on the AD. The hot spot produced upon impact is therefore also displaced in the direction of orbital motion of the donor star. A common photometric manifestation of the hot spot is a hump in the orbital light curve just prior to inferior conjunction of the donor star, at phases when the hot spot is presented most nearly face-on to the observer. A canonical example of this hump is present in U Gem (Warner & Nather 1971). If the orbital inclination is high, the hot spot can be eclipsed, resulting in an asymmetric eclipse having a momentary hesitation during egress, as the hot spot is uncovered "late." This delayed or stepped egress can be seen in a number of eclipsing DN CVs; a well-studied example is that of Z Cha (Wood et al. 1986).

These two examples, U Gem and Z Cha, are both DN-type CVs, in which the AD alternates between a cool, faint, low viscosity state (quiescence) and a hot, bright, high viscosity state (DN outburst; Cannizzo 1993). In DN quiescence, the hot spot luminosity can rival that of the disk, leading to a prominent orbital hump and for favorable high inclinations, a strongly stepped egress coming out of eclipse. However, in NL CVs such as UU Aqr, the disk remains in a bright state, and hot spot effects are more difficult to see against the competing luminosity of the accretion disk. Nevertheless, a number of NL CVs have been reported to display hot spot signatures, though the effects are weaker than in DN and not always present. Examples include UX UMa (Nather & Robinson 1974), RW Tri (Smak 1995), and LX Ser (Eason et al. 1984).

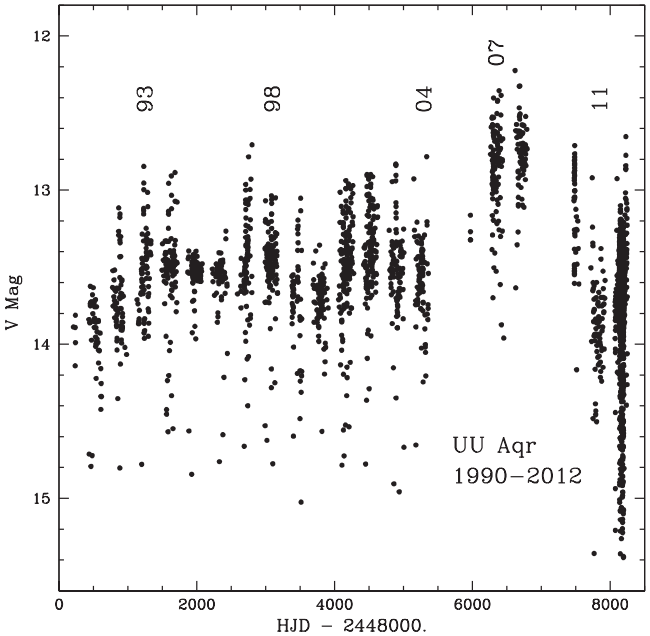

Figure 1. The full V-band light curve of UU Aqr from 1990 November 13 to 2012 November 15 (UT), obtained at the Morgan-Monroe observatory of Indiana University. Error bars have been omitted for clarity. As a guide, some observing seasons have the year labeled.

In fact, UU Aqr itself has evidence for occasional hot spot effects on the orbital light curve. Baptista et al. (1994) conclude that UU Aqr has two photometric states differing by $\sim 0^{\rm m}.25$, which they designate as a "high" state and a "low" state. A mean eclipse curve for each of the two states, using data from the years 1988–1992, found a noticeable asymmetry at egress for the mean high state, indicating a hot spot on the disk. They also noted a slight pre-eclipse hump. The low-state eclipse curves are more symmetrical. (Note that the high and low states defined in Baptista et al. 1994) each last a full observing season, so they are not stunted outbursts, which last 5–10 days. It appears that only 24 data points over 4 years were used to separate their high/low states, a sampling that would likely miss any stunted outbursts. Our data (acquired at a later epoch than that of Baptista et al. 1994) does not show discrete photometric states outside of stunted outburst, but rather more-or-less continuous meanderings (see Figures 1–8).

2. Data Acquisition and Reductions

A number of different telescopes and filters were used in this study. Table 1 lists the eight observing campaigns, each using its own telescope, filter, and CCD. Column 1 provides a designation for each series of nights that used the same setup and similar observing cadence. Columns 2 and 3 show the JD range and the UT range. Column 4 is the filter while column 5 gives the telescope used (MMO = Morgan-Monroe observatory of Indiana University, USNO/FS = U.S. Naval Observatory/ Flagstaff Station, ATU = Arkansas Tech University, WIYN = WIYN Observatory). For series S2–S8, the observing interval on most nights yielded one eclipse. On other nights, no eclipse occurred during the observing window, but such data remains useful for defining the out-of-eclipse behavior. On some nights, two successive eclipses were captured. Column 6 gives the number of nights, and column 7 is the number of eclipses observed, with the number of eclipses during stunted outburst in parenthesis. Column 8 provides the typical data spacing, in days or seconds. The last column indicates whether hot spot effects are observed.

All of the photometric series in Table 1 used secondary standards from Henden & Honeycutt (1995); however, the techniques and reductions differed among the eight series. Series S1 and S7 were acquired autonomously by two Indiana telescopes using methods that are described in Honeycutt et al. (2013). This process employed the technique of incomplete ensemble photometry contained in Astrovar, which is a custom package based on the technique described in Honeycutt (1992), but with the addition of a graphical user interface. Series S2 used IRAF[5] routines for both detector calibrations and aperture photometry. Series S3, S4, S5, S6, and S8 used IRAF for detector calibrations and Cmuniwin[6] for differential photometry. Errors for all the photometry averaged 0.01–$02^{\rm m}$.

The various series in Table 1 have differing time resolution, which might affect the observed shape of the eclipse (particularly the depth). Therefore, in studying how the eclipse might change between being in stunted outburst or not, we have used only differential comparisons among eclipses in the same series.

For Series S1, S2, and S7, multiple secondary standards were used to establish the zero point, and well-determined transformation coefficients were applied; these zero points are therefore accurate to at least $0^{\rm m}.02$. For Series S4, S5, and S6, only a single comparison star was used (plus a check star), and no transformations were applied; therefore, these zero points could be in error by up to $0^{\rm m}.08$ (but are much more accurate differentially). Series S3 (Clear filter) and S8 (g' filter) have no reliable secondary standards. For these cases, we adjusted the zero point to agree with V-band measures from Series S7 near orbital quadrature. Although the zero points for Series S3 and S8 are uncertain, the differential magnitudes remain accurate and provide reliable detection of any stunted outbursts, as well as possible hot spot signatures in the orbital light curves.

3. Analysis

Several methods were used to determine whether UU Aqr was in stunted outburst on a given night of continuous monitoring. First, the quadrature brightness of the orbital light curve obtained on a given night of continuous monitoring can be compared to the historical record of the brightness of UU Aqr during stunted outburst. The relevant historical record is best seen in Figure 1, where we see that the stunted outbursts extend $\sim 0^{\rm m}.6$ brighter than a somewhat meandering quiescence level. For most years, the quadrature brightness is 13.7–13.4 outside of stunted outburst and near 13.0 in stunted outburst. However, UU Aqr also has occasional $0^{\rm m}.4$ brightness modulations on timescales of a few years, which can confuse the situation. A second method is to use our long-term monitoring results on UU Aqr. These data (Series S1) encompass the years 1990–2012 with a typical cadence of 3–4 days. This method is very useful when we have Series S1 MMO data near the time of a given eclipse. However, gaps due to weather and equipment failures serve to compromise this method somewhat. Finally, we sometimes can compare the quadrature brightness of other orbital light curves obtained within a few days to months of the eclipse in question. Such a comparison is similar to using our long-term monitoring from

[5] IRAF is distributed by the National Optical Astronomy observatories, which are operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.
[6] http://integral.sci.muni.cz/cmunipack/index.html

Table 1
Photometric Series on UU Aqr

Series	JD-2450000	UT	Filt	Tel	#Nights	#Ecp (# During OB)	Spacing	# Hot Spot Detections
S1	1792 6246	1990 Nov 13 2012 Nov 15	V	MMO 0.41 m & 1.25 m	1278	⋯(–)	∼2–4 days	⋯
S2	1645 2201	2000 May 31 2001 Oct 19	V	USNO/FS 1.0 m	9	8 (3)	75 s	2
S3	2825 2960	2003 Jul 05 2003 Nov 17	Clear	ATU 0.31 m	29	42 (6)	105 s	∼4 of 6 (in mean)
S4	3508 3529	2005 May 18 2005 Jun 08	V	WIYN 3.5 m & WIY 0.91 m	6	4 (0)	80 s	⋯
S5	3594 3677	2005 Aug 12 2005 Nov 03	V	ATU 0.31 m	16	25 (1)	425 s	0
S6	3600 3668	2005 Aug 18 2005 Oct 25	R	ATU 0.31 m	22	28 (1)	575 s	0
S7	6075 6195	2012 May 28 2012 Sep 25	V	MMO 0.41 m	28	26 (0)	140 s	⋯
S8	6159 6257	2012 Aug 20 2012 Nov 26	g′	ATU 0.26 m	25	23 (2)	350 s	0

Series S1, but yielding more widely spaced points and somewhat reduced photometric accuracy.

Figure 1 shows the 1990–2012 MMO long-term light curve of UU Aqr from Series S1. A full discussion of this light curve will be presented in a forthcoming paper that uses MMO data on many novalikes to study long-term properties such as stunted outbursts and low states. Here, we restrict our discussion to features in Figure 1 that are relevant to our orbital photometry of UU Aqr.

In Figure 1, the concentration of points near $V = 13.6$ corresponds to UU Aqr outside of stunted outburst. The points below that level are randomly sampled eclipse points, while the points extending to near $V = 13.0$ are stunted outbursts. We see that the stunted outbursts are frequent in some years, and absent in others, but they always seem to extend $\sim 0^{\mathrm{m}}.6$ above the local quiescence level. We see that during the 2007 and 2008 observing seasons, UU Aqr was $\sim 0^{\mathrm{m}}.6$ brighter in quiescence than for preceding and succeeding seasons. Those 2007–08 data were acquired with a detector/filter combination different from most earlier and later seasons (being Campaign C as described in Honeycutt et al. 2013), leading us to initially suspect a problem with the instrument or the reductions. However, note that UU Aqr remained brighter than normal for the partial season of 2010 (which is the beginning of Campaign D) using a different CCD. We therefore judge this effect to be real (but we have no orbital light curves for 2007–08 in any case). Finally, the high density of points in 2012 is due to our orbital monitoring of UU Aqr on 25 nights, forming Series S7, which was reduced along with Series S1.

Figures 2–8 show the data of Figure 1 expanded to one observing season per panel. The range of magnitudes has been restricted to the levels of quiescence and stunted outburst. Data points spaced closer than 3.5 days are connected by straight lines. Therefore, the random eclipse points (which fall below the lower plot edge) sometimes result in line segments that lead off the bottom of the plot. Stunted outbursts are obvious during

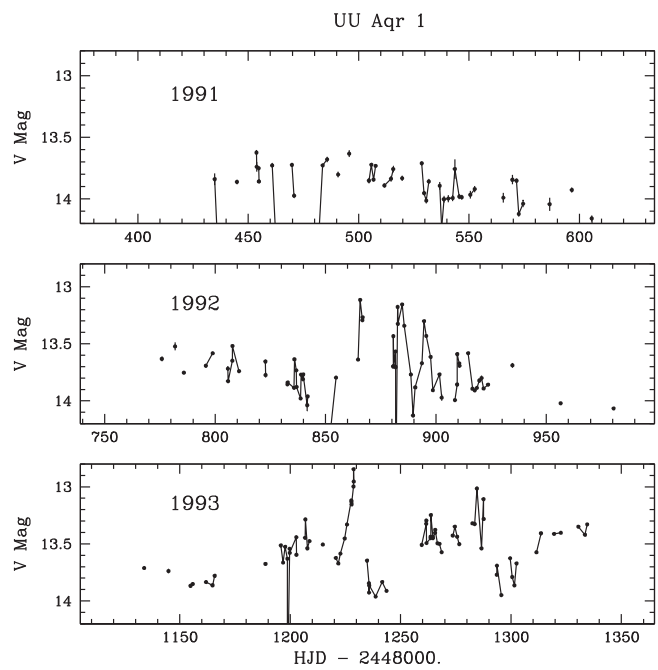

Figure 2. Seasonal light curves of UU Aqr for 1991–93, using the data plotted in Figure 1. Data points with separations less than 3.5 days are connected by straight lines. Occasional eclipse points lie off the bottom of the plot. Error bars have been omitted for clarity.

some years, with reasonably consistent amplitudes and widths. However, the quiescence level sometimes varies erratically, which (when coupled with occasionally more sparse sampling than desired) may sometimes conceal stunted outbursts that might be present. In some seasons with favorable coverage (i.e., 1994, 1997, 1998, 2001, 2002), the stunted outbursts can appear quite regular in spacing, amplitude, and width. However, in other seasons with similar good sampling (i.e., 1995, 1996, 2000) the stunted outbursts are missing. In yet

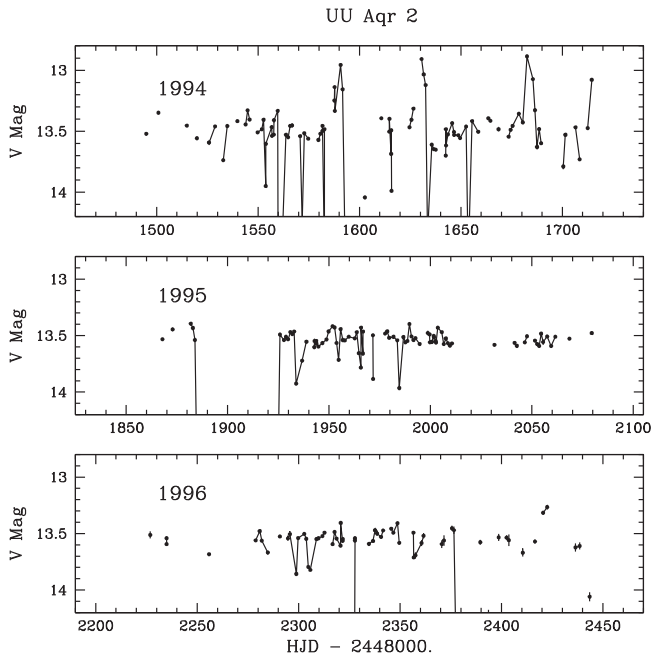

Figure 3. Like Figure 2 except for 1994–96.

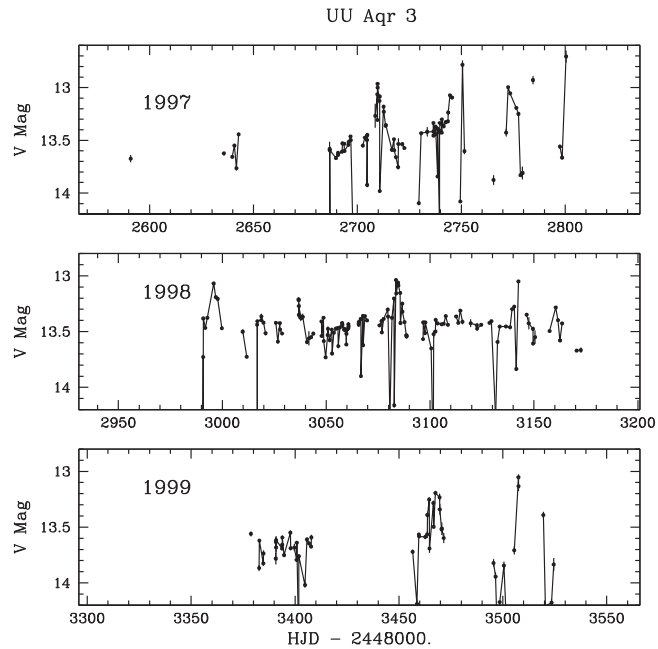

Figure 4. Like Figure 2 except for 1997–99.

other seasons (i.e., 2007, 2011), stochastic variations in the quiescence level seem to dominate.

In the top two panels of Figure 5, magenta tick marks denote the location of nights for which we measured eclipses in Series S2 of Table 1. In the top panel of Figure 6, magenta tick marks denote eclipse nights in Series S3. For Series S4, S5, and S6 in 2005, we unfortunately do not have long-term monitoring data from Series 1. In Figure 8, cyan tick marks denote eclipse nights in Series S7, while magenta tick marks represent eclipse nights in Series S8. For those orbital light curves that fell during a stunted outburst, we have plotted expanded portions of the relevant data in Figures 9 through 11. In these plots, we have omitted, for clarity, any points in eclipse.

For the full interval 2000–2012, the stunted outburst duty cycle (that is, the fraction of time spent in stunted outburst) was ∼0.04–0.05. The photometry listed in Table 1 were acquired without knowledge of the photometric state. It is therefore not surprising that few of the orbital light curves contained eclipses coincident with stunted outbursts. In the following paragraphs, we describe the coincidences that did occur and the presence (or absence) of a bright hump just before eclipse and/or a delayed egress due to a hot spot. The observational series below are ordered by increasing success in detected coincidences and/or hot spot effects.

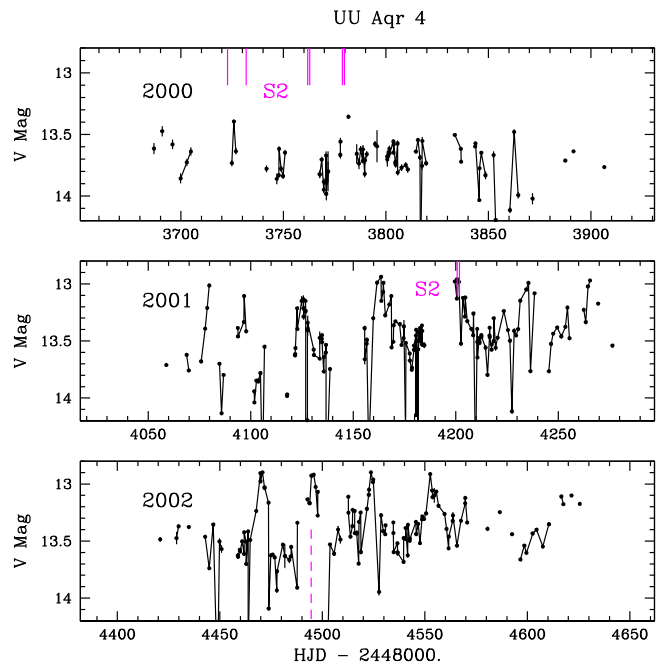

Figure 5. Like Figure 2 except for 2000–02. Magenta tic marks in the top two panels denote nights that eclipse data was obtained, as Series S2 (see Table 1).

3.1. Eclipses with No Visible Hot Spot Effects during Stunted Outburst

Series S4 (WIYN V-band in 2005) and S7 (MMO V-band in 2005) have no eclipses observed during stunted outburst, despite our having a total of 30 eclipses from these two series. The locations of the S7 eclipses are noted by cyan tic marks in Figure 8. Note the scarcity of stunted outbursts in 2012, especially near Series S7.

Series S5 (ATU V-band in 2005) and S6 (ATU R-band in 2005) each had one eclipse that is probably in stunted outburst. However, these data are compromised by a number of circumstances. First, no S1 monitoring data are available for 2005, so we must rely on our measurements of quadrature brightness from the eclipse data on nearby nights, which are spaced considerably further apart than the preferred S1 data. We have only a single isolated high quadrature brightness from S5, and another from S6, providing hardly any information about the likely stunted outburst nor where in the stunted outburst the eclipse data was acquired (see Figure 10). Furthermore, we find no indication for any distortion of the orbital light curve due to a hot spot for either of these two eclipses. Finally, we did not cover the phases needed to detect a delayed egress for the relevant S5 eclipse. Faced with these obstacles, we have chosen to omit S5 and S6 from further

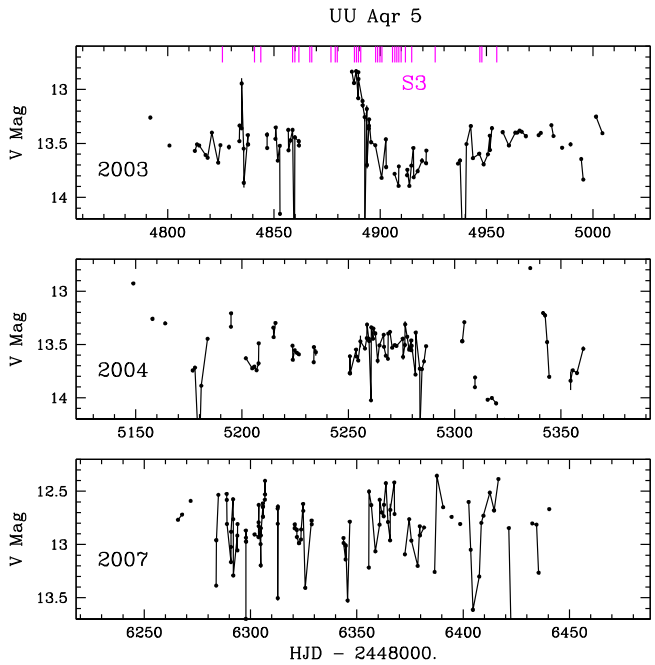

Figure 6. Like Figure 2 except for 2003, 2004, and 2007. Magenta tic marks in the top panel denote nights in which eclipse data was obtained, as part of Series S3 (see Table 1).

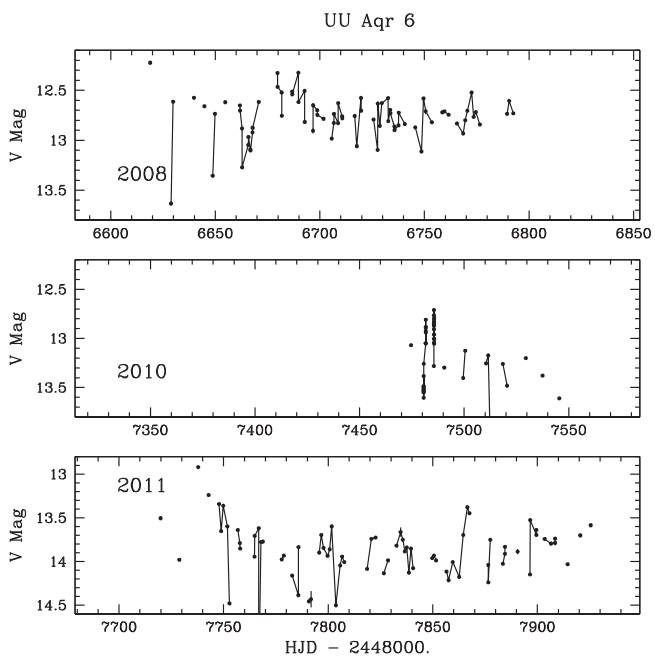

Figure 7. Like Figure 2 except for 2008, 2010, and 2011.

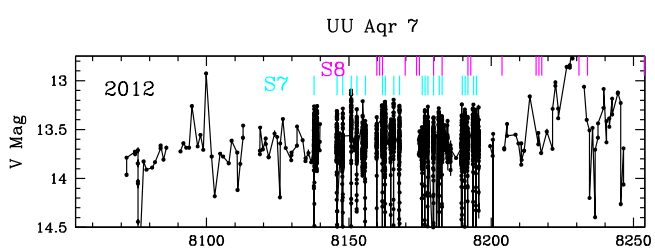

Figure 8. Like Figure 2 except for 2012. The bottom row of cyan tic marks denote nights for which eclipse data was obtained as part of Series S7 (see Table 1.) The top row of magenta tic marks denote eclipse nights for Series S8.

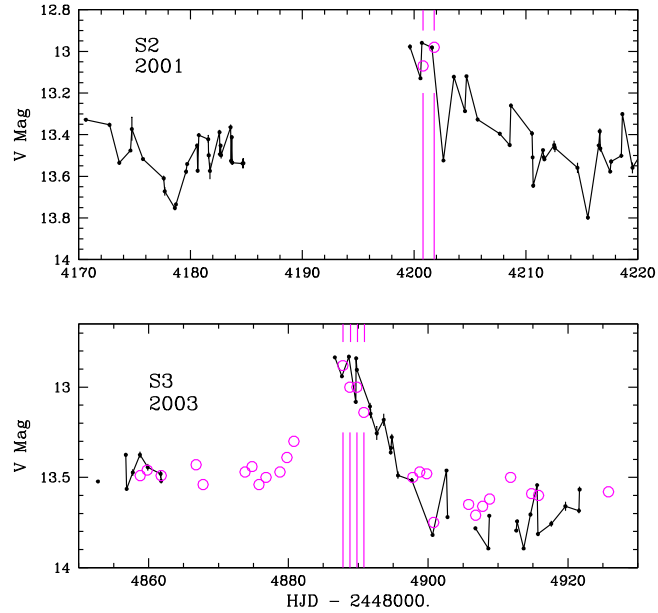

Figure 9. Light curves of UU Aqr over intervals when eclipse coincided with stunted outbursts. Top: black data points with connected lines are an expanded portion of the middle panel of Figure 5. For clarity, data points in eclipse have been omitted. Magenta vertical lines mark nights having eclipse observations from Series S2 (see Table 1). Magenta open circles are the mean quadrature brightness from the orbital photometry, which helps fill in the coverage from Series S1 data. Two nights with eclipse data appear to be in stunted outburst. Bottom: like the top panel except for an expanded portion of the top panel of Figure 6. Six eclipses are available on these four nights in stunted outburst, from Series S3.

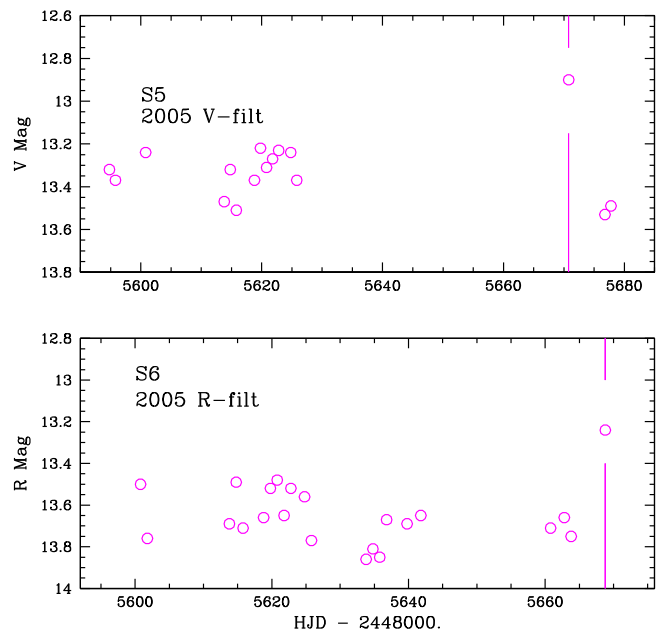

Figure 10. Like Figure 9 except that 2005 data are not available from Series S1, leaving only the quadrature brightness from the orbital photometry to be plotted. Top: a portion of the data for Series S5, showing one eclipse in stunted outburst. Bottom: a portion of the data for Series S6, showing one eclipse in stunted outburst.

discussion. For the record, the S5 eclipse found to be in stunted outburst was obtained on JD = 2453670.77, when UU Aqr was $0^{\mathrm{m}}.45$ brighter at quadrature than adjacent quadrature measurements obtained from 14 orbits spaced over 85 days (see top panel of Figure 10). The S6 eclipse found to be in

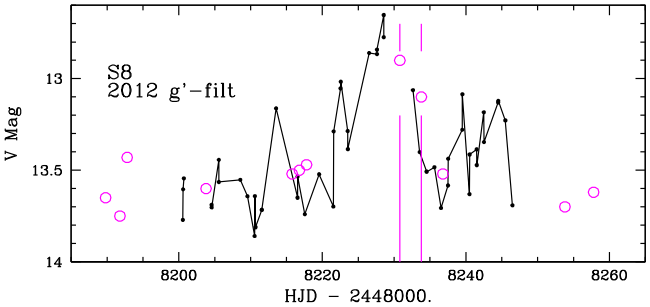

Figure 11. Like Figure 9, except for a portion of the 2012 data in Figure 8. We see two eclipses on two nights that occur in the later stages of a stunted outburst.

stunted outburst was obtained on JD = 2453668.64, when UU Aqr was $0^{\mathrm{m}}.40$ brighter than adjacent quadrature measurements obtained from 21 orbits spaced over 70 days (see bottom panel of Figure 10). It seems very likely that the relevant S5 and S6 eclipses are from the same stunted outburst.

Series S8 (ATU g′-band in 2012) has two eclipses, three days apart, during the decline of a stunted outburst. This stunted outburst is not particularly well-defined (see Figure 11) but we do see that the amplitude is $\sim 0^{\mathrm{m}}.9$. The first eclipse was obtained ∼2 days past the peak and $\sim 0^{\mathrm{m}}.2$ fainter. The second eclipse is ∼5 days past the peak and $\sim 0^{\mathrm{m}}.4$ fainter than the peak. Neither of these eclipses show signatures of a mass transfer event.

3.2. Eclipses with Some Hot Spot Effects during Stunted Outburst

For Series S3 (ATU Clear filter in 2003), six eclipses during a stunted outburst were obtained on four successive nights 2003 September 5 (UT) through September 8. The first and last nights each had two eclipses. The location of these four nights with respect to the outburst can be seen in the bottom panel of Figure 9. The mean comparison eclipse was produced using 27 orbital light curves not in stunted outburst. These locations are marked in magenta in the top panel of Figure 6. The relevant nights in stunted outbursts appear near the outburst peak. We have no data to define the rise to outburst peak, so we do not know how far into the outburst the eclipse curves were obtained. Some weak hot spot effects appear in some of the six individual eclipse curves, but we see no systematic changes in the eclipse shape as the stunted outburst progresses. Such effects may be obscured by lower S/N than desired. To improve the S/N, we have formed an average of the six eclipses that we have plotted alongside the comparison in Figure 12. (Note: in this and other phased plots in this paper, we have used the orbital ephemeris of Baptista et al. 1994.) The mean comparison eclipse curve in Figure 12 typically has 50 points per 0.01 phase bin, while the mean in-outburst light curve has 5 to 15 points per bin. A well-defined egress delay is apparent, plus perhaps a weak pre-eclipse hump.

During Series S2 (USNO-FS V-filter in 2000–2001) one eclipse was captured 2001 October 18(UT) near the peak of a stunted outburst although egress was missed. On the next night, still in stunted outburst, two eclipses in adjacent orbits were obtained, at the peak of the same stunted outburst. See the top panel of Figure 9. The locations of the non-stunted outburst comparison eclipse curves are shown in the top panel of Figure 5. The October 18 eclipse curve, and the mean comparison eclipse curve, are shown in Figure 13. The mean

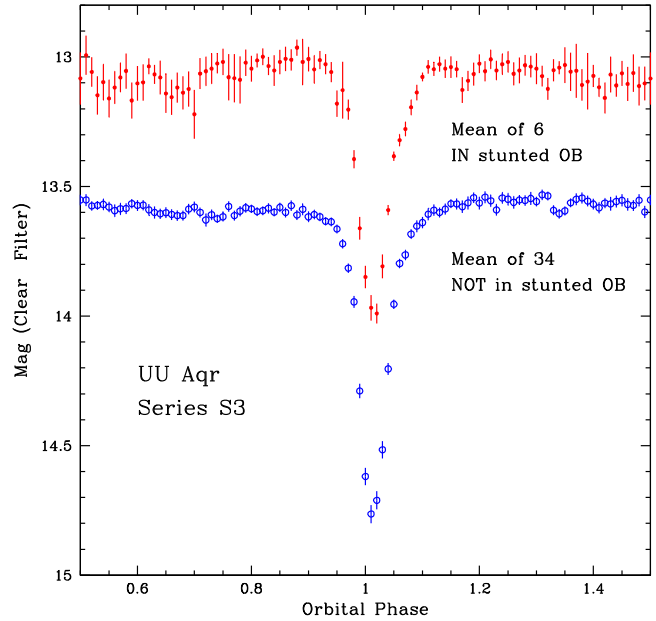

Figure 12. Top plot (small solid red points) is the average of six eclipses on four consecutive nights in stunted outburst from Series S3. The comparison is the average of 34 eclipses that are not in stunted outburst. The comparison data (open circle blue points) were taken on 25 nights over 4 months on either side of the stunted outburst data. Phase bins are 0.01 wide and the errors are the standard deviation of the mean of the points in each phase bin.

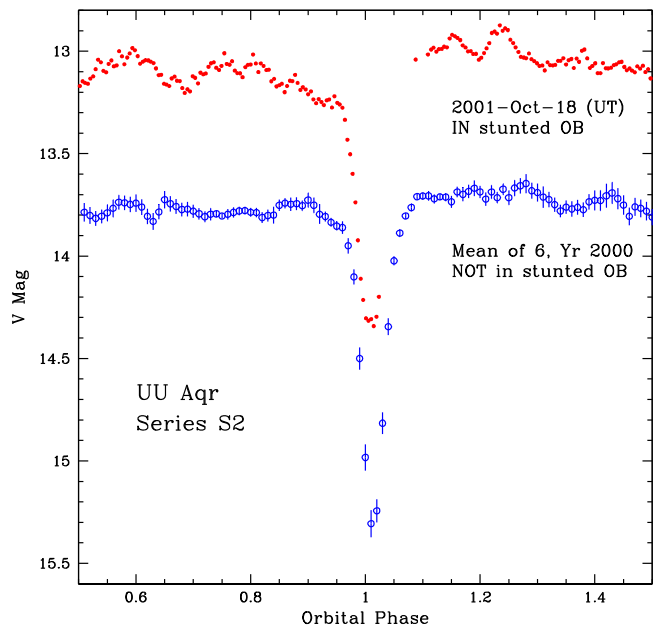

Figure 13. Top plot (small solid red points) is a single eclipse in stunted outburst from Series S2 (see Figure 9 and Table 1). The bottom plot (open circle blue points) is a comparison eclipse produced by averaging, in bins 0.01 phase units wide, the Series S2 light curves acquired during the 2000 season when the system was *not* in stunted outburst. See the vertical magenta markers in the top panel of Figure 5 for the locations of the individual light curves that make up this mean curve. There are between 2 and 7 points per bin and the error bars are the standard deviation of the mean.

comparison light curve typically has 2–4 points per 0.01 phase bin. The two October 19 eclipse curves are shown in Figure 14, along with the same comparison eclipse curve. With regard to a hot spot, Figure 14 shows that the two adjacent October 19 eclipses are remarkably similar, each showing both spot effects: a modest pre-eclipse hump and a well-defined delayed egress

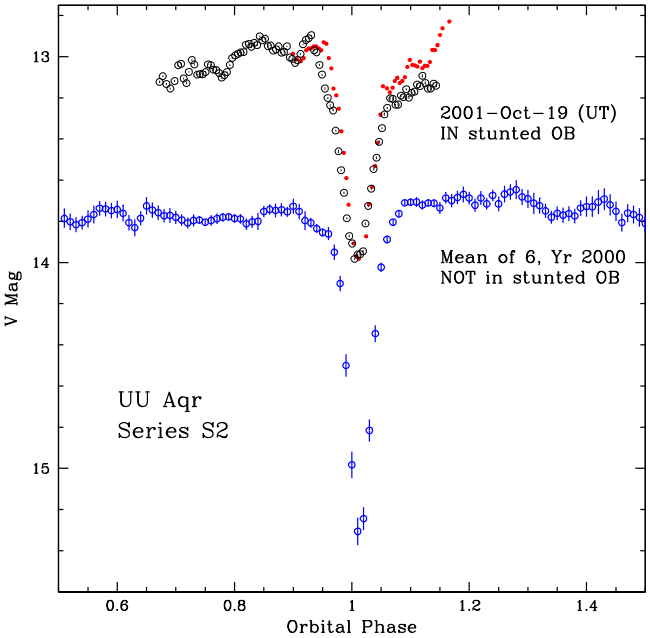

Figure 14. Top plot (small solid red points and open black circles) are two consecutive eclipses on the same night from Series S2, both acquired during stunted outburst. This is the night following the night in Figure 13. The comparison eclipse is the same one used in Figure 13.

from eclipse. The single eclipse on October 18 shows no hump, but the phase range for a possible delayed egress was not covered.

4. Discussion

The initial stunted outburst descriptions in Honeycutt et al. (1998) listed the properties of these outbursts and discussed possible causes, which generally boil down to either ADIs or mass transfer modulations (MTM). The disks in NL CVs are generally considered to be stable against DN-type outbursts, so invoking mass transfer bursts as responsible for stunted outbursts is a reasonable starting assumption. Comparisons of the distributions of separations of stunted outbursts with dwarf novae outbursts are difficult because novalike CVs typically have much better photometric coverage than dwarf novae. However, we note that Honeycutt (2001) concluded that the distributions of periodogram power with frequency for stunted outbursts and dwarf nova outbursts were quite similar, at least in the range of 5–100 days. Some of the systems having stunted outbursts also display dips, which are shaped much like inverted stunted outbursts. Dips are less numerous and more diverse than stunted outbursts. Both isolated dips and adjacent pairs of outbursts and dips are found. Some of these properties are suggestive of behaviors in Z Cam-type DN (Buat-Ménard et al. 2001; Lasota 2001; Simonsen 2011). Z Cam stars alternate between DN outbursts and stable NL light curves (i.e., standstill), and are thought to lie near the $\dot{M}$ boundary separating NL disks (which are stable against the thermal/viscous disk instability) from lower $\dot{M}$ systems that might permit DN-like outbursts. Z Cam stars can display outburst/dip pairs at times. However, important differences between stunted outbursts and Z Cam outbursts remain. For example, Z Cams typically have 2.5 mag continuous outbursts peak-to-peak during outbursting intervals (i.e., excluding standstills). Honeycutt et al. (1998) includes an evaluation of the possible Z Cam connection and also summarizes the traits that favor an ADI for stunted outbursts and those which argue against an ADI (and hence favor a MTM explanation).

Honeycutt (2001) further explored the similarities of stunted outbursts and DN outbursts, using additional data from the MMO long-term monitoring program. Similarities were noted in the range of outburst spacings, in the degree of coherence and and stability of the outbursts, and additional examples of outburst/dip pairs were provided. The overall conclusion was that the similarities between DN outbursts and stunted outbursts are so numerous that the ADI mechanism is strongly favored for stunted outbursts.

There is evidence in some of our eclipse curves that were acquired during stunted outburst for the appearance of a hot spot on the accretion disk, a spot which is not present for eclipses acquired outside stunted outburst. This strongly favors an MTM explanation for stunted outbursts. However, the situation is somewhat confused by the erratic appearance of the hot spot signatures. Let us review the results described in Sections 3.1 and 3.2 regarding hot spot effects seen (or not seen) for the eclipses we acquired during stunted outburst. We found that Series S8 has two eclipses during the decline of a stunted outburst, but neither of these eclipses have the distortions characteristic of an accretion disk hot spot. Series S3 however had more positive results. Six eclipses were obtained on four successive nights during a stunted outburst. The individual eclipse curves showed no firm evidence for a hot spot, at least partly because of lower S/N than desired. However, the mean of these six eclipses shows strong evidence for an egress delay, plus modest evidence for a pre-eclipse hump. Finally, Series S2 has one eclipse at the peak of a stunted outburst plus two successive eclipses on the next night (still in stunted outburst). The single eclipse at stunted outburst peak shows no hot spot effects, while the two eclipses the next night each display prominent hot spot distortions. In fact, the two eclipses on the second night are nearly identical. This proves that the eclipse distortions due to the hot spot are real and are not due to random slow flickering. Overall, about half of our eclipses in stunted outburst show evidence, to varying degrees, for hot spot distortions. It is quite striking that the effects are so variable. It seems unlikely that this is due to a decline in the strength of the hot spot as the stunted outburst progresses, because the first of the three eclipses in stunted outburst in Series S2 is at the peak of the outburst, and that eclipse (alone among the three eclipses) shows no evidence of a hot spot.

Variable hot spot visibility during UU Aqr stunted outburst is also supported by Baptista et al. (2011) who argued that the stunted outbursts in UU Aqr are likely mass transfer events. Four eclipse light curves during a 2002 stunted outburst (which is marked by a dashed vertical line in the bottom panel of Figure 5) were analyzed using eclipse mapping techniques. The outburst starts with a 10-fold increase in un-eclipsed light. This is conjectured to arise from a strongly enhanced disk wind, which remains mostly un-eclipsed. The disk itself starts getting brighter 2 days after the onset of the outburst. It is argued that this progression of enhanced wind followed by disk brightening is inconsistent with an accretion disk instability (ADI); rather, the stunted outburst is concluded to be caused by an episode of enhanced mass transfer. The ascending branches of the four eclipses in stunted outburst each show evidence for delayed egress. The degree of this distortion varies among the four eclipse curves, which is consistent with our results.

A reasonable candidate for a mechanism that might produce erratic hot spot effects during stunted outburst is blobby accretion.

A clumpy rain of gas onto the white dwarf was originally invoked to explain an otherwise puzzling excess of soft X-rays in polars (Kuijpers & Pringle 1982; Frank et al. 1988; Gänsicke et al. 1995). The more dense portions of the fragmented stream are able to penetrate further into the white dwarf atmosphere, where the hard X-rays are degraded into soft X-rays before escaping. Lumpy accretion was originally associated only with the interpretation of X-rays from polars (Eracleous & Horne 1996), but UU Aqr is not a polar and also has no evidence for being an intermediate polar. However, the idea of fragmented mass transfer later found broader application to a variety of CV phenomena, including the odd rapid outbursts in AE Aqr, which have been attributed to a magnetic propeller mechanism (e.g., Pearson et al. 2003; Meintjes 2004) as accretion blobs interact with the rapidly rotating magnetosphere of the white dwarf.

The mechanism for the fragmentation itself is uncertain. Some proposed mechanisms involve various instabilities associated with the interaction of the stream with the magnetosphere of the white dwarf, but others appeal to effects near L1. The latter mechanisms might be relevant to UU Aqr because they do not require that the white dwarf be a polar or IP (see Meintjes 2004 for brief discussions). In an evaluation of scenarios for the AE Aqr flares, Eracleous & Horne (1996) list ejections from the prominence field on the active secondary star (Chincarini & Walker 1981; Bruch 1991), while King (1995) appeals to instabilities in the accretion stream due to the ionization front near L1. King (1995) suggests that an inhomogeneous flow may be a generic feature of Roche lobe overflow and that an inconspicuous fragmented accretion stream might well be present in non-magnetic CVs.

Because the fragmentation mechanism is not well-constrained, the timescales for mass transfer rate modulations by the blobs is similarly not well predicted. However, there are some observational clues. The low-state optical flaring events in AM Her, which were tentatively attributed to blobby accretion by Kafka et al. (2005), have characteristic power at 0.1–0.5 days, and the AE Aqr flares have typical separations of 6 hr. Absorption dips are sometimes seen in the orbital light curves of some polars, both in X-rays and optical. They occur at repeatable orbital phases but with varying strengths and shapes (e.g., Watson et al. 1989) and are attributed to the passage of the accretion stream in front of a magnetic pole accretion spot on the white dwarf. The variability in this phenomenon (generally attributed to stream clumpiness) is sampled (at best) just once per orbital period, but the timescale is compatible with the other observational evidence cited earlier. Overall, it does not seem unreasonable to tentatively attribute the night-to-night unreliability of the hot spot eclipse distortions we find in UU Aqr to a blobby accretion stream.

Note that in this picture, the stunted outburst itself is required to continue unabated even as stream clumpiness modulates the brightness of the hot spot. This is consistent with the general tempering effect that the AD has on MTMs. Such considerations are beyond the scope of this paper and would benefit from modeling of the effects of blobby accretion on the hot spot and on the disk equilibrium in novalike CVs.

5. Summary and Conclusions

We have presented evidence for stunted outbursts being associated with mass transfer events in the novalike cataclysmic variable UU Aqr. This evidence seems very secure to us, as it was confirmed by multiple data sets acquired over 12 years. Surprisingly, the hot spot effects used to reach these conclusions are not uniform in time but instead seem to vary randomly in strength on typical timescales 0.5–5 days within a given stunted outburst. We attribute this variability to a blobby accretion stream, similar to the kind commonly invoked to address the soft X-ray excess in polars.

This study was motivated by a desire to distinguish between two competing suggestions for the nature of stunted outburst: an ADI or a temporary mass transfer enhancement. Our high confidence in the mass transfer scenario for the stunted outbursts in this data set results in a quandary, because we have equally high confidence in the association of many stunted outbursts in other novalikes with an ADI, related to the Z Cam phenomenon (based on data presented in Honeycutt 2001 plus more extensive MMO monitoring 2000–2012). All we can do at the present time is to list the broad categories of possible explanations: (1) one of our studies of the two hypotheses is somehow flawed or misleading, (2) both ADIs and mass transfer events produce stunted outbursts, either in the same novalike, or in an ADI subset of novalikes and a mass transfer subset. (3) stunted outbursts are due to a complex interaction between mass transfer and ADI.

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