Long-Term Quadrature Light Variability in Algol-Type Binary Systems

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1. Motivation

Close binaries of the Algol type show photometric and spectroscopic activity that reflect ongoing mass transfer. Especially interesting are the systems in which the gas stream directly impacts the photosphere of the mass gainer. Although the generic process of mass transfer has been understood now for about a half century, little is known about the detailed physics. How is the mass actually deposited on the mass gainer? What is the extent of shock-induced heating in the photosphere? Are there accretion-induced pulsations on the photosphere of the mass gainer? Is the mass transfer rate uniform? What are typical fluctuations in amount and location of matter deposition due to source and stream fluctuations? Are there magnetic cool spots on the surface of the mass loser, and to what extent do they influence the mass transfer?

2. The *Kepler* Program on Algol Binaries

The current focus of our program are 10 short-period eclipsing binaries (cf. Table 1) in the *Kepler* identified as Algols. Their separations are close enough that any ongoing mass transfer either dynamic or controlled by magnetic fields would produce a direct impact. Each system has been monitored at the long cadence (LC) for the duration of *Kepler* Cycles 1-4 to investigate the variability in the light curves. Short cadence (SC) observations were obtained of most systems for a duration of one month to look for and study pulsations and other short-term activity. *Kepler* photometry has revealed that several of the binaries display unequal brightness at their quadrature phases and that the quadrature brightness ratio varies from > 1 to <1 on a time scale of about 100-400 days. We call these systems L/T (*leading* hemisphere/*trailing* hemisphere) variables. To the best of our knowledge such behavior has never been reported from ground-based photometry. The prototype L/T variable is WX Dra, which is the focus of this poster.

3. Overview of WX Draconis Observations

WX Dra (P=1.80 d, primary is a δ Scuti star) is a short period eclipsing binary that displays a light curve characteristic of an Algol binary [1]. Very little is currently known about the system, but according to the online Budding Catalog [2] the components are A8 + K0 IV. Recent spectra obtained with the KPNO 4-m Echelle spectrograph suggest that this classification is reasonable and the mass ratio of the system is about 0.18. LC *Kepler* observations have been secured in Quarters (Q) 2-4, 6-8, 10-12, and 14-16 (WX Dra is located at the periphery of the *Kepler* field and fell off of the detector grid one quarter per year due to the spacecraft roll) and a month of SC observations were made during Quarter 7. In Fig. 1 we show the LC light curve of WX Dra observed over ~145 binary cycles spanning more than 260 days in Quarters 6-8. This compressed display clearly shows the development of an apparent bright spot on the leading side of the primary. The spot continues to brighten over a time scale of about 2.5 months, then fades. We have interpreted this observation as evidence for a hot accretion spot on the leading hemisphere of the mass gainer. The SC observation (Fig. 2) revealed the presence of obvious pulsations that appear to be on the primary star, since they are evident during the secondary eclipse but not throughout the primary eclipse. The dominant period is 40.56 ± 2.87 m.

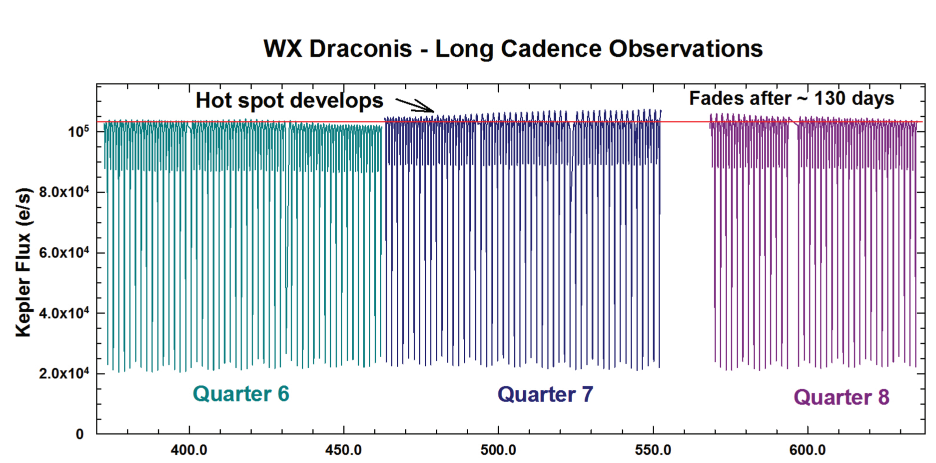

Fig. 1 - LC observations of WX Dra during Quarters 6-8 reveal the apparent development and fading of a bright spot over a time scale of ~130 days. The wavy pattern at the bottom of the primary eclipses is an artifact due to sampling with the LC filter.

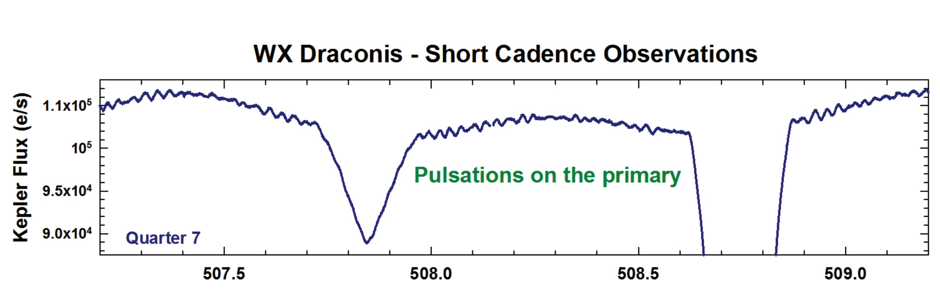

Fig. 2 - SC observations of WX Dra during Q7 show evidence for δ Scuti-like pulsations on the primary star.

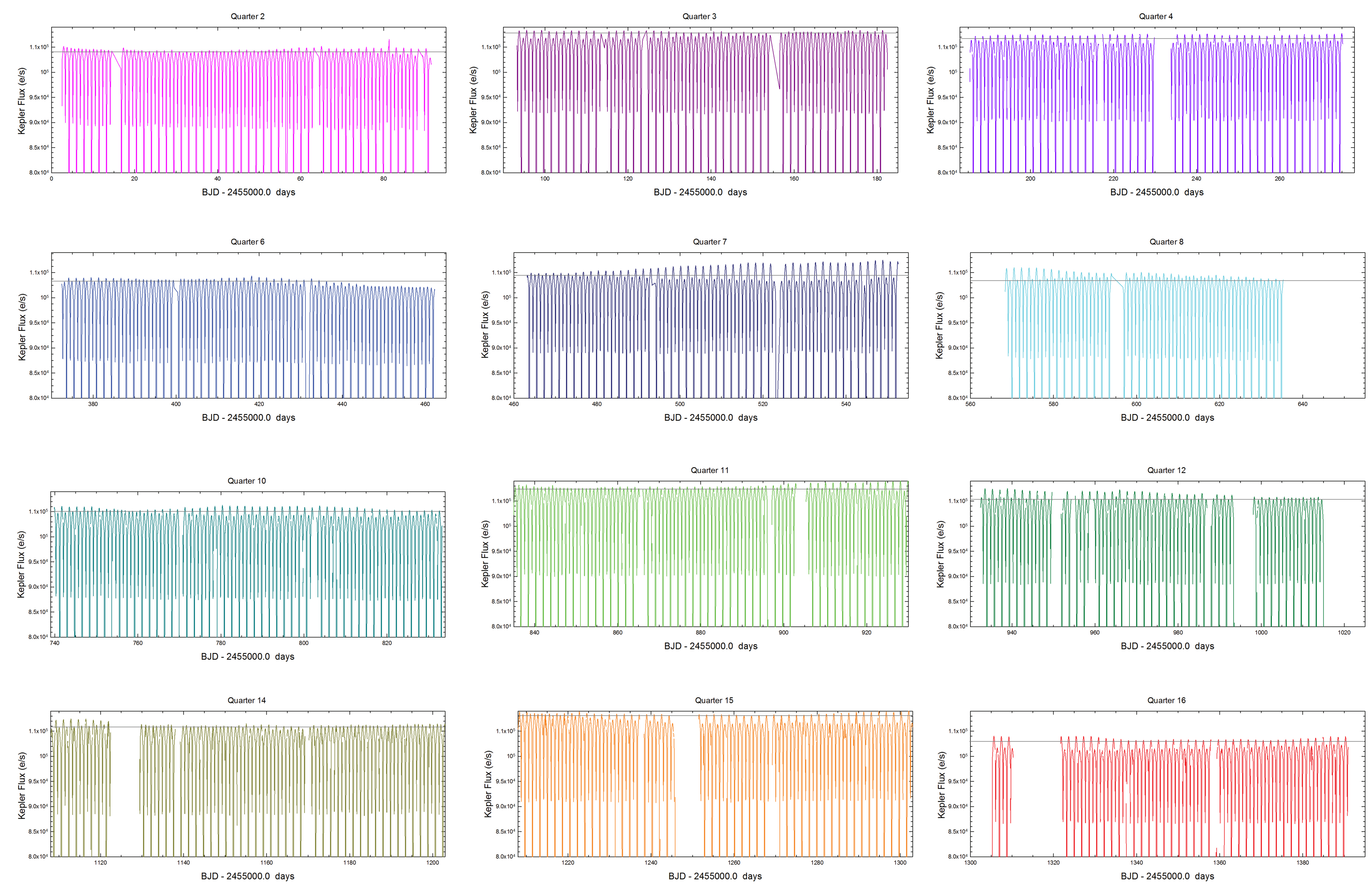

Fig. 3 - The *Kepler* light curves of WX Dra from Q2-16 expanded to show the details of the variations in the quadrature flux. The gray line shows the quadrature flux level when L ≈T.

4. Characterization of the L/T Variability in WX Draconis

The long-term behavior in the light curve in WX Dra can be seen in the expanded plots above (Fig. 3). In Q2, L ≈ T until the last month of the quarter, then T > L. T remained brighter than L until late in Q3. The inequality appears to be a flux deficiency in L. In Q4 L > T with a flux deficiency in T. Q6 initially shows L ≥ T, then T > L, ending with L ≈T. About one month into Q7 there was a dramatic increase in L with a noticeable decrease in T (cf. Fig. 1). L >> T then prevailed until the end of Q7. L/T continued to fade until mid-Q8. Q10 initially showed L ≥ T, then L = T, and ended with T >> L. The flux was deficient in L. In Q11 L ≈ T until the last month when T > L. T >> L prevailed during the first half of Q12. The T faded. In this epoch there was *no* deficiency in L. By Q14 L > T but L ≈ T at the end of the quarter. The T flux was not depressed. But in Q15 L > T, then L ≈ T with the T flux lowered. Finally in Q16 L >> T, declining over the quarter. The T flux was clearly depressed.

5. Light Curve Analysis and the L/T Phenomenon

The light curves are being analyzed with an updated version of the Wilson & Devinney (WD) program [3],[4],[5],[6],[7]. The most recent addition is a thorough makeover of the program's spot capability, including major precision improvements for spotted star light (and velocity) curves, spot motions due to drift and stellar rotation, and spot growth and decay [6]. These enhancements apply to both accretion hot spots and magnetic cool spots. The program's analysis capability includes parameters for times of spot appearance, development, and disappearance.

Initially we fit the light curves of the early Quarter 6 data during which L ≈ T to obtain the basic systemic parameters without the spot enhancement. Then we introduced a hot spot whose initial temperature is 2.3 times that of the local photosphere. In our initial modeling the spot is allowed to move in longitude but not change in size or temperature. Pulsations will be treated in a future analysis. Preliminary results are shown in Fig. 4 . Some model parameters are listed in Table 2. But a fit to an epoch when L = T (early Q2) reveals that the computed quadrature flux (assuming the system is semi-detached) is more curved than the observations (Fig. 5). This may mean that the system is detached in which case the L/T phenomenon would likely be a result of a varying dark-spotted region on the secondary. But the dark region would have to occupy 20-40% or more of the facing hemisphere of the cool star depending on the brightness of the spotted region relative to the photosphere.

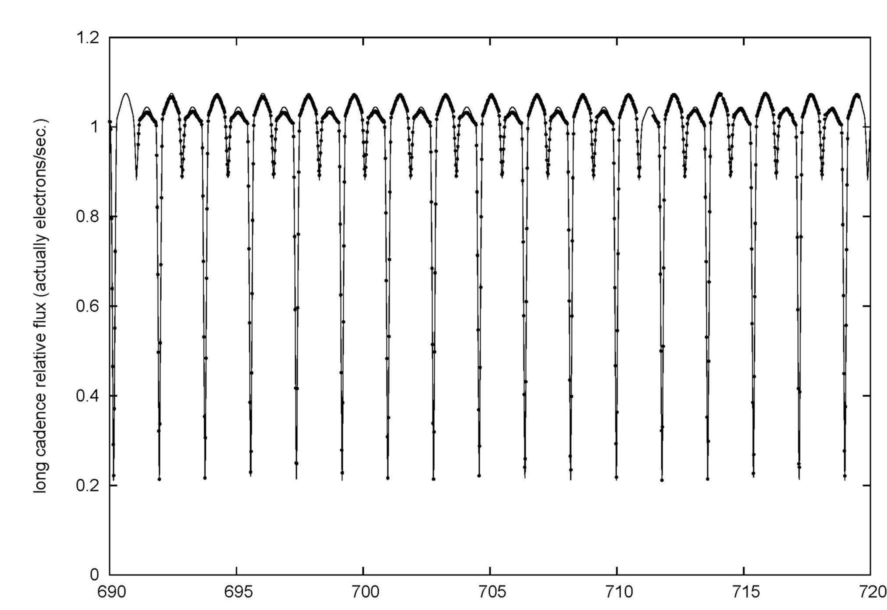

Fig. 4 - A fit to a thirty day stretch of the LC light curve observed during the latter part of Q7 when the proposed hot spot was prominent. During this epoch the spot migrated from a sub-photospheric phase of 0.25 to 0.15.The observations are given by the filled circles. The theoretical light curve is represented by the solid line.

Table 2
Model Parameters for WX Dra *

Semimajor axis: 7.9 Rsun
Inclination: 88.25 deg
Spot temperature: 18,000 K
Spot longitude: 4.7 - 5.4 radians

	A8 V star	K0 IV star
Photospheric Temperature:	7800 K	5140 K
Rpole/a:	0.22	0.20
Rside/a:	0.22	0.21
Rback/a:	0.22	0.24

* Assuming the L/T variability is caused by a hot accretion spot

Table 1
Program Systems

Star	KIC No.	Period (d) †	Spectral Types †	Kepler Mag
BR Cyg	9899416	1.33259	A3 V + G IV:	10.028
WX Dra	10581918	1.8020	A8 V + K0 IV:	12.796
UZ Lyr	2708156	1.8913	B9V + G-K1 IV:	10.672
V995 Cyg	9602595	3.5565	B8: + G6 IV	11.882
V461 Lyr	6205460	3.7217	A2 V: + K3 IV	12.746
V810 Cyg	5294739	3.7363	A0 V: + G6 IV	13.931
V850 Cyg	10206340	4.5645	A-B? + ?	11.246
V2277 Cyg	8552540	1.06		10.300
HD 180757	7599132	1.30	B8.5V +G:	9.393
V1580 Cyg	9101279	1.8114	A0 + G4IV:	13.900

† From the catalogs of Budding et al. [2] and Malkov et al. [8] .

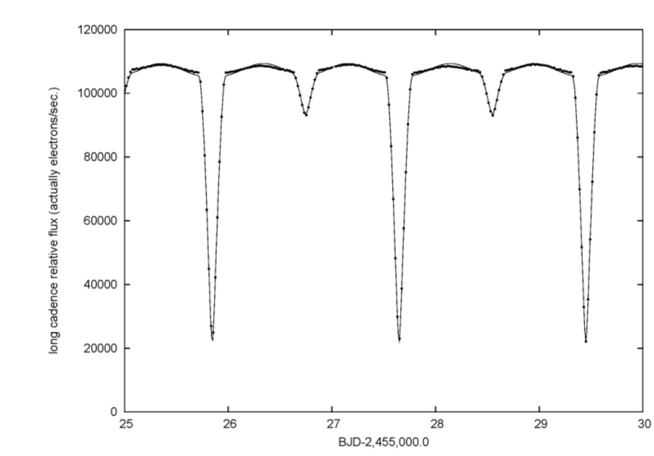

Fig. 5 - A fit to a section of the light curve during Q2 when L ≈ T reveals that the computed quadrature light curvature (for a Roche lobe-filling secondary) is too steep. The theoretical light curve is represented by the solid line.

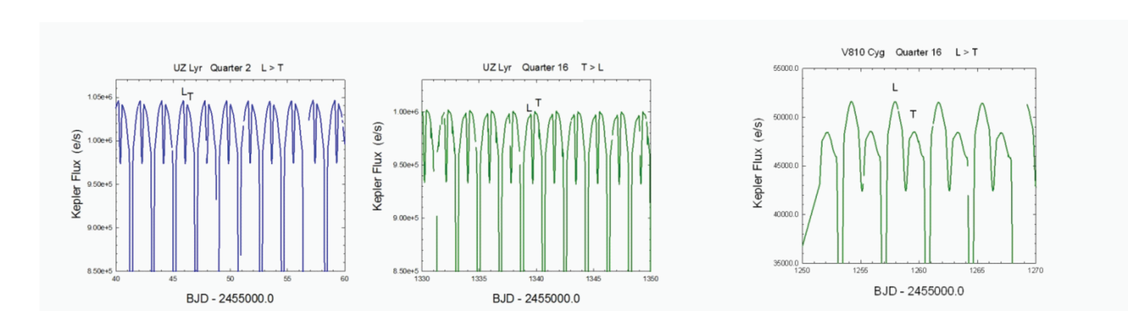

Fig. 6 - Examples of systems where the L/T effect is subtle or prominent.

6. Concluding Remarks

The L/T phenomenon is complex. In WX Dra we see evidence for both quadrature flux enhancement and flux deficiency. Hot spots must be on the primary as they would be generated from accretion heating as a result of an impacting gas stream. Cool spots would be magnetic regions on the secondary. If the hot spot interpretation is correct, the L/T behavior suggests that the spot jumps in longitude on the primary. It does not appear to uniformly migrate.In both hot and cool spot scenarios magnetic fields must play a role in the activity. The dramatic behavior seen in Q7-8 argues for the presence of a hot accretion spot on the leading hemisphere accompanied by a cool region on the secondary. There are times in which only a flux enhancement on the trailing hemisphere is observed (Q12). This is suggests classical impact heating. The L/T phenomenon is recurrent in WX Dra. Short-lived (~ 1 month), mild L/T events are frequently seen but major ones occur every 1-2 years. The visibility of the event varies, but it can be as large as 3% of the mean quadrature flux. We have now identified 21 systems that show the L/T phenomenon to some extent. The effect can either be mild or dramatic (Fig. 6). Analysis of WX Dra and the nine other system listed in Table 1 is continuing. Only when we have the results from the light curve fits to all ten binaries will we be able to say whether the L/T variability is a hot or cool spot phenomenon or both.

References

[1] Pigulski A. et al. 2009, http://www.astrouw.edu.pl/asas/ ?page=kepler
[2] Budding E. et al. 2004, A&A, 417, 263-268
[3] Wilson R. E. 1979, ApJ, 234, 1054-1066
[4] Wilson R. E. 1990, ApJ, 356, 613-622
[5] Wilson R. E. 2008, ApJ, 672, 575-589
[6] Wilson, R. E. 2012, AJ, 144, 73 (9pp)
[7] Wilson R. E. & Devinney E. J. (1971) ApJ, 166, 605-619
[8] Malkov, et al. 2006, A&A, 446, 785

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