No Longer Eclipsing—The Strange Case of RS Crateris

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Abstract For decades mistakenly classified as a solar (spectral class G0) Algol-type eclipsing binary with 0.7-magnitude amplitude, RS Crt is now listed as constant at V magnitude 10.62 in the AAVSO's International Variable Star Index (VSX). The author's 2020 differential photometry supports this reclassification, showing RS Crt to be constant (with 0.042 V mag. scatter). Investigating when its light variation ceased, the author analyzes data (including his own) from several observers obtained between 1972 and 1995 and concludes none show periodic variation. Citing the poor quality of the 1930–1944 data upon which its previous classification was based, one could argue RS Crt never was an eclipsing binary. Finding eight new minima (from 1929 to 1948) in the digitized Harvard Plate Collection/DASCH—and deriving a period of 0.8272 day that fits the early data better than the older period of 0.8168 day—the author seemingly refutes that contention. Four additional minima (from 1964 to 1971) gleaned from the APPLAUSE archive strengthen his contentions including that the period drastically shortened before eclipses ceased. Confirming it quit eclipsing—and admitting it to a tiny, select group of objects—would require spectroscopic confirmation of its binary nature. If such much-needed future observation fails to show that, speculations—of its compact binary past with spiral death march ending with coalescence into a single object, or of a history marked by a collision with a high-speed interloper—might be strengthened. Despite its recent constant classification, TESS data show RS Crt varies with amplitude <0.01 magnitude in a roughly four-day periodic fashion. Study of the beats, overtones, and damping in this light curve might lead to portraying its past in terms of pulsations, not eclipses.

1. Introduction

1.1. RS Crt may be a very unusual object—what this paper tries to do

There are at least two reasons why RS Crt deserves attention. First, it may belong in the short list of eclipsing binary stars that have been firmly established as having quit eclipsing—along with objects like V907 Sco and HS Hya. Second, prior to having ceased exhibiting eclipses in the early 1970s, it appears that the orbital period of RS Crt decayed over two or three decades at a rate seldom, if ever, seen among compact eclipsing binary systems. Like another extraordinary object, V1309 Sco, had this "spiral death" march continued, it might have ended in a dramatic outburst. Apparently that never happened. What did happen is that the eclipses ceased.

Out of the huge (approaching 100,000?) number of catalogued eclipsing binaries, up until recently only six had been convincingly established to have stopped eclipsing: QX Cas, SV Cen, SV Gem, SS Lac, AY Mus, and V907 Sco (Guinan 2012). Recently HS Hya has been added to that list. For V907 Sco, Lacy *et al.* (1999) reported: "The earliest observations of the system in the year 1899 show eclipses; the eclipses stopped around 1918, started again around 1963, and stopped again in about 1986." As a recent paper (Zasche *et al.* 2023) notes—and strives to make sense of—its eclipses have started up again a bit sooner than expected. For HS Hya, Davenport *et al.* (2021) report: "With a total baseline of over 125 yr, this unique combination of data sets—from photographic plates to precision space-based photometry—allows us to trace the emergence and decay of eclipses from HS Hydrae.... Recent TESS observations...confirm that eclipses have ceased, ...we estimate they will begin again in 2195."

While these binaries' eclipses typically ceased gradually due to system orbital inclination changes caused by a third star—something conceivably at work for RS Crt—V1309 Sco's ended after catastrophic binary interactions as part of a "common envelope" evolution. This general process has been described (Pejcha *et al.* 2017) as "short-lived and poorly understood" with an outcome having "crucial implications for all stages of stellar evolution." Prior to its coalescing into a single object, V1309 Sco, over thousands of orbital cycles of decaying period, had a light curve that "gradually morphed from a double-hump profile (typical for contact binaries) to single-hump shape...." Chiefly based on visual estimates in 1944 that poorly determined five times of minima with large scatter, RS Crt was listed as having completely different Algol-type eclipses. Yet now, having a much more complete picture of its observational history, one can argue that linking RS Crt to V1390 Sco rather than Algol might help us better understand it.

This paper takes the limited observational data—from visual estimates, from old photographic plates, all with large uncertainties—and pushes them to the limit in making the case for the reality of the assertions in this section's initial paragraph. Few, if any, who read it completely will doubt that decades ago RS Crt ceased exhibiting periodic light variations in the 0.5-magnitude range. More readers will fail to be convinced that periodic light variations once seen were caused by eclipses; a few may even dispute that RS Crt's light output varied periodically at all, but instead attribute all reports to the contrary as in error. As for RS Crt's supposed dramatic period changes, this paper challenges those who don't accept the author's admittedly highly speculative sketch of this object's history over the last century to back up their skepticism by pointing to where the observational foundation simply won't support demands made on it and/or where the analysis breaks down.

1.2. RS Crt observational history

RS Crt was discovered in 1930 and initially observed by European and Soviet observers. On 36 photographic plates taken between March 1929 and April 1934, RS Crt stayed more or less constant at photographic magnitude 10.8, with typical plus or minus 0.2-magnitude uncertainty. But one taken on April 23, 1930, recorded it had seemingly dimmed to magnitude 11.5. This (singular?) observation of a 0.7-magnitude drop would be linked with RS Crt's eclipse amplitude for the next nine decades. Based on what was also reported with that first time of minimum (Sandig 1948), had skeptics prevailed from the start, this dimming might have been dismissed as being recorded on an old and worn plate.

Lange (1935) reported two times of minima and an amplitude of 0.4 magnitude. From 51 visual estimates made in 1944, V. P. Tsesevich (1947) determined three times of minima and reported an amplitude of 0.5 magnitude. This was noted in the University of Pennsylvania—later University of Florida—Eclipsing Binary (EB) Card Catalogue and subsequent editions of "A Finding List for Observers of Interacting Binary Stars" (Wood *et al.* 1980). There, along with noting that Tsesevich provided a light curve and Algol-type classification, RS Crt was said to vary from visual magnitude 10.0 to 10.5 with period of 0.8168 day, and six-hour long eclipses. In a later publication, Tsesevich (1954) provided two additional times of minima, also based on 1944 visual observations. Table 1 lists times of minima for RS Crt.

Table 1. Times of minima for RS Crt used to determine Equation 1.

Minimum No.	*TOM (JD)*	*Method*	*N*	*O–C (d)*	*Source*
1	2426090.336	pg	–6269.5	–0.1264	Sandig (1948)
2	2427842.25	vis	–4125	0.16	Lange (1935)
3	2427890.23	vis	–4066	–0.0512	Lange (1935)
4	2431211.35	vis	0	–0.04	Tsesevich (1954)
5	2431212.27	vis	1	0.0632	Tsesevich (1954)
6	2431252.2	vis	50	–0.03	Tsesevich (1954)
7	2431256.25	vis	55	–0.064	Tsesevich (1954)
8	2431266.19	vis	67	0.0744	Tsesevich (1954)

The 0.8168-day period was most likely a provisional value derived from times of minima. Combined with some initial epoch, the period goes into an equation for computing times of minima for future eclipses:

$$\text{JD TOM} = 2431211.39 + 0.8168\ N, \qquad (1)$$

where N = number of eclipse cycle. The period can be refined using such an equation to compute time of eclipse, and O–C, the observed time of minimum minus the computed time. The fifth column in Table 1 provides these. They can be plotted vs. number N of eclipse cycle as in Figure 1, along with the line defined by Equation 1. The distance above or below the line provides a measure of how good the period is. (Note: the plot also includes a point for the mathematically determined initial epoch.)

The first minimum listed in Table 1 only fits nicely into the Figure 1 plot if it is assumed to have a one-half whole number N (= –6269.5) commonly associated with a secondary minimum—even though its associated amplitude (0.7-magnitude drop) is the greatest of the eight. Accepting this implies RS Crt exhibited noticeable brightness changes not every 0.8168 day = about twenty hours, but every ten hours. That, combined with the roughly six-hour eclipse duration—apparently from Tsesevich's light curve—implies that much of the time RS Crt will not be at maximum brightness. It is very difficult to reconcile that with Sandig's report that RS Crt was constant on 36 of 37 plates in the 1929 to 1934 era.

V. P. Tsesevich was born in 1907 and died in 1983. According to Nikolai Samus, the man in charge of recent editions of the *General Catalogue of Variable Stars* (GCVS), Tsesevich was "a famous man" in the top tier of renown amongst Russian variable star observers (Samus 2007). One suspects Tsesevich was responsible for the characterization of RS Crt in the third (1968) edition of the GCVS. Photometrically it listed RS Crt as an Algol type eclipsing binary, with primary amplitude 0.7 magnitude, and eclipses lasting six hours. Astrometrically, the position it provided was believed accurate to better than 1 second in R.A., and 0.1 arc minute in Dec. Spectroscopically, RS Crt was assigned spectral class G0. We now know the information in all three areas was wrong to some extent.

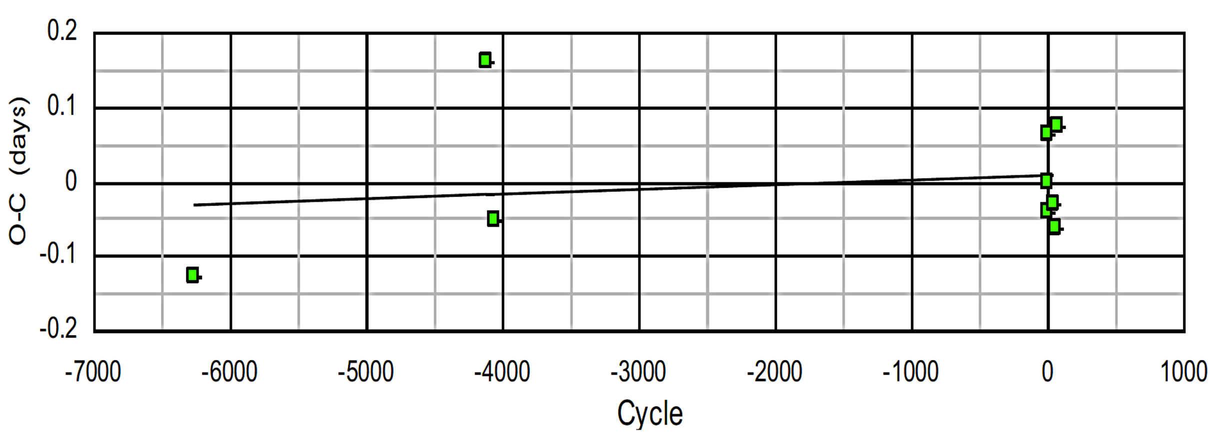

Figure 1. Observed minus Computed (O–C) diagram for RS Crt (from Nelson 2016).

Early on, RS Crt's reported six-hour eclipse duration, representing 30% of its 20-hour = (0.8168 day) period, should have raised suspicions as being too long for an Algol-type eclipser. Algol itself has an eclipse duration that is 14% of its period. Back then, V Crt—another eclipsing star with a short (0.7020 day) period, and 0.6-magnitude amplitude—was similarly listed as having five-hour eclipses. (Decades later that was revised to three hours.)

By the 1970s observers began reporting they were not seeing eclipses. Based on three nights of observing in 1972–1973, DuMont (Popper and DuMont 1977) reported it as constant at 10.67 V magnitude (with 0.01 error) and having B–V = +0.54. In March 1976, Swiss visual observer Kurt Locher (Locher 1976) reported: "The results of my survey at all phases during the past 13 months show [constant magnitude and]…estimated brightnesses scatter (RMS) less than [0.1 magnitude]." Locher used two comparison stars differing by 0.8 magnitude in brightness—the brighter one most likely GSC 005520-00393. Over a decade later, then-AAVSO Eclipsing Binary Committee Chair Marvin Baldwin likewise made visual observations of RS Crt. Unfortunately, no record exists of the comparison stars he used. After devising his own step sequence, he made 151 observations on thirty-six nights between March 1987 and May 1988—with variation ranging from a brightest of 27 on his scale to faintest of 46. His data can be found in the AAVSO International Database (AID; Kloppenborg 2023). Baldwin told the author 0.03 magnitude might be a good estimate for the value of each of these steps. Despite large scatter—discussed in section 5— no evidence for eclipses was found.

The 1990s brought spectroscopic data that challenged RS Crt's previous classification (based on low-resolution objective prism spectra) as a solar-type, spectral class G0 star. After getting three high-resolution spectra of it at Lick Observatory, in 1996 Dan Popper both reclassified it (based on sodium D lines) as a late F (F5—F8) star and, based on its narrow lines, ruled out its published short period (Popper 1996). His three spectra showed no variation in radial velocity—the current accepted value (Gaia Collab. *et al.* (DR2) 2016, 2018) is –3.66 km/sec ± 0.40.

Astrometrically, in 2004 Shawn Dvorak noted that the (2000 epoch) position of RS Crt in the 1968 GCVS (Kukarkin and Parenago 1968) as R.A. $11^h 49^m 06^s$, Dec. –10° 37' 12" was slightly off; more accurately it is R.A. 11h 49m 03.13s, Dec. –10° 37' 14.9" (Dvorak 2004). Note that the GCVS editors admit that R.A. "error may reach + or – 3 sec" (Kholopov 1985). Finally, in 2020, based on Gaia space observatory data gathered in the 2014–2017 era, a highly accurate parallax for RS Crt of 5.8463 milliarcsec ± 0.0268 was published (Gaia Collab. *et al.* (DR3) 2022,) along with proper motion data: –25.429 milliarcsec/yr in R.A., and 0.428 milliarcsec/yr in Dec. (Its parallax tells us that RS Crt is 171 parsecs distant.)

Despite all of these observations—astrometric, photometric, spectral, and radial velocity data—there are insufficient data to say with 100% certainty that it's not a member of a binary star system.

2. The author's work on RS Crt—observations and data mining

2.1. Photometry

The author first observed RS Crt on two nights in 1995 using an ST6 CCD imager attached to a small (50-mm diameter) wide-angle lens. Fifteen data points—put together from 42 images obtained on two nights in April 1995—showed roughly constant V magnitude of 10.65 with no variation beyond 0.082 mag. (standard deviation-based) scatter. The comparison "star" used was actually an average of stars A and B in Table 2. See the AID for these observations. Although he failed to see the eclipse predicted by Equation 1, given poor signal/noise ratio for this nearly 11th-magnitude object, he decided a more capable system was needed.

Table 2. Comparison stars used for the author's differential CCD photometry of RS Crt.

Star	*GSC No.*	*R.A. (2000)* *h m s*	*Dec. (2000)* *° ′ ″*	*V Mag.* *Tycho 2*	*V Mag.* *APASS DR3*	*B–V*
A	5520–0303	11 47 19	–10 45 57	10.075	9.998	+0.655
B	5520–0628	11 48 32.40	–10 43 06	10.383	10.361	+0.41
C	5520–0393	11 48 42.30	–10 32 39	10.818	10.589	+1.11

He next observed RS Crt in 2020 using a better system—though hardly state of the art! With the ST6 CCD now attached to a 130-mm f/5 reflector, photons are still under-sampled, although not as badly. Given this, and with less than perfect tracking, experience suggests that flat fielding does not noticeably improve differential photometry results (in which variable star magnitudes are obtained by subtracting instrumental variable (VAR) and comparison (COMP) magnitudes, then adding the result to an assumed catalog-based comparison star magnitude). To compensate for not taking flats, he averages many images to produce individual (normal) data points—reduced with SBIG CCDOPS software and custom spreadsheet, which computes uncertainties.

With this setup the author observed RS Crt on 13 nights between May 8 and June 15, 2020, getting 198 data points distilled from 720 V filter images, each with typical 15-second exposures. This time the comparison "star" used was an average of stars B and C in Table 2; again, see the AID for these observations. This differential (comparison star magnitude-dependent) photometry showed RS Crt to be constant at 10.582 V-magnitude with 0.042 V-mag. scatter. Note that this is somewhat brighter than the 1995 value. While averaging the 1995 and 2020 V magnitudes for RS Crt gives a value of 10.62 V magnitude, the differences between them are believed due to different comparison stars used. This is in line with the (absolute photometry) APASS DR3 listed value for RS Crt as 10.622 V magnitude with mean error 0.0482 V mag, and a Tycho Catalogue listed value of 10.625 V magnitude with mean error 0.060 V mag.

2.2. Data mining—DASCH

Software associated with the digitized Harvard Plate Collection (DASCH) project (Grindlay *et al.* 2009; Tang *et al.* 2013; Harvard Coll. Obs. 2022) was used to produce the light

Table 3. Additional times of possible minima for RS Crt from DASCH and APPLAUSE archives.

No.	Harvard Plate No. or APPLAUSE	Time of min JD Heliocentric Time	Min. RS Crt Mag.	Limiting Plate Mag.	Status
1	ai33793	28926.7702	11.80	12.37	Accept
2	ai38813	31200.6701	11.86	12.66	Reject
3	rh00931	25633.8588	11.49	12.82	Accept
4	ac28893	26341.9434	11.48	12.25	Accept
5	ac29159	26443.645	11.44	11.98	Accept
6	am17421	28245.4711	11.38	14.2	Accept
7	ai33850	28956.8107	11.39	13.82	Accept
8	bio1188	31170.5525	11.43	12.37	Accept
9	ai41592	32648.612	11.44	13.02	Accept
10	APPLAUSE	38500.9619	11.69	?	Accept
11	APPLAUSE	38551.0180	11.49	?	Accept
12	APPLAUSE	39210.3356	11.40	?	Accept
13	APPLAUSE	41039.3586	11.58	?	Accept

curve of RS Crt shown in Figure 2 spanning years 1900 to 1990 (with a 1955–1975 gap when no plates were taken). While the coverage seems adequate, finding real minima is a challenge for several reasons—magnitude measurement uncertainties, lengthy exposures (some exceed two hours!), occasional plate defects, weird star image shapes, etc. Some seeming minima may actually be outliers more associated with noise/statistical fluctuations (low probability coincidences expected in three sigma level statistical terms) than actual periodic eclipse variation. Shorter plate exposures have brighter limiting magnitudes and decreased signal to noise, leading to concerns about DASCH's ability to flag all the data points that it needs to.

To illustrate this, consider the two most obvious minima in Figure 2, from 1938 and 1944, #1 and #2 in Table 3. Both are consistent with Equation 1: #1 plots close to a best fit line in an O–C plot (with O–C = –0.0302 day); #2 a bit below (O–C = –0.1015 day.) Discussion with LSU professor Brad Schafer, a top expert in using Harvard plates in both glass plate and digitized (DASCH) forms, convinced the author that #2 (from plate ai38813) should be rejected. Given its bright, jagged elongated blob—not fainter, nicely circular stellar image—it's most likely due to a plate defect. But Schafer sees RS Crt on plate ai33793 as looking brighter than DASCH measured. Given his own experience with stars on CCD images occasionally looking brighter than they are measured, the author trusted the measurement and kept minimum #1 in Table 3.

2.3. Data mining—APPLAUSE

The Archives of Photographic PLates for Astronomical USE (APPLAUSE; Groote *et al.* 2014) yielded the 115 data points shown in Table 4 for the 1964–1974 era—and four minima listed in Table 3. The seemingly deepest one (#10) from 1964, considering comparison star magnitudes, may not actually be quite as deep as 1966 and 1971 minima. But since it is part of seven images spanning over three hours that show descent, faintest, slight recovery, then nearly as faint again, before ending brighter than in the first image, it is the most interesting. They suggest a four-hour or so eclipse duration—certainly more believable than six—and possibly a surrounding envelope?

3. Hypothesis testing and discussion: was RS Crt once an eclipsing binary star system?

3.1. No (skepticism), and yes (rebuttal)

The O–C diagram shown in Figure 1 hardly inspires confidence: its 0.03 Pearson R^2 correlation coefficient is just above random chance level! The point for minimum #1 in Table 1, much below the best-fit line, is supposedly for a secondary minimum (the only one plotted) observed in 1930.

More basically, is the Figure 2 light curve believable for RS Crt as an eclipsing binary as listed? To decide, we compare it with similar DASCH-derived light curves for two other nearby objects: 1) in Figure 3 for V Crt, an eclipsing binary with similar period and amplitude as RS Crt may have once had, and 2) in Figure 4 for the (supposedly) constant comparison star B (GSC5520-0628) from Table 2. While showing a bit more variation than this comparison star, the RS Crt light curve may look more like that of comparison star B than it resembles that of V Crt.

If RS Crt was once eclipsing per its catalog listing this is not what one would expect, but can it nonetheless be explained in eclipsing variable terms? Yes, for two reasons. First, V Crt, at the DASCH reported average magnitude 10.72, is brighter than RS Crt, with its similarly reported 11.18 average magnitude. Thus it's more likely that more minima of RS Crt were flagged by DASCH—something it does if the measured magnitude is not at least 0.5 magnitude brighter than the limiting plate magnitude. Second, and more importantly, one can hypothesize that RS Crt's eclipses were shallower than V Crt's. What if RS Crt eclipses were typically just 0.4 magnitude or less in amplitude, as reported for the pair observed in 1934? If that were so, in looking at its light curve, many such eclipses would be lost in "noise," whereas the deeper 0.6-magnitude eclipses of V Crt would rise up out of it.

The author did not think the above argument was strong until he started finding such shallow minima for RS Crt. Using Figure 2 and DASCH, he identified seven TOM for RS Crt between 1929 and 1948 corresponding to not so deep drops in its brightness. Whereas the minima listed in Table 1 are believed to correspond to 0.4- to 0.7-magnitude brightness drops, these seven additional DASCH/Harvard plates TOM (#3 through #9 in Table 3) correspond to magnitudes 0.20 to 0.31 fainter than the 11.18 average magnitude DASCH gives RS Crt in Figure 2.

3.2. Refining the period and eclipse predictions as in Equation 1

Returning to the problems with Figure 1, we ask whether an O–C diagram can be constructed with a better fitting regression line without assuming any of the TOM used are for secondary minima? Yes. In fact, Equation 2, with a slightly longer period, can do this:

$$\text{JD TOM} = 2428926.77 + 0.8272\,N, \tag{2}$$

where N = number of eclipse cycle. But can all of the 20 acceptable minima from both Table 1 and Table 3 be used in doing this with a single diagram based on a single equation like Equation 2? Alas, no, as we shall see. Referring to Table 5, note that the Equation 2 period of 0.8272 day does a better job

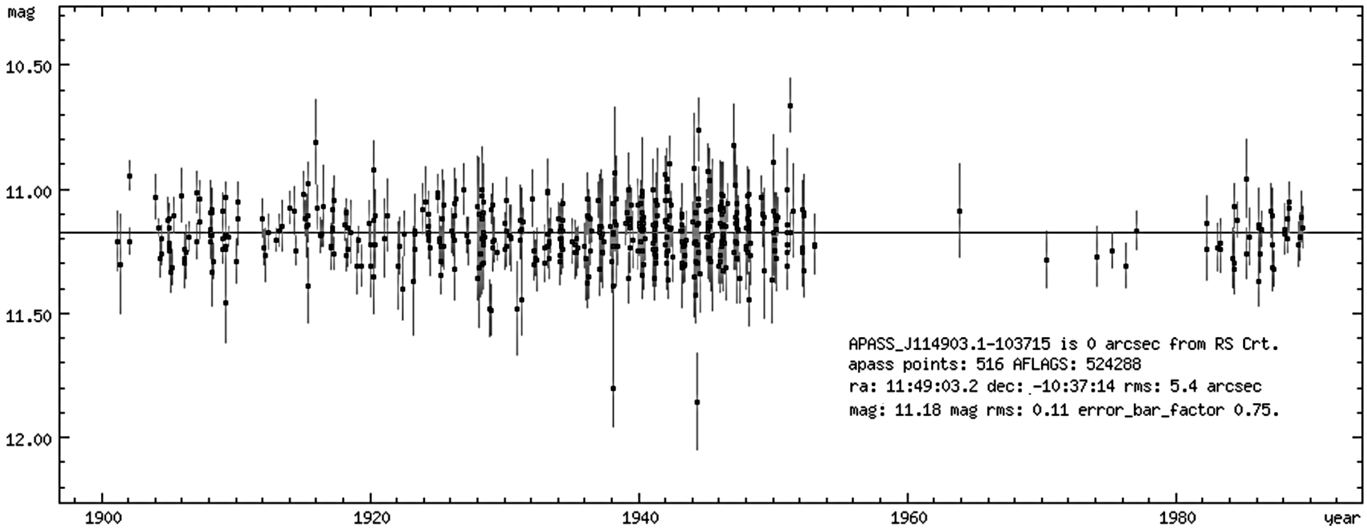

Figure 2. Light curve of RS Crt extracted from Harvard Plate Collection (DASCH project).

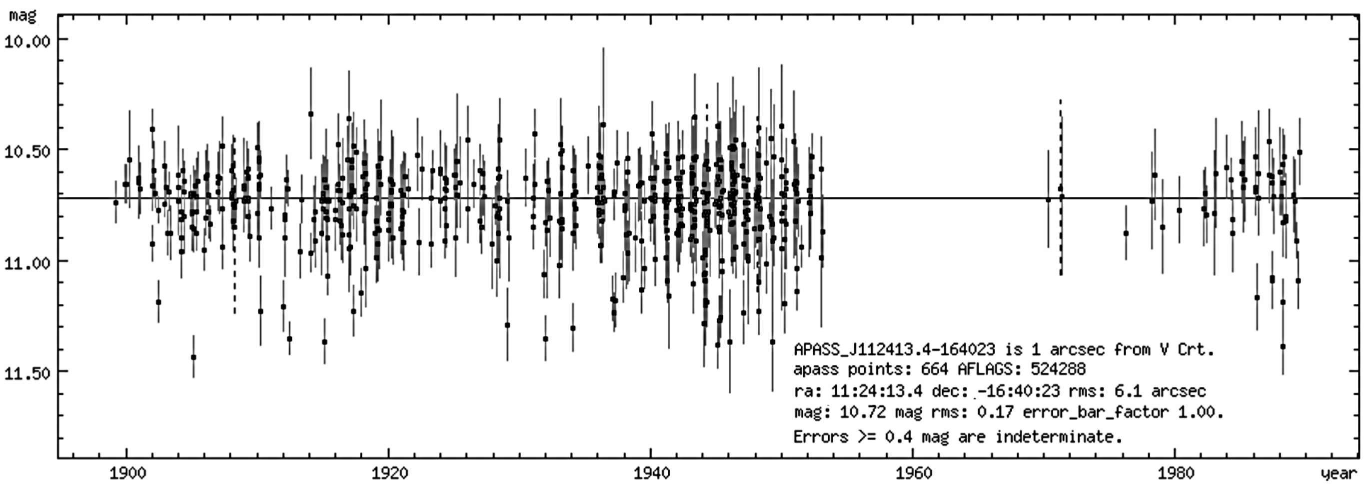

Figure 3. Light curve of V Crt extracted from Harvard Plate Collection (DASCH).

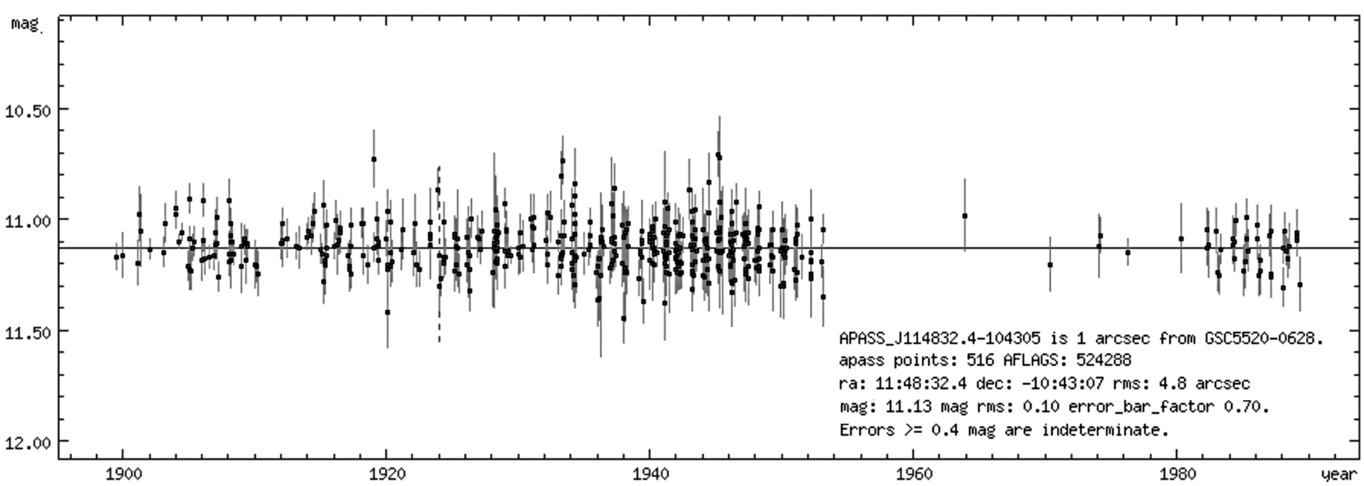

Figure 4. Light curve of GSC5520-0628 extracted from Harvard Plate Collection (DASCH).

Table 4. 1964–1974-era APPLAUSE photometry of RS Crt.

JD 2400000+	B mag.	JD 2400000+	B mag.
38498.0727	11.0095	38902.4118	11.2318
38499.0664	11.0100	38904.3910	11.2025
38500.0664	11.0963	38905.4132	11.1821
38500.9383	11.5103	38906.4119	11.2132
38500.9619	11.6994	38911.3557	11.0241
38500.9835	11.1769	38913.3536	11.1069
38501.0051	11.2870	38914.3536	11.0805
38501.0274	11.4316	38915.3530	11.1065
38501.0489	11.3095	38916.3523	11.2164
38501.0656	11.0591	39173.4803	10.9884
38501.0705	11.0827	39179.4672	11.2116
38502.0677	11.2121	39181.4311	11.2603
38503.0697	11.1203	39200.3890	11.1268
38504.0704	11.1952	39202.3869	11.1628
38505.0745	11.1896	39209.3696	11.1304
38517.0491	11.3021	39210.3356	11.3999
38518.0539	11.1134	39230.2928	11.3556
38519.0511	11.1066	39232.2540	11.1965
38520.0518	11.1131	39233.2505	11.1872
38521.0531	11.1626	39235.2450	11.1289
38524.0621	11.3653	39236.2484	11.1968
38525.0599	11.4508	39237.2436	11.2477
38529.0654	11.1944	39240.2443	11.0603
38530.0667	11.0855	39259.1765	11.1744
38546.0509	11.2927	39261.1828	11.2714
38547.0529	11.3517	39265.1731	11.1336
38548.0104	11.0143	39268.1620	11.0037
38549.0125	11.2051	39269.1405	11.2927
38551.0180	11.4892	41033.3516	11.1357
38553.0207	11.2989	41037.3496	11.4414
38554.0228	11.1432	41039.3586	11.5760
38555.0248	11.2041	41394.6999	11.1764
38556.0269	11.2473	41397.2996	11.2390
38557.0289	11.3925	41415.6247	11.1891
38560.0351	11.3081	41420.6607	11.2571
38561.0385	11.0855	41444.6529	11.2038
38562.0427	11.1702	41448.6368	11.2036
38796.7876	11.3160	41470.6360	11.3389
38797.7821	10.9240	41472.6311	11.3026
38816.6796	11.2036	41726.3436	11.1192
38817.7053	11.1995	41727.3464	11.0842
38818.7025	11.1715	41746.2799	11.0646
38820.7004	11.1463	41749.2675	10.9721
38822.6970	11.2075	41753.2453	11.0521
38825.6561	11.0939	41754.2335	11.0114
38855.5522	11.0418	41775.1740	11.0862
38872.4983	11.0838	41803.0709	10.9891
38877.4844	11.1928	41827.9844	11.0373
38878.4810	11.0397	41990.6256	11.2097
38879.4789	11.0644	41990.6362	11.1117
38879.4789	11.0420	42127.9588	11.1229
38880.4900	11.3171	42129.9158	11.2218
38881.4935	11.2542	42130.9435	11.1266
38883.4824	11.2001	42134.9352	11.1840
38884.4790	11.0109	42135.9165	11.0691
38885.4776	11.0261	42155.8612	11.1403
38887.4727	11.1112	42188.7401	11.2203
38901.4118	11.0134		

of representing Table 3 minima #3 through #9 (and predicting times of minima) than the 0.8168-day period of Equation 1 does.

3.3. Weighing evidence for and against RS Crt once being an eclipsing star

Without carefully studying the predictions in Table 5, one might conclude "RS Crt never was an eclipsing variable," based on comparison of its light curve with those of V Crt and the supposedly constant nearby comparison star. Also, based on spectroscopic evidence: 1) RS Crt has not been observed to have a spectrum with double lines that Doppler shift with orbital motion—either because, if double, the bright star hides the fainter star's spectral lines, or because it is not binary; and 2) Popper's three high-resolution spectra indicated a constant radial velocity, not what you'd expect for an eclipsing binary. Unfortunately, dates/times of those spectra were not reported, but unless they were taken at an unlikely sequence of orbital phases, they argue RS Crt is not part of a binary system.

Table 5 suggests a different conclusion. Its first prediction, using the 0.8272-day period, is a mere 0.0014 days = 2 minutes off predicting an event occurring two years (actually 708 days) later. Noting that other predictions based on that period (#3, #5, and #7 in Table 5) are respectably accurate to within 60 to 75 minutes, we conclude a 0.8272-day period works for 1929 to 1938 minima.

4. Data that challenge constant period models: a large period change for RS Crt?

Alas, the longer period model Equation 2 cannot adequately represent all of the acceptable minima presented in both Table 1 and Table 3. For starters those minima span 42 years or roughly 18,000 cycles of 0.8272-day eclipses. With only four significant figures, predictions made using it just 1000 cycles in the future incur a 1000 × 0.0001 = 0.1-day uncertainty, so more accurate period determinations would be nice, if possible. Limiting the time span over which the period is to be used mitigates the lacking in significant figures uncertainty. Doing this with minima from 1929 to 1938, using the 0.8272-day period creates the O–C diagram shown in Figure 5.

We attempt similarly to create another O–C diagram using just minima from 1938 to 1948, but face two challenges. First, the last five minima from Table 1 present problems—beginning with the strange 0.92-day interval between the N = 0 and N = 1 consecutive eclipses. Before attributing this to a possible light curve anomaly, the author assumed a period double that of 0.8272 day—1.6544 days—and postulated an observable secondary eclipse that was offset from the 0.5 phase. No good—one of the assumed secondary minima refused to fit. Instead, in creating Figure 6, minima #4 and #5 in Table 1 have been replaced by the Equation 1 initial epoch.

Second, trying to reconcile that 1944 initial epoch with the 1948 minimum (#9 in Table 3) presents another problem. As results presented in the last two rows in Table 5 show, using the longer 0.8272-day period requires invoking that the distant minimum observed almost four years later must be a secondary minimum, given the N = 1737.5 cycles elapsed since the initial 1944 epoch. This contradicts postulating RS Crt has

Table 5. Predicted RS Crt TOM Using 0.08272-, 0.8168-, or 0.8166-day periods.

No.	*TOM Being Predicted*	*TOM Used Initial Epoch*	*Time elapsed from Initial Epoch (d)*	*Period (d) used in Making Prediction*	*N (cycles)*	*O–C (d)*
1	#4 in Table 3	#3 in Table 3	708.0846	0.8272	856	0.0014
2	#4 in Table 3	#3 in Table 3	708.0846	0.8168	867	–0.081
3	#5 in Table 3	#3 in Table 3	809.7862	0.8272	979	–0.0426
4	#5 in Table 3	#3 in Table 3	809.7862	0.8168	991	0.3374
5	#5 in Table 3	#4 in Table 3	101.7016	0.8272	123	–0.044
6	#5 in Table 3	#4 in Table 3	101.7016	0.8168	125	–0.3984
7	#7 in Table 3	#6 in Table 3	711.3396	0.8272	860	–0.0524
8	#7 in Table 3	#6 in Table 3	711.3396	0.8168	871	–0.0932
9	Eq 1 init epoch	#8 in Table 3	40.8375	0.8168	50	–0.0025
10	#9 in Table 3	Eq 1 init epoch	1437.22	0.8272	1737.5	–0.018
11	#9 in Table 3	Eq 1 init epoch	1437.22	0.8166	1760	0.004

Note: Eq 1 Init Epoch" refers to what is used as a representative average of the last five minima in Table 1 (given their very large scatter).

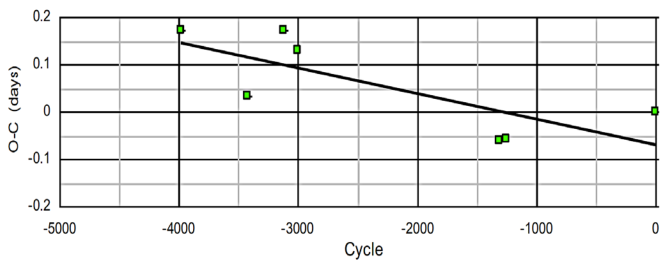

Figure 5. O–C Diagram for 1929–1938 data using period of 0.8272 day. R^2 = 0.59 points are for minima # 1, #2, and #3 in Table 1, and minima #1, #3, #4, and #5 in Table 3, with minimum #1 in Table 3 serving as the initial epoch.

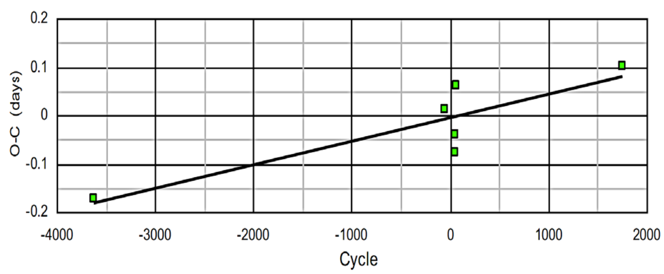

Figure 6. O–C Diagram for 1938–1948 data using period of 0.81701 day. R^2 = 0.76 points are for minima #6, #7, and #8 in Table 1, and minima #6, #8, and #9 in Table 3. Notes: minima #4 and #5 in Table 1 have been replaced by initial epoch from Equation 1; and minimum #7 in Table 3 would not fit—conceivably the mid-point of ai33850 was too far from minimum.

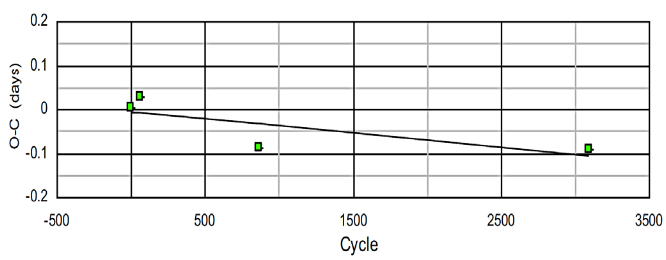

Figure 7. O–C Diagram for 1964–1971 data using period of 0.82019 day. R^2 = 0.59 points are for minima #10, #11, #12, and #13 in Table 3.

no observable secondary minimum. With an eclipse at N = 1737 the O–C is a big 0.3756 day; likewise with N = 1738 the O–C is –0.4516 day.

What to do—try a shorter period—is suggested by the results of prediction #9 in Table 5. There, starting with minimum #8 in Table 3, the 1944 initial epoch is nicely represented 50 cycles later (with an error of but –0.0025 day = 3.5 minutes) using the 0.8168-day period. If the period really shortens between 1929 and 1944, from 0.8272 to 0.8168 day, extrapolating a still shorter period in going forward from 1944 seems reasonable. In jumping ahead roughly four more years, that is, in predicting a minimum for 1948 (prediction #11 in Table 5), we note a shorter period of 0.8166 day works: it's accurate to 0.004 days = 5.6 minutes. Over the whole 1938–1948 time span, the best fit line in Figure 6 indicates that a period of 0.81701 works best.

What about the eclipse minima after 1948? APPLAUSE data (Table #4) seemingly capture four of them: #10, #11, #12, and #13 in Table #3, from 1964, 1964, 1966, and 1971, respectively. If the decreasing period change documented so far continues, we expect needing a still shorter period to represent 1948—1971 RS Crt TOM data. But alas, it seems the period decline has halted! That the linear fit captured in the Figure 7 O–C diagram for 1964–1971 works best for a 0.82019-day period supports that conclusion. (Note: with only four data points multiple solutions exist. One has 0.8071-day period, seemingly acceptable, but given its lower R^2 = 0.31—and the DFT periodicity search results of the next section—the longer 0.82019-day period is preferred.)

5. RS Crt eclipses cease around 1973?: searching for periodicity 1964–2023

A discrete Fourier transform (DFT) based-method (Belserene 1988) for searching for periodicity in time series photometric observations can be applied to the 1964–1973 APPLAUSE data for RS Crt in Table 4, parsing it in one-year (1964), two-year (1965–1966), and two-year (1972–1973) groups for three computer program runs. Table 6 provides details. Associated with the results of the second and especially the third of those three runs, where a limited number of data points are spread over two years with a big seasonal gap, is larger uncertainty than with the first run (with 1964 data). In all

Table 6. Evidence documenting large period decrease for RS Crt 1929–1973.

Time Interval	Source of the supporting evidence leading to period	Period (d)
1929–1938	O–C Diagram / Figure 5 with 7 data points	0.8272
1938–1948	O–C Diagram / Figure 6 with 7 data points	0.81701
1964–1971	O–C Diagram / Figure 7 with 4 data points	0.82019
1964	DFT period search: 37 data points, strongest signals and relative strength: 0.8204 day @ 2.50; 4.17 day @ 2.13	0.8204
1965–1966	DFT period search: 49 data points, strongest signals and relative strength: 0.8148 day @ 3.31; 7.42 day @ 2.57; 2.00 day @ 2.52	0.8148
1972–1973	DFT period search: 19 data points, strongest signals and relative strength: 0.8028 day @ 3.56 3.15 day @ 2.18	0.8028

DFT program runs signals were sought that were associated with a wide range of possible periods, from 0.4 day to 10 days.

The run using 1964 data (fourth entry in Table 6) definitely had the best coverage with 37 data points spread over just 64 days, as can be deduced from Table 4 data. It found four signals of greater than relative strength 2.0; the strongest of these was at period = 0.8204 day, a result that fits nicely with the Figure 7 O–C diagram period.

The last entry in Table 6 is the last suggestion—and a not especially strong one—that eclipses of RS Crt might have lasted as late as 1973. The 1971 minimum—#13 in Table 3—is better evidence for an eclipse. Recall (from section 1) that Locher's 1975–1976 observations reported RS Crt as constant in brightness as far as visual estimates could detect.

While Baldwin's 1987–1988 151 visual data points and the author's 198 CCD data points of spring 2020 show no sign of eclipses, do they show any signs of periodicity? If so, for what period? To facilitate DFT analysis with Baldwin's data, his step values were converted to magnitudes assuming one step = 0.03 mag. The resulting standard-deviation based scatter is large—0.154 magnitude. One explanation for it: Baldwin was seeing real changes as the common envelope of stars in contact presented itself differently. Another involves possible use of an inappropriate comparison star. RR Lyr star X Crt, 11.1 to 11.75 V magnitude range, period 0.7328 day, is in the same one-half degree square field as RS Crt. There is no evidence Baldwin used it, but it represents a possible pitfall all observers of RS Crt must avoid. DFT analysis of his data provided no evidence in support of anything close to an 0.82-day period. Its strongest signals and relative strength were: 7.395 days with 20, 3.14 days with 10.9, and 4.037 days with 6.5.

Such analysis using the author's data offered no support for that 7.395-day period, and likewise provided no evidence of an 0.82-day period. Its strongest signals and relative strength were: 3.16 days with 12.1, 1.46 days with 11.2, and 1.298 days with 10.9. Other than being a product of the cadence of the observations, the author can offer no explanations for the significance of the periods associated with the strongest signals in these last two searches for periodicity.

6. An unprecedented period decrease for an eclipsing binary star; then what?

If the period of the RS Crt binary system really shortened from 0.8272 day (Figure 5) to 0.81701 day (Figure 6) in the 1929 to 1948 interval, would this be unprecedented behavior for an eclipsing binary? The answer: an extraordinarily unusual yes, but not totally unprecedented.

Over these two decades, RS Crt, one calculates from the data presented above, had an overall 1.2% decrease in its orbital period, declining at a rate of -5.1×10^{-4} day/year. The latter is 27 times greater than the largest rate of period decrease identified in a study of 14,127 contact eclipsing binaries (CEBs) based on the OGLE-III and IV observations in the Galactic bulge (Hong *et al.* 2022). Still, this rate is much slower (roughly only one fourth of) than the catastrophic period decay rate of V1309 Sco, another star also studied using OGLE survey data, based on 2001–2007 data. This binary system, with 1.4-days period, suffered a 1% period decrease in a seven-year period at a rate of 2.0×10^{-3} day/year (Pejcha *et al.* 2017). This rapid period decay resulted in a "spiral death" and luminous red nova or luminosity optical transient outburst. It is truly a special object, thought to represent "the only confirmed non-compact stellar merger" (Mason and Shore 2022).

Finally, if its period really recovered in the 1948–1971 era from 0.81701 day to 0.82019 day (Figure 7), its rate of period increase of $+1.6 \times 10^{-4}$ day/year again exceeds by a factor of 18 the highest rate among the CEBs the Hong *et al.* group studied. If true, one wonders what stopped RS Crt's orbital period decay?; and of course, why did the eclipses stop? Consider three possibilities.

First, the eclipses stopped because the inclination of the binary star orbital plane changed, possibly due to the gravitational force of a third star, such that it was no longer enough edge-on. The expected gradual transition would have resulted in shallower and shallower eclipses, then no variation. There are three problems with this: 1) the amplitudes of the best documented later eclipses in the 1964–1971 era appear to be as great as the best documented ones from the 1930s and 1940s; 2) this changing inclination scenario does not explain the large (> 1%) period changes documented above; and 3) most recent TESS observations show no signs of what should still be preserved if just inclination changed: a roughly 0.82-day period showing (outside of any eclipses) expected very slight ellipsoidal modulation in the photometric signal.

How does RS Crt look today? Is it strictly constant in brightness today, as its VSX listing suggests? The short answer is no, as the light curve in Figure 8—from TESS, the best recent source of photometric data available—shows. Admittedly the variations shown are tiny, in the peak-to-peak range of at most 0.01 magnitude, but look to be periodic (with signs of damping and beats?). The period is around 4.05 days—not anything like the expected 0.82 day from a supposed changing-inclination, eclipses-quit past for the object.

A second possibility as to why eclipses ceased—appealing to those who like the period decay spiral death scenario—

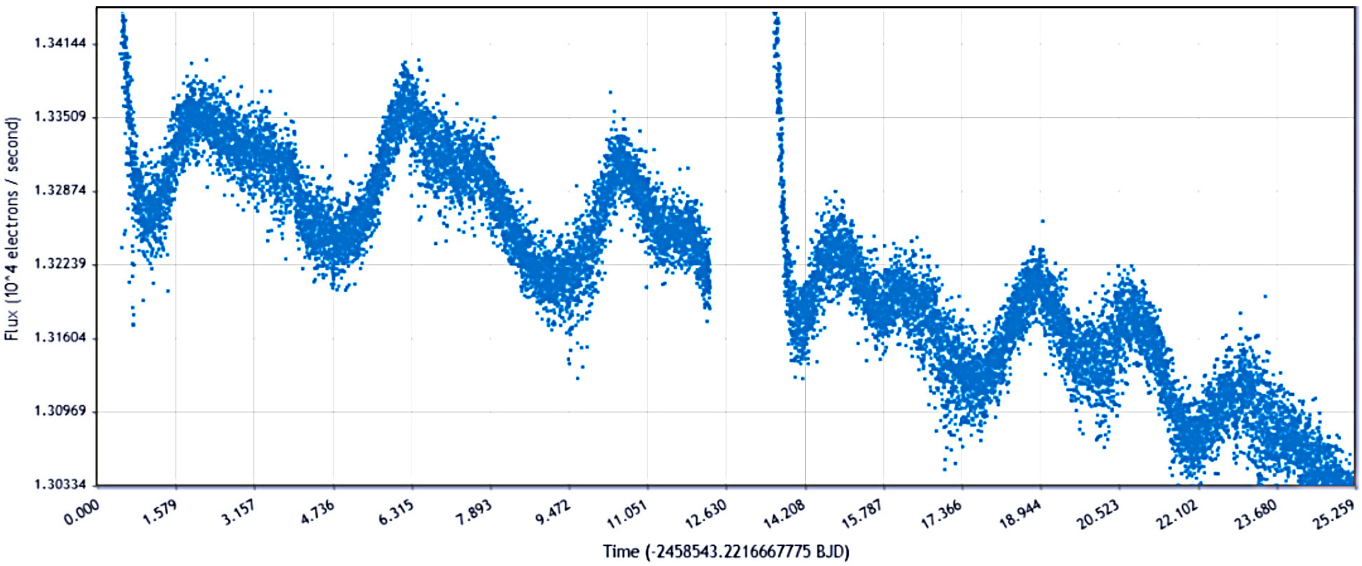

Figure 8. Recent light curve of RS Crt from TESS data.

is that the two stars in the system merged into a single object of some sort. Perhaps the observed four-day or so variation seen today is due to rotation of a common envelope that an increasingly close compact binary system evolved into after all the mass transfer/ejection and orbital angular/rotational angular momentum tradeoffs? Problems: if there was a stellar merger, why wasn't it accompanied by a dramatic, short-lived (several magnitudes) increase in luminosity as V1309 Sco exhibited? And, recall that evidence suggests the period decay stopped, suggesting no spiral death merger single object end product.

A third possibility as to why eclipses ceased: based on the previously cited astrometric discrepancy, RS Crt was jolted by a collision with some fast-moving object. The collision destroyed not only the geometric alignment producing the eclipses but also either dramatically changed (lengthened) the orbital period or destroyed the binary system altogether. Note: most likely the astrometric discrepancy is due to a long ago very poorly determined position.

7. Alternate explanation: RS Crt periodic light variation as pulsating, not eclipsing in origin

Many will find the above speculation unbelievable. Certainly, if future high-resolution spectra firmly establish RS Crt is not binary, then single star explanations including pulsating star, rotational variable, etc. may become more attractive.

7.1. A simple pulsating star model of RS Crt

Equation 1- and Equation 2-based models—instead of being associated with two periods used to predict times of eclipse minima—could be reinterpreted and used to predict a characteristic feature (minimum, maximum, inflection point, etc.) in the light curve of a pulsating star. Also, in conceiving of what was physically happening, instead of using periods, the emphasis would shift to pulsation mode frequencies. RS Crt's changing behavior and light curve might be explained in terms of the dynamic interplay of two fundamental pulsation modes.

7.2. Connecting RS Crt to real types of pulsating stars, and imagining pulsation ceases

Given its late F spectral type, one might speculate RS Crt was once a high amplitude δ Scuti (HADS) star that quit pulsating. Both its half magnitude amplitude and spectral type are at the extreme, but not implausible, edge of what is typical of HADS stars. A bigger problem is RS Crt's period of 0.82 day—it's much too long. The suggestion of a secondary minimum for it suggests the real pulsation period might have been one-half of that: around 0.4 day. This is still rather long, and more typical of RRa variables. But RS Crt's low luminosity, with its absolute visual magnitude of +4.45, disqualifies it from fitting into that category. Even if RS Crt were once pulsating, why its pulsation would so quickly—in the blink of an eye compared to typical stellar evolution time scales—diminish and cease is unknown.

8. A final mystery

DASCH-based Figure 2 suggests RS Crt wasn't doing anything unusual in 1916, just continuing to shine at around 11th (photographic) magnitude. Why then does the APPLAUSE archive contain seven data points from the early spring of that year—all from a 30 minute interval on a single night—that list it as 16th (B) magnitude? At the time in question, APPLAUSE records the magnitudes of (Table 2) nearby comparison stars as normal; and two data points from the early in 1919 again show it at 11th (B) magnitude. (These nine data points are the only ones in the APPLAUSE archive for RS Crt prior to 1948.) Was RS Crt really five magnitudes or 100 times fainter for a brief time in 1916?

9. Suggestions for future work

These are the observational priorities for RS Crt:

1) Obtaining high-resolution spectra to definitely establish whether or not RS Crt is a binary star is a top priority. If it is binary, these data could determine its orbital inclination.

2) If established to be binary, finer probing of the Harvard/DASCH, APPLAUSE, and other plate collections could help in more firmly characterizing RS Crt's eclipsing binary past and inform speculation and predictions as to the possibility of its eclipses resuming at some future date.

3) If binary, searching for a third star in the system, one responsible for changing inclination.

4) If not binary, investigating the nature of the variation suggested in Figure 8 might lead to modeling it as a pulsating star—once more active, now seeming in a quiet state. Investigation of this now barely-perceptible periodic light variation might point the way to understanding the much higher amplitude past periodic light variation this paper has documented.

10. Conclusion

As promised, the observational data have been pushed to the limit in conducting the analysis, which was in some way informed by all twenty of the acceptable minima recorded in Tables 1 and 3. Careful weighing of all data best supports the belief that RS Crt once showed a periodic light variation somewhere in the 0.3- to 0.6-magnitude range with a period around 0.82 day, and that not only can eclipses best account for that variation, but that the period of those eclipses changed, perhaps dramatically, before ceasing. This star definitely needs continuing attention—even if high-resolution time series spectroscopy establishes that it is now a single star.

11. Acknowledgements

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