POSSIBLE LARGE INTRINSIC VARIABILITY IN THE SHORT PERIOD ECLIPSING BINARY RS SCUTI

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Abstract

An intrinsic variation in the Beta Lyrae type eclipsing binary RS Sct is indicated, based on 82 visual estimates. Comparison of primary eclipse (composite) light curves obtained in 1984 and 1992 show this star 0.5 magnitude fainter in 1992. Critical re-examination of published magnitude ranges also suggests an intrinsic variation. As to its cause, starspot activity and the presence of a third body are considered. An O-C plot for 1909 - 1992 is analyzed, new ephemeris elements are derived, and no evidence of a third body is found.

1. Introduction

RS Sct was discovered by A. J. Cannon (Pickering 1907) from Harvard patrol plates. Ichinohe (1910) published the first complete, seemingly Algol-like light curve of it from 122 visual observations. Orbital elements were derived by Shapley (1913) and revised, and there was confusion as to whether the period was 0.664 day or 1.328 days. Zinner (1916), who observed a shallow - 0.2 magnitude deep - secondary minimum, resolved the period confusion in favor of the former value, and suggested the period varies. Piotrowski (1937) and Kwee (1958) published period studies. No simple explanation of O-C residuals was uncovered.

Reviewing the literature for RS Sct revealed uncertainty as to whether the system was of Algol or Beta Lyr type and the depth of the secondary minimum. Prior to 1979, photoelectric observers had largely ignored this star, prompting Koch *et al.* (1979) to include it in a list of "p. e. neglected" objects. Shortly thereafter, Buckley (1980) obtained a BVRI light curve for this system. This showed that its light was not constant between eclipses, indicating non-spherical components of high ellipticity, and that the system required Beta Lyr classification. He also derived elements for making ephemeris (time of primary eclipse) predictions:

$$\mathrm{Min}(\mathrm{JD}_{\mathrm{hel.}}) = 2444437.1658 + 0.6642384\ \mathrm{E}. \qquad (1)$$

These elements were adopted in the *General Catalogue of Variable Stars* (GCVS) (Kholopov *et al.* 1985) along with the following visual magnitude range (presumably also based on Buckley's work): primary minimum 9.78-10.91; secondary minimum 9.78-10.08.

King and Hilditch (1984) presented radial velocity curves for both components of RS Sct based on Reticon spectroscopy, derived orbital parameters, and calculated minimum masses. They also did photometry but, as it was "not sufficiently complete...to provide definitive light curves" it was not used to obtain absolute masses for each component. To my knowledge they have not published any new results.

The following rather tentative picture of RS Sct emerges from this observational history. It assumes the orbital inclination is close to 90°, as Shapley suggested, thus fixing masses and orbital dimensions. RS Sct is a near-contact system with the two gravitationally distorted components filling substantial portions of their respective Roche lobes. The primary is a brighter, hotter F5 star of 1.4 solar masses, the secondary, a fainter, cooler mid- to late-G star of 0.85 solar mass. They are of nearly equal size - around 1.5 to 2 times the solar radius - and orbit each other in circular orbits with a center-to-center distance a little more than 4 solar radii.

Having (too naively?) sketched a seemingly well-behaved system, I turn to evidence to the contrary. Along with the light curve classification and secondary minimum uncertainties, published data for RS Sct show considerable discrepancy in values of maximum/minimum brightness. These are collected in Table 1. Of course, given the nature of stellar magnitude determinations, some discrepancy is to be expected, but data for RS Sct seem unusual in this regard. Unaware of these discrepancies, upon comparing my observations of eclipses of this object in 1984 and 1992, I also concluded that RS Sct may not be so well-behaved.

Table 1. Published eclipse magnitude ranges of RS Sct.

Primary		*Mag.*	*Mag.*	
Max.	*Min.*	*Ampl.*	*Type*	*Authority/Date/Notes*
9.3	10.3	1.0	visual	Ichinohe (1910) used BD mags., light curve shows no secondary min.
9.3	10.4	1.1	visual?	Kukarkin (1928)
10.4	11.2	0.8	visual?	Nijland (1931)
9.2	11.2	2.0	pV?	Tsesevitch (1954) (cited in *GCVS,* Kukarin 1969) (based on 1925-26 photographs measured later) light curve shows no secondary min.
8.6	9.75	1.15	V	"Kordylewski 1975" (this appears in *Rocznik Ephemerides* 1985) 0.34 mag. secondary eclipse ampl. cited
9.78	10.91	1.13	V	1980 Buckley (cited in *GCVS,* Kholopov 1985) 0.34 mag. secondary eclipse ampl.

2. Observations

In 1984, I observed three primary eclipses of RS Sct (Sept.7-8, Sept.11-12, Sept. 13-14) using a 15-cm f/10 reflector. Altogether, 34 visual estimates were made using comparison stars marked B, C, D, and E in Figure 1 and my own step sequence given in Table 2. After phases were calculated based on equation (1) and heliocentric corrections made, combining these estimates yielded the light curve (black triangles) of Figure 2. Using equation (1) and a modified tracing paper method, I determined the following:

$$\mathrm{Min}(\mathrm{JD}_{\mathrm{hel.}}) = 2445955.623 \quad E = +2286 \quad O\text{-}C = +0.008 \text{ day.} \qquad (2)$$

Because eclipses of this star seemed to be coming (nearly) right on schedule, I concluded that no further observations were immediately warranted.

Table 2. Comparison star information for RS Sct finder chart

Star	*Catalogue #*	*Step*	*Adopted visual Mag.*	*Spect.*	*Notes*
A	BD-10° 4817	----	9.0	B8	Ichinohe, Tsesevitch used
B	BD-10° 4820	0	9.6	K0	Ichinohe, Nijland used
C	BD-10° 4809	9?	10.1		Ichinohe, Tsesevitch used; not used 1992 since it seemed fainter
D	BD-10° 4822	16	10.5		Ichinohe used
E	-----	23	10.9		
F	-----	35	11.6		added 1992 (a comp. star fainter than E wasn't needed in 1984)
Z	BD-10° 4816	----	9.0	F5	Buckley used for PEP work

I returned to RS Sct eight years later using the same telescope. In 1992 I observed five primary eclipses (Aug. 28-29, Sept. 3-4, Sept. 7-8, Sept. 9-10, Sept. 27-28) and made other random observations. Altogether, 48 visual estimates were made using comparison stars marked B, D, E, and F in Figure 1. Combining these estimates as before yielded the light curve (open squares) of Figure 2. As before, I determined the following:

$$\mathrm{Min}(\mathrm{JD}_{\mathrm{hel.}}) = 2448875.610 \quad E = +6682 \quad O-C = +0.003 \text{ day.} \qquad (3)$$

Again, eclipses predicted with equation (1) were observed right on schedule, but comparison of the two light curves of Figure 2 showed something unexpected: while the shapes of these two light curves are nearly identical, RS Sct was considerably fainter during 1992 than in 1984. Indeed, vertically shifting the 1992 curve an average 9 steps brighter is needed to align the curves. The step sequence used in gathering the data for Figure 2 can be converted to a magnitude sequence. I did this visually, using comparison stars from the AAVSO chart for nearby 1910-07 W Aql and obtaining magnitudes given in Table 2. Comparing the two sequences yields an average step size of 0.055 mag/step. Using this factor, 9 steps are equivalent to about 0.5 magnitude.

The observed visual magnitude range was thus: for 1984, 9.7-10.8; for 1992, 10.25-11.3, with each value uncertain by about ±0.05 magnitude. Note the light curves in Figure 2 are confined to phases < ± 0.15, so the actual maximum expected at phase ± 0.25 was not observed. Examination of Buckley's light curve (Buckley 1980) suggests the actual maxima may be 0.15 magnitude brighter than the maxima reported here.

3. Interpretation/Questions

Any good astronomer, noting that the above 0.5 magnitude intrinsic variation was deduced from visual, not photoelectric, observations will ask, "Is it real?" To this I reply, "very possibly, yes!" because scenarios where such a gross change appeared to occur, but didn't really, seem highly unlikely. For example, not just one, but two variable comparison stars would be needed, since both maxima and minima were affected. I have visually timed hundreds of eclipsing binary minima in the last 25 years and have neither had two comparison stars fail nor observed anything like what I've seen RS Sct do. I have also discussed various possibilities with other veteran AAVSO eclipsing binary observers.

How large are the intrinsic variations in RS Sct? Couldn't one accept the published data in Table 1 at face value and conclude that this system shows large intrinsic variations? Yes, but to do so I feel would be premature. Certain entries in Table 1 may simply be wrong. Indeed, after reviewing the original papers of Ichinohe (1910), Nijland (1931), and Tsesevitch (1954), and using the adopted magnitudes for comparison stars in Table 2, I reduced their ranges to yield the magnitude ranges of Table 3. These data also suggest an intrinsic variation.

Table 3. Published eclipse magnitude ranges of RS Sct, revised.

Primary		*Mag.*	*Mag.*	
Max.	*Min.*	*Ampl.*	*Type*	*Based on Authority*
9.7	11.05	1.35	V	Ichinohe (1910)
9.8	10.6	0.8	V	Nijland (1931)
10.02	10.83	0.81	pV?	Tsesevitch (1954)

If one accepts the above evidence for an intrinsic variation on the order of 0.5 magnitude, how unusual is this star? RS Sct may be unusual, not just because intrinsic variations in eclipsing binaries are somewhat rare, but also because the amplitude of its intrinsic variation is relatively large. Nearly all such variations in other eclipsing binaries are much smaller.

Often eclipsers among ex-novae and dwarf novae show rapid, small amplitude flickering. Components of eclipsers that are red giants or supergiants can vary, e.g., VV Cep. Two Beta Lyrae type eclipsers that vary intrinsically are RX Cas, which includes an A5 giant which varies by 0.46 magnitude with a period of 518 days, and Beta Lyrae itself, whose primary minimum depth varies by 0.25 magnitude with a semi-periodicity of 275 days (Guinan 1989). The cause of the former object's variation is unknown; the latter's has been interpreted as associated with either pulsations in the B giant component or with the rotating disk of gas around the other star. Both these objects have much longer periods than RS Sct and are physically quite different from it.

Starspot/flare activity can produce intrinsic variations in eclipsers, as originally noted in systems with red dwarf components such as YY Gem and CM Dra. More recently, and of more relevance to the case of RS Sct, a related mechanism on a larger scale in G or K dwarfs, subgiants, or giants has been studied in RS CVn binaries. Some of these objects show intrinsic variations in one star of up to 0.5 magnitude (Doyle *et al.* 1988) or 0.6 magnitude (Nolthenius 1991) in V.

What causes the intrinsic variation in RS Sct? There are three possibilities:

1) either the primary and/or secondary components are intrinsically variable,
2) there is a third body in the system which is variable, or
3) there are changes in the opacity and/or the amount of circumstellar gas associated with this system.

In considering possibility 1, it may be that the rapidly rotating mid- to late-G secondary component is the source of the variation. Given the strong tidal effects, its rotation and orbital periods should be equal. Following Hall (1991), one can demonstrate that RS Sct lies far below the Rossby number = 1 line on a rotation period vs. B-V plot. Accordingly, we expect it to be an active dynamo star and, like members of RS CVn binaries, to show variations as a result of starspot activity.

If possibility 2 is the case, the presence of a third body in an eclipsing binary system can show up in an O-C vs. time plot. A light-time variation with a periodicity equal to the period of revolution of the third body (around the common center of mass) would be noted.

After a lengthy literature search, I have collected around 260 times of primary eclipse minima for RS Sct. Using these data, weighted according to their precision, I optimized the epoch and period to produce the best fit linear ephemeris

$$\mathrm{Min}(\mathrm{JD}_{\mathrm{hel.}}) = 2444437.1716 + 0.6642385\,E, \qquad (4)$$

where E = 0 here refers to the same eclipse as in equation (1) but with the epoch and period slightly revised. O-C residuals computed with equation (4) are plotted in Figure 3.

This plot, for years 1909 - 1992, is distinguished by the large scatter, some attributable to the preponderance of visually timed minima based on a single eclipse. Most of these in the last 25 years are the work of Bedeckungsveränderlichen Beobachter der Schweizerischen Astronomischen Gesellschaft (BBSAG) observers. K. Locher feels that the light curve of RS Sct changed during this time, making it more difficult to establish time of minimum precisely. Locher (1992) writes, "I am sure that the minimum has flattened roughly about 1980..." but can provide no data to document this or assess suggested intrinsic variations.

The quality of these data made searching for short term periodicity difficult. The data were averaged and assigned weights indicative of their precision. These averages are plotted in Figure 4 and this cleaned-up O-C curve was used to investigate possible long-term periodicity. After writing a computer program to do least squares fits of unequally weighted data points, I fit a sine curve of semi-amplitude 0.0063 day and period 15,910 eclipse cycles to the data. This is the dashed curve in Figure 4.

If this seemingly periodic variation is real, can it be explained as a light-time variation due to a third body in the RS Sct system? No, its small amplitude constrains the orbital dimensions in a way difficult to reconcile with the long period (≈29 years).

4. Conclusions

There is evidence for an intrinsic variation in RS Sct of around 0.5 magnitude on a time scale of a year or years. While one can speculate about starspot activity in this system's secondary component, additional, especially photoelectric, observations are needed before the nature and origin of this variation can be considered understood.

5. Acknowledgements

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References

Buckley, D. 1980, *Inf. Bull. Var. Stars,* No. 1867.
Doyle, J. G., Butler, C. J., Morrison L. V., Gibbs P. 1988, *Astron. Astrophys.,* **192**, 275.
Guinan, E. 1989, in *IAU Colloquium,* No. 107, 35.
Hall, D. S. 1991, in *IAU Colloquium,* No. 130, 353.
Ichinohe, N. 1910, *Astron. Nach.,* **184**, 190.
King, D., and Hilditch, R. 1984, *Mon. Not. Roy. Astron. Soc.,* **209**, 645.
Kholopov, P. N. *et al.* 1985, *General Catalogue of Variable Stars,* Fourth Edition, Moscow.
Koch, R. H., Wood, F. B., Florkowski, D. R., Oliver, J. P. 1979, *Inf. Bull. Var. Stars,* No. 1709.
Kordylewski, K. 1931, *Acta Astron.,* Ser. C, 1, 164.
Kukarkin, B. 1928, *N.N.V.S.,* **1**, 3.
Kukarkin, B. V. *et al.* 1969, *General Catalogue of Variable Stars,* Third Edition, Moscow.
Kwee, K. K. 1958, *Bull. Astron. Inst. Netherlands,* **14**, 131.
Locher, K. 1992, private communication.
Nijland, A. A. 1931, *Astron. Nach.,* **242**, 14.
Nolthenius, R. 1991, *Inf. Bull. Var. Stars,* No. 3589.
Pickering, E. 1907, *Harvard Circ.,* **129**, 2.
Piotrowski, S. 1937, *Acta Astron.,* Ser. C, 3, 26.
Rocznik Astronomiczny Obserwatorium Krakowskiego Ephemerides, 1985, Cracow.
Shapley, H. 1913, *Astrophys. J.,* **38**, 168 (2).
Tsesevitch, V. P. 1954, *Odessa Izvestia,* IV (2).
Zinner, E. 1916, *Astron. Nach.,* **202**, 241.

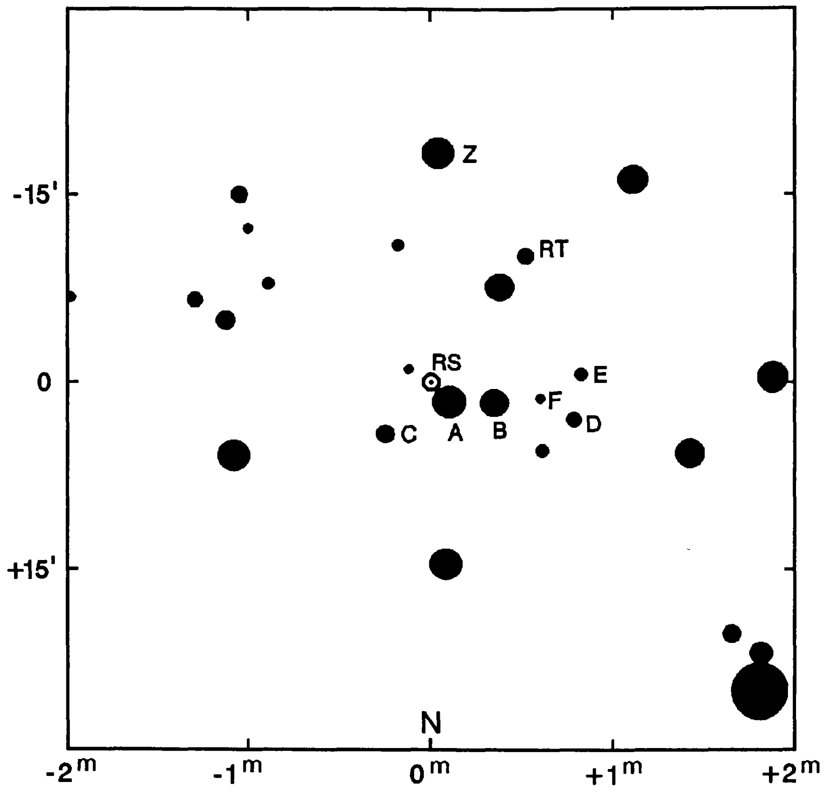

Figure 1. Finder Chart for RS Sct showing comparison stars. Comparison star step and magnitude sequence is given in Table 2. RT Sct is also marked.

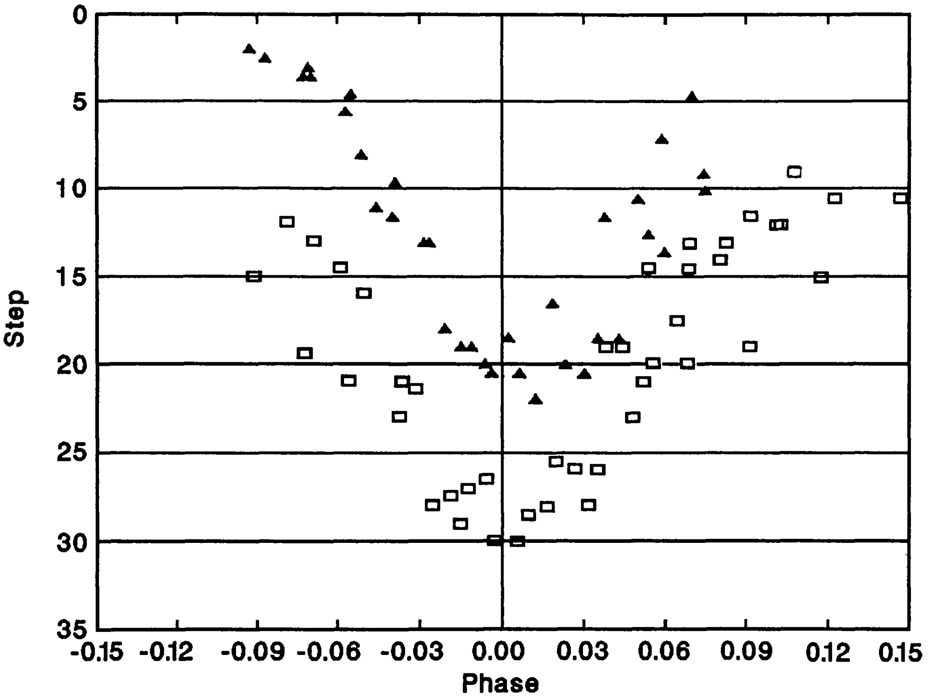

Figure 2. Composite primary eclipse light curves for RS Sct. Black triangles denote 1984 visual estimates; open squares denote 1992 visual estimates.

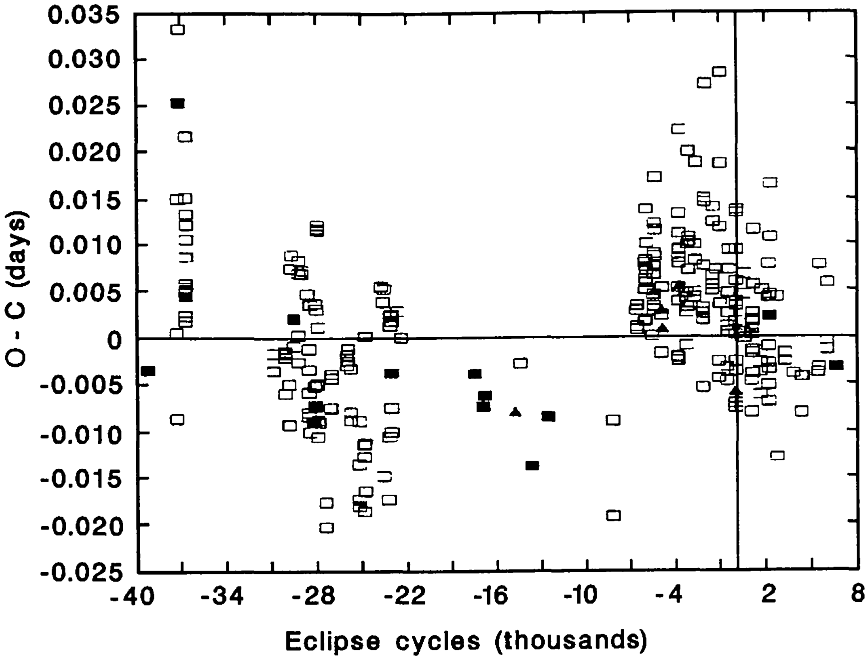

Figure 3. O-C vs. time plot for RS Sct spanning 1909 - 1992. Both O - C and eclipse cycles E are reckoned from the elements of equation (4). E = 0 corresponds to mid - 1980. Open squares denote visual or photographically determined minima based on single eclipse; black squares denote normal minima from visual or photographic estimates covering several eclipses; black triangles denote minima based on photoelectric observations.

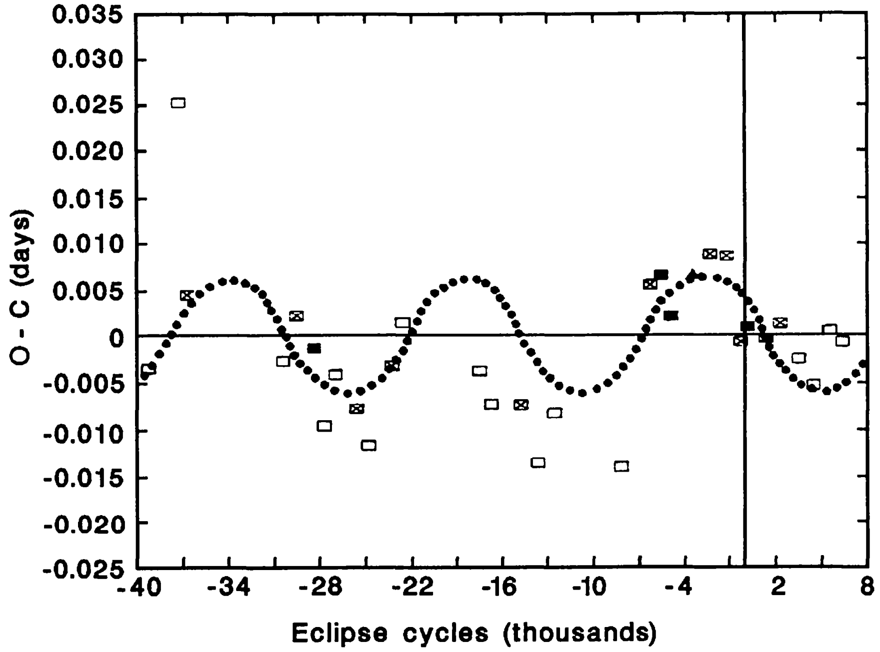

Figure 4. The O-C vs. time plot for RS Sct from Figure 3 has been cleaned up through bin analysis. The resulting points plotted above are weighted as follows: black triangle highest weight; black square high weight; "crossed" square average weight; open square low weight. The dotted curve depicts the least squares "best fit" sine curve (see text).