The Pulsational Behavior of the High Amplitude δ Scuti Star RS Gruis

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Abstract RS Gruis is a high–amplitude δ Scuti–type variable star with a mean amplitude of almost half a magnitude in V and a period of almost 3.5 hours. The most recent study of this star by Derekas *et al.* (2009) suggests the presence of a low–mass dwarf star companion close to the variable star with a period of 11.5 days. Rodriguez *et al.* (1995) have also shown a decreasing rate of the period of $dP/Pdt = -10.6 \times 10^{-8}$ / y. Using an extended dataset comprising BVIc CCD observations acquired at the Astronomical Observatory of the Instituto Copérnico, data from ASAS and HIPPARCOS, and the existing CCD observations in the AAVSO International Database, we have performed an extensive periodgram and times of maximum analysis looking for long term variations. As a preliminary result, we confirmed that the period varies, but, since 1995, instead of decreasing, it has increased. We also found a small peak in the power spectrum in good agreement with the period suggested for the binary companion.

1. Introduction

RS Gru (HD 206379, HIP 107231) is a monoperiodic high–amplitude δ Scuti variable star, or HADS, for short, with a pulsation period of 0.147 d (3.5 h), corresponding to a frequency of 6.8027 d^{-1}, and a mean magnitude of 7.9 mag, and an amplitude of 0.6 magnitude in Johnson V filter.

Its light variation was first detected by Hoffmeister (1956) and studied later by Eggen (1956) and Oosterhoff and Walraven (1966).

Kinman (1961) made photometric and spectroscopic observations and measured a mean velocity of 81 km s^{-1} with a velocity amplitude of 45 km s^{-1}.

Further photometric studies from McNamara and Feltz (1976) and later by Rodriguez *et al.* (1995) led to determined period variations.

Extended radial velocity studies by McNamara and Feltz (1976), Balona and Martin (1978), and more recently by Derekas *et al.* (2009) show that RS Gru is a spectroscopic binary with a companion completing an orbit once approximately each 11.5 days.

2. Observations

We use the following datasets in V:

- AAVSO International Database (3,837 Johnson V measurements covering HJD 2454373–2455525) (Henden 2011)
- ASAS3 (479 V measurements covering HJD 2451873–2455129) (Pojmański 2002)
- HIPPARCOS (198 V measurements covering HJD 2447880–2449062) (Perryman *et al.* 1977)
- Our own observations (For this paper we used only the Johnson V dataset, 313 Johnson V, 343 Johnson B, 344 Cousins I_c measurements covering HJD 2455390–2455482)

Our observations were made using the remotely controlled equipment from the Instituto Copérnico Astronomical Observatory, located at Lat. 34° 42' 33" S, Long. 68° 21' 44" W, in Rama Caída, Mendoza, Argentina. The telescope is a Schmidt–Cassegrain Celestron 11–inch with a focal reducer operating at *f*/3.3. The telescope control software is THE SKY X+ASCOM without auto guiding system. The CCD camera is a ST402MXE with a KAF chip 765 × 510 pixels at 9 µm, with a field of view of 26' × 17'. The filters used were the standard set BVIc provided by the camera producer. The camera control and image calibration were performed using MAXIM DL software (Diffraction Limited 2004). For the photometry we used IRAF software.

All data were reduced with standard tools and procedures. The transformation coefficients for the Observatory were obtained using the M67 field photometry (Henden 2011). We performed the corrections for the model of the atmosphere for each night using Landolt (1992) standards and Cousins (1976) pairs.

The CCD observations were reduced in MAXIM DL, including bias and dark removal and flat–field correction using sky–flat images taken during the evening or morning twilight. Magnitudes were calculated with aperture photometry using two comparison stars of similar brightnesses; Table 1 gives information on these comparison stars. In Figure 1 we can see the field including the comparison stars.

To avoid a shift in magnitude, the V magnitudes of the HIPPARCOS dataset were corrected using the table published by Otero (2003).

3. Analysis

The aim of this work was an extensive study of period variations, since the most recent study covering this issue was seventeen years old (Rodriguez *et al.* 1995). Their study was carried out nineteen years after the previous one by McNamara and Feltz (1976). The very short period of the star means that in the seventeen years since the last study the star had completed more than 50,000 cycles.

This paper covers two analyses, first a Fourier analysis of the observed datapoints, and second a classical O–C analysis of maximum light epochs.

Using our data plus the three other datasests described above we performed a DCFT analysis by means of PERIOD04 software from Lenz and Breger (2005).

The result of the analysis gives the higher peak in frequency at 6.8021777 d^{-1} equivalent to a period of 0.14705874 d, clearly shown in Figure 2. The folded light curve for all four datasets over that frequency is shown in Figure 3.

After an extensive periodogram analysis (16 frequecies were pre–whitened), we found that the strongest peak in the region trough 0 to 2 d^{-1} was centered on ~0.087 d^{-1}, corresponding to a period of ~11.5 days (with a S/N ratio of 2.5). This result was in good agreement with the results for the binarity from radial velocity data obtained by Derekas *et al.* (2009). The portion of the power spectrum can be seen in Figure 4.

Regarding the O–C analysis, we picked times of maximum light available in the literature in order to improve the elements for the ephemeris and to try to verify the increase in period that we had already determined in the periodogram analysis. We also established times of maximum light in Heliocentric Julian Date for the sets of observations from the AAVSO International Database and for our own observations, for a total of 37 times of maximum light covering the long span from 1952 to 2010 (Table 2).

We computed the O–C diagram, adopting the ephemeris from Rodriguez *et al.* (1995):

$$\mathrm{HJDmax} = 2447464 + 0.147010864\ \mathrm{E}, \tag{1}$$

and we perceived that the tendency reflected in the periodogram analysis was also present in the O–C diagram.

We searched for a better linear fit, performing a least squares fit, and we found the new elements T_0 = 2447464.7228 (0.0008444) and P_0 = 0.147011323 (0.00000001773) d, reflecting the behavior in Figure 5 and with the computed O–C values in the fourth column of Table 2.

As the standard error of the fit was 0.005, we performed a further cubic regression. As a result we find the following ephemeris for the maximum light of RS Gru:

$$\begin{array}{llllll} T_{max} = \mathrm{JD} & 2447464.71497 & + 0.147011239\,\mathrm{E} & + 4.230\times10^{-12}\,\mathrm{E}^2 & + 4.188\times10^{-17}\,\mathrm{E}^3 & (2) \\ & \pm 0.00101 & \pm 0.000000026 & \pm 0.511\times10^{-12} & \pm 0.816\times10^{-17} & \end{array}$$

The standard error of the fit was 0.0028, and the computed O–C values can be seen in the fifth column of Table 2.

4. Conclusions and future work

The increase in period seen in RS Gru is not usual behavior for a HADS, which normally present a decrease in period, such as seen in DY Per, VZ Cnc, or BS Aqr. We will continue the long term monitoring of RS Gru, and we will study other HADS in search for another specimen showing this unusual behavior.

5. Acknowledgements

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Table 1. Comparison star information used to observe RS Gru.

Comparison Stars	*R. A. (J2000)* *h m s*	*Dec. (J2000)* ° ′ ″	*V*	*B*
C1 = HD 206480	02 43 41.37	–48 07 54.77	10.389	10.769
C2 = UCAC3 84–413359	21 43 53.04	–48 09 19.45	11.143	11.799

Table 2. Times of maximum light of RS Gru.

Max	(HJD)	Epoch	(O–C)l	(O–C)c	Origin
1	2434325.2940	–89377	0.00226859	–0.00133290	1
2	2434573.4510	–87689	0.00415386	0.00029731	1
3	2436756.5710	–72839	0.00599404	0.00142493	2
4	2436760.5380	–72812	0.00368829	–0.00087989	2
5	2436801.5540	–72533	0.00352893	–0.00102922	3
6	2436853.3030	–72181	0.00454292	–0.00000149	3
7	2441538.4027	–40312	0.00036174	0.00067392	4
8	2441538.5490	–40311	–0.00034958	–0.00003718	4
9	2441610.4379	–39822	0.00001304	0.00043395	4
10	2441611.3200	–39816	0.00004509	0.00046734	4
11	2441611.4677	–39815	0.00073377	0.00115624	4
12	2441612.3493	–39809	0.00026582	0.00068963	4
13	2441915.4856	–37747	–0.00078404	0.00010108	4
14	2442687.5892	–32495	–0.00065713	0.00141754	5
15	2443355.4610	–27952	–0.00130158	0.00179679	6
16	2443355.6092	–27951	–0.00011291	0.00298569	6
17	2443360.4584	–27918	–0.00228660	0.00081935	6
18	2443360.6050	–27917	–0.00269792	0.00040825	6
19	2447464.7095	0	–0.01332706	–0.00547332	7
20	2447468.5324	26	–0.01272149	–0.00486554	7
21	2447468.6793	27	–0.01283281	–0.00497678	7
22	2447472.6489	54	–0.01253856	–0.00468025	7
23	2452920.0196	37108	0.00056588	0.00359375	8
24	2452921.9311	37121	0.00091867	0.00394131	8
25	2452922.0772	37122	0.00000735	0.00302958	8
26	2452923.9905	37135	0.00216014	0.00517714	8
27	2452925.0188	37142	0.00138087	0.00439505	8
28	2454373.9612	46998	0.00017257	–0.00168922	9
29	2454374.9930	47005	0.00289331	0.00102738	9
30	2454387.9288	47093	0.00169680	–0.00022118	9
31	2454417.0373	47291	0.00195467	–0.00008102	10
32	2454417.9216	47297	0.00418673	0.00214745	10
33	2454423.9464	47338	0.00152245	–0.00054130	10
34	2455391.7254	53921	0.00497726	–0.00147251	11
35	2455394.6654	53941	0.00475078	–0.00171373	11
36	2455481.6920	54533	0.00064703	–0.00625784	11
37	2455482.5796	54539	0.00617909	–0.00073029	11

1 Hoffmeister (1956); 2 Oosterhoff and Walraven (1956); 3 Kinman (1961); 4 Dean et al. (1977); 5 McNamara and Fetz (1976); 6 Balona and Martin (1978); 7 Rodriguez et al. (1995); 8 Derekas et al. (2009); 9 AAVSO ID (ARX); 10 AAVSO ID (DSI); 11 present paper

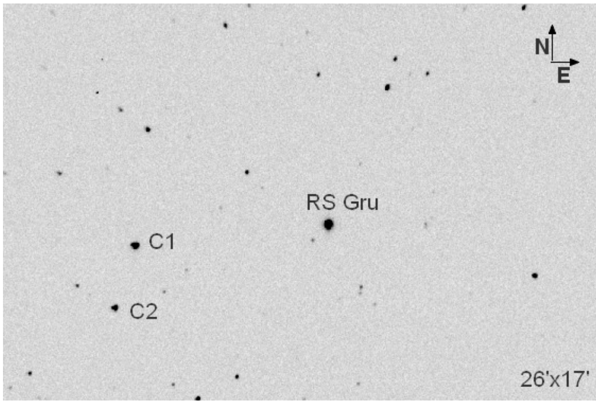

Figure 1. Finder chart for RS Gru. Information on comparison stars is in Table 1.

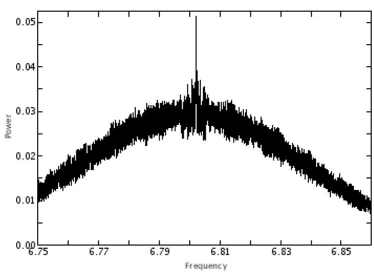

Figure 2. Fourier analysis results for RS Gru showing peak in frequency at 6.8021777 d^{-1} equivalent to a period of 0.14705874 d.

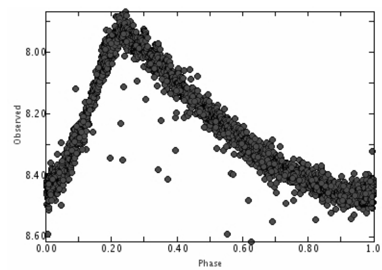

Figure 3. V–band light curve for RS Gru (AAVSO, ASAS, HIPPARCOS, and author's data) folded to frequency 6.8021777 d^{-1} = period 0.14705874 d.

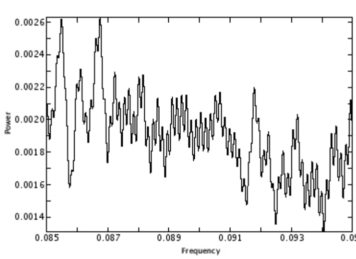

Figure 4. Power spectrum of RS Gru.

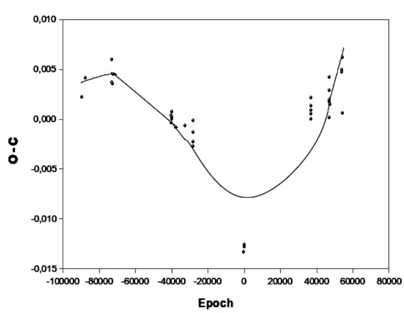

Figure 5. O–C diagram for RS Gru based on the new elements T_0 = 2447464.7228 (0.0008444) and P_0 = 0.147011323 (0.0000001773) d.