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# HAS THE $\delta$ SCUTI STAR BS Aqr A COMPANION?

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The light variation of BS Aqr was discovered by Hoffmeister (1931). Since then, BS Aqr has been observed by many authors and become one of the 19 $\delta$ Scuti stars which have reasonable long-time span observations for us to calculate their reliable period change rates (Jiang 1993). Yang et al. (1993) collected 48 times of light maximum for this star in the literature and provided a new one determined by themselves.

We observed BS Aqr on December 20, 1995 in Xinglong station of Beijing Astronomical Observatory with a 60 cm telescope and its CCD camera. One new moment of light maximum was derived and then all the times are listed in Table 1 with 50 data points over more than six decades.

With the times of light maxima of BS Aqr which are listed in Table 1, the linear fit is used to determine the calculated light maxima by the formula of $C_l = T_{01} + P_{01}E$. The results of fitting are: $T_{01}$ = HJD2428095.3346, $P_{01}$ = 0.197822612 days. The values of $(\mathrm{O-C})_l$ are also listed in Table 1. The residual obtained ($\sigma_{01}$) is 0.0043 days. Then the quadratic curve is used to fit the data as: $C_Q = T_{02} + P_{02}E + 0.5\beta_{01}E^2$. The fitting parameters are: $T_{02}$ = HJD2428095.3319, $P_{02}$ = 0.197822744 days, $\beta_{01} = -1.2 \times 10^{-12}$ days/cycle, with the residual ($\sigma_{02}$) of 0.0044 days. The $(\mathrm{O-C})_l$ diagram and the fit curve using the quadratic function are shown in Figure 1 (a).

From this figure, one may find that the fit is not good, and the differences between the points and the curve may imply another intrinsic periodic variation. Thus, the formula of $C_{orb} = T_{03} + P_{03}E + 0.5\beta_{02}E^2 + A\sin\phi + B\cos\phi$ is used to fit the original times of light maxima, where $\phi$ is the solution of $\phi - e\sin\phi = 2\pi f(P_{03}E - \tau)$. The related parameters are determined as: $T_{03}$ = HJD2428095.3320, $P_{03}$ = 0.197822675 days, $\beta_{02} = -0.5 \times 10^{-12}$ days/cycle, $A = -0.0040$ days, $B = 0.0001$ days, $P_{orb} = 34.05$ years, $e = 0.5$, and $\sigma_{03} = 0.0036$ days. The O−C diagram and the fit curve using both the quadratic and the trigonometric functions are shown in Figure 1 (b).

From Figure 1 and the comparison of the residuals after different fits, one may find that the model of explaining the discrepancies between the observed and calculated times of maximum light as the consequence of a continuously changing (decreasing) period, combined with the light-time effect caused by the orbital motion of BS Aqr around the mass center of a binary system with an unseen companion, is reasonable.

Based on the coefficients provided by the fitting, some additional parameters of the binary system of BS Aqr can be estimated. The projection of the orbit radius: $a_1 \sin i \approx$ $\approx$ 0.699 AU; the mean velocity of the primary star projecting on the orbit: $K \approx$ $\approx$ 0.61 km s$^{-1}$; the mass function: $f(m) \approx 0.00029$. Under the values of the mass and the radius of BS Aqr: $M_1 = 1.89 M_\odot$, $R_1 = 4.04 R_\odot$ (McNamara & Feltz 1978), the semi-major axis of the orbit and the mass of the companion are derived with different inclination angles and the result is listed in Table 2.

Obviously, more observations are needed to check the binary hypothesis for BS Aqr. However, since the calculated orbital radial velocity amplitude (K) is very small, the spectroscopic measurements might not be very helpful to confirm the binary model for BS Aqr.

There is an interesting possibility to determine the pulsation constant (Jørgensen & Grønbech, 1978). Combining Kepler's third law and the pulsation constant formula,

$$\frac{a^3}{P_{orb}^2} = \frac{G}{4\pi^2}(M_1 + M_2), \quad \text{and} \quad Q = P_{pul}\left(\frac{M_1}{R_1^3}\right)^{1/2}$$

we obtain

$$Q = 0.1159 \frac{P_{pul}}{P_{orb}}\left(\frac{R_1}{a}\right)^{-3/2}\left(1 + \frac{M_2}{M_1}\right)^{-1/2}$$

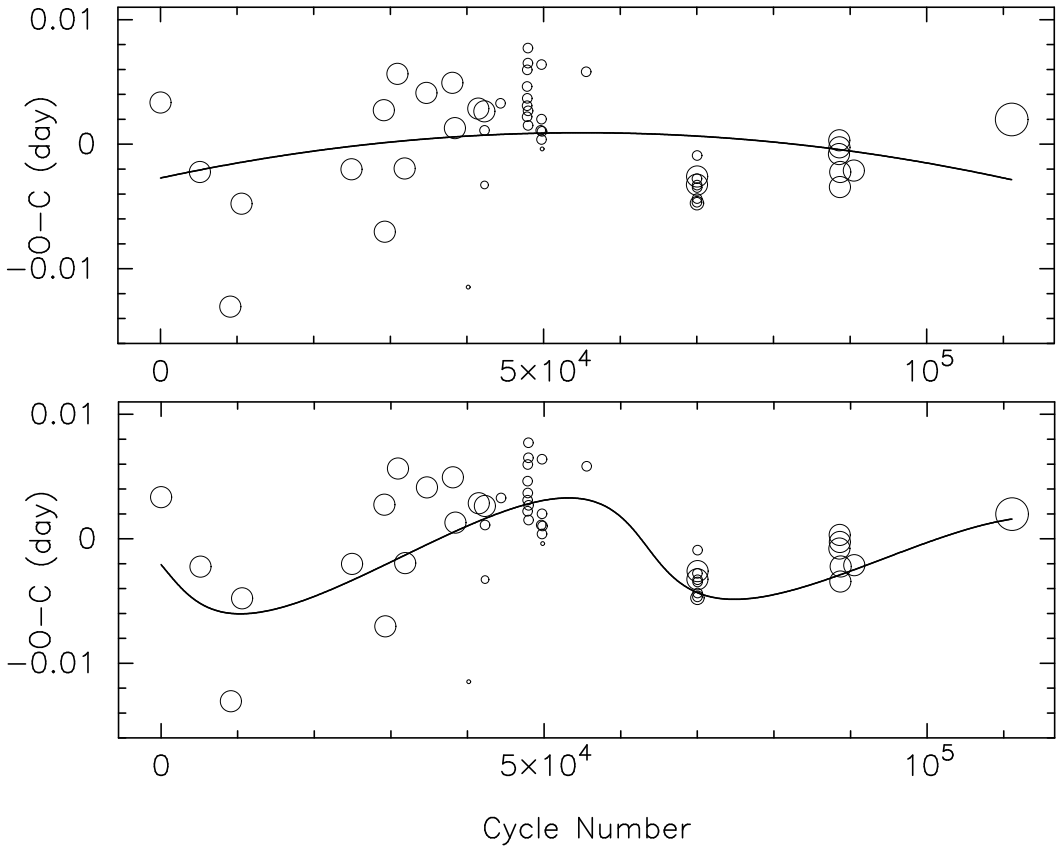


**Figure 1.** The O−C diagrams and the fit curves by using (a) the quadratic function, and (b) both the quadratic and the trigonometric functions for BS Aqr

Table 1: Times of light maxima of BS Aqr

| No. | HJD (2400000.0+) | E | (O-C)$_l$ (day) | W | Ref. | No. | HJD (2400000.0+) | E | (O-C)$_l$ (day) | W | Ref. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 28095.3380 | 0.0 | 0.0033 | 1.0 | An | 26 | 37584.2934 | 47967.0 | 0.0015 | 0.5 | TS |
| 2 | 29111.7450 | 5138.0 | −0.0022 | 1.0 | As | 27 | 37584.4924 | 47968.0 | 0.0027 | 0.5 | TS |
| 3 | 29899.2660 | 9119.0 | −0.0131 | 1.0 | Sa | 28 | 37911.4916 | 49621.0 | 0.0011 | 0.5 | TS |
| 4 | 30187.3040 | 10575.0 | −0.0048 | 1.0 | Sa | 29 | 37932.4617 | 49727.0 | 0.0020 | 0.5 | TS |
| 5 | 33027.4460 | 24932.0 | −0.0020 | 1.0 | Sa | 30 | 37933.4552 | 49732.0 | 0.0064 | 0.5 | TS |
| 6 | 33862.4600 | 29153.0 | 0.0027 | 1.0 | Sa | 31 | 37934.4383 | 49737.0 | 0.0004 | 0.5 | TS |
| 7 | 33888.3650 | 29284.0 | −0.0070 | 1.0 | Sa | 32 | 37946.3083 | 49797.0 | 0.0010 | 0.5 | TS |
| 8 | 34211.4220 | 30917.0 | 0.0056 | 1.0 | Sa | 33 | 37947.2960 | 49802.0 | −0.0004 | 0.1 | TS |
| 9 | 34400.3350 | 31872.0 | −0.0019 | 1.0 | Sa | 34 | 39087.1561 | 55564.0 | 0.0058 | 0.5 | HP |
| 10 | 34961.3660 | 34708.0 | 0.0041 | 1.0 | Sa | 35 | 41946.6714 | 70019.0 | −0.0047 | 0.6 | El |
| 11 | 35631.3920 | 38095.0 | 0.0049 | 1.0 | Sa | 36 | 41946.8693 | 70020.0 | −0.0047 | 0.5 | El |
| 12 | 35696.4720 | 38424.0 | 0.0013 | 1.0 | Sa | 37 | 41947.6620 | 70024.0 | −0.0032 | 1.0 | El |
| 13 | 36040.0771 | 40161.0 | −0.0115 | 0.1 | Ki | 38 | 41947.8603 | 70025.0 | −0.0028 | 0.5 | El |
| 14 | 36300.4260 | 41477.0 | 0.0029 | 1.0 | Sa | 39 | 41948.6500 | 70029.0 | −0.0044 | 0.5 | El |
| 15 | 36458.0904 | 42274.0 | 0.0026 | 1.0 | Sp | 40 | 41948.8489 | 70030.0 | −0.0033 | 0.5 | El |
| 16 | 36460.8540 | 42288.0 | −0.0033 | 0.3 | Sp | 41 | 41949.6400 | 70034.0 | −0.0035 | 0.5 | El |
| 17 | 36461.8475 | 42293.0 | 0.0011 | 0.5 | Sp | 42 | 41950.6300 | 70039.0 | −0.0026 | 1.0 | El |
| 18 | 36874.1120 | 44377.0 | 0.0033 | 0.5 | Ki | 43 | 41950.8295 | 70040.0 | −0.0009 | 0.5 | El |
| 19 | 37561.3491 | 47851.0 | 0.0046 | 0.5 | TS | 44 | 45612.7240 | 88551.0 | −0.0008 | 1.0 | Me |
| 20 | 37561.5445 | 47852.0 | 0.0022 | 0.5 | TS | 45 | 45620.6380 | 88591.0 | 0.0003 | 1.0 | Me |
| 21 | 37562.5345 | 47857.0 | 0.0031 | 0.5 | TS | 46 | 45625.5830 | 88616.0 | −0.0003 | 1.0 | Me |
| 22 | 37563.5242 | 47862.0 | 0.0037 | 0.5 | TS | 47 | 45637.6470 | 88677.0 | −0.0034 | 1.0 | Me |
| 23 | 37564.5156 | 47867.0 | 0.0060 | 0.5 | TS | 48 | 45644.5720 | 88712.0 | −0.0022 | 1.0 | Me |
| 24 | 37582.5180 | 47958.0 | 0.0065 | 0.5 | TS | 49 | 45997.0920 | 90494.0 | −0.0021 | 1.0 | Ya |
| 25 | 37583.3105 | 47962.0 | 0.0077 | 0.5 | TS | 50 | 50072.0441 | 111093.0 | 0.0020 | 1.5 | pp |

*An: Andrews (1936)
*As: Ashbrook (1943)
*El: Elst (1976)
*HP: Harding and Penston (1966)
*Ki: Kinman (1961)
*Me: Meylan et al. (1986)
*pp: present paper
*Sa: Satanova (1961)
*Sp: Spinrad (1959)
*TS: Tremko and Sajtak (1964)
*Ya: Yang et al. (1993)

Table 2: Inclination, semi-major axis of the orbit and mass of the companion of BS Aqr

| i(deg) | a(AU) | $M_2(M_\odot)$ |
|---|---|---|
| 10 | 14.74 | 0.726 |
| 20 | 13.70 | 0.330 |
| 30 | 13.47 | 0.218 |
| 40 | 13.36 | 0.167 |
| 50 | 13.30 | 0.139 |
| 60 | 13.26 | 0.122 |
| 70 | 13.24 | 0.112 |
| 80 | 13.23 | 0.107 |
| 90 | 13.22 | 0.105 |

Adopting $P_{pul} = 0.197822675$ days, $P_{orb} = 12436$ days, $M_1 = 1.89M_\odot$, $R_1 = 4.04R_\odot$, $a = 13.5$ AU (see Table 2), and $M_2 = 0.105 \sim 0.330M_\odot$ (the value of $0.726M_\odot$ is too big, due to the fact that we have not seen its light), the pulsation constant is calculated: $Q \approx 0.034$. This value corresponds to the radial fundamental mode (e.g. Petersen and Jørgensen 1972).

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