BS Tauri—Evidence for Cyclic Activity in an Orion Irregular

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Received April 30, 2009; revised June 9, 2009; accepted June 9, 2009

Abstract The irregular variable star BS Tauri (type Inbs?) is found to have not only H-α emission and an irregular brightness variation but also an underlying six-year periodicity in brightness. BS Tau should actually be classified as a classical T Tauri star (Int, CTTS), but whether the cyclicity is caused by starspots, a companion, or a circumstellar disk is not certain. Tests to determine the origin of variation are listed.

1. Introduction

Off the east edge of the Taurus T-association, northeast of Aldebaran, lies the variable star BS Tauri (R.A. $04^h\,58^m\,51^s$ Dec. +28° 31' 24" (2000)), discovered by Hoffleit (1935) and originally classified as "L"—a possible slow irregular with no known period—and with no known emission spectrum. Fadeev (1972) (sometimes spelled as "Fedeyev") reported slow irregular variations, but with superimposed rapid changes in brightness of up to 2.5 magnitudes over a couple of days. The brightness range was stated as "14.4 to 17.0 photographic." In his article was a chart without marked comparison stars. BS Tau on Palomar plates (POSS) appeared yellow to him, and it lies near a noticeable group of dark clouds. The present author, as an undergraduate student, discovered BS Tau to be an emission-line star on two 1974 H-α sensitive objective prism plates (Bidelman 1976).

The star was included in an unpublished 1978 study by the author in which variability was researched using Harvard College Observatory photographic plates. At that time, magnitudes for the field stars were estimated from the Palomar POSS-blue charts using the relation of image size to magnitude by Liller and Liller (1975). The average error in any *B* magnitude estimate was determined to be ±0.2 magnitude by estimating the brightness of stars in the Landolt (1967) standard star fields in Taurus. The 1978 light curve, based on estimates made from plates at the Harvard Observatory Plate Stacks, showed a waviness indicating a periodicity of around six years in more than thirty years of magnitude estimations but no further work was done on the investigation.

Recently a more extensive article by Fedeev (1973) came to the writer's attention. In it Fedeev classified the star as "Insb?" based on several nights of extensive photographic studies, and this time a finder chart with a fine net of comparison stars was included. To check the old periodicity finding, we revisited the Harvard Plate Stacks early in 2009 and re-measured BS Tau using the original magnitude framework and Fedeev's. Only one star was common to both the Fedeev and Krumenaker systems and its magnitudes differed by 0.4 magnitude. The averaged magnitudes for BS Tau in the two systems differed by 0.36 magnitude and a comparison of the estimates of individual plates consistently differed by 0.33 on average. This new study indicated the two scales gave consistent results but averaging one-third of a magnitude different. Also, the star estimates in the author's system rarely differed over the intervening thirty years. In the 2009 study, a field star was chosen as a check and data were added from the 1960s and 1970s. The finer Fedeev-comparison-star derived values will be used in this analysis.

2. Observations

Table 1 lists, and Figure 1 plots, the *B* magnitudes for BS Tau derived from the 2009 visit to the Harvard Plate Stacks. The bulk of these magnitudes, from observations between 1922 and 1951, are plotted versus Julian date in Figure 1. Two very early observations from 1899 and 1903, and eight from 1969 to 1978, are not plotted.

The study yields a mean *B* magnitude of 14.9 with a standard deviation of 0.5. Known *V*-magnitude values, including some photoelectric observations taken in 1980, are in Table 2. The arithmatic *V*-magnitude average is 14.1, causing BS Tau to have an approximate *B–V* value of 0.8, comparable to a yellowish G-type star, confirming the POSS coloration. No MK classification for BS Tau is known to us.

3. Analysis

Visually noting some waviness to observations plotted in Figure 1, the 1920–1950s data was inserted into a period-finding program called AVE, yielding a periodogram (Figure 2) that shows the strongest period to be 2,176 days (5.96 years), confirming our 1979 observation of a six-year-long periodicity. Using all 79 years of estimates provides an uncertainty of 100 days; the few very early and very recent observations act as overly influential outliers in the statistical analysis. The plateau beginning around 4,000 days also shows up in the non-variable field star and thus signifies a technological origin and not a stellar one. All others are regarded as aliases or low-number statistics noise.

To be sure, a False Alarm Probability (FAP) was calculated using the formulations of Horne and Baliunas (1986). The high peak has an FAP of 1.4%, the next highest peak, around 1500 days, is about 99%. The plateau came in at an FAP of 88%. A phase diagram (Figure 3) was then made using the 2,176-day period with the time origin five cycles before our earliest brightest observation so all 79 years of observations could be included.

Very clearly, the irregular light variations have an underlying cyclicity, causing times when the brightness can be higher or lower than usual. Note that the range of the irregular variation is generally unchanged throughout the whole cycle, with only extremes a bit accentuated or, conversely, the mean varying cyclicly. Such long-term variations are not unknown in T Tauri-type and other related variables. T Tauri itself has a 2,200-day period (Melnikov and Grankin 2005), DI Cep has a cycle varying between 14 and 19 years (Kolotilov *et al.* 2004), and PZ Mon has one of 50 years' length (Alekseev and Bondar 2006).

4. Discussion

If this periodicity is due to a non-visible but obscuring companion star, then one can estimate the companion's orbital distance with a simple application of this period into Kepler's Third Law. T Tauri stars are generally considered to be around one solar mass (Petrov 2003). Estimating the combined mass to be at least 2 solar masses gives us a minimum distance of around 4 AU. Assuming its position near the T-Tauri association clouds indicates BS Tau is at a distance of 140 parsecs, the binary separation is well under 100 mas, far too close for any telescope to separate. Possibly speckle interferometry or an infrared survey might be able to split it, as was done for T Tau itself, at 700 mas and 100 AU separation (Melnikov and Grankin 2005; Appenzeller and Mundt 1989). An occultation might also resolve this binary but faintness of the star likely precludes this as a viable method of observation.

Ismailov (2005) suggests there are five kinds of T Tauri light curves which all depend on external factors such as companion stars, adding to the natural rapid variations. His Type III is defined by the mean brightness changing but not the amplitude of the rapid, irregular variations, which he says requires a companion of equal brightness plus cool starspots. These two requirements would cause variation in brightness but not much in color. Ismailov's Type IV has both mean magnitude and rapid variation amplitude changing over time and caused by a combination of chromospheric activities and eclipses, though by what he does not specify. He puts T Tau in this class.

The BS Tau 30-year light curve would seem very close to his Type IV, as the amplitude in brightness varies from small to several magnitudes, but this could be because of our small number of observations. However, Ismailov did not examine phase diagrams for those stars he studied that had long-term variations. If one examines BS Tau's phase diagram, the rapid variation amplitude does not change with phase, just the mean. This result would make BS Tau more likely a Type III. Since at least 42% of all T Tauri's may have companions (Petrov 2003), and with BS Tau's minimum centered at phase 0.1–0.2 and maximum centered around 0.70–0.80, a companion star eclipse could be possible.

Another possible explanation for this long-term variation is a Schwabelike sunspot cycle. The irregular variations in T Tauri stars are caused either as cool ("cold") starspots or hot spots. For the cool type, as the spot count goes up and surface area is more covered with cooler areas, the magnitude may be slightly fainter than normal. Halfway through the cycle, there may be less than normal coverage and the star slightly brighter. Not all peaks and valleys would be identical in intensity. Our own Sun's Schwabe sunspot cycle varies slightly, ranging from ten to twelve years and with varying peaks. An examination of the BS Tau phase diagram shows that at the extremes, the star gains and loses about a magnitude over the general range of the general rapid variation.

Starspots have been indicated for other pre-main sequence and T Tauri variables, with coverage up to 50%; cold spots causing variations maximizing at up to a one-third of a magnitude (Alekseev 2006), whereas hot spots due to accretion from a circumstellar disk can cause long-lived spots that change the brightness by 1–3 magnitudes (Petrov 2003). The late-type flare star PZ Mon at its minimum brightness can have a variation in magnitude up to 1.0 magnitude over a 50–60-year cycle (Alekeev and Bondar 2006). Starspot periodicities would be most easily viewed in periodically changing colors, particularly in the *U–B* or *B–V* color ranges (Kolotilov *et al.* 2004), such as those seen in DI Cep. Alekseev (2006) reports spots can also be detected using molecular band spectrophotometry over time. Although some spotted stars have cycles measuring into the decades, most starspot-suspected cycles are measured in mere days.

A better explanation for the periodicity might be a circumstellar disk that periodically and partially occults the star. Such disks can cause up to a three-magnitude decrease in minimum brightness, and it is more common in the earlier spectral types such as that of BS Tau (Petrov 2003). Pinte and Menard's (2004) model of the classical T Tauri star AA Tau indicates that eclipses by the disk can skip a period and the magnitude changes can range up to 1.4 magnitudes. (A classical T Tauri star, or CTTS, as summarized by Appenzeller and Mundt (1989), has a central star surrounded by a disk, showing spectral lines in emission, as opposed to weak T Tauri's that do not have emission.) If the disk is not uniform, it could explain the variations from one cycle to another.

To test the hypotheses of companion star, sunspot cycle, and circumstellar disk, there is the need to measure BS Tau's polarization in infrared and its color, particularly the blue or ultraviolet spectral regimes, at minimum and maximum. Specifically:

- to test for a companion, monitor color during entire cycle; there should be no color or polarization changes;
- to test for a sunspot cycle, monitor color (*U–B* or *B–V*) for changes over the cycle; also, changes in spots can be detected with molecular band spectrophotometry (Alekseev 2006);

• to test for a circumstellar disk, observe linear polarization at minimum and maximum of cycle; the linear polarization should increase at minimum.

5. Conclusions

On the basis of our light curve, the classification for BS Tau should be changed from "Orion Insb" type to "T Tauri (Int)" and falling into the Classical T Tauri (CTTS) regime. BS Tau's brightness over time has an underlying cyclical nature with an period of 5.96 years that could be caused either by a Schwabe-type variation in spot coverage or a partially eclipsing circumstellar disk or companion. The most recent maximum should have been around 2006, the next maximum should be centered around 2012, with BS Tau currently in a minimum period centered around this year, 2009. This would be a good time to begin checking BS Tau's light for polarization and color changes over the cycle to determine characteristics that would depend the cause of the long-term variation.

6. Acknowledgements

The writer wishes to thank: Dr. W. P. Bidelman for guiding the original undergraduate work, the late Dr. Martha Hazen who gave access and instruction to the plate stacks in 1979, and Ms. Alison Doane for allowing me the privilege thirty years later, R. Levrault for photoelectric observations, the Pisgah Astronomy Research Institute for giving access to the Case Western Reserve objective prism plates, and Dr. Amy Lovell and Dr. Rick Williamon for valuable discussions.

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Table 1. *B* Magnitude Observations of BS Tau.

Date	*Plate*	*B**	*Date*	*Plate*	*B**
1899 12 9	I 24204	14.4	1937 10 30	RH 7831	15.7
1903 11 28	I 31216	14.4	1937 11 3	BM 696	15.4
1922 11 13	MC 19241	14.9	1937 11 30	RH 7899	15.4
1923 10 17	MC 20151	14.4	1937 12 1	RH 7906	15.8
1924 10 30	MC 21098	14.2	1938 1 6	B 62728	14.4
1926 11 5	MC 22195	15.3	1938 1 20	RH 8044	15.2
1926 12 29	MC 22300	14.7	1938 2 20	B 62845	15
1927 9 29	MC 22725	14	1938 10 25	RH 8542	15.5
1928 2 13	MC 23184	15.4	1938 11 1	RH 8541	15.5
1928 10 14	MA 2321	15.5	1938 11 20	RH 8594	15.5
1928 10 20	MC 23739	15.4	1938 11 25	RH 8608	14.7
1928 11 9	MC 23805	15.3	1938 12 13	RH 8650	15.6
1928 12 5	MC 23862	14.7	1938 12 15	BM 1067	15.3
1929 2 12	MC 24078	15.3	1938 12 22	RH 8667	14.7
1929 10 13	MC 24558	15.5	1939 10 15	RH 9199	15.5
1931 11 4	MC 25729	15.4	1939 11 8	RH 9288	15.2
1932 11 27	RH 4731	14.7	1939 11 15	BM 1739	15.1
1933 12 11	RH 5598	14.2	1939 12 12	RH 9369	14.5
1934 2 6	RH 5738	14.4	1940 1 1	RH 9422	15.4
1935 1 24	RH 6413	13.9	1940 1 2	RH 9425	14.5
1935 2 28	RH 6463	13.8	1940 1 9	B 65049	14.9
1935 10 2	B 60296	14.4	1940 1 29	MC 30768	15.4
1936 2 18	RH 7044	14.2	1940 2 4	BM 2096	14.4
1936 2 23	RH 7063	14.6	1940 2 9	BM 2114	14.3
1936 11 10	RL 1097	15	1940 11 25	MC 31203	14.8
1937 1 16	RL 1184	14.4	1940 12 3	IR 4391	15.3
1937 1 16	RL 1185	14.5	1940 12 31	IR 4501	15.5
1937 2 2	B 61629	16.3	1941 8 25	B 67047	14.8
1937 9 12	B 62515	14.7	1941 11 23	B 67271	14.8

(Table 1 continued on following page)

Table 1. *B* Magnitude Observations of BS Tau, continued.

Date	Plate	B*	Date	Plate	B*
1942 8 12	B 67925	15.2	1948 11 7	RH 14835	14.4
1942 9 15	B 68025	14.7	1948 11 27	B 74314	14.7
1942 10 12	IR 6218	15.5	1948 11 29	RH 14850	14.9
1942 10 15	B 68105	14.6	1948 12 28	RH 14882	14.6
1944 8 24	B 69839	15.2	1949 2 18	B 74452	14.3
1944 10 17	IR 7451	15.2	1949 8 29	B 75043	14.9
1944 10 23	IR 7486	15.6	1949 10 19	RH 15170	15.4
1944 12 18	B 70052	14.7	1949 10 20	RH 15173	16.3
1945 2 5	RH 12888	14.9	1949 11 23	B 75162	14.4
1945 10 5	B 71257	15.7	1950 1 14	RH 15238	15.4
1946 10 3	RH 14079	14.7	1950 10 13	RH 15467	14.9
1946 10 5	RH 14086	15.1	1950 11 13	RH 15513	14.4
1946 10 23	B 72119	15.5	1951 1 29	B 75706	15.7
1946 10 29	B 72306	13.8	1951 9 9	RH 15753	15
1946 11 18	RH 14157	14.9	1951 11 29	RH 15793	14.3
1946 12 24	B 72378	15.2	1967 11 6	DNY 86	15.9
1947 1 22	RH 14210	15	1967 12 1	DNY 88	15.9
1947 8 24	B 73086	14.3	1969 1 15	DNB 238	15.3
1948 1 11	RH 14430	14.8	1969 1 15	DNY 156	15.7
1948 1 30	B 73288	13.8	1969 10 19	DNY 201	15.7
1948 9 2	B 74059	14.4	1974 12 6	DNB 865	14.9
1948 10 26	B 74249	14	1978 11 2	DNB 2183	14.1

** Magnitudes are from blue plates, with comparison star magnitudes in Johnson B.*

Table 2. *V* Magnitudes of BS Tau.

Year	V	Source
1997	13.5	Kohoutek and Wehmeyer
1996	14.4	Lasker *et al.*
1980	14.0	R. Levrault, photoelectric
1980	14.0	L. Krumenaker, photoelectric

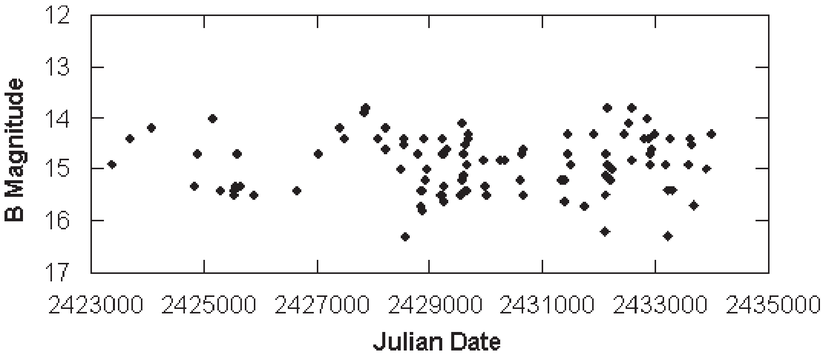

Figure 1. Light curve of BS Tau (1922–1951), using Fedeev comparison stars.

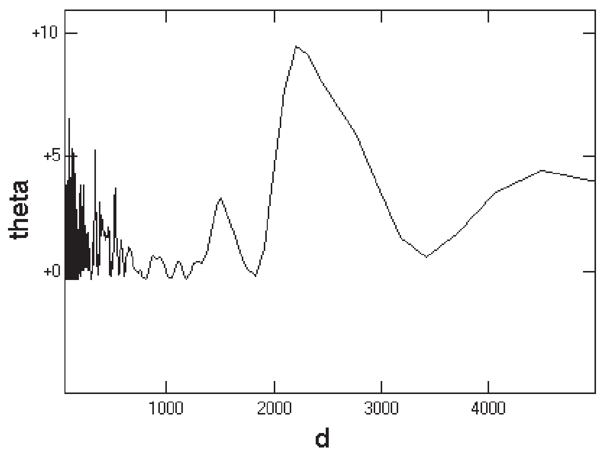

Figure 2. Periodogram created from the 1922–1951observations of BS Tau.

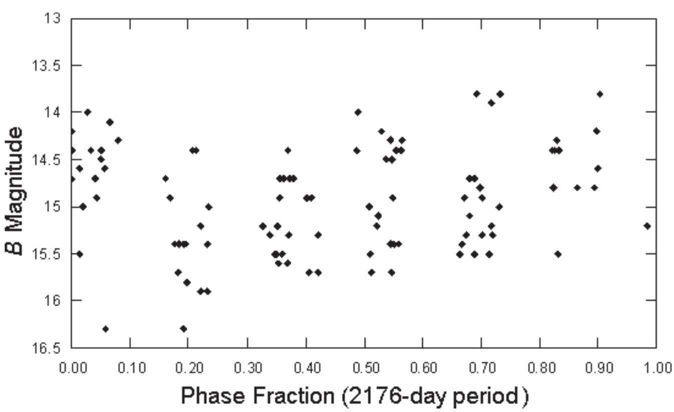

Figure 3. Phase Diagram for BS Tau based on a 2,176-day period.