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The eclipsing binaries BV and GR Tauri

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BV Tauri is catalogued as a Beta Lyrae variable with a period of 12.349 days. Visual observations by Brelstaff, however, indicate that the period is only 0.93047 days. For GR Tauri, the catalogue gives the period as 0.474012 days, but the observed period is 0.429853 days; and the mean visual range is $10^m.5$-$10^m.8$ (with Min II = $10^m.6$), only half the photographic range in the catalogue. GR Tau is catalogued as an Algol system, but it appears most probably to be a Beta Lyrae system with an unusually short period.

Introduction

The first author, Tristram Brelstaff, started observing variable stars in 1971. For the first few years he made regular estimates of all sorts of stars using small binoculars mounted on a tripod.

In 1976 he went away to university and found that he could observe only in the holidays. He began to concentrate on making timings of the minima of eclipsing binaries, because the necessary observations for many of these systems could be completed within a single evening. Results of comparable value for other variable stars usually require regular observations over several months, and these were not possible under the circumstances.

After university he took advantage of a short spell of enforced leisure to make an independent discovery of the period of the eclipsing binary NN Cep. Ian Howarth, who was then Director of the BAA Variable Star Section, encouraged him to write up the discovery for the *Journal*[1]. This discovery boosted his confidence in his own observing technique and also showed him that there was still scope for original work in the field of eclipsing binaries.

Melvyn Taylor introduced him to the *General Catalogue of Variable Stars*[2] and to the Cracow yearbook[3], both of which list many neglected eclipsing binaries. Most of these were too faint for his binoculars so he had to wait until 1981, when he could afford a 200mm reflector, before he could start to observe them.

A major problem lay in identifying stars fainter than magnitude 9, the limit of the commonly available star atlases. This was overcome by using the *Smithsonian Astrophysical Observatory Star Catalog* in conjunction with the *Papadopoulos Photovisual Star Atlas*. The former lists accurate positions for most stars down to magnitude 9, while the latter is a collection of photographs showing stars to about magnitude 13. For each variable, several nearby reference stars were selected from the *Catalog*. Their angular separations from the variable were calculated and then multiplied by the scale of the *Atlas* to give distances in millimetres. The reference stars were then picked out on the *Atlas* and the variable was identified as the only star that was the correct distance from each of them. This was checked with a millimetre ruler.

Charts were copied freehand from the *Atlas*, and these were found to be adequate for identifying the variables and their comparison stars at the telescope.

Magnitude estimates were made by the Pogson step method, which allows the estimates to be analysed

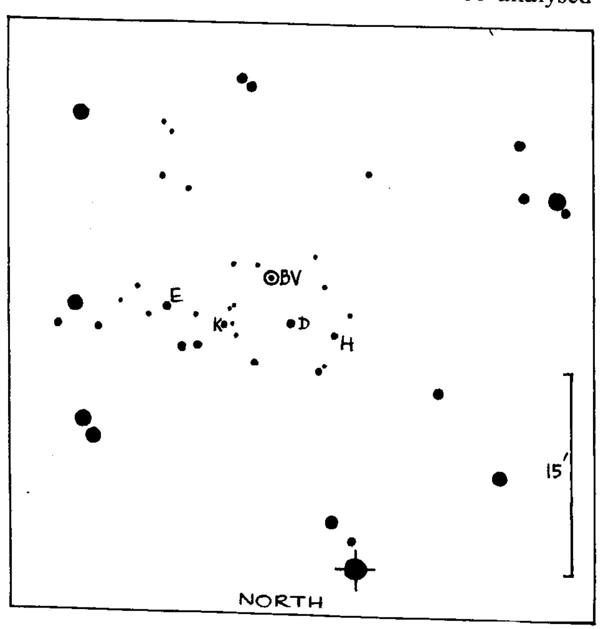

Figure 1. Field chart for BV Tau (1950.0: 05^h $35^m.6$, $+22°$ 53′). Grades of comparison stars have been derived from Brelstaff's step estimates as follows: D=0.0; E=2.1; H=6.6; K=9.5. If the visual range is the same as the photographic range in the catalogue, these equate to the following magnitudes: D=11.4; E=11.6; H=12.1; K=12.4.

without knowing the magnitudes of the comparison stars. This is important in the case of fainter stars like these, for which accurate sequences are generally not available.

Of the stars discussed below, BV Tau was selected for observation because the Cracow yearbook indicated that it had been completely neglected since its discovery. The catalogued period suggested that it would be relatively easy to cover the whole light curve within a year by making one estimate per night. GR Tau was chosen because of its unusually short eclipses which, according to the catalogue, were only 82 minutes long. If this were correct, then timings of minima could be made with very little observational effort.

Table 1

Observed minima of BV Tau

Helio JD (244....)	*Cycle No.*	*O–C (d)*	*Number of estimates*
5053.316:	0	+0.006:	1
5079.373:	28	+0.010:	1
5414.323:	388	-0.009:	1
5440.368:	416	-0.018:	1
5815.392:	819	+0.027:	1
6052.633	1074	-0.002	12

Cycle No. and *O–C* are based on the revised elements derived in the text.

BV Tauri

This object was listed in the 1969 catalogue[2] as a Beta Lyrae variable with photographic range $11^m.7$–$12^m.4$, secondary minimum $11^m.9$, and elements

$$\text{Min I} = 2425952.0 + 12.349\,E.$$

The reference is to a 1938 report by Kanda[4], according to which these elements were determined from only 13 photographic observations made in the period 1929 December to 1930 January, and 18 visual estimates in 1938 February to April. The catalogue adds a remark that the elements require confirmation. The 1971 supplement[5] repeats these details with the addition that the spectral class is B9, but notes that the identification on the spectral plate is uncertain.

Brelstaff began observations of BV Tau in 1981 August, and by 1984 October had made one estimate on each of 66 nights. The comparison stars used are indicated in figure 1. It had become evident early on that the period was not 12.349 days, but it was not obvious what the true period was.

The observations were then reported to the second author, John Isles, who is Secretary of the BAA Variable Star Section's Eclipsing Binary Programme. The true period was then identified in the following way.

BV Tau had been seen fainter than usual at about the following times in 1982 February to April:

JD 2445014.27
040.30
053.32
079.38

The successive intervals are 26.03, 13.02 and 26.06 days. This suggested that the period was about 13.02 days, or a submultiple thereof. An observation had however been made at about JD 2445027.38, showing BV to be bright. This was less than 0.1 day after a minimum should have occurred if the period were 13.02/n days. The duration of minimum was therefore probably no more than 0.2 day. But about one-fifth of the observations showed BV to be faint, so the duration of minimum was probably at least one-fifth of the period. The period was therefore probably less than a day.

The first period tried, 13.02/14 = 0.93 day, was immediately found to fit all the 1982 observations well—better in fact than any other submultiple of 13.02 days down to about 0.3 day. Observations in other years appeared to confirm that this period was about right, and by using a 'length of a piece of string' computer search of the kind described by Dworetsky[6], the period was refined to 0.9304 days.

To be absolutely certain that the revised period was correct, it was necessary to observe a predicted minimum and verify that its duration was about 0.2 day. Accordingly, a minimum was predicted for 1984 December 17, between 14 and 15 hours GMAT. This was successfully observed by Brelstaff. At 12.29 GMAT the star had begun to fade; minimum was reached at about 15 hours; and observations were continued until 16.15 when it was still on the rise. The revised period was thus confirmed, and a preliminary announcement was published[7].

Table 1 lists the times when BV Tau was seen at its faintest, that is, below grade 9 on the scale of the relative brightnesses of the comparison stars (see figure 1). The first five times are those of single faint estimates, which give only approximate times for the minima, but the last is the observed time of the minimum on 1984 December 17, determined using the computer programs adopted for reducing the results of the Eclipsing Binary Programme[8]. The best-fitting elements determined by least squares (with standard errors) are:

$$\text{Min I} = 2445053.31 + 0.93047\,E.$$
$$(0.01)\quad(0.00002)$$

A second solution, obtained by giving the last observation ten times the weight of the others, gave the same result, to the above level of rounding.

Using these elements, the mean light curve was derived (figure 2). The light curve is typical of a Beta Lyrae variable. The minima have depths of about $0^m.7$ and $0^m.2$, in exact agreement with the catalogue.

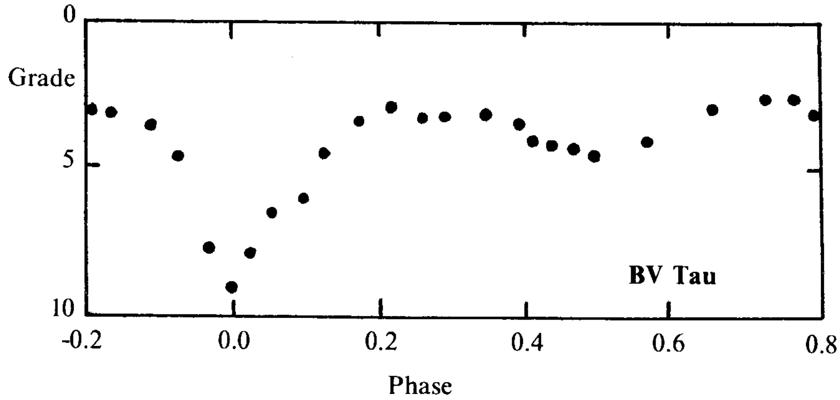

Figure 2. Mean visual light curve of BV Tau, from observations by Brelstaff 1981-84. Phases are against the revised elements derived in the text. Each point is the mean of about four estimates.

Most Beta Lyrae systems have periods longer than a day. Eclipsing binaries with periods less than a day are usually either of the Algol type (with nearly constant brightness between eclipses), or of W UMa type (with continuously varying brightness, and minima of approximately equal depth.) The short period of BV Tau is however by no means exceptional for a Beta Lyrae star.

GR Tauri

This object was listed in the 1969 catalogue as an Algol variable with photographic range $10^m.3$–$10^m.9$, secondary minimum $10^m.5$, and elements

$$\text{Min I} = 2426350.355 + 0.474012\,E,$$

the reference being to a 1963 report by Strohmeier and others[9]. The spectrum is given as approximately A9. The Cracow yearbook indicates that timings of minima have been reported from time to time, but details are not given.

Brelstaff began observations of GR Tau in 1981 August, at the times of minima predicted by Cracow. The comparison stars used are indicated in figure 3. It soon became evident that minima were not occurring at the predicted times, and so observations of GR Tau were made at every opportunity to enable the true period to be determined. By the end of 1984, 369 estimates had been made on 61 nights. They yield the 12 timings of minima listed in table 2, after reduction by Isles using the computer programs mentioned earlier. The variable was also seen faint on several other occasions, but reliable timings could not be derived as the observations did not cover both the fade and the rise.

The approximate length of the true period was determined from the 1982–3 data by noting that the intervals between minima in each apparition were close to multiples of 0.43 days. By experiment, a value of 0.42985 days was found to link together satisfactorily the timings made in different apparitions, the single timing in 1981 turning out to be of a secondary minimum.

The final estimate of the period was made when the data from 1984 had become available. This was made by a least squares fit to the data, giving half weight to the primary minima indicated as uncertain in table 2 (either because the observations were somewhat discordant, or because there was incomplete coverage of one branch of the curve). Secondary minima were not used, because we could not safely assume that they fell exactly half-way between primary minima. The result (with standard errors) is:

$$\text{Min I} = 2444982.334 + 0.429853\,E.$$
$$(0.008) \quad (0.000006)$$

The revised period as determined by Isles was close to a value that Brelstaff had independently identified as a possible period.

The correctness of the revised elements was verified by checking that GR Tau had been seen fainter than usual on all occasions when a primary minimum was to be expected and observations had been made.

Strohmeier *et al.*[9] list 24 minima between 1931 and 1962, the times presumably being those of patrol plates on which GR Tau appeared faint. These all fit the catalogue elements within $\pm 0^d.07$, and the revised elements within $\pm 0^d.09$. But the times would fit any period of around $0^d.4$ within at worst $\pm 0^d.1$, because each time must be within $0^d.1$ of either a primary or a secondary minimum. We have not been able to use these early data to refine the elements, because of uncertainty in the numbers of cycles between times so far apart.

Table 2

Observed minima of GR Tau

Helio JD (244....)	*Cycle No.*	*O–C (d)*	*Number of estimates*
4841.599:	-372.5	+0.042:	4
4982.335	0	+0.001	8
5012.422	70	-0.002	10
5052.394:	163	-0.006:	11
5198.539:	503	-0.011:	4
5322.355	791	+0.007	11
5326.226:	800	+0.010:	8
5341.263	835	+0.002	5
5671.388	1603	0.000	11
5674.384	1610	-0.013	8
6059.338	2505.5	+0.007	8
6059.548	2506	+0.002	11

Cycle No. and *O–C* are based on the revised elements derived in the text.

Using the revised elements, the mean light curve was derived from Brelstaff's observations (figure 4). The depths of the minima appear to be only $0^m.3$ and $0^m.1$, compared with the catalogue's $0^m.6$ and $0^m.2$. The caption to figure 3 gives the magnitudes of the comparison stars, based on Brelstaff's step estimates. These have been checked by Isles on an approximately photovisual photograph by the late Walter Pennell, against the AAVSO sequence for the nearby Mira star AK Tauri, and they appear to be correct. It seems safe to conclude that the mean visual amplitude of GR Tau is only half the photographic range as given in the catalogue. The mean visual range is $10^m.5$–$10^m.8$, with Min II = $10^m.6$.

It should, however, be noted that the observed depths of secondary minima have varied. The two secondary minima listed in table 2 had recorded depths of about $0^m.2$, whereas on other nights little or no variation was recorded at the phase of secondary minimum. The mean curve shows an average depth of only $0^m.1$. In view of the limitations of visual observation (accidental error, variation of step value, bias, *etc*) it is not possible to draw any firm conclusions on whether the depths of minima have really changed.

GR Tau does not seem to be an Algol system, as classified in the catalogue. The light curve appears to show continuous variation. It is possible that there is a constant phase between eclipses, but the duration of eclipse seems to be at least 0.35 of the period. This would be exceptional for an Algol star.

The shape of the light curve is indicative of Beta Lyrae type, though a period of 0.43 days is rather short for this class. Among Beta Lyrae systems listed in the Cracow yearbook, only W Corvi has a shorter period ($0^d.39$), but its minima are of nearly equal depth ($A_1 = 0^m.6$, $A_2 = 0^m.5$) and its B-V colour index (+0.66 at maximum) puts it neatly on the well-established period-colour relation[10] for W UMa stars, so W Crv may be wrongly catalogued as a Beta Lyrae star. There is, however, no reason in theory why a non-contact binary should not have a period as short as $0^d.43$; in fact, the difficulty for theory is that there are no observed systems with periods shorter than $0^d.4$ that show Beta Lyrae type light curves[10].

The inequality of the minima of GR Tau would be inconsistent with its being a W UMa star (contact binary). ER Vul[11] ($A_1=0^m.22$, $A_2=0^m.08$, $P=0^d.70$) would be an apparent precedent, though its G0V+G5V spectrum implies a B-V of about +0.7, which does not fit the period-colour relation for W UMa stars. ER Vul may therefore also be a Beta Lyrae star. The A9: spectrum of GR Tau implies a B-V of about +0.2 which again does not fit the period-colour relation for W UMa stars.

We conclude that GR Tau is probably a Beta Lyrae variable with a particularly short period.

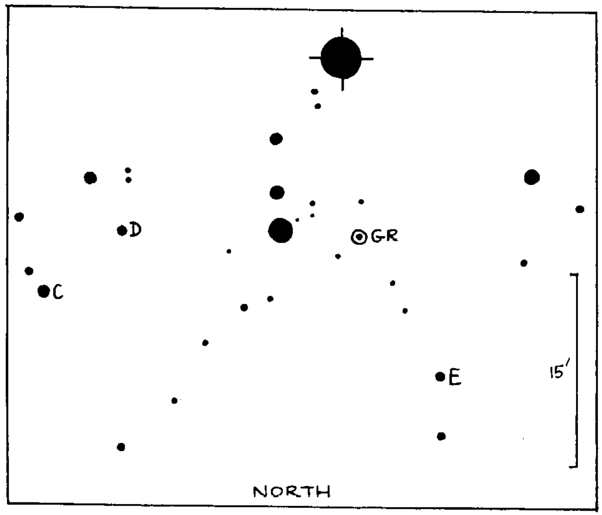

Figure 3. Field chart for GR Tau (1950.0: 03^h $58^m.1$, +20° 17′). Grades of comparison stars have been derived from Brelstaff's step estimates as follows: C=5.0; D=7.4; E=10.3. If the mean visual magnitude is the same as the mean photographic magnitude according to the catalogue, these equate to the following magnitudes: C=10.4; D=10.6; E=10.9.

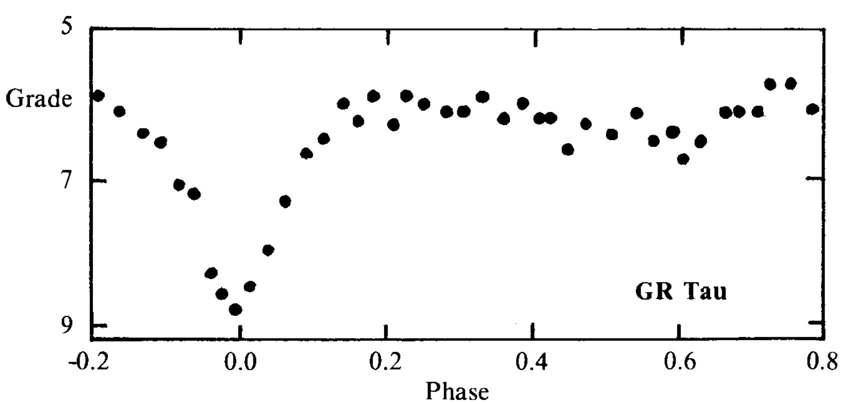

Figure 4. Mean visual light curve of GR Tau, from observations by Brelstaff 1981-84. Phases are against the revised elements derived in the text. Each point is the mean of nine estimates.

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