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Analysis of AAVSO Visual Measurements of T Tauri Variable Stars

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Abstract T Tauri stars are stars in the final stages of birth, in which accretion from a circumstellar disc of gas and dust is still taking place. By some definitions, T Tauri stars include only GKM types; in this paper, we include higher-mass pre-main-sequence variables as well. AAVSO observers have made tens of thousands of visual measurements of T Tauri stars, but most of the measurements were never validated because their scientific value was not clear. We have used Fourier and self-correlation techniques to analyze AAVSO visual measurements of eleven T Tauri stars, namely AB Aur, RW Aur, SV Cep, R CrA, S CrA, RY Lup, R Mon, UX Tau, BP Tau, DL Tau, and WW Vul. We have compared the results to those obtained from long-term CCD measurements of the same stars. Using our methods of analysis, it is possible to detect periods, even if the amplitude is only a few hundredths of a magnitude, or to set upper limits, as small as 0.01 magnitude, on any periodic component to the variability. For each star, periodic or not, we have determined the variability "profile"—the relation between time scale and amount of variability. We conclude that the AAVSO visual measurements of T Tauri stars have definite scientific value. It would therefore be desirable to validate the visual measurements of other T Tauri stars.

1. Introduction

Classical T Tauri stars are sun-like stars in the final stages of birth, in which accretion from a circumstellar disc of gas and dust is still taking place. T Tauri stars are actually defined not by their photometric variability but spectroscopically, on the basis of a cool spectrum, excess continuum emission, strong emission in selected lines, and lithium absorption lines indicative of youth. See Jayawardhana (2000) for an excellent non-technical review of star and planet birth.

In addition to the classical T Tauri stars (CTTS), there are weak-line (WTTS) or "naked" T Tauri stars that have little or no accretion disc left, Herbig Ae/Be

(HAEBE) stars that are higher-mass analogues of T Tauri stars, and FU Orionis stars—rare T Tauri stars that undergo brightenings of several magnitudes, followed by slow declines; also, F and G type T Tauri stars are occasionally referred to as GTTS (Herbst *et al.* (1994). The *General Catalogue of Variable Stars* (GCVS, Kholopov *et al.* 1985) has a descriptive classification system for T Tauri variable stars which seems to have little or no physical significance. In this paper, we use the general term "T Tauri star" to include both the classical (GKM-type) stars, and also the higher-mass relatives.

All T Tauri stars are photometrically variable, in different and sometimes multiple and complex ways. They can exhibit periodic variability due to the rotational modulation by hot or cool spots, or large or small random variability and flickering due to non-steady accretion from the disc. A few T Tauri stars undergo eclipsing variability by a companion star and/or its disc. Others may undergo variable obscuration by their disc.

The most extensive studies of the photometric variability of T Tauri stars are by Herbst and his collaborators (e.g., Herbst *et al.* 1994). They classify T Tauri stars, according to their photometric variability, as

- Type I: cyclic variations with periods of 0.5 to 18 days or more, seen mostly in WTTS, and due to rotational modulation by cool starspots;

- Type II: generally irregular variations on time scales of hours to days, seen mainly in CTTS, and due to variable accretion; some rotational variability, caused by hot spots, may also be present;

- Type IIp: like Type II, but quasi-periodic;

- Type III, or UXors (named after UX Ori): generally irregular variability on time scales of days to weeks; possibly due, in some cases, to variable circumstellar obscuration, but more often due to variable accretion (Herbst and Shevchenko 1999).

An important criterion for classification and understanding of T Tauri stars is the presence of periodicity. This periodicity may be strict, or it may be semiregular. For instance: if the variability is due to rotational modulation by cool spots, the rotation will be periodic, but the spots may disappear and reappear at different longitudes on the star.

But periodicity is difficult to detect in T Tauri stars because of the complexity of the variation, and because the periodic component may be semiregular at best. Some claims of periodicity are based on insufficient data or inadequate analysis (Herbst and Wittenmyer 1996; Herbst 2001). With care, periods can be determined; Lamm *et al.* (2004) have recently identified and studied 543 periodic variables in NGC 2264, as well as 484 irregular variables.

Self-correlation, a simple form of time series analysis, has proven to be useful in studying variable stars which are only semiregular (e.g., Percy and Mohammed 2004 and references therein). Percy *et al.* (2006) therefore undertook a pilot project to reanalyze long-term CCD measurements of T Tauri stars, obtained by Herbst and his collaborators, using self-correlation as an adjunct to Fourier analysis. The project was successful, and was continued by Percy *et al.* (2007).

In this paper, we use both self-correlation and Fourier analysis. The latter is carried out using the publicly-available Period04 package (Lenz and Breger 2005). For T Tauri stars, the Fourier spectrum characteristically rises at low frequencies, because of the irregular slow variations. The spectrum may, of course, show peaks if there are periodic components to the variability. The challenge is to distinguish real peaks from peaks which are a result of observational "noise."

The self-correlation package is publicly available at: http://www.astro.utoronto.ca/~percy/index.html.

2. Self-correlation analysis

Self-correlation analysis is a simple method of time-series analysis which measures the cycle-to-cycle behavior of the star, averaged over all the data. For all pairs of measurements, the difference in magnitude (Δmag) and the difference in time (Δt) are calculated, and binned in Δmag; the average Δmag in each bin is then plotted against Δt from zero up to some appropriate upper limit which, if possible, is a few times the expected period, but less than the total time span of the data. In the present project, for instance, we might expect rotational periods of a few days, or eclipse periods of a few tens of days. Useful features of the self-correlation diagram are:

- there are minima at multiples (N) of any period or time scale, each of which can be used to estimate the period;
- the level of the zeroth minimum (the one at Δt = 0) is a measure of the measurement error; it may also reflect very rapid variability (see section 5.1);
- minima will gradually disappear, with increasing N, if the periodicity is not strict;
- the difference between the levels of the minima and maxima, especially for small N, is about 0.9 times the amplitude (half-range) of the variability; the factor 0.9 is determined from the analysis of synthetic data;
- even in stars with no periodicity, the self-correlation diagram provides a "profile" of the variability—the average change in magnitude for a given difference in time between the measurements.

In the Figures, we will call attention to some representative examples of applications of self-correlation diagrams.

3. AAVSO visual observations of T Tauri stars

T Tauri stars tend to be concentrated in regions of star formation, such as the Orion Nebula. They are therefore relatively easy for visual observers to measure in large numbers, as little or no telescope movement is needed between variable star fields. However, great care needs to be taken with visual observations of the stars in the Orion Nebula region because of the nebulosity; AAVSO Director Janet A. Mattei believed that a strict observing protocol needed to be followed to yield the most scientifically valuable data. The AAVSO recognizes observers who make the largest numbers of measurements in each fiscal year. In 1978–1979 and 1979–1980, the leading observers were ones who made large numbers of measurements of T Tauri stars in the Orion Nebula region. The majority of these measurements were made without adequate documentation or observing protocol. In 1980–1981, to discourage indiscriminate observations of the Orion Nebula variables, the AAVSO Director therefore discounted measurements of T Tauri stars in the Orion Nebula region: in her annual report, she stated "The totals also include the 1,500 adjusted observations of the Orion variables, in which ten observations are counted as one, as detailed in my February 1981 letter to observers" (Mattei 1981). Thereafter, the measurements languished, due both to the discounted total policy and the observing protocol requirement. Most of the data on T Tauri stars were not validated (quality-controlled) when many other measurements in the AAVSO International Database were (Malatesta *et al.* 2006), and they were not available on-line (though the unvalidated measurements can be displayed on the light-curve generator on the AAVSO website). They were excluded from the two-year validation project because a very significant amount of staff time would have been needed to assess the data, and their scientific value was uncertain. (They were slated to be validated in the next round, which would also include the many suspected variables also excluded from the validation project due to time limits.)

Great progress has been made, in the last decade, in understanding star formation. Furthermore, the analysis of the CCD measurements by Herbst and others demonstrates the kind of information that could be gleaned from studies of T Tauri star variability. It also provides a possible model for the analysis of the visual measurements. AAVSO staff kindly validated the visual measurements of several T Tauri stars, and provided them to us.

The eleven stars analyzed were chosen on the basis of two criteria: adequate number and time-span of the visual measurements, and available results of the analysis of long-term CCD photometry of the same stars. Some of the stars were known or suspected to be periodic based upon CCD photometry, and we wanted to see whether the same period was detectable in the visual measurements.

The measurements were typically made by 10–20 different observers; their names can be accessed by calling up the star on the light-curve generator on the AAVSO website. They used a variety of small-to medium-sized telescopes, and made their measurements using standard AAVSO charts and comparison stars. In some cases, the measurements may have been complicated by the presence of nebulosity around the star. For each star, the average measurement error can be estimated from the self-correlation diagram.

4. Results

Table 1 lists the eleven stars that were studied, giving the GCVS type, photometric range and filter, and spectral type, all taken from the SIMBAD database, the sub-class according to Herbst's database, and the value of Δmag at Δt = 0 from the visual (E(vis)) and the CCD (E(CCD)) measurements.

We compare the results of the analysis of the visual measurements with those of the CCD measurements, which will be reported elsewhere (Percy, Grynko, and Herbst 2007, in preparation).

4.1. AB Aur

This is one of the brightest T Tauri stars. The visual measurements are mostly between 6.5 and 7.5; the light curve amplitude is small. The Fourier spectrum is featureless, except for rising at low frequencies, i.e., there is some variability on long time scales. In the self-correlation diagram (Figure 1), there is no coherent, cyclic variability ≥ 0.005. (Here and throughout, the units associated with the self-correlation diagram are magnitudes.) The diagram rises only slightly from 0.18 (the value of Δmag at Δt = 1 day) to 0.19 at Δt = 40 days, indicating little or no variability on time scales of 1 to 40 days.

The CCD measurements show little or no variability, with absolutely no evidence of periodicity at the millimag level. The self-correlation diagram rises from 0.016 (the measurement error) to 0.026 at Δt of tens of days.

Shevchenko *et al.* (1993) propose a period of 2.92 days for this star. We find absolutely no evidence for this period.

4.2. RW Aur

The visual light curve varies slowly between about 9.5 and 12.0. The Fourier spectrum is featureless, except for rising at low frequencies. The self-correlation diagram (Figure 2) rises rapidly from 0.3 at Δt = 0.5 day to 0.4 at Δt = 2 days, indicating considerable random variability on these short time scales. But there are no coherent, cyclic variations ≥ 0.01.

There are 563 CCD measurements. The Fourier spectrum shows a *weak* peak at a period of 5 days and an amplitude of 0.1, and there are also *weak* minima in the self-correlation diagram at 5 and 10 days, also with an amplitude of 0.1. The Fourier spectrum shows peaks at about 50 days, but there is no corresponding signal in the self-correlation diagram.

We conclude, from both sets of measurements, that there is no detectable cyclic variability in this star. The visual measurements provide the more complete picture of the variability.

4.3. SV Cep

The visual light curve ranges between 10 and 12, and is a bit sparse; there is some slow variability. The Fourier spectrum is featureless except for rising at low frequencies. The self-correlation diagram shows no coherent, cyclic variations with amplitudes greater than 0.03 magnitude.

There are 912 CCD measurements. The Fourier spectrum is featureless except for rising at low frequencies. There is no periodic signal in the self-correlation diagram. The light curve is dominated by non-periodic waves with time scales of hundreds of days.

4.4. R CrA

The visual light curve ranges between 11 and 14; this star is quite variable. The Fourier spectrum (Figure 3) shows peaks at about 65 days and half this value; this suggests a 65-day variation with a non-sinusoidal light curve. This period is confirmed by the self-correlation diagram (Figure 4), which shows minima at multiples of 66 days. The difference between maxima and minima corresponds to a half-amplitude of 0.13. The value of Δmag at $\Delta t = 0$ is 0.25 or less. The height of the minima is 0.55. This means that there are sources of random variability, on time scales of tens of days, above and beyond the measurement error.

A photometric period of 65 days has been noted in the literature for this star (Shevchenko *et al.* 1993) but is not mentioned in the many subsequent papers on this star. The CCD measurements are very sparse, but their Fourier spectrum shows several peaks at 30–40 days. The self-correlation diagram has minima at 45 and 70 days, but these are based on very sparse data. This is not inconsistent with the visual results, but the visual measurements provide a more complete picture of the variability of this star than do the CCD measurements.

4.5. S CrA

The visual light curve ranges between 11 and 13, with no obvious systematic long-period variations. The Fourier spectrum (Figure 5) shows a small peak at 6 days, but is otherwise featureless except for rising at low frequencies. This period is confirmed by the self-correlation diagram (Figure 6), which shows minima at multiples of 6.0 days. The difference between maxima and minima corresponds to a half-amplitude of the periodic component of only 0.03 ± 0.01!

There are 189 CCD measurements, but they are spread over 4500 days, and the observing seasons are very short. The Fourier spectrum has many peaks in the range of 3–5 days, and suffers from severe aliasing. There is no clear signal in the self-correlation diagram, though it is not inconsistent with a period of about 6 days and a small amplitude. Again, the visual measurements provide the more complete picture of the variability of this star.

4.6. RY Lup

The visual light curve ranges between 9.5 and 13.5, and shows slow, irregular variations. The Fourier spectrum (Figure 7) rises at low frequencies, and also shows a peak at 0.265 cycle/day (period 3.7 days). This period is confirmed by the self-correlation diagram (Figure 8), which shows minima at multiples of 3.7 days. The difference between maxima and minima corresponds to a half-amplitude of 0.1.

There are 152 CCD measurements. The Fourier spectrum and the self-correlation diagram are both consistent with a period of 3.75 days, with an amplitude of several tenths of a magnitude! The periods derived from the visual and CCD measurements are thus consistent.

The difference between the amplitudes derived from the visual and the CCD measurements may be due to the different time spans that they cover. The amplitude of the rotational modulation can vary on time scales of years (Percy *et al.* 2007).

4.7. R Mon

The visual light curve ranges from 10 to 13.5, and is densely covered. The Fourier spectrum is featureless, except for rising at low frequencies. There is a hint of a peak at a frequency of 0.035 cycle/day (about 30 days), but there is no evidence for this in the self-correlation diagram, which shows no coherent, cyclic variability greater than 0.02. The value of Δmag at $\Delta t = 0$ is 0.56. This may be due to both measurement error, and rapid variability. If it reflects measurement error, the large value may be due to the difficulty of measuring the variable stars and the comparison stars in this very nebulous region of the sky.

The CCD measurements are very sparse; they number 72, spread over about ten seasons. The Fourier spectrum provides no useful information. The self-correlation diagram shows a possible minimum at 12–14 days, but this is based on very sparse data.

4.8. UX Tau

The visual light curve ranges from 10 to 12, and occasionally fainter. The Fourier spectrum is generally featureless, except for rising at low frequencies; there is a hint of a peak at a frequency of 0.04 cycle/day (25 days) with an amplitude of 0.08, but this is not confirmed by the self-correlation diagram, which shows no coherent, cyclic variability greater than 0.05.

There are over 400 CCD measurements, but the observing seasons are rather short. The Fourier spectrum shows several peaks at 30–40 days and an amplitude of 0.2. The self-correlation diagram shows a clear minimum at 32 days with an amplitude of 0.2, and shallower minima at about 70 and 100 days. At $\Delta t = 0$, the Δmag is over 0.3 mag. This is too large to be measurement error, for CCD photometry. It must reflect a large amount of rapid flickering in this star.

4.9. BP Tau

The visual light curve ranges from 11.5 to 12.5 with no obvious systematic long-term variations. The Fourier spectrum is featureless except for rising at low frequencies. The self-correlation diagram is also featureless, rising from 0.16 at $\Delta t = 1$ day to 0.20 at $\Delta t = 40$ days. This indicates little or no variability on these time scales. In particular, there is no coherent periodic variability greater than 0.02.

There are 547 CCD measurements. Neither the Fourier spectrum nor the self-correlation diagram shows any coherent periodic signal greater than 0.01 mag. For Δt greater than 10 days, the Δmag is about 0.15 mag, including measurement error.

4.10. DL Tau

The visual light curve ranges from 12 to 14, and is rather sparse. The Fourier spectrum is featureless except for rising at low frequencies. There is a hint of a peak at 0.2 cycle/day (5 days), but this is not confirmed by the self-correlation diagram, which shows no coherent, cyclic variability greater than 0.03.

There are 347 CCD measurements. The Fourier spectrum shows a strong peak at 9.35 days, with an amplitude of 0.13 mag. The self-correlation diagram is consistent with this, but suggests a smaller amplitude. At $\Delta t = 0$, the Δmag is over 0.2, which is much larger than the expected measurement error, suggesting a high level of rapid flickering in this star. The self-correlation diagram plateaus at $\Delta mag = 0.3$.

The Fourier spectrum of the visual measurements is noisy; a 9-day signal as large as 0.08 could be present. In the self-correlation diagram, there is a minimum at 9 days but not at 18 or 27 days; the amplitude of a 9-day signal is less than 0.05.

4.11. WW Vul

The visual light curve (Figure 9) ranges between 10.2 and 11.4, with slow variations, typically occurring on time scales of tens of days. There are also unusual discrete minima reaching 12.6 (Table 2). The Fourier spectrum is featureless, except for rising at low frequencies. There is a hint of a peak at 0.035 cycle/day (about 30 days), but this is not confirmed by the self-correlation diagram, which shows absolutely no coherent, cyclic variability greater than 0.01. It rises from 0.17 at 1 day to about 0.23 at $\Delta t = 40$ days, indicating little or no variability on these time scales.

There are 861 CCD measurements. The light curve is characterized by many minima of up to one magnitude deep. The Fourier spectrum shows no particular features, but the self-correlation diagram shows shallow (0.04) minima at 30 and 70 days. It plateaus at $\Delta mag = 0.3$; its value at $\Delta t = 0$, namely 0.1 mag, suggests that there is significant rapid flickering in this star. Shevchenko *et al.* (1993) propose periods of 1.11 years, 43: days, and 6.2 days for this star. We find no evidence for any of these periods. Further observation and analysis of this star, especially its deep minima, would be worthwhile.

5. Discussion

5.1. Observational error and rapid variation

As Δt approaches zero, the value of Δmag approaches the measurement error, since two measurements that are very close in time will differ only because of measurement error. T Tauri stars may also vary physically on very short time scales, due to flickering and flaring as accreted material impacts the star. Unfortunately the stars are most often observed once a night, so it is difficult to separate the effects of measurement error, and flickering.

One way to approach this problem is to compare the visual measurements with the CCD measurements, in which the measurement error should be about 0.02. These values are tabulated in the last two columns in Table 1. For some stars, there is clearly variability on short time scales because, for the CCD measurements, the value of Δmag, at Δt = 0 is much larger than 0.02. For the visual measurements: in most cases, the value of Δmag at Δt = 0 is close to the expected measurement error of 0.15–0.25, suggesting that the short-term variability is small.

5.2. Period determination

The most pleasant surprise in this project was that, using the combination of Fourier and self-correlation analysis, we could detect significant periods in the visual data, even when the amplitude was only a few hundredths of a magnitude. In fact, we could set upper limits to the amplitude of the periodicity, in some cases, of less than 0.01 mag (e.g. Figure 1). The periods of S CrA (6.0 days) and RY Lup (3.75 days) are consistent with rotational modulation. The 65-day period of R CrA is most likely due to eclipses. Periods of days would normally arise from rotational modulation. Periods of weeks are likely due to eclipses by a companion and/or its disc. Because of the spacing of the data, we cannot reliably detect periods less than a day.

5.3. Variability profile

For each of the stars, the self-correlation diagram provides a "profile" of the variability—the average Δmag for any given Δt (e.g. Figure 2). That average will be a combination of the measurement error (section 5.1) and the actual variability at that Δt.

5.4. Comparison between visual and CCD results

For most of the stars, the results of the analysis of the visual measurements are consistent with those of the CCD measurements. In some cases, the visual data provide the more complete picture of the variability; in one or two others, the CCD data provide the more complete picture. In one or two cases, the results are somewhat inconsistent, either because the results of one or the other dataset are marginal, or because of the limitations of the datasets, or possibly because the variability of the star changes on time scales of years or decades; the visual and CCD data do not necessarily cover the same time span.

5.5. An additional role for visual observers

Although we have not shown any examples here, it is possible that systematic visual observers can discover new examples of FU Orionis stars—T Tauri stars that increase in brightness by several magnitudes over weeks to months, then fade more slowly. Since FU Orionis stars are rare, and their brightenings are poorly-understood, such discoveries would be a significant contribution to this research field. Observers who become familiar with star fields such as the Orion Trapezium should be on the lookout for such events.

Likewise, visual observers should be on the lookout for T Tauri stars that fade by several magnitudes. These may be undergoing eclipse by circumstellar matter. WW Vul may be an example of such a star.

6. Conclusions

The most important conclusion is that the AAVSO visual measurements of T Tauri stars have scientific value. In some cases, they provide a more complete picture of the variability than long-term CCD measurements. Despite their lower accuracy, they may be more numerous and cover a greater time span with fewer gaps. AAVSO Headquarters staff kindly validated the measurements of the eleven stars that we have reported. Measurements of all other T Tauri stars in the visual program should be validated also. Because of the number and time span of these data, they can potentially provide information about the variability profile (including periodicity) of T Tauri stars, and how the profile is related to the physical properties of the stars. This, in turn, will help astronomers understand the complex processes of star and planet formation.

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Table 1. Characteristics of the T Tauri variable stars studied.

Name	*GCVS Type*	*GCVS Range/ Filter*	*Spectral Type*	*Sub-class*	*E(vis)*	*E(CCD)*
AB Aur	INA	6.9–8.4V	B9neqIV-V	HAEBE	0.18	0.014
RW Aur	INT	9.6–13.6p	G5Ve(T)	CTTS	0.30	<0.08
SV Cep	ISA	10.35–12.15V	A0ea	HAEBE	0.15	0.025
R CrA	INSA	10.0–14.36B	A5IIpe	HAEBE	0.25	0.20!
S CrA	INT	10.49–13.2V	Ge(T)	CTTS	0.28	0.16
RY Lup	INSB	9.9–13.0p	G0Vea	GTTS	0.30	<0.06
R Mon	INA	11.0–13.8	A3:e-Fpe	HAEBE	0.56	0.13:
UX Tau	INT	10.6–13.7p	G0Ve-K2Ve(Li)	CTTS	0.35	0.33!
BP Tau	INT(YY)	10.7–13.6	K3Ve-M0Ve(T)	CTTS	0.16	<0.04
DL Tau	INST(YY)	13.4–15.9B	GVe-K7Ve(T)	CTTS	0.19	0.21
WW Vul	ISA	10.25–12.94V	A3ea	HAEBE	0.17	0.05

Table 2. Minima of WW Vul fainter than magnitude 11.5 (an arbitrary value chosen by the authors).

Julian Dates 2400000+			
41121	44770	47030	49952
41170	44820	47270	50355
41593	44858	47716	50370
41842	44867	49130	50390
41894	46327	49213	50690
42003	46350	49237	50740
43705–43750*	47020	49785	50940

**(the star appeared to remain below 11.5 during this period)*

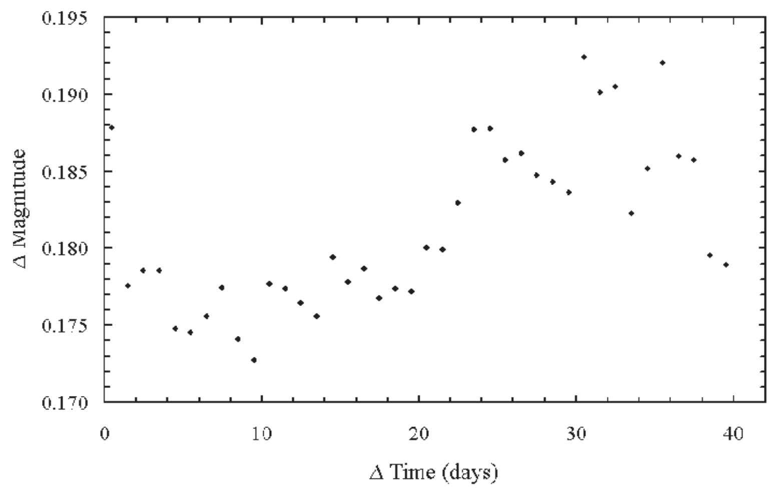

Figure 1. The self-correlation diagram of AB Aur. In this and Figures 2, 4, 6, and 8, the value of Δmag, as Δt approaches zero, is a measure of the measurement error, and of very rapid variability, if any. There are no repeated minima in the diagram, i.e., at integral multiples of a basic period, greater than 0.005 magnitude.

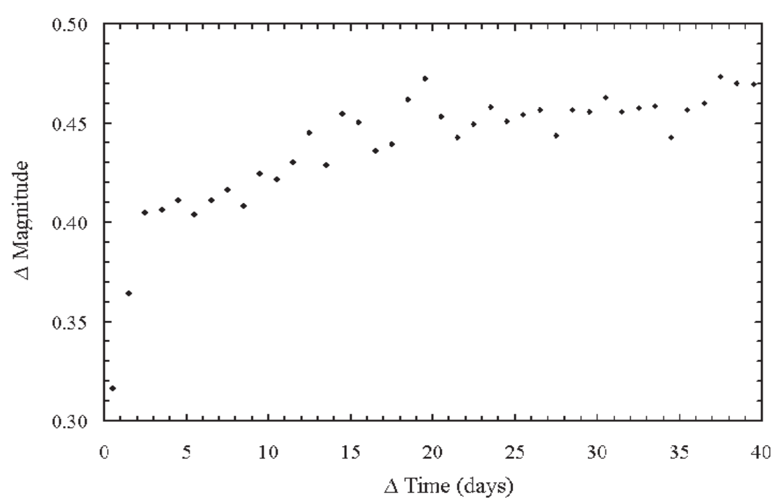

Figure 2. The self-correlation diagram of RW Aur. The value of Δmag rises rapidly from 0.31 or less at Δt = 0.5 day to 0.40 at Δt = 2 days, indicating significant variability on time scales less than 2 days. There are no repeated minima with amplitude greater than 0.01 magnitude.

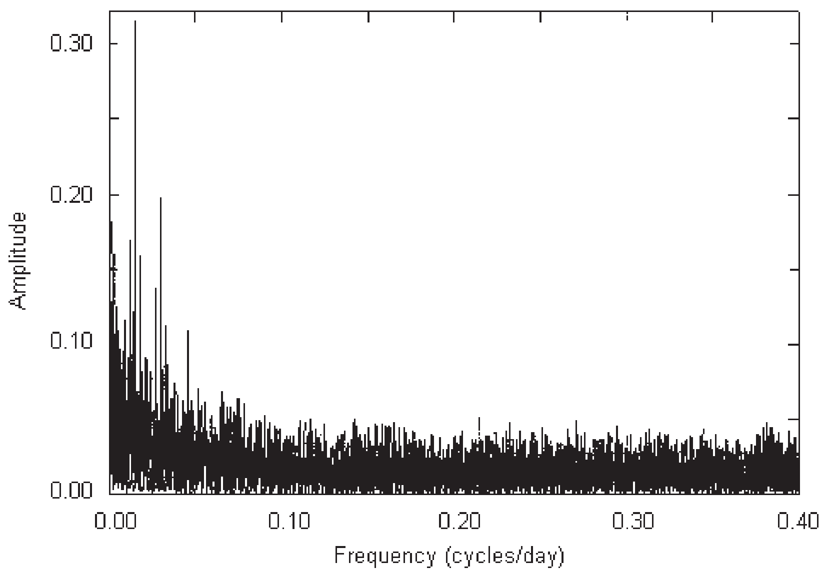

Figure 3. The Fourier spectrum of R CrA. In this and Figures 5 and 7, the spectrum rises at low frequencies, indicating slow variability. There is a peak at 0.0154 cycle/day (period 66 days); the same period is found in the self-correlation diagram in Figure 4.

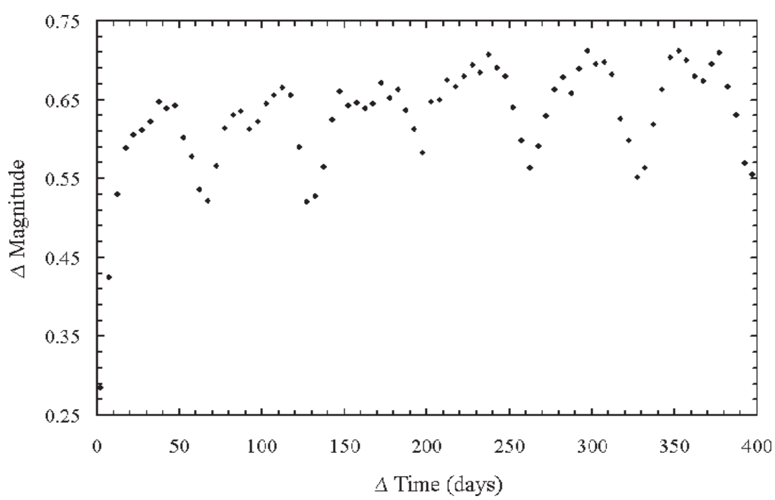

Figure 4. The self-correlation diagram of R CrA. There are minima at multiples of 66 days; the difference between maxima and minima corresponds to an amplitude of 0.13 magnitude.

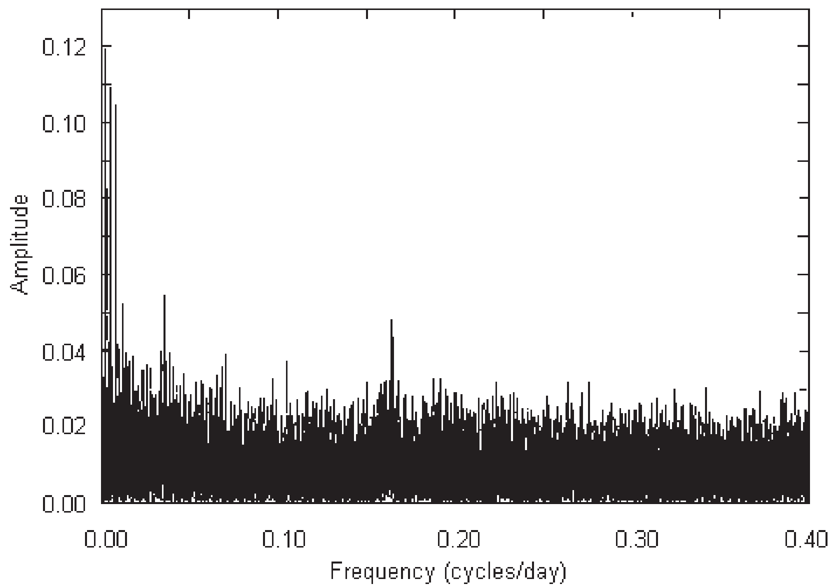

Figure 5. The Fourier spectrum of S CrA. There is a peak at 0.16 cycle/day (period 6 days); the same period is found in the self-correlation diagram in Figure 6.

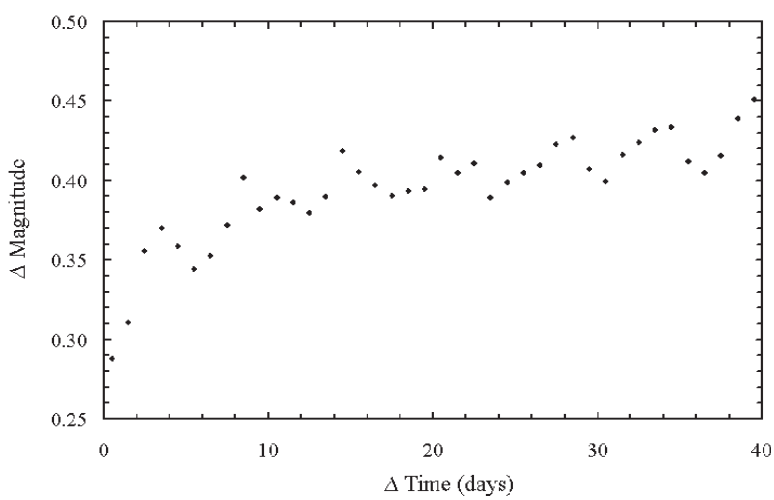

Figure 6. The self-correlation diagram of S CrA. There are minima at multiples of 6.0 days; the difference between maxima and minima corresponds to an amplitude of only 0.03 magnitude.

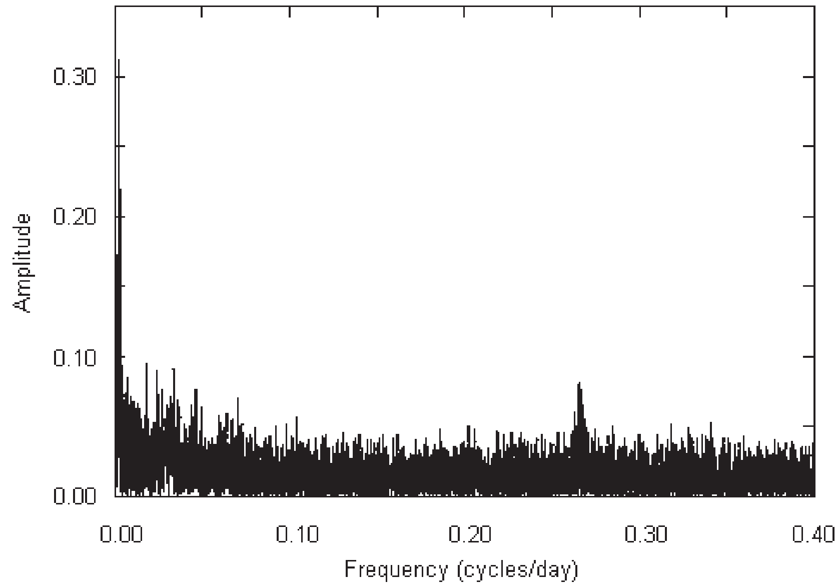

Figure 7. The Fourier spectrum of RY Lup. There is a peak at 0.267 cycle/day (period 3.75 days); the same period is found in the self-correlation diagram in Figure 8.

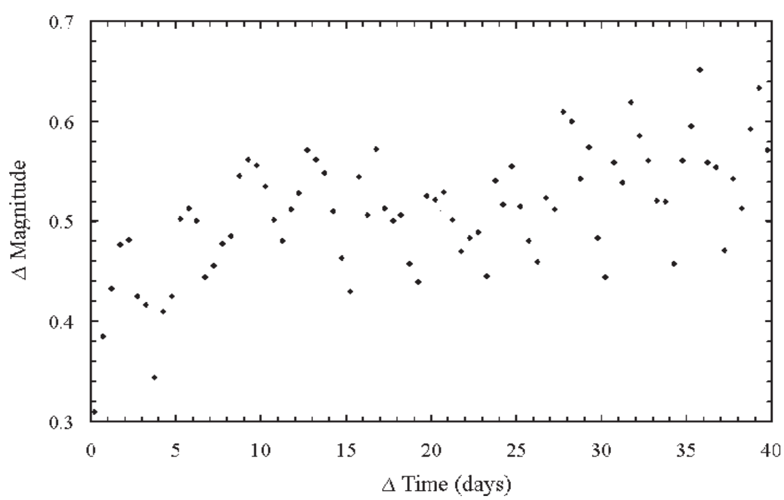

Figure 8. The self-correlation diagram of RY Lup. There are minima at multiples of 3.75 days; the difference between maxima and minima corresponds to an amplitude of 0.10 magnitude.

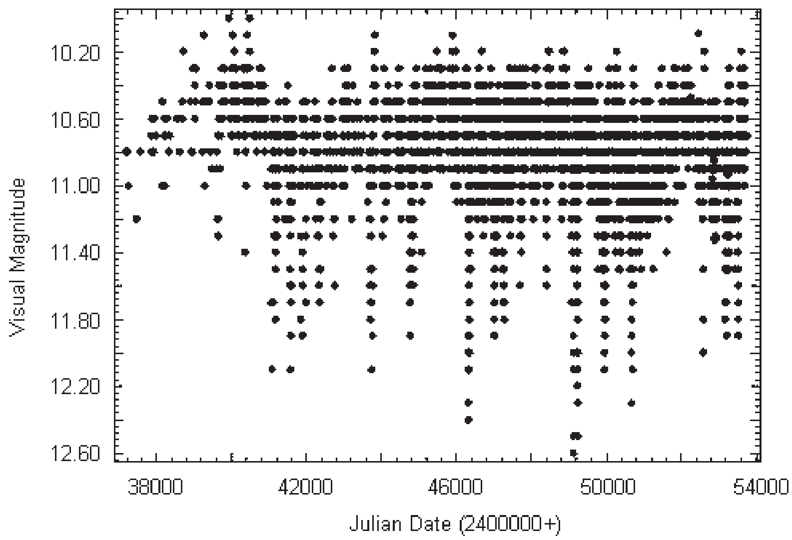

Figure 9. The light curve of WW Vul. Note the slow variations, and also the distinct minima which extend to magnitude 11.5 or fainter (see text).