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ET And, HD 219891, or HD 219668 – which one shows short-term variability?

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Abstract. The result of recent photometric observations of the CP star ET And, published by Weiss et al. (1998), shows that the known brightness variation of about 145 min has to be obviously assigned to the comparison star HD 219891. In order to test this statement we investigate the Hipparcos photometry of ET And, HD 219891 and the check star, HD 219668, on the existence of pulsations. The significance of peaks found in the periodograms is estimated using empirically determined false alarm probability distributions derived from a large number of synthetic data sets. Results show that the probability of large peaks produced in the periodograms by only noise cannot be described by the well-known statistics valid for an evenly spaced time sampling. In the photometry of ET And we find a period of $0\overset{d}{.}103966$ with a false alarm probability of 6% or less. For the two comparison stars we could not detect any signal in the data.

Key words: stars: binaries: spectroscopic – stars: chemically peculiar – stars: individual: ET And – stars: oscillations

1. Introduction

The B9p star ET And is the main component of a spectroscopic binary system with high eccentricity, Ouhrabka & Grygar (1979). Spectroscopic and photometric observations put the star doubtless between the hot border of the δ Scu stars and the cool edge of the slowly pulsating B-type stars in the Hertzsprung-Russell diagram. It is also a photometric variable due to rotational modulation with a period of about $1\overset{d}{.}6$ determined by Hildebrandt & Hempelmann (1981). Later on the period was improved and confirmed by Scholz et al. (1985) and Weiss et al. (1998). Rapid light variations with a period of about 140 min and amplitudes in U, B, and V of about 15 mmag were found by Panov (1978) and Hildebrandt et al. (1985) using the star HD 219891 as the comparison. Recently, photometry of ET And from several observatories, using the same comparison and the K0 check star HD 219668, was published by Weiss et al. (1998). Their observations yielded a brightness variation with the period of about 145 min and a semiamplitude of 2.5 mmag, which they assign to the comparison star HD 219891. Therefore, ET And would only show the $1\overset{d}{.}6$ light variability produced by the rotational modulation and not be a representative of a pulsating A-type star. Because HD 219891 is lying in the δ Scu instability strip the result would re-establish the conventional idea that pulsations in A-type stars do not exist. However, new findings of several other A-type stars, using the Hipparcos photometry data and radial velocities, give evidence for pulsational instability in some of them, Scholz et al. (1998). One of the investigated stars is ET And where a light variation of 150 min is indicated.

Taking into account the different statements to the existence of pulsations in ET And it seems to be appropriated to reinvestigate the Hipparcos photometric data of the star. The Hipparcos data reduction procedures and variability indicators used are described in the Introduction to the Hipparcos and Tycho Catalogues, a comprehensive overview can be found in van Leeuwen (1997). A star is classified in the Hipparcos catalogue as variable or constant on the basis of a χ^2 hypothesis test with certain thresholds on the H0 hypothesis (the star is constant). The stars HD 219668 and HD 219891 are considered to be constant and ET And is marked as a variable star. We will investigate if the brightness variation of ET And is caused only by the rotation of the star or if there exist further short-term variations. Because of the very poor window function of the Hipparcos data we have to establish a method to test the significance of possibly detected periods, and we will check this method on both comparison stars, HD 219891 and HD 219668, too.

2. Observations

The Hipparcos photometry data of the comparison stars and of ET And are quite similar distributed in time and cover nearly the same observational period. Table 1 lists the parameters of the observations. HIP is the Hipparcos catalogue number and $N_{\rm HIP}$ is the total number of measurements included in the Hipparcos Epoch Photometry Annex. N_0 is the number of data with error flag 0 (reliable data) which we used in general for our investigations. N_{012} is the number of measurements with error flags of 0, 1 and 2 (flags 1 and 2 mean that the corresponding measurement is derived or accepted by only one of the two Hipparcos

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Table 1. Observational parameters.

star	HD 219668	HD 219891	ET And
spectral type	K0 IV	A5 V n	B9p (Si) IV
HIP	114981	115120	115036
$N_{\rm HIP}$	117	126	178
N_{012}	106	113	166
N_0	95	105	151
JD 2 440 000+	7883–9037	7864–9037	7864–9016
Hp [mag]	6.6205	6.5671	6.4780
rms_1 [mmag]	8.4	7.4	10.6
rms_m [mmag]	8.4	7.5	8.0

commissions, FAST and NDAC, these data are commented in the catalogue as “may be reliable”). Hp is the averaged mean of the brightness in the Hipparcos photometric system. rms_1 is the mean deviation of a single measurement from this mean, and rms_m is the averaged mean of the individual errors given in the catalogue for the corresponding star. Both rms_1 and rms_m refer to the N_0 data sets. From the last two rows in Table 1 it is clear that for the two comparison stars the total variance is equal to the mean error of measurement and for ET And the total variance is only slightly above that.

3. Period search

The determination of periods in the $0\overset{\rm d}{.}1$ range in the Hipparcos data is at the detection limit for several reasons as

- the data sampling rate is inconvinient in terms of the classical Nyquist frequency
- the noise level and the dispersion of the data are of the same order (see Table 1)
- the quality of every measurement is variable.

The first point is crucial and requires some basic considerations on the expected significancy of possibly detected periods which will be given in the next section. The second point will be considered in the context of the false alarm probability distributions. In general it is quite possible to detect periods in data sets containing a sufficient number of data points also if the amplitude signal-to-noise ratio is of the order of one (e.g. Scargle 1982). The third point we will take into account within the construction of our synthetic data sets for empirical tests.

For ET And we have to solve the problem of double period search which introduces additional complications in its statistical treatment. The situation is simplified by the fact that we already know the order of one period, namely of the rotational period of ET And of $1\overset{\rm d}{.}62$, however. The period search was done by two methods. First by succsessive pre-whitening of the data, that means we determined first the dominating period of rotation and then we searched for a second period. And second, we applied an algoritm which optimizes two periods and their harmonics simultaneously: Starting with the previously obtained period of rotation we searched for a second period, and for each frequency point the amplitudes and phases of both periods were adjusted. For ET And the periods found by the two methods are identical and also the peak heights in the periodograms have the same value. So we think that it is justified in this case to pre-whiten the data for the period of rotation and to apply then a single period statistics to the periodograms of the residuals to obtain a measure of the significance of further found periods.

3.1. Data sampling and Nyquist frequency

For period analysis we use a least squares fit of sinewaves, the ordinate of our periodogram is a measure for the reduction in the sum of squares:

$$S = 1 - \sigma_r^2/\sigma_0^2. \tag{1}$$

σ_r^2 is the variance of the residuals of the fit and σ_0^2 is the total variance of the data. Least squares fit and Scargle periodogram have the same statistical properties as it was shown by Scargle (1982). Our value S is related to the Scargle periodograms ordinate z by

$$z = \frac{N-1}{2} S, \tag{2}$$

where N is the number of data. Scargle (1982) and Horne & Baliunas (1986) showed that the probability W that a peak P at frequency ν in the periodogram is of height z or higher possess an e^{-z} distribution:

$$W[P(\nu) > z] = e^{-z}. \tag{3}$$

Koen (1990) argued that because of the a priori unknown population variance the e^{-z} distribution has to be replaced by the F-distribution:

$$W[P(\nu) > z] = \left(1 + \frac{2\,z}{N-1}\right)^{(N-1)/2}. \tag{4}$$

In any case the so-called false alarm probability (FAP hereinafter), which is the probability that a peak of given height z or higher could be produced by noise, calculates from

$$F = 1 - (1 - W[P(\nu) > z])^{N_I}, \tag{5}$$

where N_I is the number of statistically independent frequencies.

For regular samples there exist a well-defined set of statistically independent frequencies $\nu_i = i/T$ with $i = 1..N/2$, where T is the total time interval of the N observations. Frequencies range from $1/T$ up to the Nyquist frequency $\nu_{\rm Ny} = N/(2T)$, which can be expressed also in terms of the even time sampling interval $\triangle t$:

$$\nu_{\rm Ny} = (2\triangle t)^{-1}. \tag{6}$$

The problem is that for unevenly spaced data there is no unique definition of the Nyquist frequency and the number and spacing of independent frequencies is principally unknown. Horne & Baliunas (1986) derived from empirical tests a relationship $N_I(N)$, and similar tests were made by Koen (1990), but all tests underlies the value of the Nyquist frequency for the evenly spaced case. In other words, the statistics valid for a search for

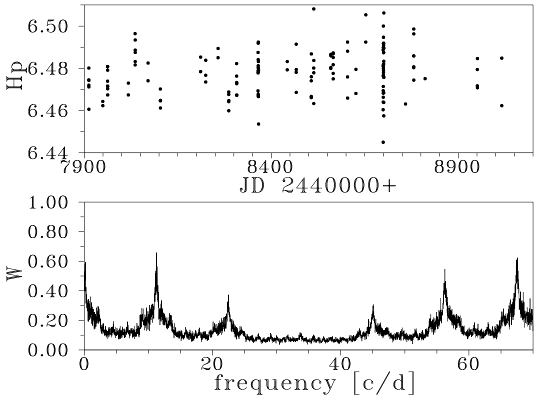

Fig. 1. Upper panel: Hipparcos data of ET And. Lower panel: Corresponding window function [2].

Table 2. Sampling properties.

		HD 219668	HD 219891	ET And
N		95	105	151
T	[d]	1125	1125	1104
$\widehat{\triangle t}$	[d]	11.9	10.7	7.3
$\nu_{\rm Ny}$	[d^{-1}]	0.042	0.047	0.068
$P_{\rm Ny}$	[d]	23.8	21.3	14.7
N_I		47	52	75
$\triangle t_{\rm min}$	[d]	0.0143	0.0143	0.0143
$\nu_{\rm Ny}$'	[d^{-1}]	35	35	35
$P_{\rm Ny}$'	[d]	0.029	0.029	0.029
N_I'		30400	39400	38700

periods above this "classical" Nyquist frequency in unevenly spaced data has not yet been investigated.

Recently, Eyer & Bartholdi (1999) published a paper on the problem which Nyquist frequency should be used for irregularly sampled data. They show that the largest information containing frequency is larger or at least equal to the frequency determined by $(2\triangle t)^{-1}$ and give a formula to calculate this frequency from the time sampling. This calculation is not necessary if we can directly observe a symmetry point in the window function, that means a frequency above which the window function is mirrored. Fig. 1 shows the sampling and the window function of the Hipparcos data of ET And which are representative also for the two other stars. It is seen that there is a symmetry point of the window function at about 34 d^{-1}. This value corresponds almost exactly to the value of the Nyquist frequency of Eq. 6 if we replace $\triangle t$ by the smallest time step observed, which is $\triangle t_{\rm min} = 0\overset{\rm d}{.}0143$. This may be explained by the fact that the Hipparcos data are sampled in groups; within each group the time sampling is nearly evenly spaced, and there are larger gaps between these groups. The two strong peaks which are further seen in the window function reflect the time sampling of the Hipparcos photometric runs, the corresponding alias frequencies are related to the time of one revolution of the satellite around its spin axis.

In the first part of Table 2 we give the basic sampling properties N and T for the three stars (here we refer only to the Hipparcos measurements with error flag 0). In the second part we give the mean sampling interval $\widehat{\triangle t} = T/N$ and the values of Nyquist frequency, period and number of independent frequencies which we would obtain by a transcription of the regular case by setting $\triangle t = \widehat{\triangle t}$ in Eq. 6. A comparison with the window function of Fig. 1 shows that this transcription yields rather poor results, a Nyquist frequency of 0.068 d^{-1} derived in this way does not describe the sample properties. The third part of Table 2 gives the time sampling rate within the data groups, $\triangle t_{\rm min}$, and the values which we would obtain if we evaluate the observations into an regular sample based on this time sampling rate, that means by filling the data gaps by some (unknown) values. The actual number of independent frequencies we expect to be somewhere between N_I and N_I' (the expression "number of independent frequencies" means in this context only a number which best approximates the statistical distributions derived for the regular case).

3.2. Empirical false alarm probability distributions

Because we do not know the number and spacing of statistically independent frequencies, we have to develop the periodograms at the limit of the peak-to-peak resolution[1], for the given time sampling into a number of about 200 000 frequencies[2]. Our proceeding has an essential constraint on the statistical properties of the periodograms obtained: The observed peaks are not statistically independent. The significance of detected peaks we can therefore estimate only by empirical tests based on a large number ($\sim 20\,000$) of synthetic data sets. The empirical determination has the advantage to give valid FAPs for any frequency range used. In the following we will assume that we can determine significant periods up to a frequency of 34 d^{-1}. This is certainly an upper limit and so the empirical FAPs represent upper limit values too for all peaks found in the periodograms below 34 d^{-1}.

We derive the FAP by constructing randomly generated data sets with the same time sampling as the Hipparcos data and include only white noise. To each data point we assign a value having a deviation from zero mean which is gaussian distributed, and the sigma of each gaussian corresponds to the individual error given in the Hipparcos catalogue for the data point. The computed FAPs are represented in Fig. 2 by dots, S is the peak height in our periodogram.

Although we did not develop our periodograms at independent frequencies it is instructive to compare the empirical results with the statistics for regular samples. The number of indepen-

[1] Peak-to-peak resolution means that we can certainly detect the true height of any peak in the periodogram.

[2] We have reduced the resulting large amount of data for the representation of the periodograms by recursively omitting all local minima until we reached a number of below 7000 data points per periodogram or window function.

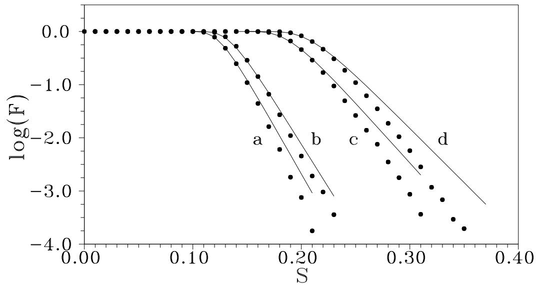

Fig. 2. FAP distributions for the Hipparcos data of ET And based on the data with error flags 0,1,2 **a** and 0 only **b** and HD 219891 **c** HD 219668 **d** based on the data with error flags 0. Dots show the empirically determined distributions, solid curves represent the distributions derived from the statistics for regular samples.

dent frequencies N_I can be obtained from Eqs. 2,3,5 by linear regression:

$$\ln(1-F) = N_I \ln[1-\exp(-\frac{N-1}{2}S)]. \tag{7}$$

Our tests show that a representation of F, S in the form of Eq. 7 contains a linear part only for moderate values of S. From that part we deduced a value of N_I and calculated then the theoretical FAP according to Eqs. 3,5. Results are shown by the solid lines in Fig. 2. N_I yields 25 000 for ET And and about 20 000 for the two comparison stars. The obtained values are of the order of the number of peaks occuring in the periodograms at all. It is clearly seen that the theoretical distributions give much higher FAP values at larger peak heights as we determined empirically. This deviation is even higher if we use the F-distribution of Eq. 4. As we have expected: If we take any peak occuring in the periodogram into account, the statistics valid for statistically independent frequencies fails. Additionally we should remark that beside the partial dependence of the investigated frequencies there is a second violation of the premises necessary to obtain an e^{-z} like FAP distribution. Due to the different accuracy of the Hipparcos measurements we allowed in our synthetic data sets for gaussian noise having different variances for different data points. The derivation of the e^{-z} distribution of the Scargle periodogram (Scargle 1982) is valid only for a unique noise variance, however.

4. Results

The results of the frequency analysis are listed in Table 3. In the last row we give the periods following from the period search method PERIOD98 provided by the Viennese colleagues[3].

ET And. In Fig. 3 we give the periodogram following from the Hipparcos data of ET And pre-whitened for the period of rotation. The strongest peak occurs at $\nu_{\max} = 9.61853$ d^{-1} (period of $0\overset{\mathrm{d}}{.}103966$). A comparison with the periodogram obtained from a synthetic noise-free data set based on the same time sampling as the Hipparcos data and containing only the $0\overset{\mathrm{d}}{.}103966$ period shows a good correspondence. Beside the main

[3] ftp://dsn.astro.univie.ac.at./pub/PERIOD98/current/

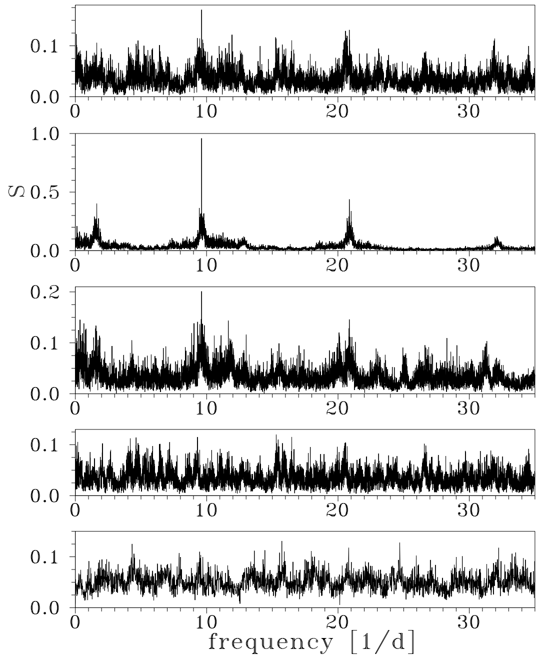

Fig. 3. Periodograms. From top to bottom: Hipparcos data of ET And after pre-whitening for the rotational period, noise-free synthetic data set containing only the $0\overset{\mathrm{d}}{.}103966$ period, synthetic $0\overset{\mathrm{d}}{.}103966$ period and noise, residuals after pre-whitening the Hipparcos data for both the rotational period and the $0\overset{\mathrm{d}}{.}103966$ period, and synthetic data set with noise only.

peak in both diagrams occur the alias peaks due to the main alias frequency of the window function, $\nu_a \sim 11$ d^{-1}, at $\nu_{\max} + \nu_a$ and $\nu_{\max} + 2\,\nu_a$. The zero frequency wrap around peak from $-\nu_{\max}$ is washed out by noise, however. Also the periodogram of a randomly generated data set containing the $0\overset{\mathrm{d}}{.}103966$ period and appropriate noise (see Sect. 3.2.) shows very similar features to that of ET And. A comparison of the periodograms of the residuals of the ET And data and of a randomly generated noise spectrum verifies that the pre-whitening for the $0\overset{\mathrm{d}}{.}103966$ period removes all significant features from the periodogram.

Further evidence for the existence of a second short-term contribution beside the brightness variation due to the rotation comes from the investigation of the periodogram of the original (not pre-whitened) Hipparcos data. The second panel in Fig. 4 shows the periodogram obtained from a noise-free variation containing only the period of rotation. It shows that the peaks at $\nu_{\max} + \nu_a$ and $\nu_{\max} + 2\,\nu_a$ are doubled, this is due to the wrap around of the main peak from negative frequency. In the Hipparcos periodogram (upper panel) we can clearly see a third component, however, which can be perfectly modeled if we take the $0\overset{\mathrm{d}}{.}103966$ period into account too (lower panel).

The phase diagram of the Hipparcos data using the $0\overset{\mathrm{d}}{.}103966$ period is shown in Fig. 5. If we calculate the variance of the residuals of the sinusoidal fit, there are four data points outside the $3\,\sigma$ range. These data points can be identified also in Fig. 5. If we omit them in the calculation of the periodogram, the peak at $0\overset{\mathrm{d}}{.}103966$ is much more pronounced ($S = 0.26\,!$), even if we omit all data outside the $3\,\sigma$ range for every frequency in

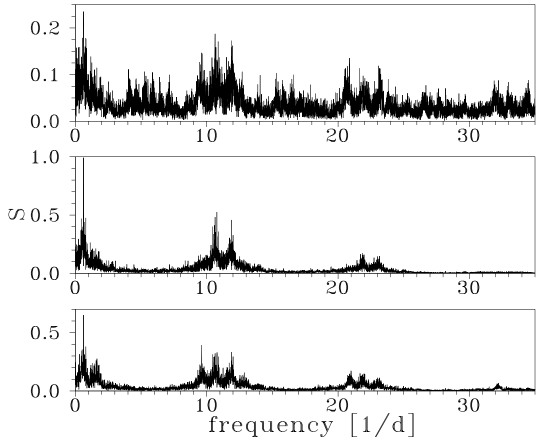

Fig. 4. Periodograms. From top to bottom: Original Hipparcos data of ET And, noise-free signal including only the rotational period of $1\stackrel{\rm d}{.}61887$, and noise-free signal containing both the rotational period and the $0\stackrel{\rm d}{.}103966$ period.

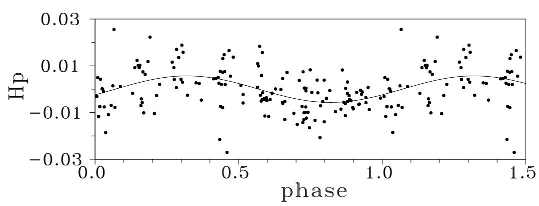

Fig. 5. Phase diagram of the Hipparcos data of ET And pre-whitened for the period of rotation, folded with the $0\stackrel{\rm d}{.}103966$ period.

the periodogram. Unfortunately we are not able to calculate the FAPs for this procedure, it would require an enormous amount of computing time.

Regarding the periodogram of all Hipparcos data with error flag 0, also noise can produce a peak of the same height as that of the $0\stackrel{\rm d}{.}103966$ period in about 6% of all cases (Table 3). If we include the Hipparcos data with error flags 1 and 2 in the period search too, the peak at $0\stackrel{\rm d}{.}103966$ is even more pronounced. From the empirical FAP distribution of the 166 data points (Fig. 2) it then follows a FAP of only 1%. For both the rotational period and the short-term period the results obtained by our program and by the PERIOD98 program are identical.

HD 219668 and HD 219891. Fig. 6 shows the periodograms for the two comparison stars. The strongest peaks found in these periodograms, as listed in Table 3, we consider to be not significant. Beside the large FAP derived for both stars, there are two other reasons to reject the found periods.

For HD 219891 we find two different frequencies by our method and by the PERIOD98 program (the reason is that there is no really pronounced single peak in the periodogram). If we include the data with error flags 1 and 2 too, the periodogram remains almost unchanged. So we conclude that the signal-to-noise ratio of the Hipparcos data is not sufficient to confirm or exclude the 2.5 mmag amplitude variation found by Weiss et al. (1998).

For HD 219668 we assume that the strongest peak is identical with the alias frequency $2\nu_a$. This assumption is supported by the fact that, if we include the data with error flags 1 and 2, the strongest peak is found at another position, namely at ν_a.

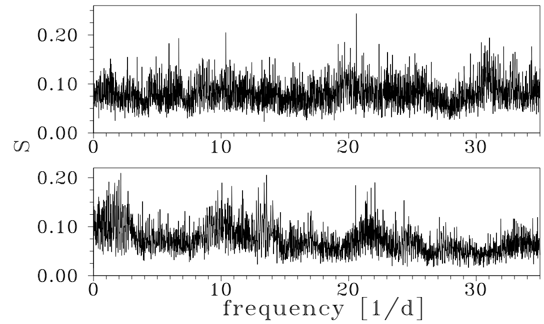

Fig. 6. Periodograms of the Hipparcos photometry of HD 219668 (top) and HD 219891 (bottom).

Table 3. Results of period search. The table lists the periods P related to the strongest peaks in the periodograms, the corresponding semi-amplitudes A and S-values, and the FAPs following for regular samples (see second part of Table 2), and the empirically determined values. In the last row we give the periods found by the PERIOD98 program.

star	HD 219668	HD 219891	
$P(N_0)$ [d]	0.048525	0.46697	
A [mmag]	5.9	4.8	
$S_{\rm max}$	0.244	0.209	
FAP($\nu_{\rm Ny}$)	$5\cdot10^{-4}$	$1\cdot10^{-3}$	
FAP($\nu_{\rm Ny}$')	0.32	0.20	
PERIOD98 [d]	0.048525	0.82999	
star		ET And	
	$P_{\rm rot}(N_0)$	$P(N_0)$	$P(N_{012})$
period [d]	1.61887	0.103966	0.103966
A [mmag]	6.8	5.7	5.6
$S_{\rm max}$	0.235	0.171	0.176
FAP($\nu_{\rm Ny}$)	$2\cdot10^{-6}$	$2\cdot10^{-4}$	$6\cdot10^{-5}$
FAP($\nu_{\rm Ny}$')	$2\cdot10^{-4}$	0.06	0.01
PERIOD98 [d]	1.61887	0.103966	0.103966

5. Discussion

The investigation shows that despite of the very poor window function of the Hipparcos photometric data it is possible to find short-term variations far above the classical Nyquist frequency. Because of the lack of independent frequencies we have to evaluate the periodograms at the peak-to-peak resolution and the FAP distribution can no longer be described by the e^{-z} statistics. To proof the significance of detected periods it is necessary to derive empirical FAP distributions which have regard to the concrete properties of the data samples. Results show that the statistics based on $N/2$ even spaced data assuming a Nyquist frequency of $N/(2T)$ would seriously underestimate the FAP.

For the Hipparcos data of ET And the classical Nyquist frequency is of the order of 15 days. The $1\stackrel{\rm d}{.}61887$ rotational period of the star can be detected without doubt, here, the FAP is of only 0.02%. Beside this period, we got a strong hint to the existence of a short-term period of $0\stackrel{\rm d}{.}103966$ with a semi-amplitude of about 6 mmag and a FAP of 6%, or, if we believe in the accuracy of the Hipparcos data with error flags 1 and 2 too, of only 1%. The found period is quite similar to the value of about 140 min given already many years ago (Panov 1978, Hildebrandt et al. 1985).

For the comparison stars the negative result is in agreement with their notation as non-variable stars in the Hipparcos catalogue. In particular, the signal-to-noise ratio of the data of the two comparison stars does not permit to detect periods with a semi-amplitude of 2.5 mmag as given by Weiss et al. (1998) for a possible 10.08 d^{-1} variation of HD 219891.

Summarizing the investigation on the variability of the three stars, we find a distinct hint on pulsation alone in ET And. Therefore, at present it seems to be justified to consider the pulsation of ET And as a reality.

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