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Research Note

Searching for the short timescale variations in the lightcurve of minor planet 1689 Floris-Jan in 1999 and 2002

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Abstract. CCD imaging photometric observations were carried out with Cousins filters in 1999 (I filter) and 2002 (R filter) on eight nights in order to search for the intrinsic short-period oscillations in the lightcurve of the slowly rotating minor planet 1689 Floris-Jan. The principal objective of the observations is to perform independent verification or rejection of the short-period oscillations in the lightcurve reported by Pych (1999, A&A, 343, L75). Observations made in 1999 and 2002 (this work) do not show any short-period sine-like oscillation. The observations were taken at relatively large airmass conditions and the atmospheric effects introduced large point to point scatter in some data sets in 1999 and 2002. Further observations and a detailed frequency (period) analysis of the short timescale lightcurve variations of this asteroid are strongly encouraged during the next oppositions: the next one will be in March 2005.

Key words. minor planets, asteroids – techniques: photometric

1. Introduction

Due to its unusually long period of $6\overset{\mathrm{d}}{.}042 \pm 0\overset{\mathrm{d}}{.}021$ ($145\overset{\mathrm{h}}{.}0 \pm 0\overset{\mathrm{h}}{.}5$) the asteroid 1689 Floris-Jan is considered as a small body possibly in a tumbling rotational motion state among some similar slowly spinning asteroids (Schober et al. 1982; Schober 1982; Harris 1994, 2000, 2002). The possible tumbling rotational state of the asteroid 1689 Floris-Jan drew attention to the need for observations in order to search for another period in its lightcurve. CCD photometry of this long period asteroid was made in 1997 (Pych 1999) and he reported that in the lightcurve from nights 1997.02.10/11 and 1997.02.11/12 coherent sine-like oscillations were detected with a period of $P_{\sin} = 0\overset{\mathrm{d}}{.}003461 \pm 0\overset{\mathrm{d}}{.}000006$ ($4\overset{\mathrm{m}}{.}98 \pm 0\overset{\mathrm{m}}{.}01$, i.e., ~289 c/d in frequency) and a full range amplitude of about 0.11 mag. During the two consecutive nights in February, 1997, short-period oscillations in the lightcurve were observed but no light oscillations were found on March 7/8, 1997.

The minor planet Floris-Jan was observed on the nights of 10/11 and 11/12 February 1997 (Pych 1999) just few days after its opposition on February 8.8 UT (Batrakov et al. 1996), and the observations were continued about one month later, on March 7/8 (Pych 1999). The details of the 1997 observations were described by Pych (1999) and the parameters of the instrument and detector system were given by Udalski & Pych (1992). Taking into account the time of the observations and the coordinates of the observing site reported by Pych (1999) we traced back that the airmass changed from 1.21 to 1.24 on 10/11 February; between 1.33 and 1.27 on 11/12 February, and it was 1.18 at the culmination on 07/08 March 1997. Consequently, there were good airmass conditions around the opposition of this asteroid in 1997.

The discovery of short-period oscillations in the lightcurve of the asteroid 1689 Floris-Jan, as reported by Pych (1999) from only two nights observations in 1997, would be very interesting with respect to the physical properties of this asteroid. It could even have extraordinary implications for the physics of the asteroids as a whole. But there is a difficulty with this short-period oscillation if the rotation period is ~6 days: if the two frequencies are very different, the inferred differences of the axes must be very small (and also those in the moments of inertia) and such a nearly-spherical asteroid would have no perceptible lightcurve at all. Even if the lightcurve amplitude is large enough to see at all, the wobble frequency cannot be so different from the ~6-day rotation period of 1689 Floris-Jan.

However, there have not yet been other independent observations which could have shown a similar short-period variation in the lightcurve confirming the short-period oscillations observed by Pych (1999). Pych (1999) stated that he had checked if these oscillations could have been due to possible instrumental effects, and found that this was not the case. However, the detection of the short-period variations was based

Table 1. Journal of observations of the asteroid 1689 Floris-Jan in 1999 and 2002, as well as qualification of the variability from autocorrelation periodograms made both for the asteroid and the first comparison star to the second one.

Date	RA	Dec	α	Filter	Expos.	Asteroid		Comparison 1 to 2	
0h UT	(J2000)		(deg)		(s)	δ^2/σ^2	Remark	δ^2/σ^2	Remark
1999 Sep. 04/05	23:11.5	–13:50.3	3.97	I	10	1.148	some curve?	1.641	some curve?
						2.054	no trend	2.001	no trend
1999 Sep. 06/07	23:09.9	–14:08.4	4.01	I	10	1.330	some curve?	1.306	some curve?
						2.119	no trend	2.036	no trend
1999 Nov. 12/13	23:00.7	–15:14.1	28.27	I	20	1.936	no trend	2.258	oscillation?
						1.868	some curve?	1.839	some curve?
1999 Nov. 13/14	23:01.5	–15:06.8	28.42	I	30	1.701	some curve?	2.046	no trend
						2.205	oscillation?	2.048	no trend
1999 Nov. 20/21	23:08.1	–14:10.9	29.30	I	20	1.896	some curve?	1.962	no trend
						1.959	no trend	2.105	no trend
2002 Jun. 17/18	15:25.5	–10:21.7	12.16	R	60	2.181	no trend	2.443	oscillation?
						1.647	some curve?	2.075	no trend
2002 Jun. 18/19	15:24.9	–10:22.1	12.48	R	60	1.934	no trend	1.736	some curve?
						2.267	oscillation?	1.989	no trend
2002 Jun. 19/20	15:24.3	–10:22.7	12.80	R	60	2.230	oscillation?	1.714	some curve?
						1.802	some curve?	2.335	oscillation?

(RA, Dec): equatorial coordinates; α: solar phase angle.
δ^2/σ^2: variability trend qualifier in the autocorrelation (Burki et al. 1978).
First row: original data as input, second row: random permutation of the data as input.

on only two nights' observations and there are no other independent observations. Consequently, we are still not certain of the existence of the short-period variations in the lightcurve of this asteroid, and whether the short-period oscillations in question are an intrinsic physical property of the asteroid or if they are connected to specific conditions of the observations, e.g., instrumental and atmospheric ones. Pych (1999) reported that the observed oscillations were seen on only two nights during which 120-s exposures were taken contiguously. On a third night, 60-s exposures were taken contiguously (the data rate is slightly less than double presumably due to readout time of the CCD), and the oscillations were not seen. For example, to explain the short timescale variations, it seems much more likely that the explanation lies within the telescope: perhaps some instrumental effect is causing the variation, which manifests itself in the 2-min exposures, but not in the one-minute ones. Moreover, we should consider about effects which are in front of the telescope: these may be possible atmospheric effects. Since the observations reported by Pych (1999) were made near the culmination of the asteroid at a reasonable good airmass (the elevation was similar to that of the celestial equator) the atmospheric transparency should have been good. But unseen cirrus might have caused color effects, even when applying differential photometry. Using a broad band or unfiltered data the magnitude of the effect due to the change in the color extinction depends on the color difference between the variable and the comparison star multiplied by the mean value of the airmasses for the two objects (Eqs. (28a,b) and (31a,c) of Hardie 1962). At longer wavelengths (e.g., with V, R, I filters) this effect can be negligible at photometric sky conditions but it can amount to a few 0.01 mag in the presence of cirrus clouds. But the full range amplitude of the short-period oscillations reported by Pych (1999) is about 0.11 mag which seems to be significant.

Since the existence of the intrinsic short-period oscillation in the lightcurve of minor planet Floris-Jan is uncertain, we decided to return to the telescope to collect confirming or refuting photometric observations. We carried out a series of observations for Floris-Jan using completely separate instrumentation at another observational site with different observing conditions (technical, atmospheric, weather, etc.). The results are presented in the following sections.

2. Observations in 1999 and 2002

CCD imaging photometric monitoring observations were made in the Cousins $BV(RI)_c$ photometric system but with two different CCD cameras in 1999 and 2002, respectively. The telescope was the same: the cameras were attached to the Cassegrain focus of the 1 m Ritchey-Chrètien-Coudé (RCC) telescope at Piszkéstető station of the Konkoly Observatory. The technical and atmospheric circumstances which were realized in our observations in two different years 1999 and 2002 are completely different from both of those reported by Pych (1999). In addition, the circumstances in 1999 and 2002 differ from each other. The oppositions of this asteroid were on September 09.1 UT, 1999 and May 20.9, 2002 UT (Batrakov et al. 1998, 2001). The journal of observations is summarized in Table 1: these are the dates of the nights, equatorial coordinates, solar phase angle, filter, exposure, and other results of the data analysis.

In 1999 the CCD camera was an S300:7896 series made by the Photometrics Ltd. The detector chip is a TH 7896, which has been coated for extended UV response with 1024×1024 19×19 micron sized imaging pixels. The focal length of the telescope is 13.6 m, i.e., the scale is 0.288 arcsec/pixel. The camera has a Peltier plus liquid cooling systems, normally operating at $T = -40$ C (233 K). Typical saturation level is 37 500 electrons/pixel, the nominal dark current value is 0.4 electrons/pixel/s. The linearity error is normally smaller than 0.07%. The exposures were 10, 20, 30 s with the I filter on the following nights: 10 s 04/05 and 06/07 September, 20 s on 12/13 November, 30 s on 13/14 November, and 20 s on 20/21 November 1999.

In 2002 the Wright Instruments Ltd. Peltier-cooled CCD camera was used. The CCD detector chip itself is an EEV CCD05-20 MPP UV-coated. The dimensions of the chip are 770×1152 pixels, 22.5 micron each. The scale is 0.352 arcsec/pixel. The typical saturation level is 120 000 electrons/pixel. The nonlinearity is almost negligible. Further information on the technical details of the Wright Instr. CCD camera hardware and the related control software can be found in the documentation (Wright 1990). The exposure was 60 s with the R filter on all of the nights of 17/18, 18/19 and 19/20 June 2002.

Standard reduction procedures were applied to the CCD images including bias corrections and flat-fielding. The dark current is negligible with these CCD cameras for exposure times less than about five minutes. The trailing of this asteroid moving on the CCD frames was negligible within the exposures ($\leq$60 s) taken (the telescope operated at sidereal rate). Differential aperture photometry (concentric aperture photometry from DAOPHOT, Stetson 1987) was applied between the asteroid and always two comparison stars were selected in the same star field in the CCD field-of-view. Criteria of the selection of comparison stars are as follows: i) their color should be close as possible to the solar color (we are observing an asteroid); and ii) the magnitude difference should be minimum between the asteroid and the comparison stars. For the estimation of the colors of stars in the field of the CCD frame we used the USNO-SA2.0 catalog (September 1998, US Naval Observatory) from which the color index $(B - R)$ of the stars can be obtained. Unfortunately, both in 1999 and 2002 the asteroid was below the celestial equator when the telescope time was scheduled and the sky was clear, i.e., when the weather permitted the observations. The declination was between $-10°$ and $-15°$, and the airmass ranged between 2.1 and 3.0 during the observations in 1999. The observations were carried out on two nights in September and three others ones in November. The situation was slightly better in 2002 when the airmass varied between 1.8 and 2.8 and we recorded data during three consecutive nights (Table 1). Consequently, the observations might have been disturbed by atmospheric degrading effects like extinction or possible temporal changes. But fortunately, we have performed differential photometry between the asteroid and comparison stars selected from the same frame with nearly solar colors and we used R and I filters therefore we cannot expect large effects due to the color extinction of more than ~0.01 mag. Differential photometric results are shown for each night in Fig. 1.

3. Data analysis and results

In order to get reduced scatter in the observed data we should have applied prefiltering of the data sets. We checked the histogram of the input magnitude difference (Δm) data points and we omitted a few obvious outliers. We also removed some low frequency trend (sky transparency variations) to facilitate the reader's perception of the oscillations. A straight-line was fitted to the data and the fitted trend was subtracted.

In order to search for the periodicity in a noisy signal we applied the method of random permutation of the original measurements on each night, that is, we re-assigned the measurement values randomly to other time slots of the night (i.e., we applied a random permutation of the data), then analyzed these data using different periodicity tests to see if only the real data sequence yield the claimed periodicities. If so, one could gain a measure of confidence by comparing the amplitudes found for the randomized data compared to the real sequences. If such significance tests fail, the conclusion is that the claimed periodicity does not exist.

First we computed the power spectrum of the data including all data points using Kurtz's (1985) further implementation of Deeming's (1975) Discrete Fourier Transform (DFT) algorithm for unequally spaced data. Periodograms were computed from both the original and randomly re-assigned data and the results are shown in Fig. 2. The Fourier spectrum contains all information on the observed signal and there is no significant peak at the expected frequency of the short-period oscillation (~289 c/d) from either the original signal or the randomized input data. Note that since we had noisy spectra we also attempted to clean them using the WindowCLEAN method (Belton & Gandhi 1988) but we did not found dramatically enhanced and unambiguously stable frequency in the spectra.

Then we applied the Analysis of Variance (AoV) method (Schwarzenberg-Czerny 1989, 1991) which was also used by Pych (1999) for this asteroid. The AoV periodograms do not show the short-period variation at the expected frequency (~289 c/d). Note that we also used randomized input data to calculate the AoV spectra but the spectral features are very similar to those which are obtained if we use the original data sequence as input, therefore only the spectra of the original data were plotted in Fig. 3. We are now switching to another method which usually yields a more stable indications for the periodicity in the presence of noise than Fourier and Analysis of Variance methods.

Autocorrelation analysis is useful to detect quasi-periodic trends in a time series when other periodogram analyses fail to give unambiguous results. The autocorrelation parameter $\Theta(\tau)$

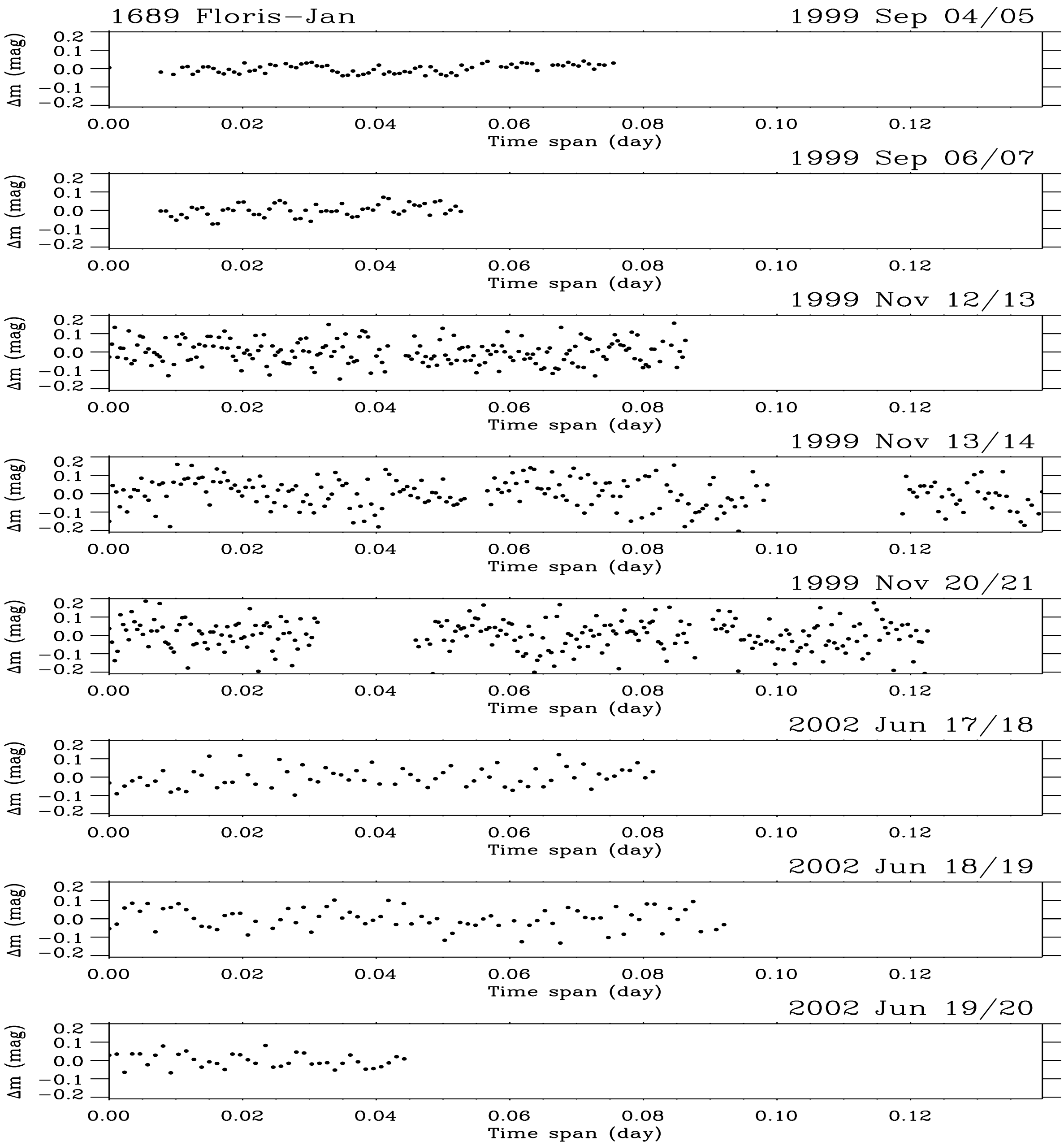

Fig. 1. Photometric observations of the asteroid 1689 Floris-Jan in 1999 and 2002. The observations were made with I filter in 1999 and R filter in 2002. The Δm magnitudes are determined from differential photometry and these are plotted on a common scale. The zero point of the time scale is the time of the first observation on the given night.

used by Burki et al. (1978), where τ is the time lag or trial period, possesses several properties which allow the detection of trends in segments of data in the presence of noise. The method has been successfully applied to extremely noisy photometric data (cf. Burki et al. 1978). We assumed that the intrinsic lightcurve of the asteroid is periodic and is generated by a stationary process during the observed interval, i.e., that the period and shape of the lightcurve did not change. A modified autocorrelation (MAC) technique, which utilizes a statistical parameter $\Theta(\tau)$ defined by the mean-square successive differences for nearly equally-spaced data, was applied to our photometric observations. The MAC parameter Θ is defined by the ratio of the mean square successive difference, δ^2, and the variance, σ^2. The ratio δ^2/σ^2 of the two estimates of the data dispersion qualifies the possible trend in the data as a function of time. Three situations may be distinguished (Burki et al. 1978): i) there is no trend in the data as a function of time. Then δ^2/σ^2 is nearly 2; ii) the data follow some curve. In this case $\delta^2/\sigma^2 < 2$; iii) the data oscillate rapidly around the mean. Then $\delta^2/\sigma^2 > 2$.

We analyzed both the asteroid lightcurve and the lightcurve of one comparison star with respect to the other checking star. Table 1 summarizes the values of δ^2/σ^2 for both the asteroid and the comparison star. We calculated the autocorrelation periodograms of both the asteroid and comparison star from both the original and randomized data (Table 1, Fig. 4). It is obvious

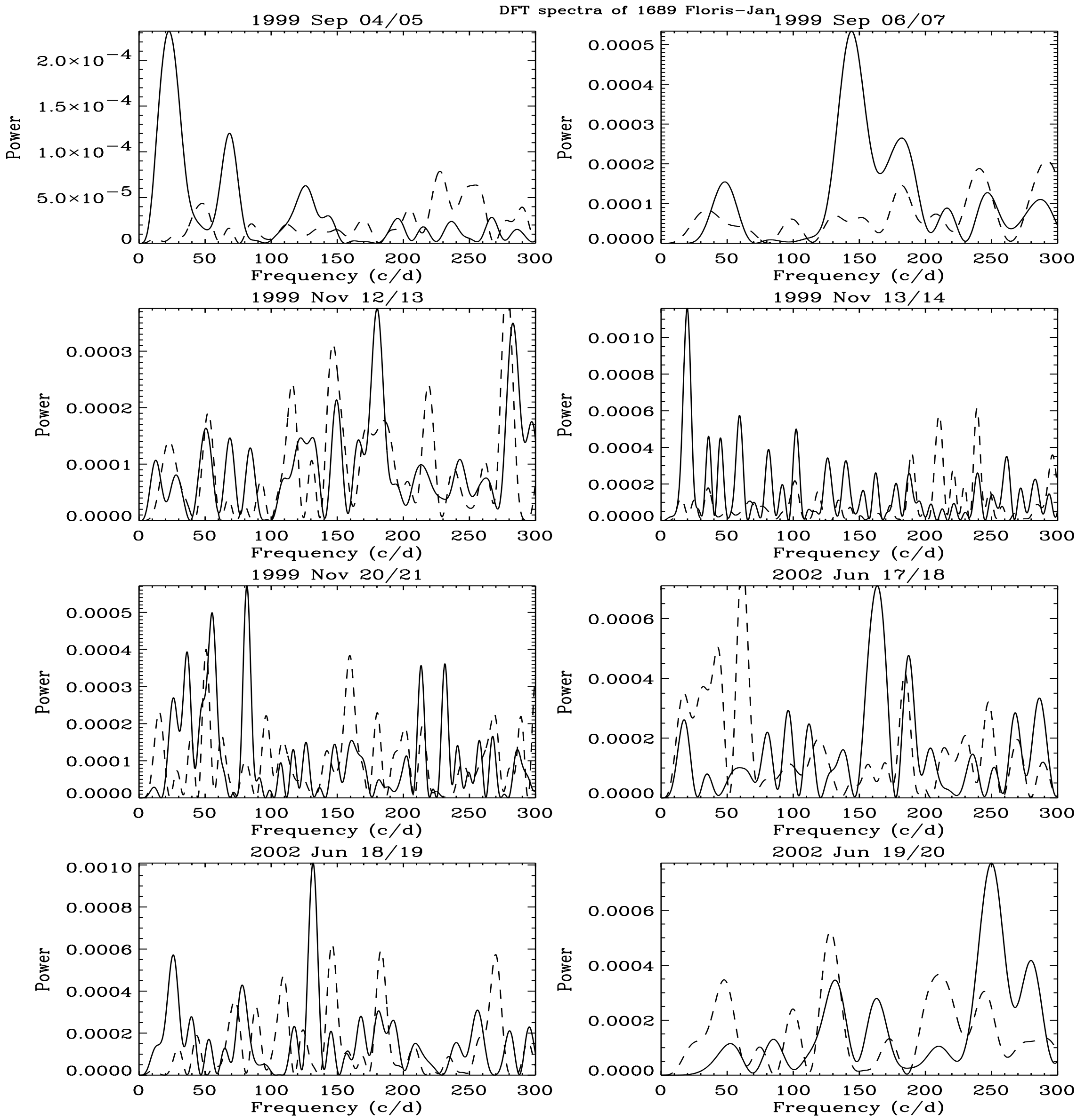

Fig. 2. Discrete Fourier Transform (DFT) periodograms (Deeming 1975; Kurtz 1985) of the photometric observations of the asteroid 1689 Floris-Jan in 1999 and 2002. The solid lines represent the original observational data as input and the dashed lines show random permutation of these as input for the DFT method. We notice the noisy spectra on each night and that there is no significant peak at the expected frequency for the short-period variation (at ~289 c/d).

from Table 1 that the values of the variability trend qualification parameter δ^2/σ^2 show some curve-like or oscillation-like trend in the data but do not differ significantly from 2, i.e., there is no significant trend in the data. Moreover, Fig. 4 shows that quasi-periodic trends in the data have not been detected from an examination of plots of the MAC parameter against time lag: the curves crowd around $\Theta = \delta^2/\sigma^2 = 2$, and there is no significant minimum peak in the periodograms to indicate any periodic signal.

4. Conclusions

We have made independent CCD observations with two different CCD cameras in different years, to search for intrinsic short timescale oscillations of the asteroid 1689 Floris-Jan on 3 nights taken in 1997 (Pych 1999) and on 8 other nights in 1999 and 2002 (this work). We have made observational efforts to clarify the situation and we note that the observations taken in 1999 and 2002 were made at relatively large airmass conditions and the atmospheric effects introduced large scatter in the data. We applied differential photometry from the CCD frames taken with R and I filters and selected comparison stars, so the color errors were minimized, which altogether improved the quality of the observations. We applied various methods of searching for periodicity: discrete Fourier Transform, Analysis of Variance, and Modified Autocorrelation Method.

Our observations made in 1999 and 2002 (this work) do not show the sine-like short-period oscillations at the expected frequency 289 c/d (0.00346 day, i.e., 4.98 min period) at a

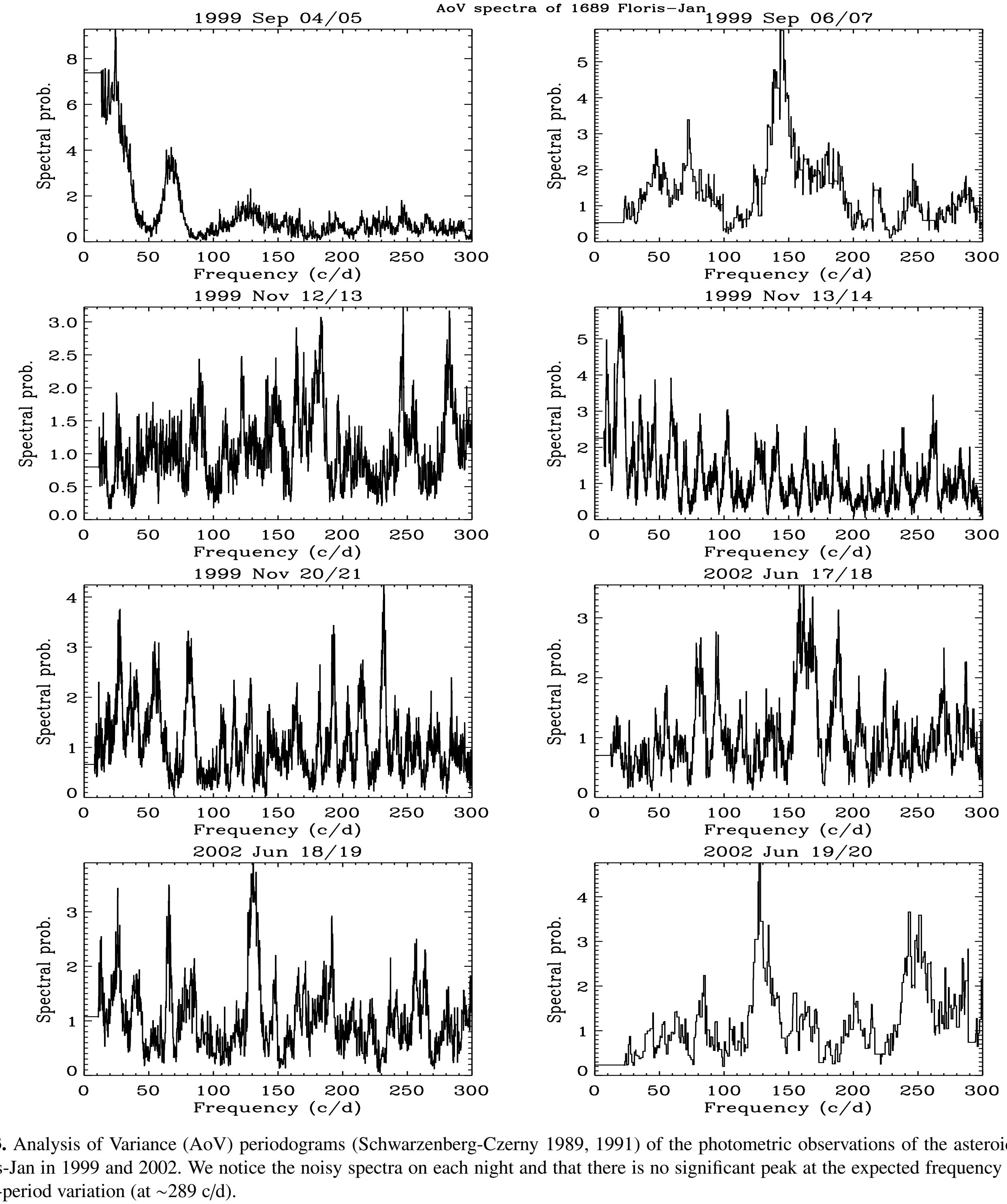

Fig. 3. Analysis of Variance (AoV) periodograms (Schwarzenberg-Czerny 1989, 1991) of the photometric observations of the asteroid 1689 Floris-Jan in 1999 and 2002. We notice the noisy spectra on each night and that there is no significant peak at the expected frequency for the short-period variation (at ~289 c/d).

reasonable signal-to-noise ratio. The present data are not able to show a variation with an amplitude less than ~0.1 mag.

To confirm this result, nights of excellent photometric quality are needed to perform photometric measurements of 1689 Floris-Jan, because the lowest airmass attained for this asteroid in 1999 and 2002 was too large (~1.8). Further high-speed photometry of this asteroid should be acquired in the near future. Its next opposition will be in March 2005 and the object will be in the northern celestial sphere. For the purpose of other confirmations, further observations and a detailed frequency (period) analysis of the variations of this asteroid are strongly encouraged.

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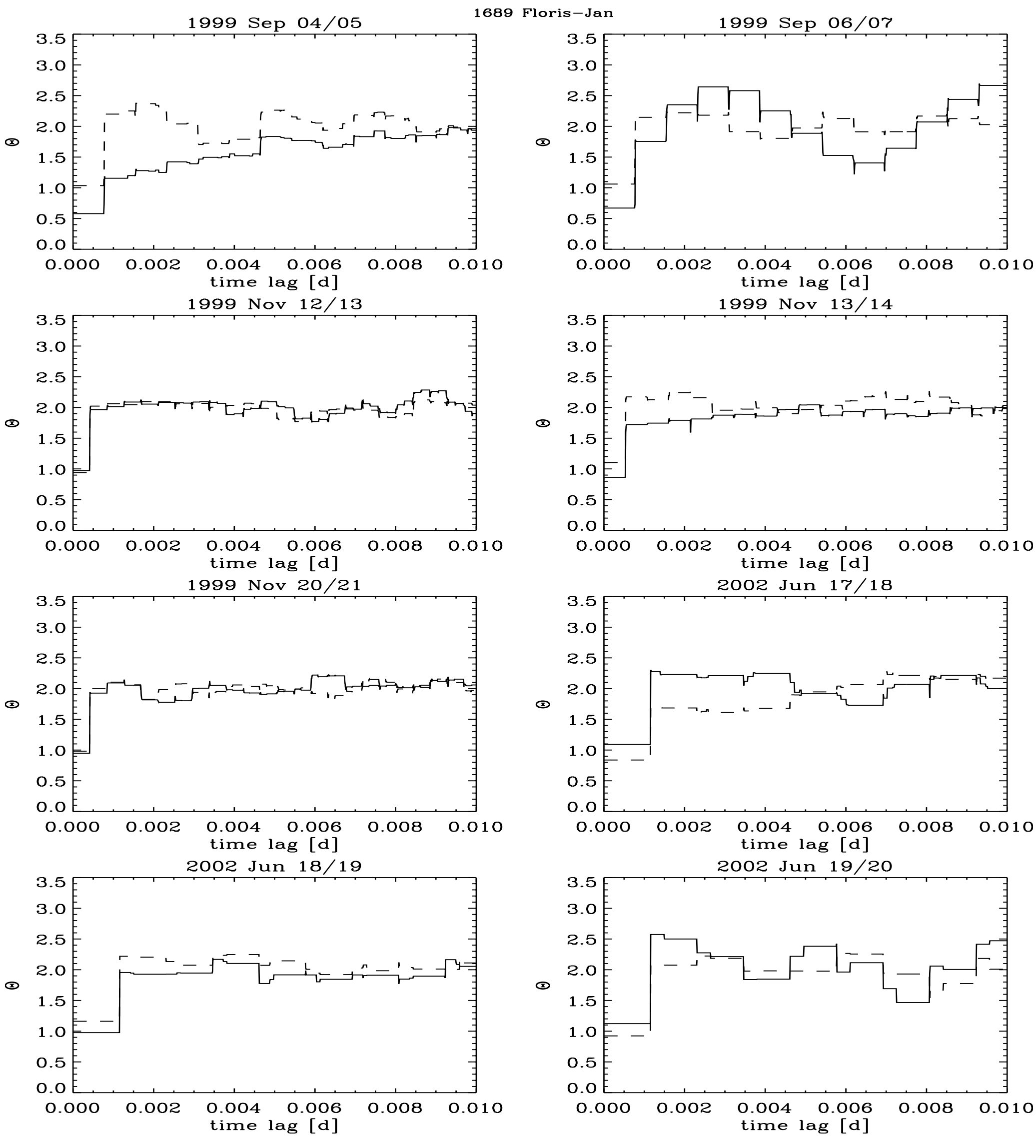

Fig. 4. Modified autocorrelation periodograms of the photometric observations of the asteroid 1689 Floris-Jan in 1999 and 2002. The solid lines represent the original observational data as input and the dashed lines show random permutation of these as input for the autocorrelation method. We notice that there is no significant minimum anywhere in the periodograms as is expected for a periodic signal. The curves are crowding around $\Theta = \delta^2/\sigma^2 = 2$, i.e., there is no significant trend of periodic variability.

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