Transient high frequency optical oscillations of the Flare star AD Leonis

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Abstract

Thorough investigations on the red dwarfs EV Lac and YZ CMin indicate that transient high frequency oscillations occur during the flare event and during the quiet-star phase as well. The postulation that this is a general characteristic of the active red dwarf is a very important task. In the frame of his consideration we present in this paper the results of the analysis of the U-light curve for the flares of the red dwarf AD Leo, which were observed on February 2002, with the help of the 30-inch Cassegrain telescope of the Stephanion Observatory. The combined use of Fractal analysis, DFT-analysis enable us to estimate the proper random noise and detect possible weak transient optical oscillations. In accordance to the results of the previous studies, the results of the present study indicate that AD Leonis also present high frequency transient oscillations during the flare state and the quite state as well. Occasionally the frequencies range from 0.0083Hz (period 2 minutes) and 0.3 Hz (period 3 seconds).

Key words: *Flare stars, Fractal analysis, DFT-analysis*

1. Introduction

High-frequency small amplitude optical oscillations during a flare maximum of HII 2411 with a period of 14.4 sec has been reported by Rodono (1974) while high-frequency optical oscillations of amplitude 10% in U and 2.5% in B and period 14.4 seconds on a flare of EV Lac around the flare maximum phase (Zhilyaev et al. 2000). A multitude of high-frequency oscillations with amplitudes ranging between 1.4% and 2.6% and periods ranging between 6.9 sec and 20 sec around maximum phase and the subsequent stages of the flare evolution of a flare on EV Lac has been reported by Contadakis et al. (2004a). The resolution of the data was 1.2 sec. It appears that the frequencies of the oscillations become higher and the amplitude decreases as the flare evolves. In addition Contadakis et al. (2004b) analyzing a flare of 1992 on EV Lac with a data resolution of 12 sec they discover high-frequency oscillations on a flare of EV Lac with periods ranging between 30sec and 125 sec. Zhilyaev et al. (2006) reported high-frequency oscillations just after the flare maximum with periods ranging between 4 sec and 6 sec. Finally Contadakis et al. (2006) reported oscillations with periods ranging between 3.5s and 72s as well as during the pre- and the post- flare phase while in a similar study on the red dwarf YZ CMin they get similar results (Contadakis et al. 2007a). These results are consistent with the phenomenology of the evolution of a fast mode magneto-acoustic wave generated at the impulsive phase of the flare and travelling through the loop and that this is happened more than once before during and after an observed event. In this paper we analyse nine flares of the red dwarf AD Leonis in order to detect the presence of any high-frequency transient oscillation.

2. The Observations

Photoelectric observations of AD Leonis were carried out in February 2002 at the Stephanion Observatory ($\lambda = 22^{\circ}\,49'45''$, $\varphi = +37^{\circ}45'9''$, $H = 900$ m) using the 30-ich Cassegrain equipped with a formal Johnson photometer with a 1P21 photomultiplier using the typical U,B,V,R,I filters of the International UBVRI – system. The digitized recording system has a sampling interval of 0.108s. The Observations on AD Leonis consist of continuous monitoring in the U-band for the nights 05/06, 06/07, 09/10, 10/11, 12/13, 13/14, 14/15 of February, 2002. During the 16h52m of monitoring time nine flares were observed. The Table displays the characteristics of these flares while Figure 1 displays the nine flares.

3. Analysis

In stellar photometry and particularly in the programs where unexpected stellar brightness variation are searched, the standard procedure is the patrol monitoring of the star under investigation and the acquired data is a star brightness time series. The further analysis follows by analysing these time series in order to discover any systematic, abrupt or periodical variation, which off course would have a particular physical meaning. The Standard procedures for the analysis of the time series are: Discrete Fourier Transform and Wavelet analysis. Both methods have their advantages and disadvantages:

Table: *Characteristics of the observed Flares in the first half of 2002*

Flare No	Date Febr 2002	UT max (h)	t_b (min)	t_a (min)	$\frac{I-Io}{Io}$ max	P (min)	σ_I	σ_{BW}
1	05	22.76	8.93	7.39	0.362	1.999	0.097	0.097
2	05	23.03	2.76	24.16	0.399	3.159	0.097	0.085
3	06	00.68	1.00	3.02	0.566	0.409	0.127	0.087
4	07	00.17	7.62	5.35	0.286	0.778	0.107	0.082
5	10	23.53	22.50	13.33	0.291	1.411	0.107	0.083
6	12	23.75	1.78	30.25	0.936	3.751	0.107	0.084
7	13	22.60	0.78	4.03	0.238	0.394	0.107	0.074
8	13	23.45	1.68	29.09	0.732	4.953	0.107	0.080
9	14	23.22	0.27	4.45	0.826	0.754	0.107	0.073

UT max	Universal Time at the Flare maximum
t_b	Time period from the beginning to the Flare maximum
t_a	Time period from the Flare maximum to the end
$\frac{I-Io}{Io}$ max	Normalized Flare intensity at Maximum
$P=\int\frac{I-Io}{Io}dt$	Normalized Flare energy in minutes
σ_I	Standard deviation of the deflection random noise, estimated from the quite state of the star.
σ_{BW}	Standard deviation of the deflection random noise, estimated from the particular Flare deflection on the base of the Brownian walk characteristic of the random noise (see analysis) .

Discrete Fourier Transform Analysis

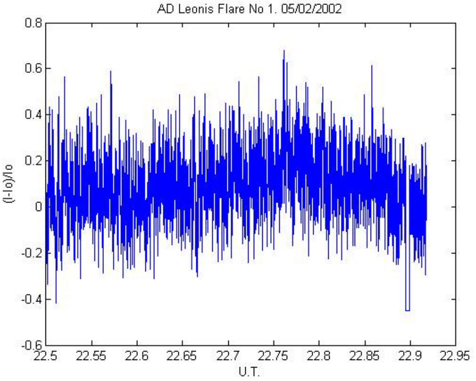
Advantage: Accurate frequency determination

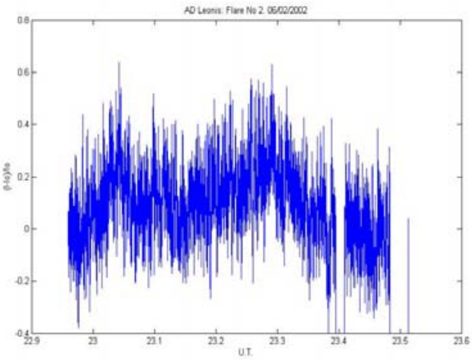
Disadvantage: (a) Poor time resolution.
(b) Weak transient oscillations fail to be reliably identified.

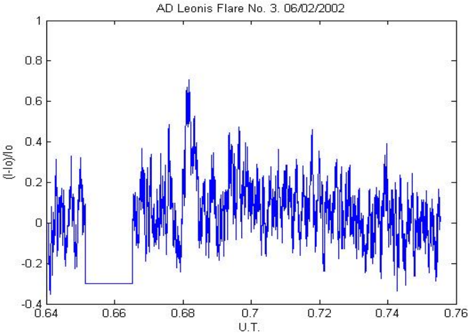
Wavelet Analysis

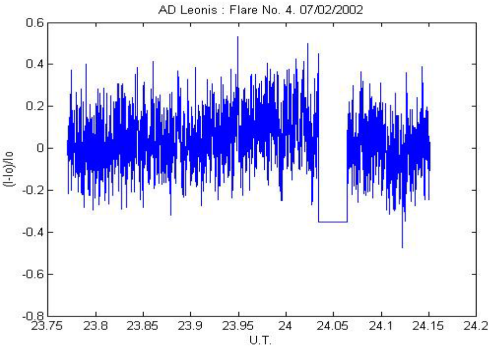
Advantage: Very good time resolution. A very good surveillance of brightness variations

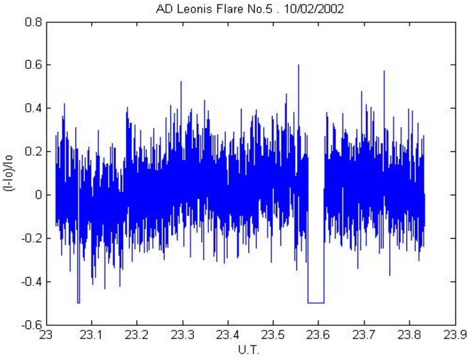
Disadvantage: (a) Poor frequency resolution.
(b) Result depend on the choice of the wavelet.
(c) No reliability argument for the identified frequency.

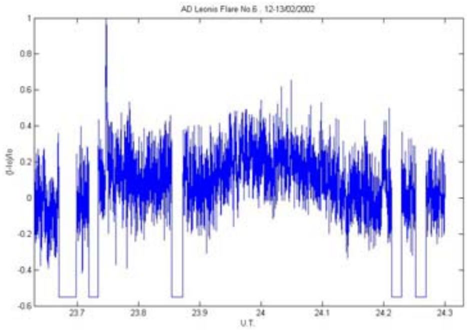

AD Leonis Flare No 1. 05/02/2002
(I-Io)/Io
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
22.5
22.55
22.6
22.65
22.7
22.75
22.8
22.85
22.9
22.95
U.T.

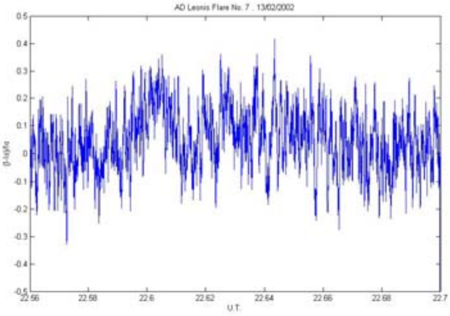

AD Leonis: Flare No 2. 06/02/2002
(I-Io)/Io
0.6
0.4
0.2
0
-0.2
-0.4
22.9
23
23.1
23.2
23.3
23.4
23.5
23.6
U.T.

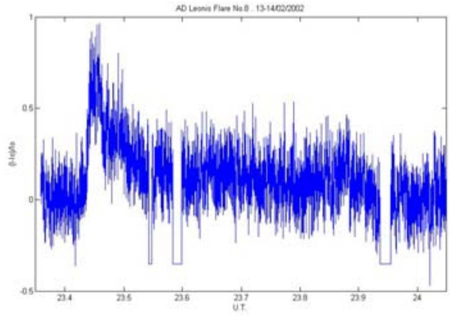

AD Leonis Flare No. 3. 06/02/2002
(I-Io)/Io
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
0.64
0.66
0.68
0.7
0.72
0.74
0.76
U.T.


AD Leonis : Flare No. 4. 07/02/2002
(I-Io)/Io
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
23.75
23.8
23.85
23.9
23.95
24
24.05
24.1
24.15
24.2
U.T.


AD Leonis Flare No.5 . 10/02/2002
(I-Io)/Io
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
23
23.1
23.2
23.3
23.4
23.5
23.6
23.7
23.8
23.9
U.T.


AD Leonis Flare No.6 . 12-13/02/2002
(I-Io)/Io
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
23.7
23.8
23.9
24
24.1
24.2
24.3
U.T.


AD Leonis Flare No. 7 . 13/02/2002
(I-Io)/Io
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
22.56
22.58
22.6
22.62
22.64
22.66
22.68
22.7
U.T.


AD Leonis Flare No.8 . 13-14/02/2002
(I-Io)/Io
1
0.5
0
-0.5
23.4
23.5
23.6
23.7
23.8
23.9
24
U.T.

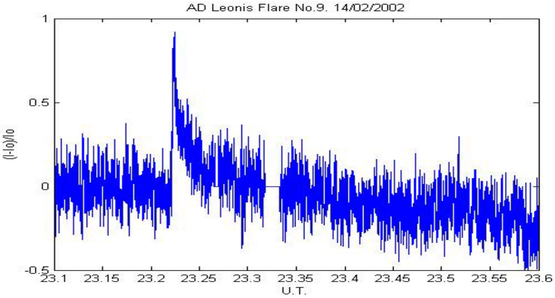


Figure 1: *The observed nine Flares of AD Leo*

For the determination of the reliability of the results key roll play the standard deviation of the photometry which is determined from the standard deviation of a certain part of the star deflection, as it is recorded by the recording facility at hand. This sample is considered, according to the observer’s estimation (judgment) to reflect the noise of his photometric system and is clear from any real stellar brightness variations, which is assumed to be white noise. However The quiet star deflection is the sum of three component

(a) the noisy stellar brightness assumed to be white noise

(b) the inherent atmospheric noise which we assume to be random i.e. white noise and

(c) the white noise of the recording system.

If the memory of the recording system is short i.e. the system has large sampling intervals then the quiet star deflection is white noise. If the memory of the recording system is large i.e. the sampling interval is very short the quiet star deflection is Brownian Walk. This is the case of the most stellar recording systems.

Brownian walk is an affine fractal and has a power low spectrum with $b = -2$. (Contadakis et al. 2006, Contadakis 2007a and b, Contadakis 2009(in Greeks)).

Our system has a sampling interval of 0.108 seconds which is very short. Figure 2 displays the logarithmic power spectrum of the dark-current of our system (the photometer is not exposed to any source). It is apparent that the random noise of the dark-current do not affect successive recordings since the recording is purely white noise ($b = 0$).

Figure 3 displays the Logarithmic Power Spectrum of the standard source. From this diagram is apparent that the high frequencies of the noise of the standard source do not affect successive recordings and they produce white noise ($b = 0$) while the low frequencies does thus they produce Brownian walk ($b = -2.0$).

Figure 4 displays the Logarithmic Power spectrum of the sky-deflection. It is apparent that the random noise generate a Brownian walk over all the spectrum ($b = -2.0$). This means that the sky deflection sustain random fluctuations.

Figure 5 displays the Logarithmic power spectrum of a standard star (a not variable star which is used for comparison star). It is apparent that the fluctuations of the standard star are random ($b = -2.0$).

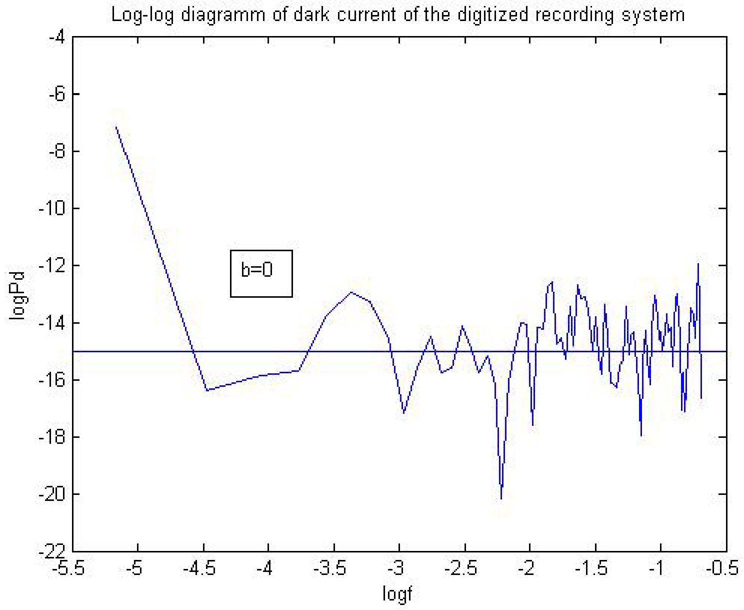


Figure 2: *Logarithmic Power Spectrum of the dark current*

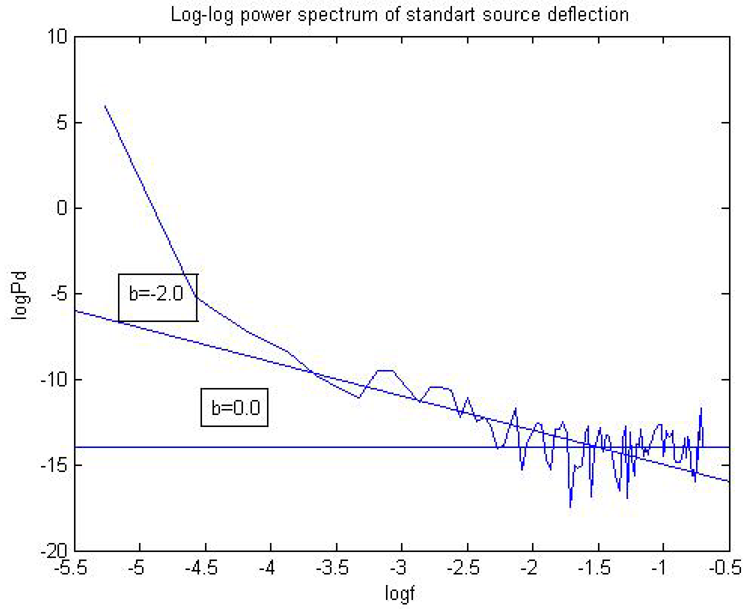


Figure 3: *Logarithmic Power Spectrum of the standard source.*

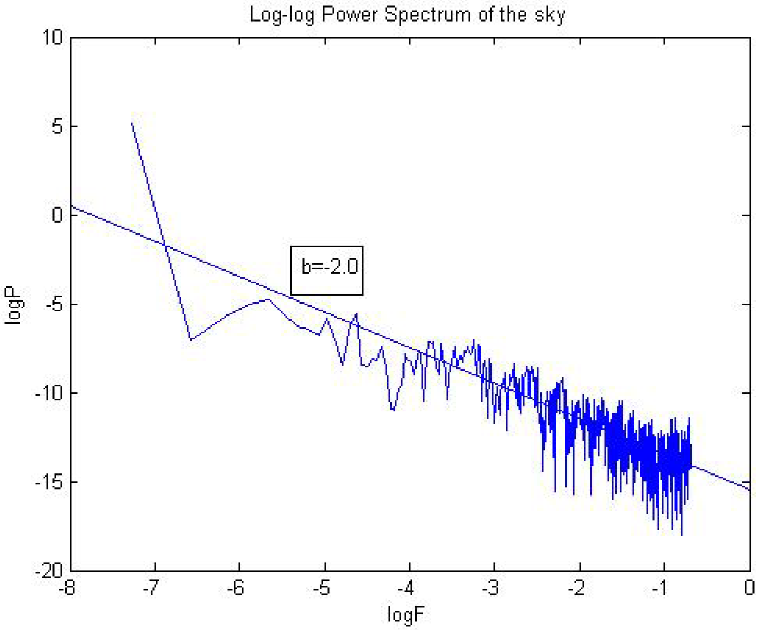


Figure 4: *Logarithmic Power Spectrum of the sky-deflection.*

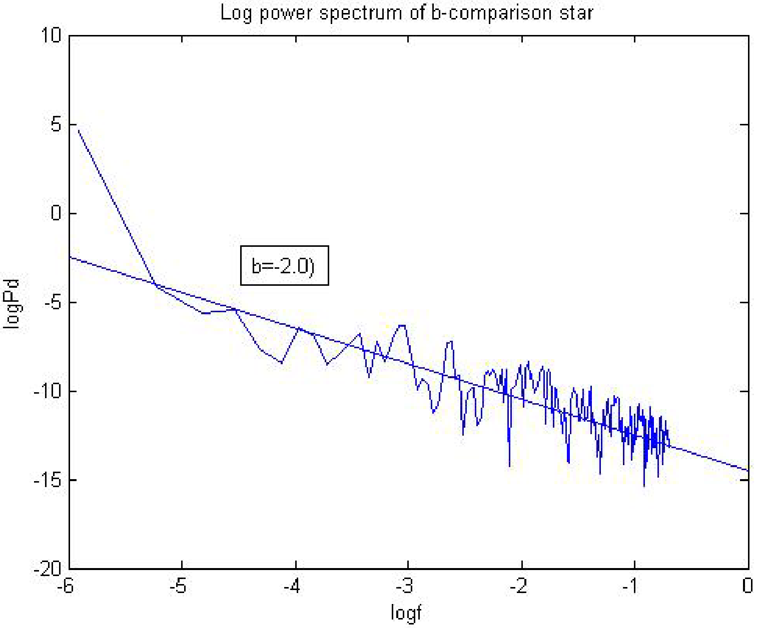


Figure 5: *Logarithmic Power Spectrum of a non variable star.*

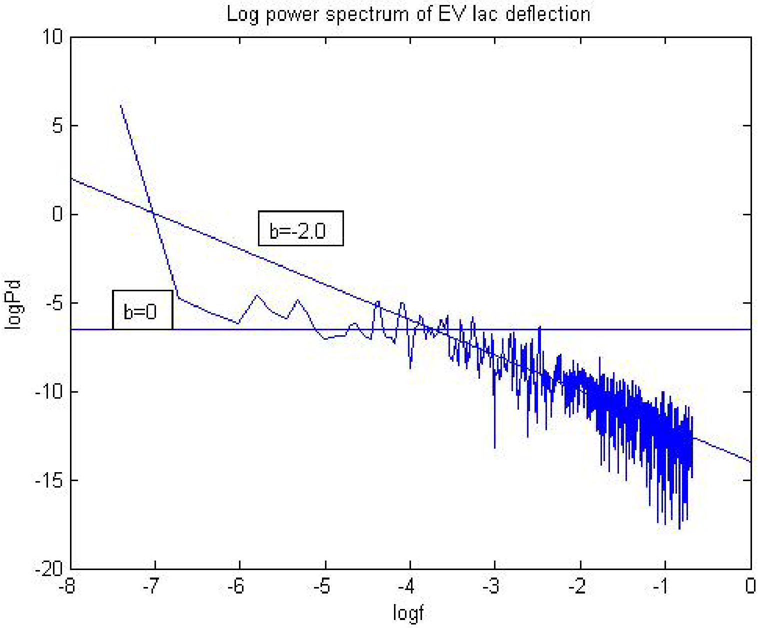


Figure 6: *Logarithmic Power Spectrum of the flare star EV Lac*

On the contrary from Figure 6, which displays the Logarithmic power spectrum of the flare star EV Lac in the quiescent state, the random fluctuations of its deflection with frequencies higher than $\log(-3.8) = 0.0224$ c/gap i.e. 0.2074 Hz (period of 4.82 second) show random behavior $(b = -2)$, while the lower frequencies doesn't, indicating that they contain non random variations. Shortly speaking, we see that if the star deflection present non random fluctuations the logarithmic power spectrum present a breaking point at the frequency where the non random fluctuations begin.

On the base of this property it is possible to separate the random noise of our data from the not random variations even from the signal of the active star and further more to determine any non random deflection variation.

The standard deviation which is derived using the Brownian Walk part of the frequencies we call σ_{BW} and may be up to 30% smaller than the conventional one. The respective σ_{BW} for each flare is given in the last column of the table. This standard deviation we use for the estimations of the confidence level. So the analysiscomprise the following steps:

1. With the help of DFT-analysis we deduce the power spectra and the logarithmic power spectra of the flares and the quiet state star deflection. The logarithmic power spectrum will enable us to separate the random part of the spec-

trum from the non random.

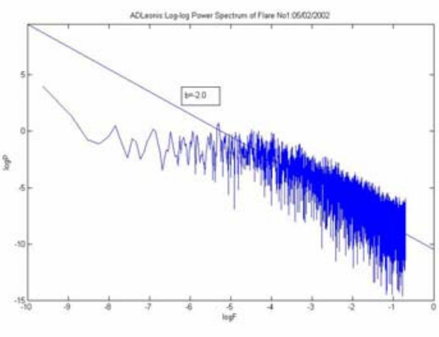
2. We isolate by filtering the random part of the spectrum and we estimate the standard deviation of the random noise σ_{BW}.
3. We identify the potential frequencies of oscillations from the power spectrum.
4. We filter out the identified frequencies from the star deflection.
5. We estimate the confidence level of those frequencies identifications comparing their magnitude with the respective σ_{BW}.

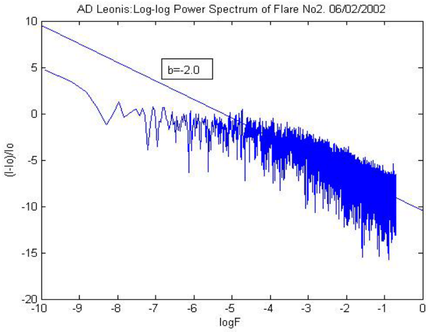
4. Results

Figure 7 displays the logarithmic power spectra of the nine flares and the quiet state star deflection. From these logarithmic power spectra is obvious that all the flares and the quiet state star deflection present non random part of the frequencies. The random part of the quiet state star deflection extent to frequencies higher than $\log(-3.8) \Rightarrow 0.207\ \mathrm{Hz}$ (period 4.8s) and the random part for the flares extent to frequencies higher than $\log(-4.5) \Rightarrow 0.1028\ \mathrm{Hz}$ (period 9.7s).

For the quiet state is $\sigma_{BW} = 0.0608$ while the respective standard deviation for each flare is given in the last column of the table.

By inspection of the power spectra we identify the potential frequencies of the transient oscillations. It was found that transient high frequency oscillations occur during the flare as well as during the quiet-star phase. The Observed frequencies range between $0.0083\ \mathrm{Hz}$ (period 2min) and $0.3\ \mathrm{Hz}$ (period 3s) not rigorously bounded. Their magnitudes ranges from 15% to 25% and the confidence level ($p(1-\alpha)$) of their identification is greater than 70%. The phenomenon is most pronounced during the flare state.





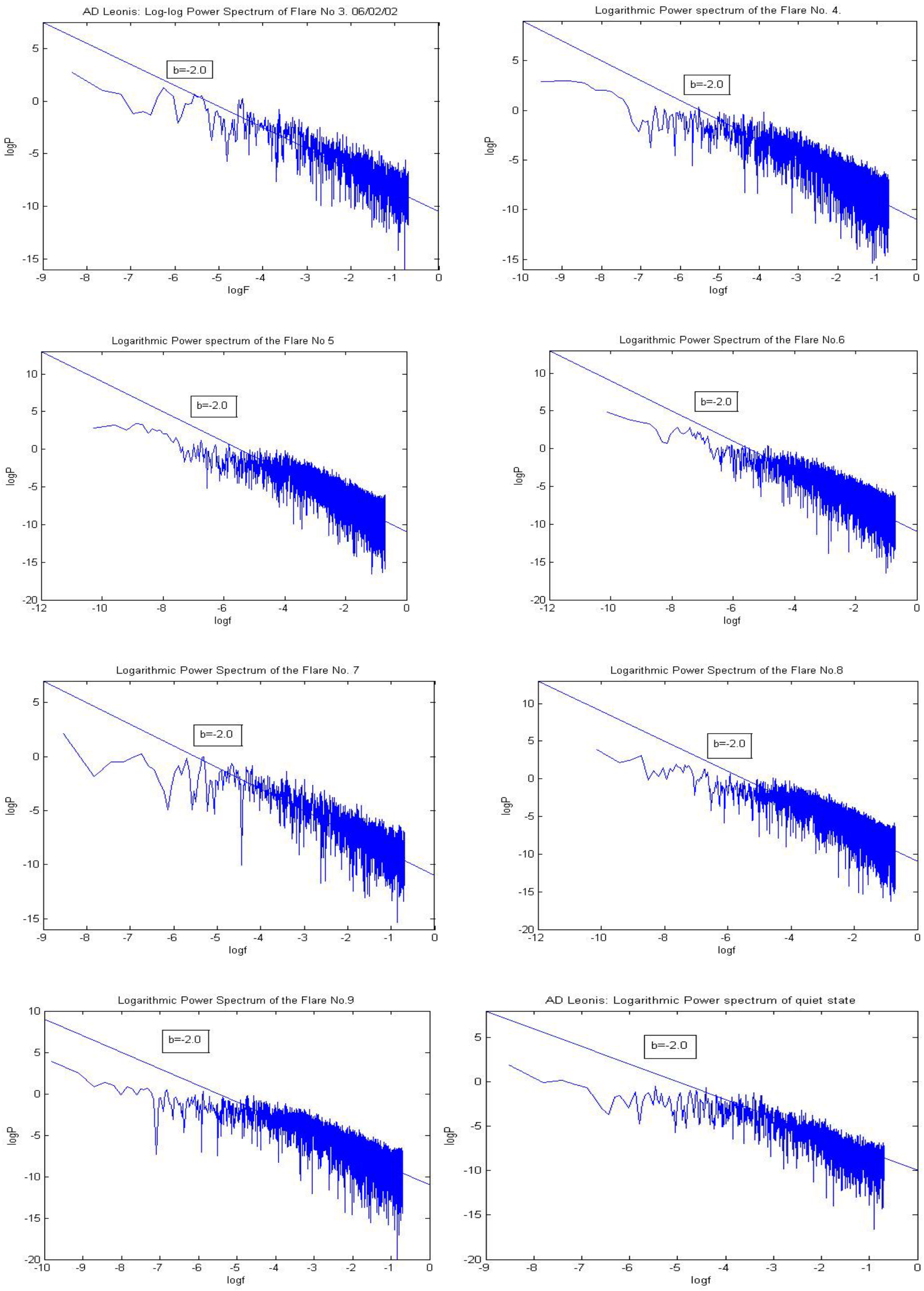


Figure 7: *The logarithmic power spectra of the nine flare and the quiet state star deflection.*

The following figures display some examples of the identified transient high frequency oscillations concerning one of the weakest flares (Flare No.1), one of the largest flares (Flare No 9) and the quiet-star state.

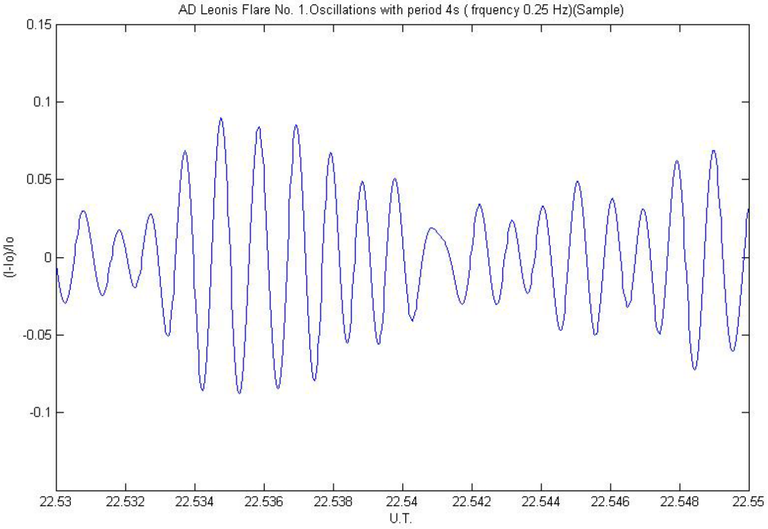


Figure 8: *Transient oscillations with period 4s (frequency 0.25Hz) during the Flare No.1.*

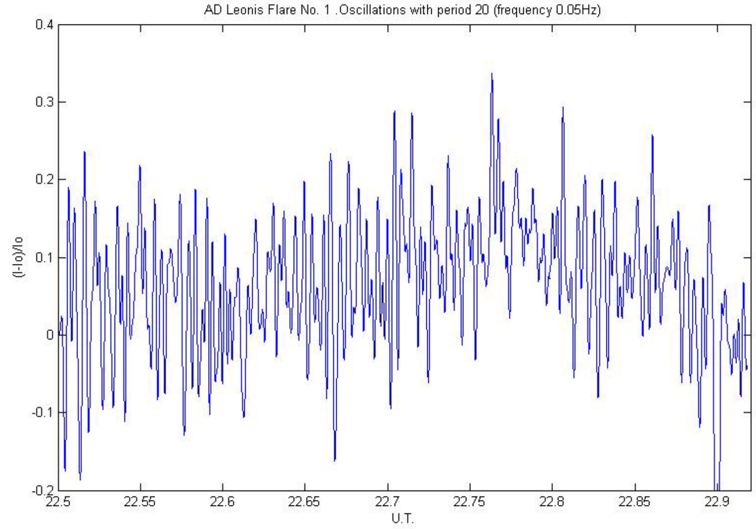


Figure 9: *Transient oscillations with period 20s (frequency 0.05Hz) during the Flare No.1.*

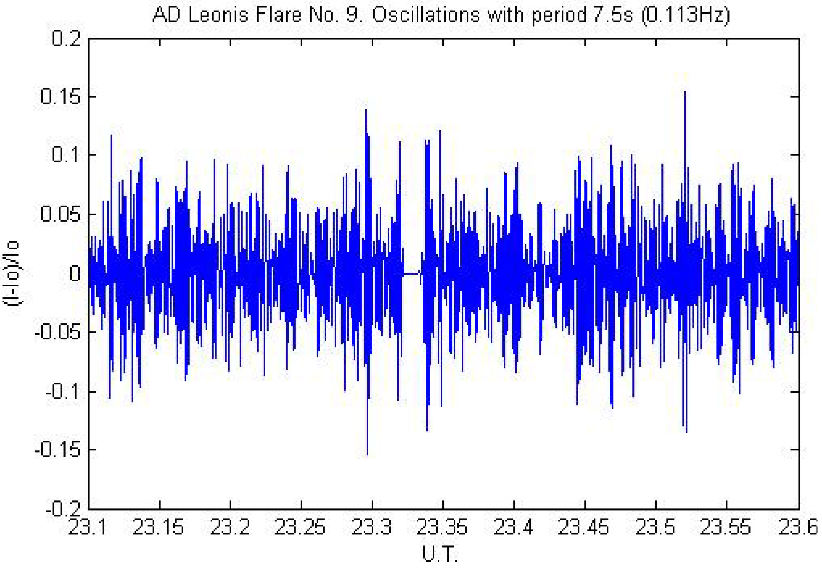


Figure 10: *Transient oscillations with period 7.5s (frequency 0.113Hz) during the Flare No.9.*

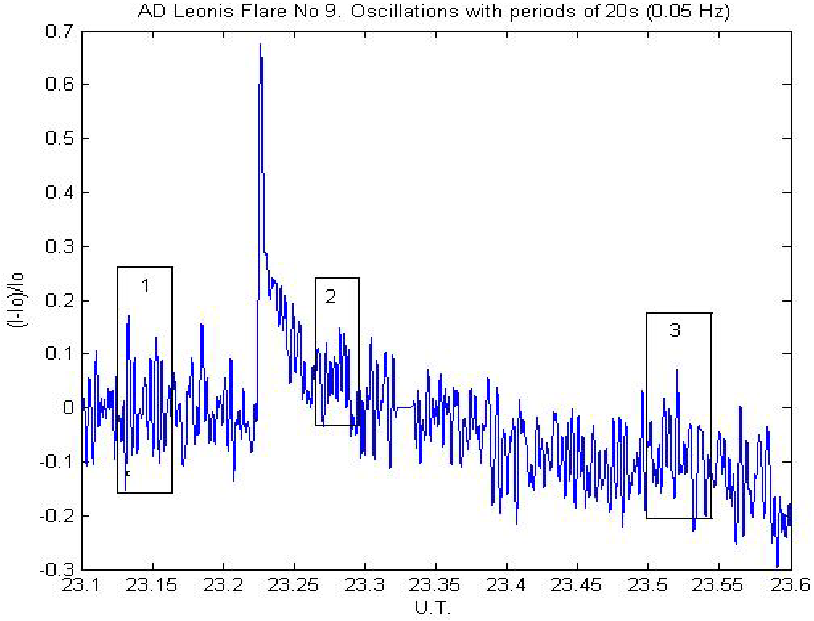


Figure 11a: *Transient oscillations with period 20s (frequency 0.05Hz) during the Flare No.9.*

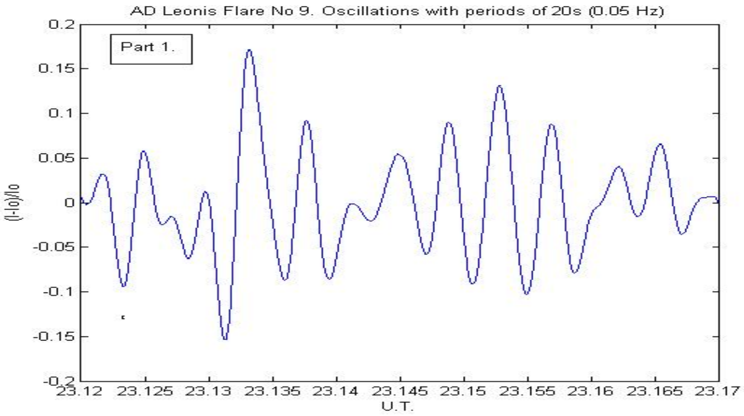


Figure 11b: Focusing on the parallelogram 1 of figure 11a

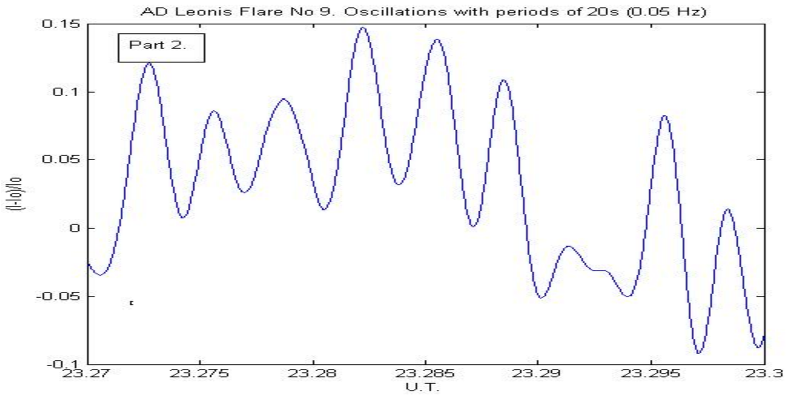


Figure 11c: Focusing on the parallelogram 2 of figure 11a

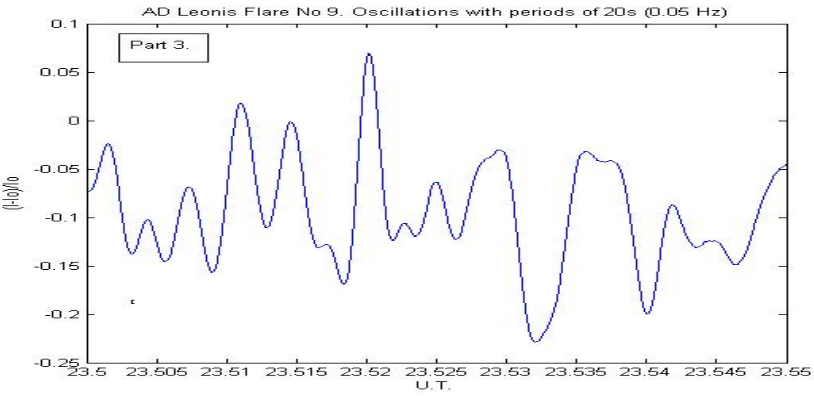


Figure 11d: Focusing on the parallelogram 3 of figure 11a

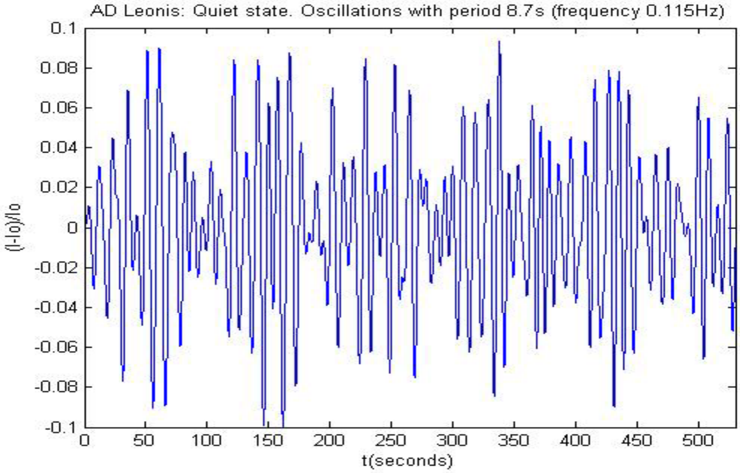


Figure 12: *Transient oscillations with period 8.7s (frequency 0.1028Hz) during the quiet-star state.*

5. Concluding remarks

In accordance to the results of the previous studies on EV Lac and YZ CMin the results of the present study indicate that transient high frequency oscillations occur during the flare as well as during the quiet-star phase. The Observed frequencies range between 0.0083Hz (period 2min) and 0.3 Hz (period 3s) not rigorously bounded. Their magnitudes ranges from 15% to 25% and the confidence level ($p(1-\alpha)$) of their identification is greater than 70%. The phenomenon is most pronounced during the flare state. This result is in favour of (or does not contradict) the suggested explanation, i.e. the evolution of a fast mode magneto-acoustic wave generated at the impulsive phase of the flare and travelling through the magnetic loop (Williams et al. 2001, Williams et al. 2002, Roberts 1984). This procedure may occur many times during the development of a large flare. Finally, the transient optical oscillation, which occurs during the quiet-star state, are not necessary connected with any flare and may be a general characteristic of the active stars atmospheres.

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