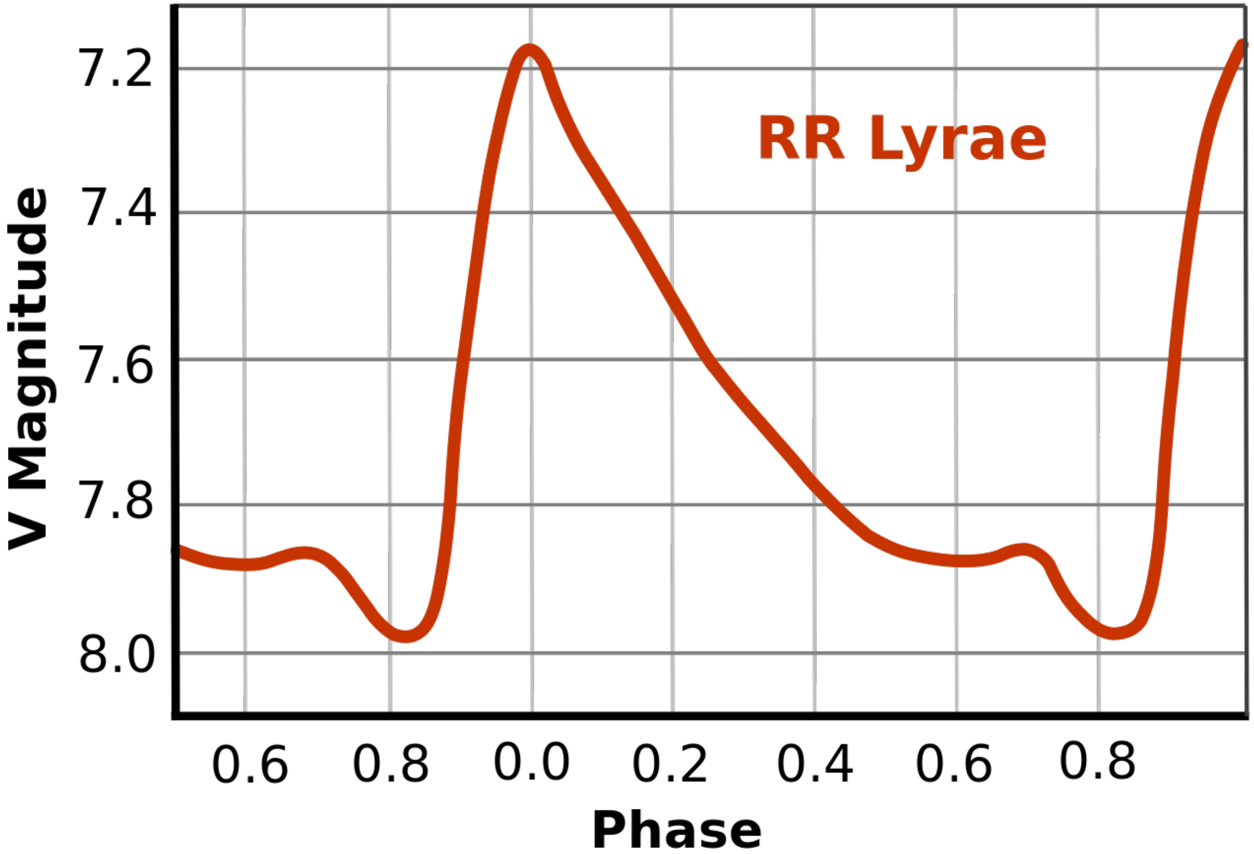
The Blazhko RR Lyrae variables and phase modulation in binary systems

Hiromoto Shibahashi
University of Tokyo

RR Lyrae variables :
Horizontal branch stars in classical instability strip
Period ≃ 0.5d



https://commons.wikimedia.org/wiki/File:Rr_lyrae_ltcrv_en.svg

Blazhko effect:
Phase and/or amplitude modulation of RR Lyrae variables

Sergey Blazhko

Harlow Shapley

...NT INSTITUTE FOR LABOR...

UNIVERSITY OF COLORADO
BOULDER, COLORADO 80309

NATIONAL B...

...OF COLORADO

9 March 1983

Dr. D. W. Kurtz
Department of Astronomy
University of Cape Town
Rondebosch
South Africa

Dear Dr. Kurtz,

Today I am writing you about the problems of rapidly oscillating Ap stars. I read interestingly your papers concerning them and your oblique pulsator model, and I am now trying to understand why such rapid pulsations are excited in Ap stars. Enclosed is a brief summary of my idea. I would appreciate it if you could critically read it and comment on it.

Sincerely,

Hiromoto Shibahashi

HS:b
Enc.

UNIVERSITY OF CAPE T...
(WITH WHICH IS INCORPORATED THE SOUTH AFRICAN COLLEGE...

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Department...
RONDEBOSC...
SOUTH AFRIC...

25th Marc...

Dr. Hiromoto Shibahashi,
J.I.L.A.,
University of Colorado,
Boulder.
COLORADO 80309.
U.S.A.

Dear Dr. Shibahashi,

Thank you for your interesting preprint, "On the Rapidly Oscillating Ap Stars". I have examined some early Ap and Bp stars and some Am for oscillations and I have not detected any variations. However, the problem of determining the constancy of non-variable stars using high speed photometry is severe; I enclosed a preprint discussing this problem.

I also enclose a preprint of further observations of HD24712. As you will see, there appear to be at least six independent oscillation modes in this star with a rather curious pattern of amplitudes.

Yours sincerely,

Don Kurtz

DON KURTZ.

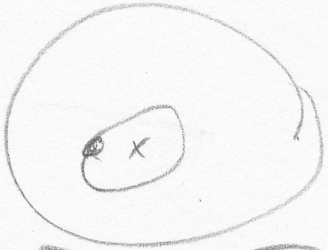
1984.08 Hakone

2011.03 Hakone

$$\frac{\Delta L}{L} = A_0 + A_1 \cos(\omega t + \varphi)$$

$$= A_0 + A_1 \cos(2\pi f t + \varphi)$$

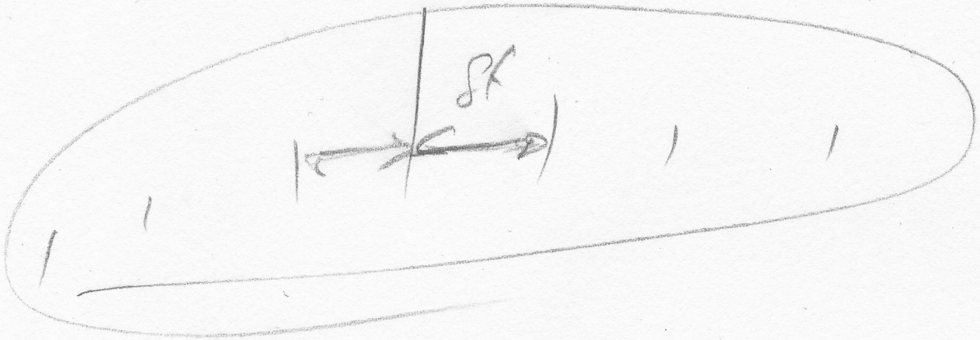
$$f = f(t) = f_p + \delta f(t)$$



$$\frac{\delta f}{f} = \frac{v}{c} \quad v(t)$$

$$\delta f = \frac{v}{c} f_0$$

$$\delta f = A' \cos(2\pi f_{rot} t + \varphi_{rot})$$



O-C

2011.03 Hakone

Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY

Mon. Not. R. Astron. Soc. **422,** 738–752 (2012) doi:10.1111/j.1365-2966.2012.20654.x

FM stars: a Fourier view of pulsating binary stars, a new technique for measuring radial velocities photometrically

Hiromoto Shibahashi[1]★ and Donald W. Kurtz[2]

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Accepted 2012 January 30. Received 2012 January 28; in original form 2011 December 21

ABSTRACT

Some pulsating stars are good clocks. When they are found in binary stars, the frequencies of their luminosity variations are modulated by the Doppler effect caused by orbital motion. For each pulsation frequency this manifests itself as a multiplet separated by the orbital frequency in the Fourier transform of the light curve of the star. We derive the theoretical relations to exploit data from the Fourier transform to derive all the parameters of a binary system traditionally extracted from spectroscopic radial velocities, including the mass function which is easily derived from the amplitude ratio of the first orbital sidelobes to the central frequency for each pulsation frequency. This is a new technique that yields radial velocities from the Doppler shift of a pulsation frequency, thus eliminates the need to obtain spectra. For binary stars with pulsating components, an orbital solution can be obtained from the light curve alone. We give a complete derivation of this and demonstrate it both with artificial data, and with a case of a hierarchical eclipsing binary with *Kepler* mission data, KIC 4150611 (HD 181469). We show that it is possible to detect Jupiter-mass planets orbiting δ Sct and other pulsating stars with our technique. We also show how to distinguish orbital frequency multiplets from potentially similar non-radial m-mode multiplets and from oblique pulsation multiplets.

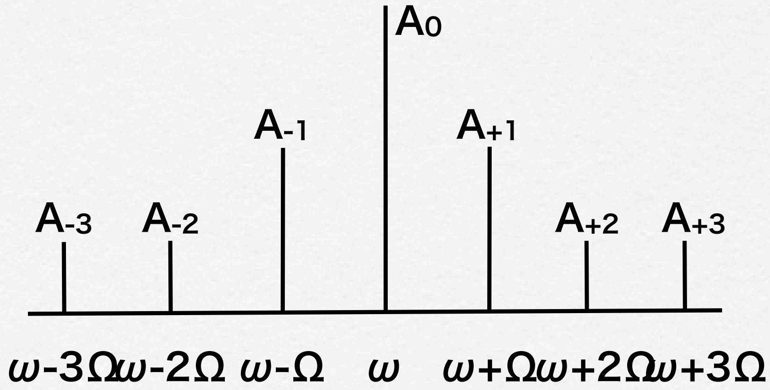
Key words: techniques: radial velocities – binaries: general – stars: individual: KIC 4150611; HD 181469 – stars: oscillations – stars: variables: general.

The light travel time effect on luminosity variation:

$$\Delta L(t) \propto \cos\left\{\omega_0\left[t - \underbrace{c^{-1}\int_0^t v_{\rm rad}(t')\mathrm{d}t'}_{\text{arrival time delay}}\right] + \phi\right\}$$

$$= \cos\left(\omega_0 t + \phi + \alpha \sin \Omega t \right)$$

$$= \sum J_n(\alpha) \cos\left[(\omega_0 + n\Omega)t + \phi\right]$$



Questions

1. Are phase modulations of Blazhko RR Lyrae variables distinguishable from the light travel time effect caused by binary motion?

2. Aren't RR Lyrae variables in binary systems misclassified as Blazhko variables?

FM features as evidence for binarity

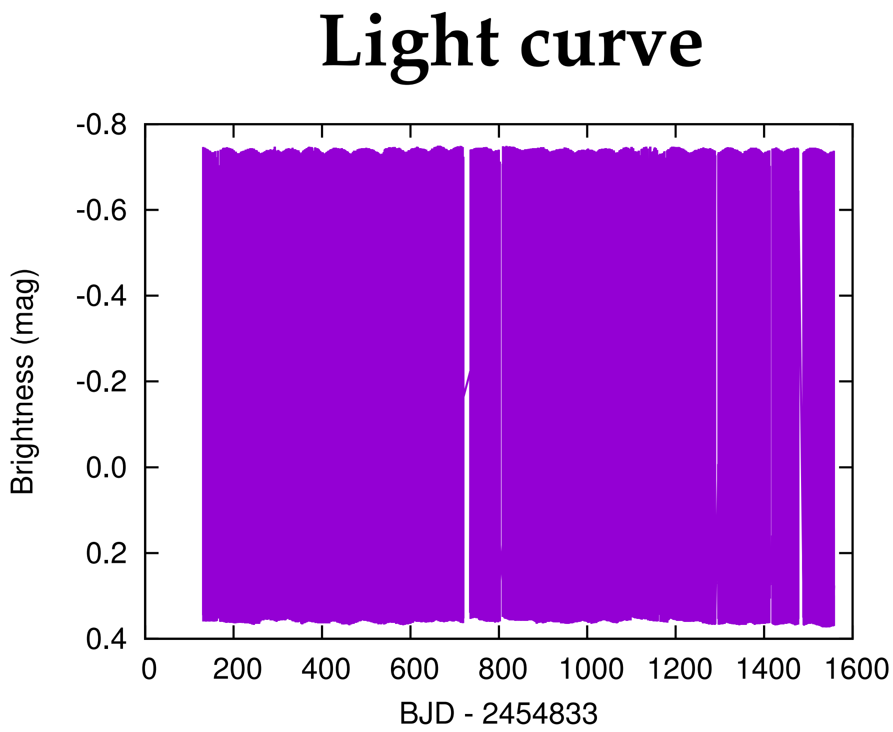
- Multiplet fine structures with an equal spacing in Fourier spectrum.
- The amplitude ratio $(A_1+A_{-1})/A_0 \propto \nu_{puls}$
- The phase difference $\Phi_{\pm1}- \Phi_0 \simeq \pi/2$ rad

Binary information from FM features

- The frequency spacing gives the orbital frequency.
- The amplitude ratio $(A_1+A_{-1})/A_0$ gives $a_1 \nu_{\rm puls} \sin i/c$.
- A quintuplet fine structure gives e and ϖ.

Kepler data

KIC 10789273



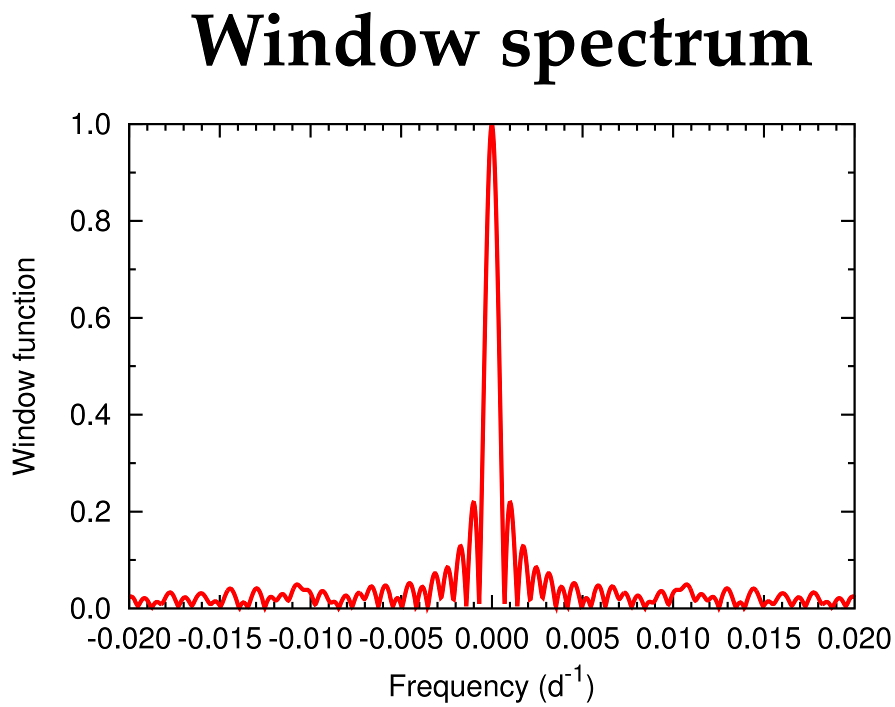


Figure 1: Left: Light curve of 10789273 as a function of time. Right: Zoom-in of the window spectrum.

Amplitude spectrum

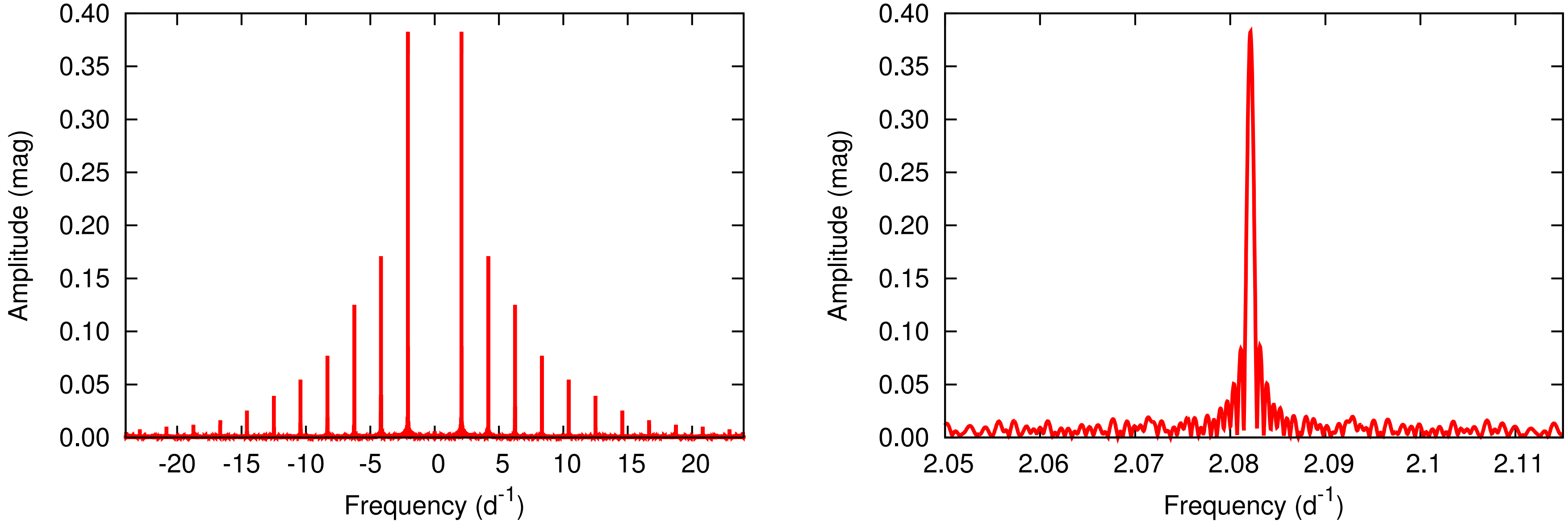


Figure 2: Left: An amplitude spectrum of the light curve shown in Fig. 1. Right: Zoom-in of the amplitude spectrum around ν_1.

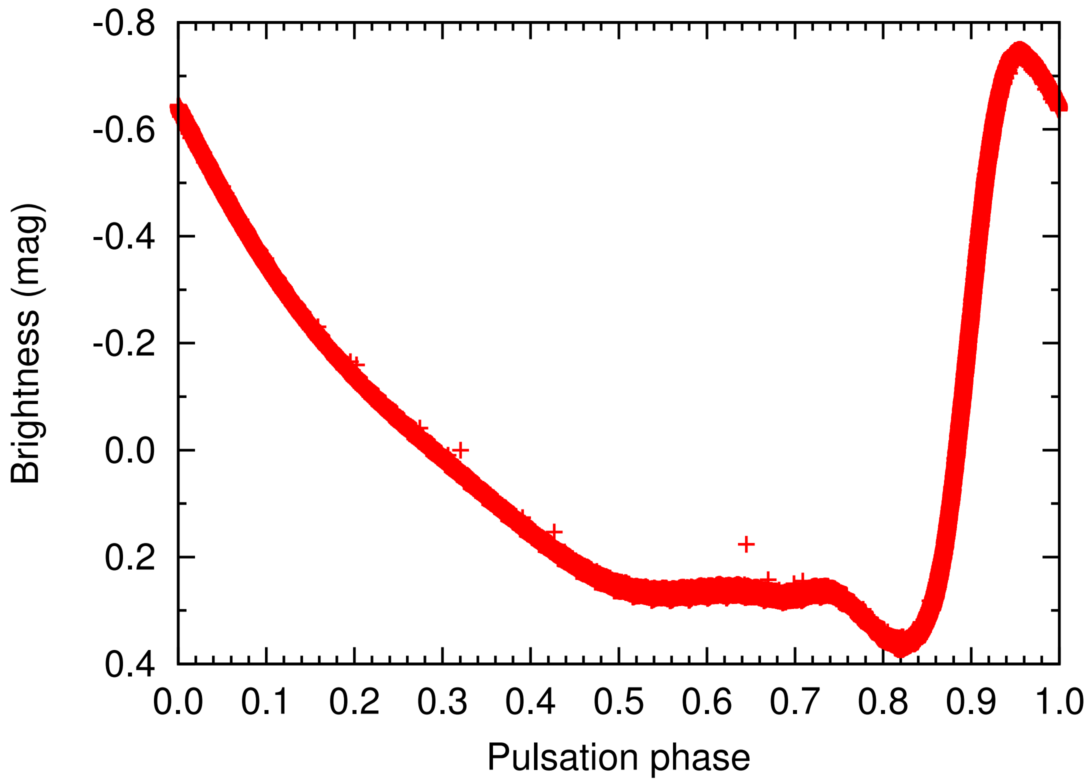


Figure 3: Light curve of KIC 10789273, folded with ν_1^{-1}.

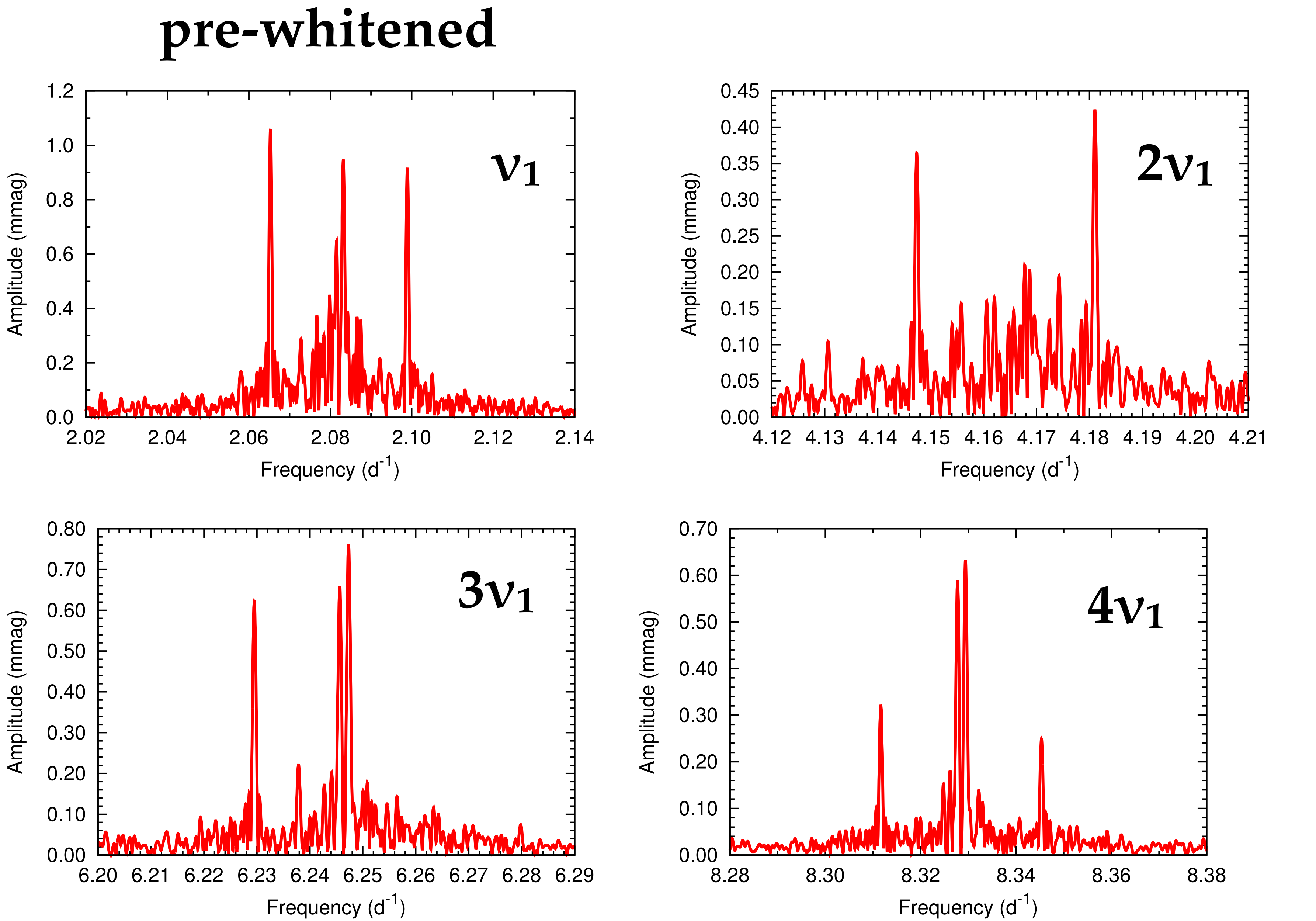
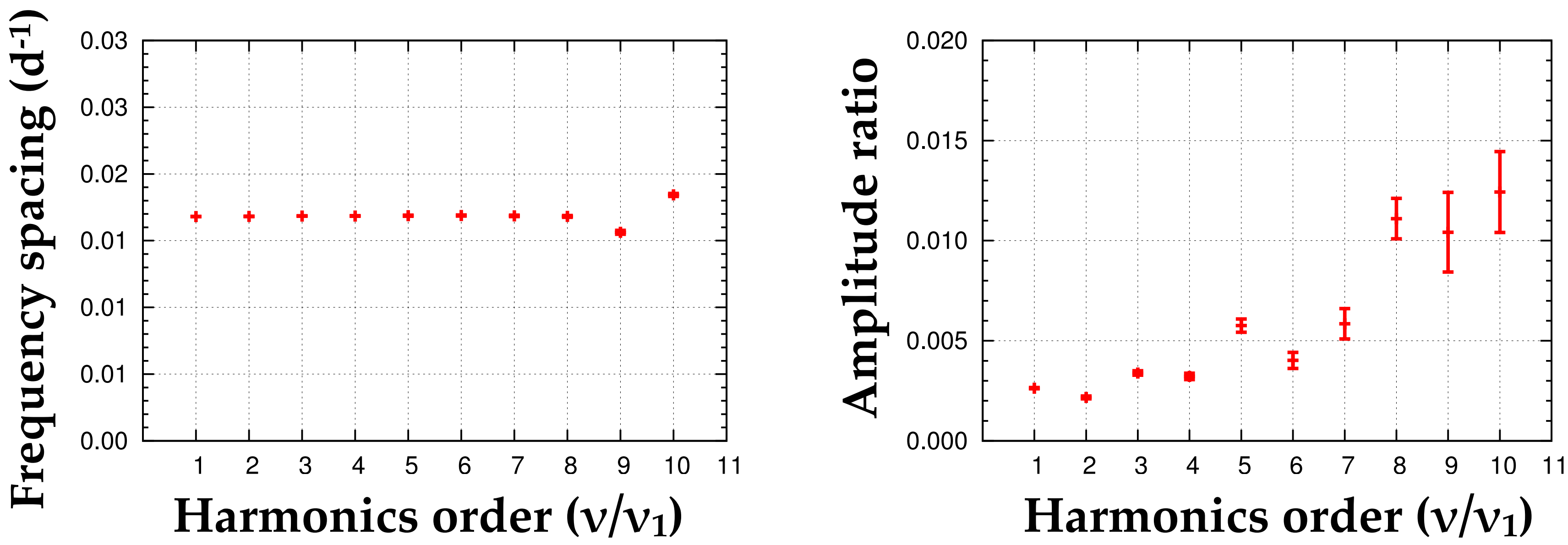
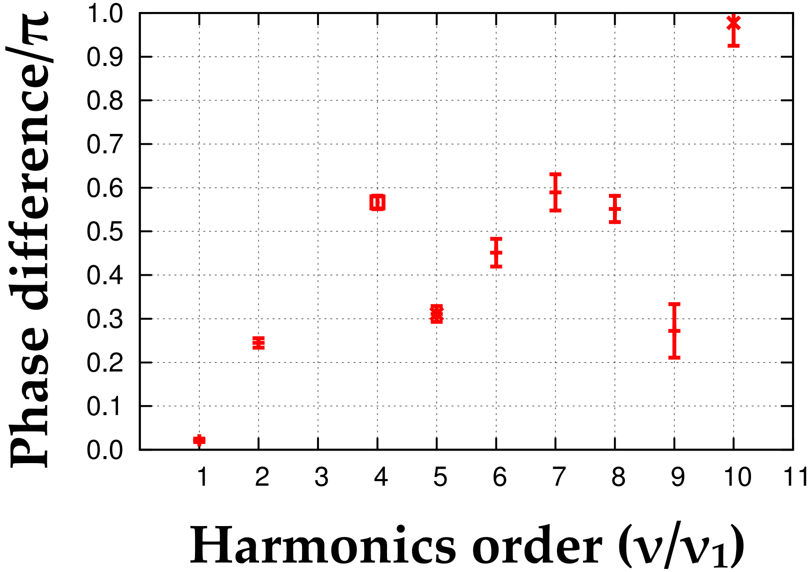


Figure 4: An amplitude spectrum after pre-whitening the highest peak, ν_1, $2\nu_1$, $3\nu_1$ and $4\nu_1$.





- **Multiplet fine structures with an equal spacing in amplitude diagram.**
- **The amplitude ratio $(A_1+A_{-1})/A_0 \propto \nu$?**
- **The phase difference $\Phi_{\pm1}- \Phi_0 \simeq \pi/2$?**

Figure 5: Top left: Frequency spacings among multiplets vs harmonics. Top right: Amplitude ratio between the side lobe and the central component of triplets vs harmonics. Bottom: Phase difference between the mean of the sidelobes and the central component of triplets vs harmonics.

OGLE data

OGLE 06498

Light curve

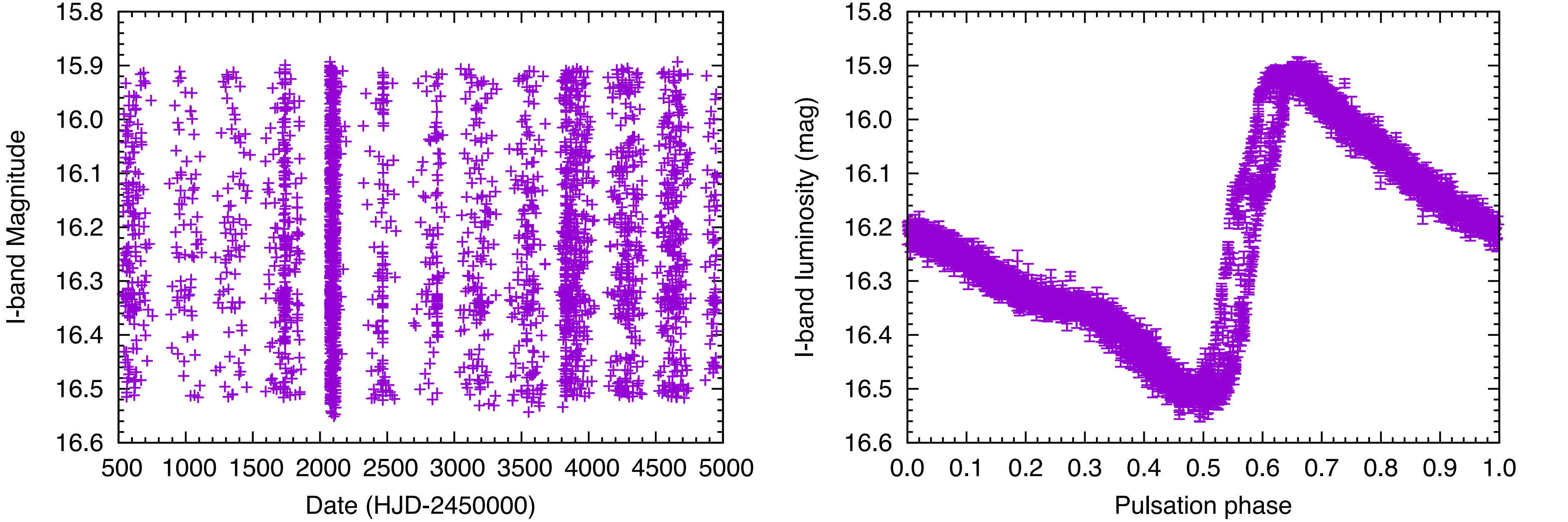
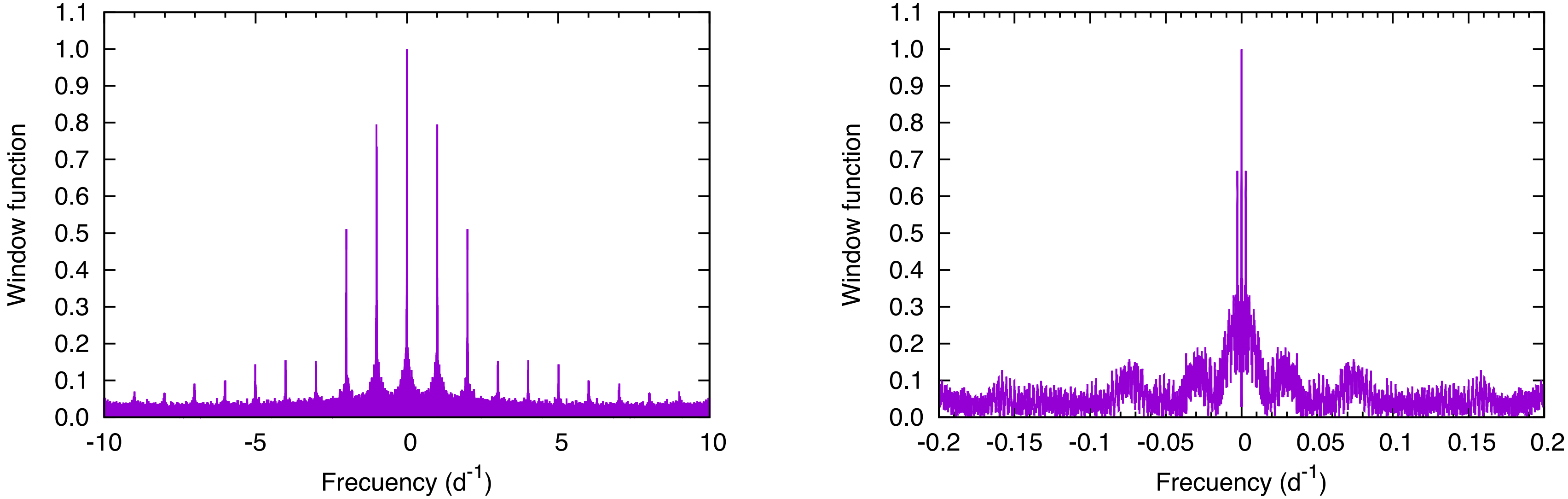
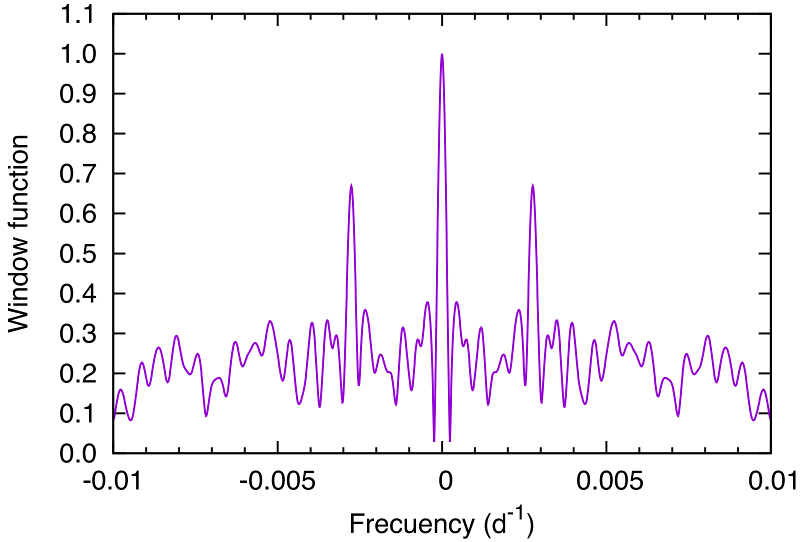


Figure 1: Left: Light curve of 06498 as a function of time (left panel) and as a pulsation phase (right panel).





Window spectrum

Figure 2: Window spectrum. Top left: A day-night gap leads the comb structure with spacing $1\,\mathrm{d}^{-1}$. Top right: Zoom-in of the window spectrum shown in the right panel. Bottom: Further zoom-in of the window spectrum. A year gap leads the comb structure with spacing $\sim 0.003\,\mathrm{d}^{-1}$.

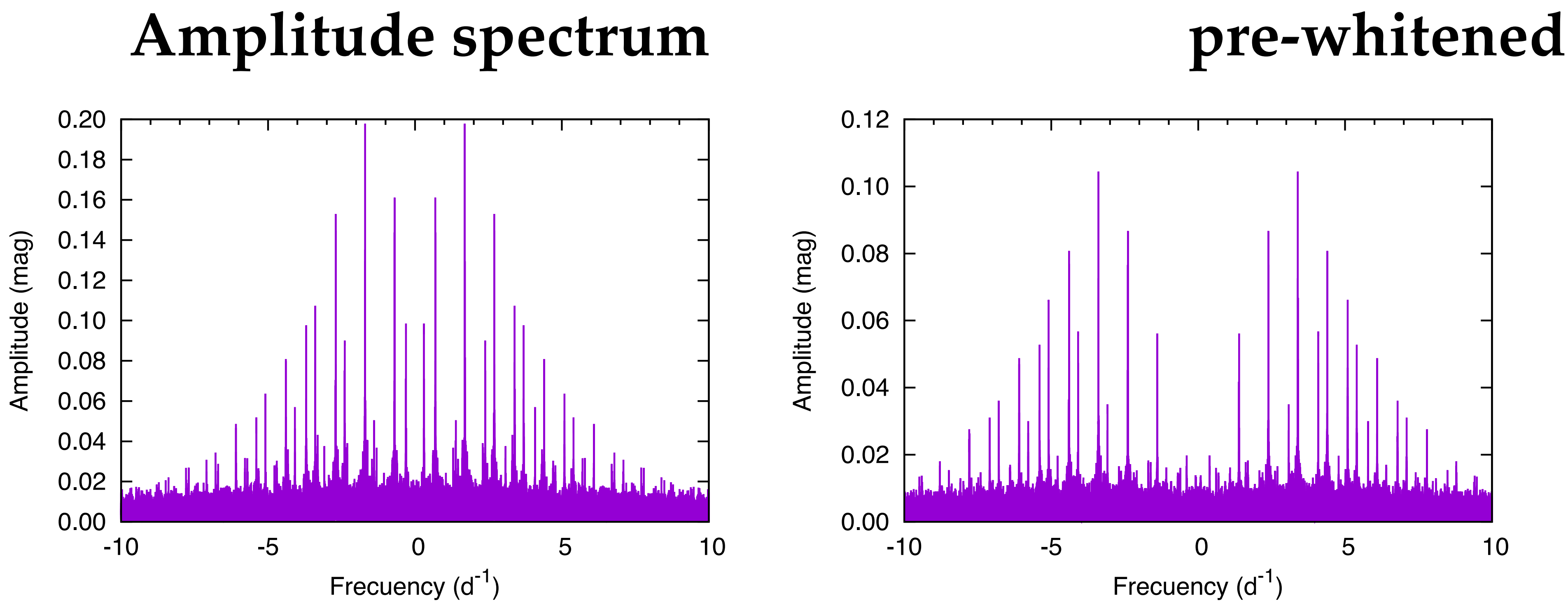


Figure 3: Left: An amplitude spectrum of the light curve shown in the left panel of Fig. 1. Right: An amplitude spectrum after pre-whitening the highest peak, ν_1 Aliases of the highest peak with spacing $1\,\mathrm{d}^{-1}$ automatically disappear.

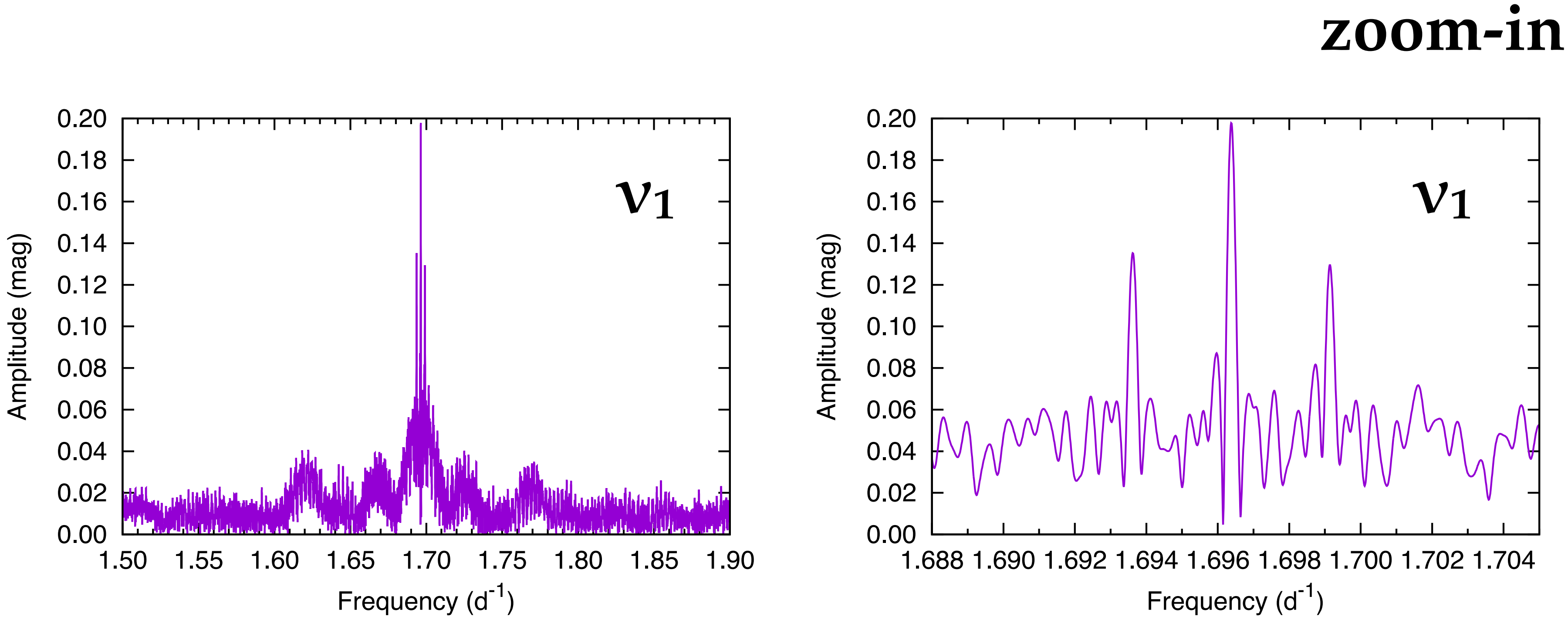


Figure 4: Left: Zoom-in of the amplitude spectrum around the highest peak, ν_1. The shape reflects the window spectrum shown in the left panel of Fig. 2. Right: A further zoom-in of the amplitude spectrum around the highest peak. The shape reflects the window spectrum shown in the right panel of Fig. 2.

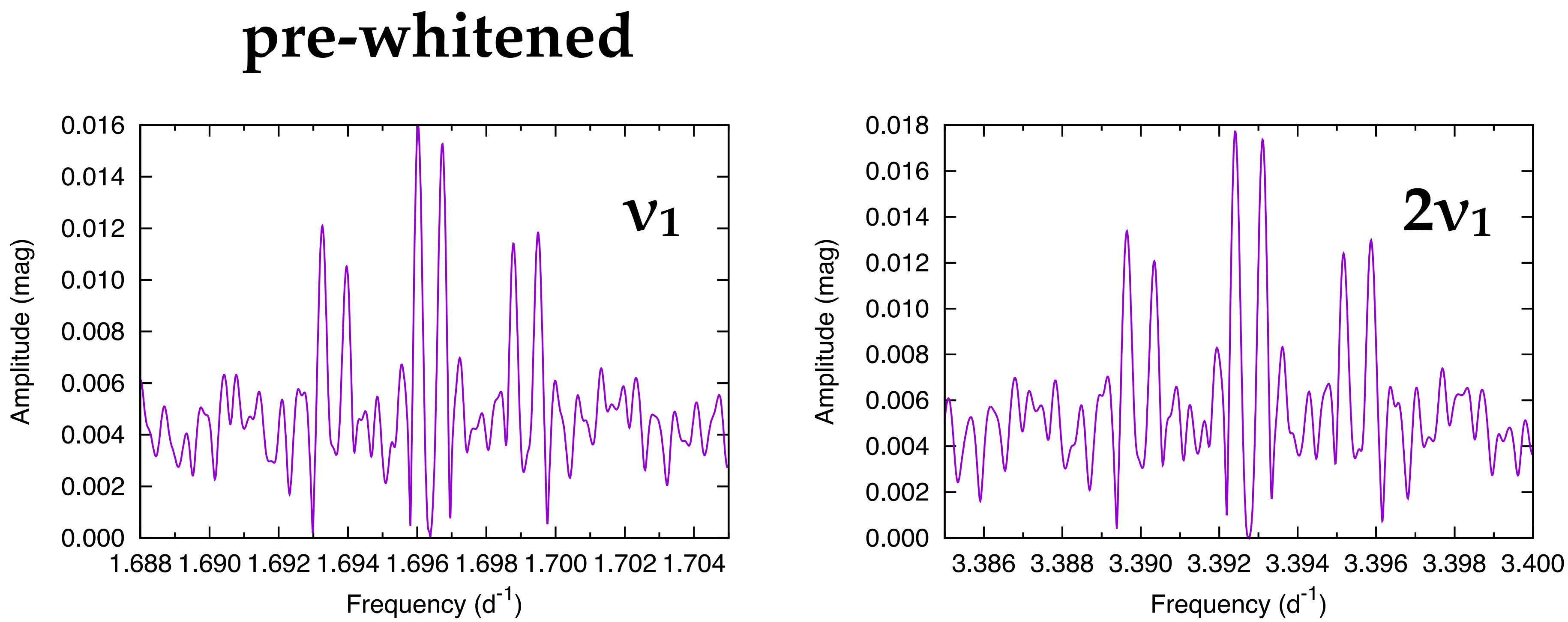
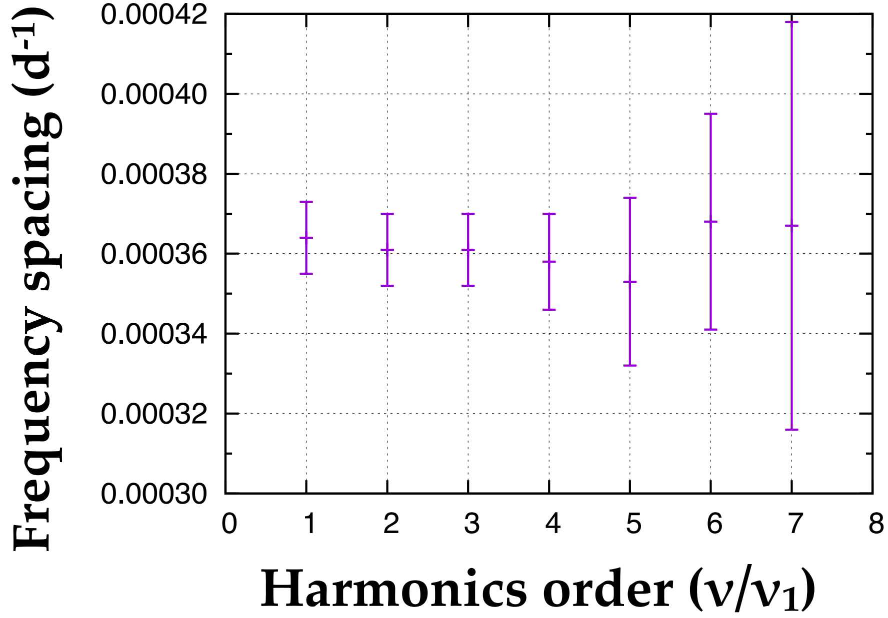
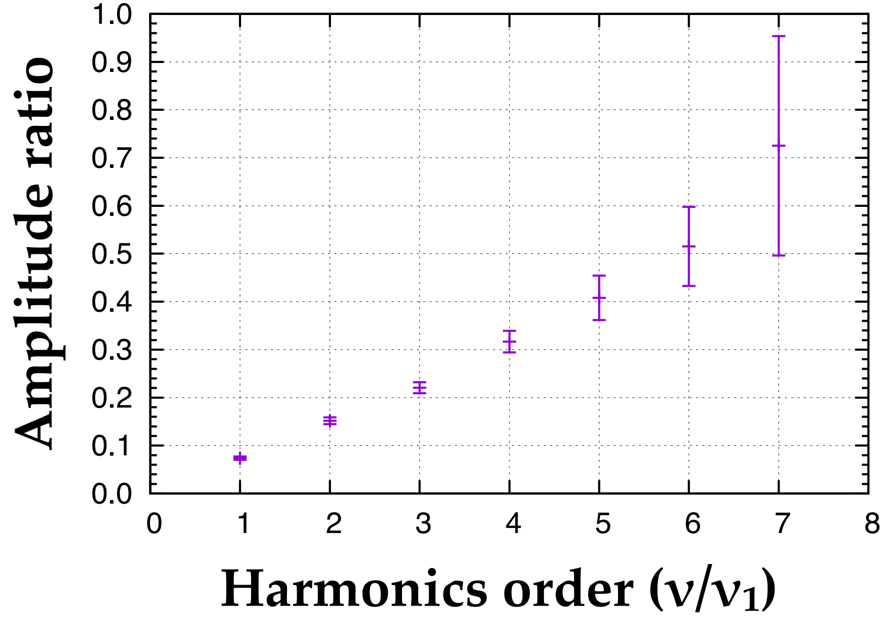
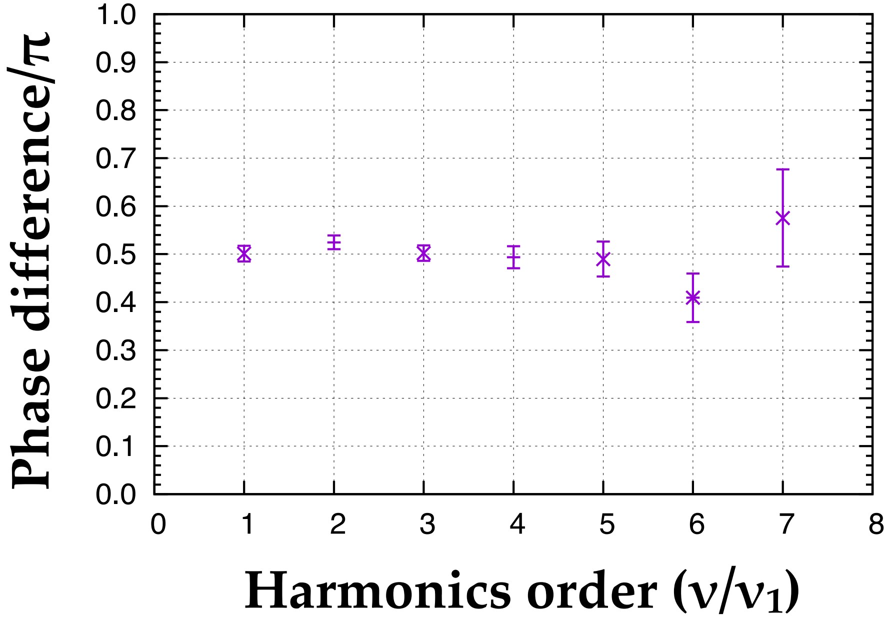


Figure 5: Amplitude spectrum around ν_1 (left panel) and around ν_2 (right panel) after pre-whitening the highest peak. A pair of sidlebes and their aliases caused by a year gap are clearly seen.







- **Multiplet fine structures with an equal spacing in amplitude diagram.**
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- **The phase difference $\Phi_{\pm 1}-\Phi_0 \simeq \pi/2$**

Figure 9: Top left: Frequency spacings among multiplets vs harmonics. Top right: Amplitude ratio between the side lobe and the central component of triplets vs harmonics. Bottom: Phase difference between the mean of the sidelobes and the central component of triplets vs harmonics.

Summary

1. The FM method is a powerful tool to distinguish Blazhko phase modulation and the light travel time effect caused by binary motion.

2. The FM method does work efficiently for the ground-based OGLE data.

3. Some RR Lyrae stars thought to be Blazhko stars are not Blazhko stars in reality but RR Lyrae stars in binary systems.

2011.09 Oxford


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AN EASY
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