THE AMPLITUDE DECREASE OF V BOOTIS

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Abstract

We explain the amplitude decrease in V Bootis by interference between two close periods. We also discuss V Bootis in comparison with theoretical predictions and with other stars that have undergone amplitude decrease.

1. Introduction

V Bootis (= HD 127335 = SAO 64180 = HIP 70885 = GSC/TYC 3036 0577 1) is a well known semiregular variable with a catalogued period of 258 days and magnitude variations between magnitude 7.0 and 12.0 visually (Kholopov *et al.* 1985). V Boo is undergoing a long-term amplitude decrease, which led Szatmáry *et al.* (1996) to use it as a practical demonstration of wavelet analysis upon visual variable star data. Mattei *et al.* (1997) investigated the AAVSO International Database containing over 28,000 visual observations of V Boo and found two periods, namely P_1 = 257.6 and P_2 = 134.4 days. Recently, Kiss *et al.* (1999) attributed the amplitude decrease to evolution from the Mira state to the semiregular state.

In this study we present a new hypothesis explaining the amplitude decrease of V Boo based on beating between two close periods.

2. Analysis

We have collected observations of V Boo from the visual databases of the Association Française des Observateurs d'Étoiles Variables, British Astronomical Association Variable Star Section, Variable Star Observers League in Japan, Variable Stars Network, and Hungarian Astronomical Association Variable Star Section. Standard 10-day means were calculated and used in further analysis in order to smooth the light curve and remove deviating points. The reliability of such processed data was verified by Kiss *et al.* (1999).

For the period searching part of the analysis we used Discrete Fourier Transformation (DFT) as per the implementation of the software Period98 (Sperl 1998). For purposes of detailed study of amplitude and phase we employed a technique of "moving window fourier decomposition," now usually called AMPSCAN (see Howarth 1991).

In Figure 1 we present the DFT spectrum of V Boo. We confirm earlier results that V Boo pulsates in two periods of P_0 = 257.8 days and P_1 = 137.1 days, respectively. There are also hints of one-year aliases of P_0 with frequency $f_{1,2} = 1/257.8 \pm 1/365.25$. As a test that these frequencies are really aliases we fitted and subtracted P_0 from the data and performed DFT on the residuals. The frequency spectrum of

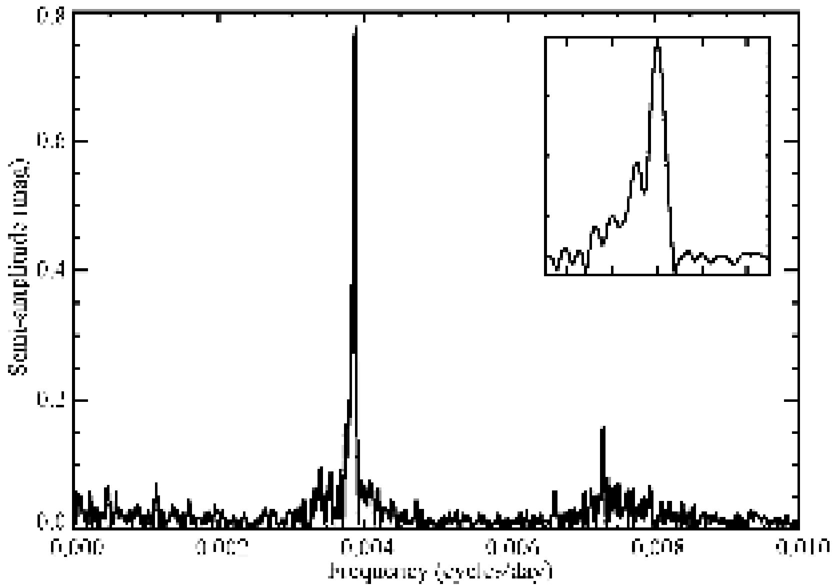

Figure 1: The Discrete Fourier Transform (DFT) spectrum of V Boo. The inset plot shows close vicinity of another peak to the main peak (f = 0.00388).

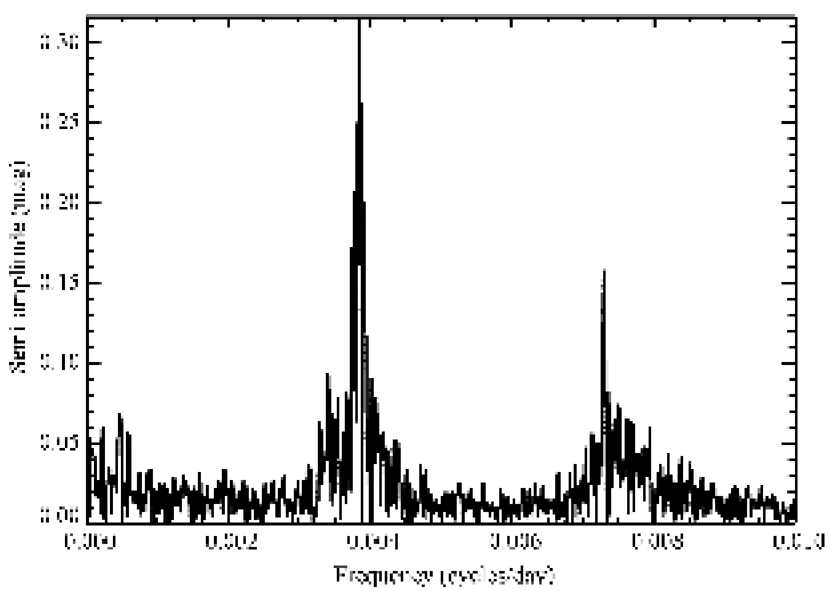

Figure 2: The DFT spectrum of V Boo after subtraction of the main period at 257.8 days (P_0).

the residuals is presented in Figure 2. All hints of the one-year aliases of P_0 have disappeared, but not the peak adjacent to P_0. Precise investigation reveals that this peak is not identical with P_0, because it has a somewhat smaller frequency (the corresponding period is 259.2 days) and as can be seen in the inset to Figure 1, lies very close to P_0. For the same reason the close component cannot be an alias of P_0, because in such a case the peak would disappear following the DFT of data which had had P_0 subtracted.

This phenomena was mentioned previously by Greaves and Howarth (2000), who concluded that this is caused by some instability of P_0. However, the small peaks are located in the DFT spectrum only towards the longer periods in comparison to P_0. This would suggest that period is stable most of the time, but sometimes changing to a slightly longer value. This is not observed in the phase plot of Figure 3 (representative of the difference between the selected and the actual period), which shows only some irregularities due to the semiregular nature of the variable.

We have prepared in Figure 3 the amplitude and phase scans of P_0. Due to a slightly wider frequency bin of AMPSCAN, the results presented here should be taken as valid for the whole star and the whole region around P_0 (including the close component). It is obvious from Figure 3 that V Boo exhibits amplitude decrease, whilst the value of the period remains unchanged. More interesting is the apparent slowing down of the decrease of amplitude in the middle third of the data. This was confirmed also by linear fitting to the data as divided into separate thirds: the rate of amplitude decrease lowers to about one third of the normal value during the middle third of data.

For the detailed study of the close frequency component to P_0, we fitted and subtracted P_0 from the original data. The residuals were then subjected to the AMPSCAN procedure. The resulting amplitude and phase plots are shown in Figure 4. It can be seen that progress in amplitude of the close component to P_0 was rather parabolic with minimum almost exactly at the halfway point in the data. The maximum semi-amplitude of this close component is about 0.6 magnitude, the mean value about half that, *i.e.*, 0.3 magnitude; the same value can be found in the DFT spectrum in Figure 1. The phase plot part of Figure 4 is, on the other hand, rather complicated. Due to the low amplitude of the close component to P_0, the phase plot is rather messy; the noisiest places coincide obviously with places of low amplitude. During the phases of low amplitude, it is hard for AMPSCAN to keep track of the data and to compare the test sinusoid with them.

We have prepared similar plots also for the 137.1-days period, but these plots don't reveal anything interesting, and are thus not included.

3. Discussion

The decreasing amplitude behavior of this star has been known for quite a long time, and several explanations have arisen for it. All theories have to cope with the fact that the decrease of amplitude is observed only at P_0, while its value and mean magnitude remain very stable. The amplitude and value of P_1 are almost exactly constant. Recently, Kiss *et al.* (1999) attributed the amplitude decrease of V Boo and other similar variables to their evolution from the Mira state towards the semiregular state. However, V Boo was never a Mira variable, because of P_1, if only by definition (Kholopov *et al*. 1985–88). This period caused only some asymmetry in the main period, P_0, early in the light curve's history. Now, after the drastic decrease in amplitude of the star, its contribution to the general variations of V Boo is very important: P_1 causes double maxima and minima.

In Section 2 we commented about the reality of the close component to the period P_0 and found it real. It is generally known that the presence of two close periods will result in apparent amplitude modulation with the amplitude of the object rising and lowering periodically; this period is dependant on P_0–P_1. We have prepared artificial data for testing purposes, using a time span lasting 32000 days and consisting of three sine waves. The first sinusoid has a period of 258 days (rounded value of 257.8 days = P_0. No additional uncertainty was added due to rounding, because the period errors are about 0.3 day) and semi-amplitude 0.7 magnitude, the second sinusoid has a period 259 days (the rounded value of the close component to P_0) and semi-amplitude 0.6 magnitude, and the third sinusoid has a period of 137 days and semi-amplitude 0.3 magnitude (corresponding to P_1). Phases of all sinusoids were adjusted to zero at the beginning of the data set for illustrative purposes. The resultant light curve is shown in Figure 5, along with the real light curve of V Boo for comparison. The light curves are quite similar: even the small humps on the profile due to P_1 are seen in the real light curve of V Boo.

Accordingly, the situation for V Boo appears to be well stated by the following. There exist two periods with values 257.8 and 259.2 days, respectively, and both with semi-amplitude about 0.6 magnitude. There is also one shorter period of 137.1 days with semi-amplitude about 0.3 magnitude. The 257.8- and 137.1-day periods are quite stable both in amplitude and phase. The 259.2-day period displays behavior unstable both in phase and amplitude. The 257.8- and 259.2-day periods interfere and cause the systematic amplitude decrease. This amplitude decrease is apparently slower in the middle third of the data (see Figure 3), which also corresponds to the state of lower amplitude of the 259.2-day period (see Figure 4): *i.e.*, during a time when this period was not overly prevalent. The amplitude plot of the 259.2-day period in Figure 4 can be interpreted also as a decrease of amplitude for the whole star. The amplitude of V Boo is currently at its minimum. In this interpretation, the cyclicity of beating will bring about an increase in future amplitude, on a timescale of a few decades.

Recently, Kiss *et al.* (2000) discussed the star RX UMa, which exhibits amplitude modulation due to the beating between two close periods. They also mention additional examples of beating: RY Leo and V CVn. However, differences between their "close periods" are much higher than is the case for V Boo—typical values of P_0–P_1 are in the range 8 to 15 days, which is an order of magnitude higher than in V Boo. The phenomenon of beating between two close periods was found unambiguously in semiregular variables, with the small number of known cases (currently four; in addition to Kiss *et al.* 2000 there is Z Sge, investigated by Mantegazza 1988) attributable to the lack of long term light curves with good time coverage.

There exist other cases of amplitude decrease in semiregular variables aside from that of V Boo: R Dor, RU Cyg, and Y Per. The star Y Per changed its behavior rather abruptly instead of continuously. Also, the original monoperiodicity changed to a double periodicity with lower amplitude. Here we are probably dealing with a phenomenon different from that found in V Boo. The amplitude decrease shown by R Dor is rather chaotic and there *may* also exist some mode switching between its two periods (Bedding *et al.* 1998). Also, RU Cyg doesn't behave as regularly as V Boo. Although there is a close component to the main period of RU Cyg in Figure 14 of Kiss *et al.* (1999), we don't think it is possible to explain amplitude decrease in RU Cyg by beating. The amplitude of the close component is too small, and the rather irregular behavior doesn't support the possibility of beating. We cannot discuss the case of Z Sge, because Mantegazza (1988) published only Fourier spectra without any light curve; also, the probable membership of this star in the peculiar Galactic globular cluster M71 makes it a problematic object in comparison to field semiregular variables.

The theoretical explanation for the periods in V Boo is not clear. The ratio of the two main periods $P_0/P_1 = 257.8/137.1 = 1.88$ lies in a range quite common among semiregular variables and suggests pulsation in the first and third overtones (*e.g.*, Bedding *et al.* 1998; Kiss *et al.* 1999). Close periods are thought to be produced by

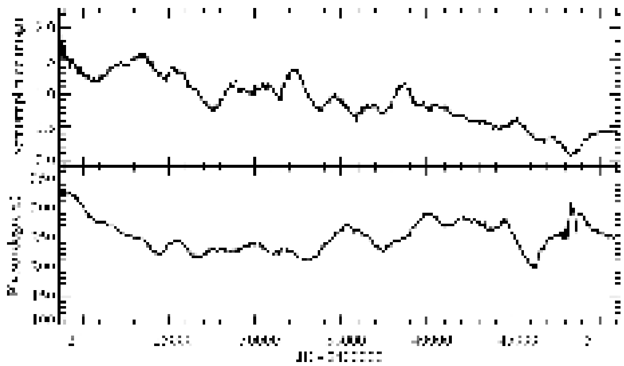

Figure 3: The semi-amplitude (upper panel) and phase (lower panel) plots of the region around period 258 days.

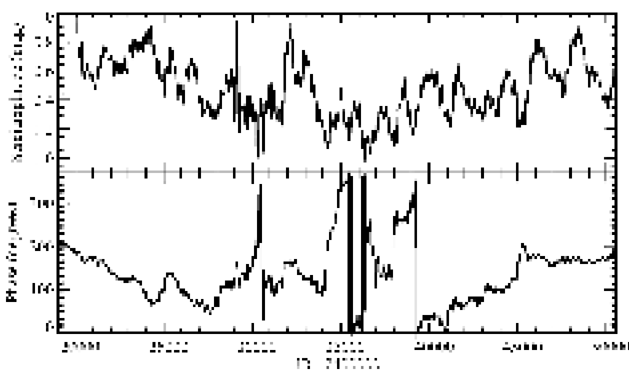

Figure 4: The semi-amplitude (upper panel) and phase (lower panel) plots of the 259.2-day period.

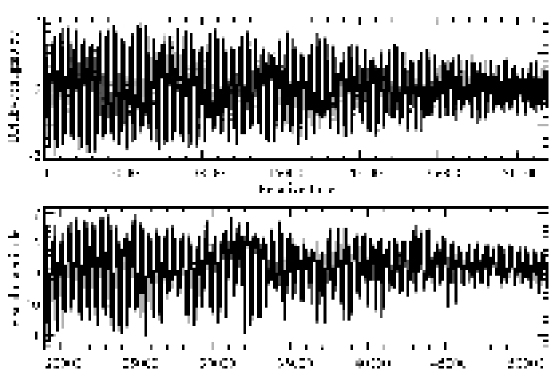

Figure 5: Comparison of simulated (upper panel) and observed (lower panel) light curves of V Bootis (see text).

very high overtones (3rd–5th) (Xiong *et al.* 1998; Kiss *et al.* 2000), but purely radial oscillations are not able to explain such close periods as those observed in V Boo. A more probable explanation comes from the combination of radial and nonradial modes, which were examined by Van Hoolst and Waelkens (1995) in the Cepheid V473 Lyr. However, the stars' variability types and period ranges are quite different.

4. Conclusions

We have shown that long term amplitude decrease in V Boo can be explained by the presence of a period component with a value of 259.2 days lying close to the main 257.8-day period. The interference between these periods is resulting in amplitude decrease, while not affecting the secondary 137.1-day period. The rate of amplitude decrease is closely dependant upon the amplitude of the 259.2-day period, which has resulted in the slowing of the rate of amplitude decrease during intervals when the 259.2-day period was of low amplitude. Comparison with other known cases of amplitude decrease revealed that among none is amplitude decrease so clear and uncontaminated by mode switching or other effects as in the instance of V Boo. Other stars with amplitude modulation due to beating between two close periods exist, but none where the periods are so close as in V Boo. Theory doesn't exclude close periods, but suggests damping in high overtones, which are needed for a period ratio close to one.

5. Acknowledgements

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