

Binarity and Pulsation: What do low-frequency peaks in the Fourier Diagram tell us?

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Abstract. We examine the origins of low frequencies observed in the photometric variations of some stellar pulsators. These include both nonbinary and binary effects such as systematic observational or instrumental effects, stellar rotation, combination frequencies, tidal distortions, self-excited as well as tidally induced gravity-mode pulsation.

1. Introduction

The binary nature of pulsating stars is an important tool to study stellar evolution. Binaries can be detected in a number of ways. One of the methods involves the examination of the stellar light variability: light-time corrections in the orbit cause systematic shifts in the arrival time, i.e., the well-known (O-C) variations. Furthermore, a low-frequency peak in the power spectrum of the light variations can also be a signature of stellar duplicity. The assumption here is, of course, that the pulsation periods have different timescales than the orbital period. In this paper we examine a number of different causes for such a low-frequency peak. Here we concentrate on δ Scuti variables, but many of the arguments apply to other types of pulsators as well, or even to constant stars.

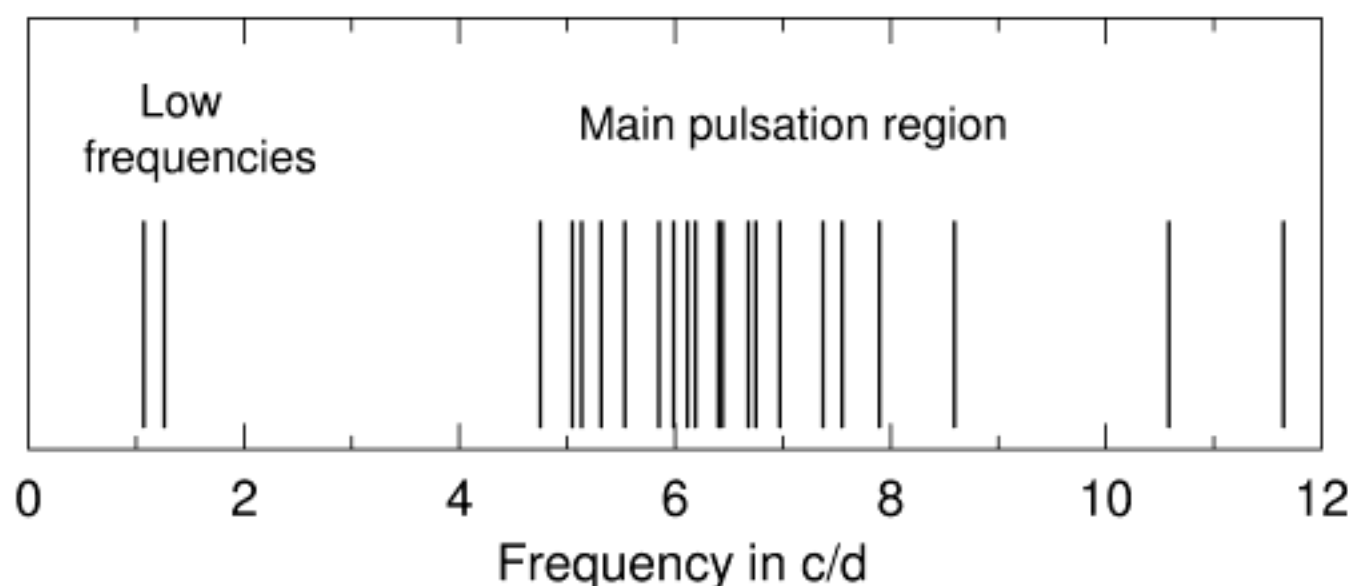


Figure 1. The problem: Apart from the frequency range in the power spectrum expected for pulsation, we observe a few low-frequency peaks. Are they a sign of binarity?

Statistically significant detections of a low frequency can have a number of different origins, ranging from observational problems to the effects of a close binary companion:

- Observational effects
- Combination frequencies
- Stellar rotation
- Gravity modes excited in an unstable star
- Gravity modes induced by a close companion
- Tidal distortions from a close companion

2. Observational effects

There exist several types of systematic observational errors which can lead to a statistically significant detection of a low frequency in the light variation of a star. Observing runs at a particular observatory cannot be continuous and are, therefore, spaced one or more nights apart. The combination of observational errors with regular spacing leads to frequencies of multiples or fractions of 1 c/d.

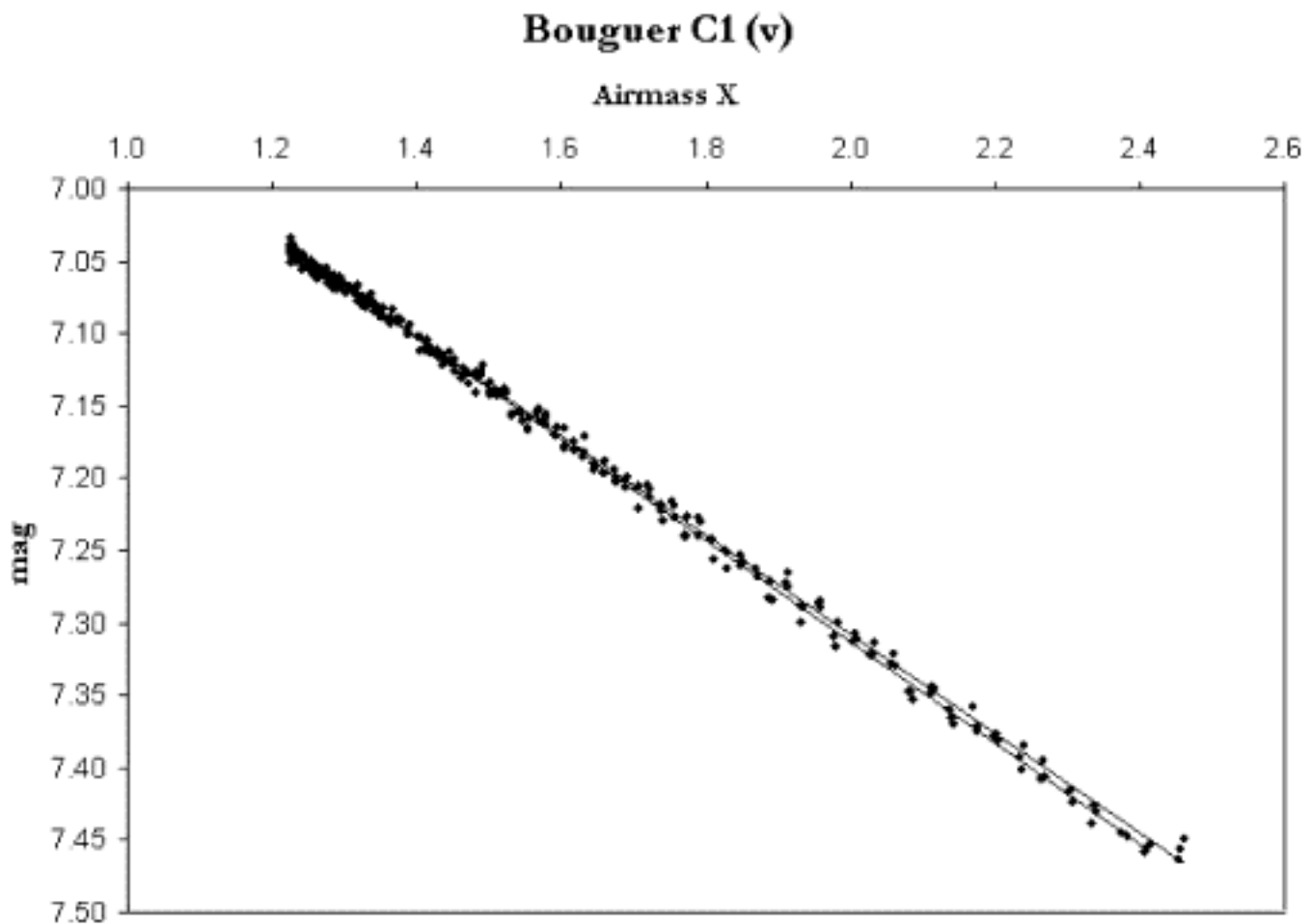


Figure 2. Example of constant extinction with no photometer drift. Source: Vienna Automatic Photoelectric Telescope, 2004 March 15

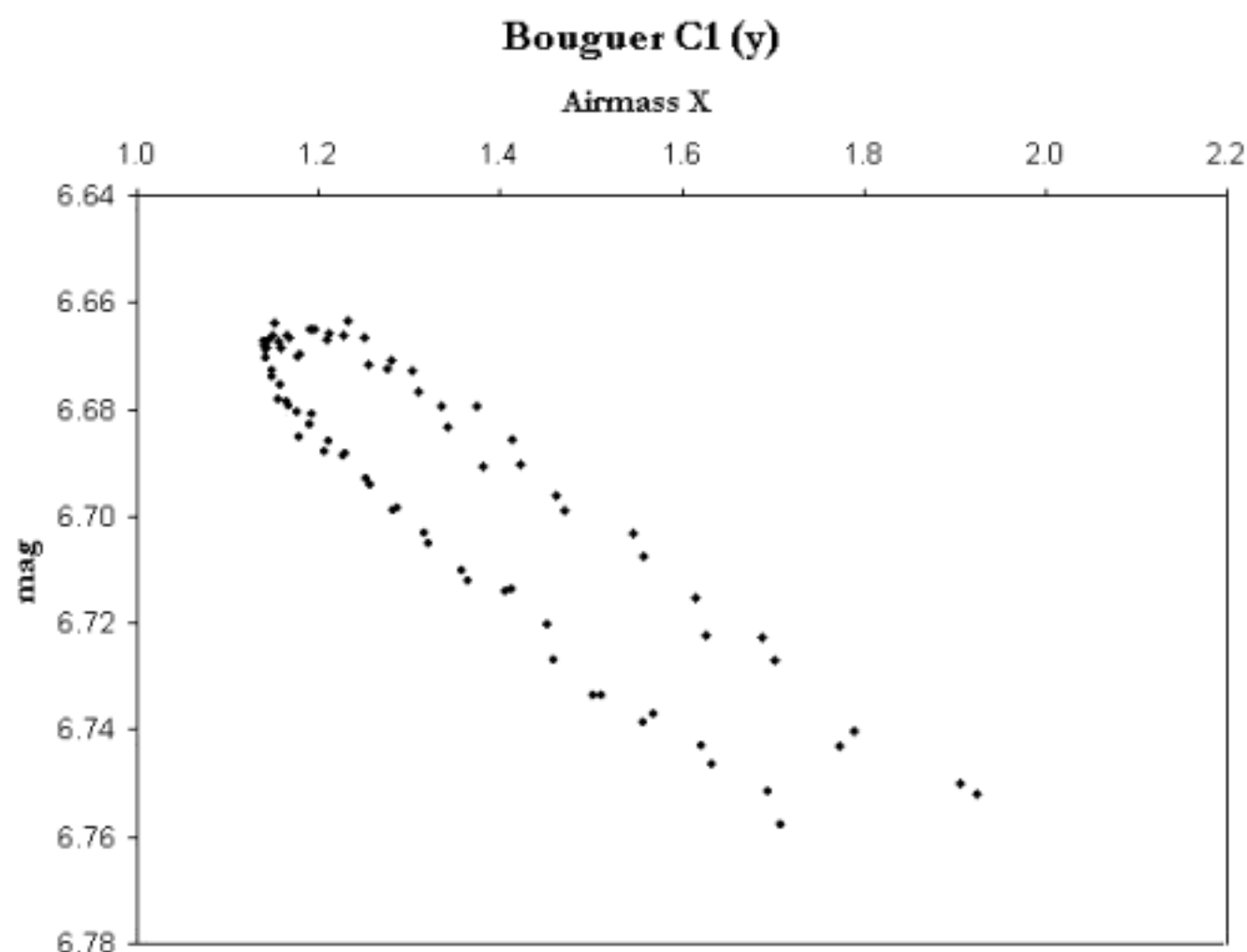


Figure 3. Example of measurements which may lead to low-frequency noise in the final data. The data show a different behavior for the branches of the star rising or setting. This can be explained by three effects: the extinction coefficients could be variable throughout the night, there might exist an East-West difference in the extinction coefficients, or the photometer might drift. Source: SAAO, 2004 April 12. Note that data from other nights obtained at SAAO are much better.

2.1. Atmospheric problems

Figures 2 and 3 show two recent examples of magnitude–airmass plots. In the ideal case, the parts obtained with the star East and West of the meridian should be the same. The first diagram shows this agreement and leads to a very reliable, constant extinction coefficient. The extinction coefficient to be adopted for the second night is less obvious. The extinction may actually be constant accompanied by detector sensitivity drifts. On the other hand, Poretti & Zerbi (1993) argue ‘that even in good photometric sites the extinction coefficient can display large variations during a night. If not corrected, this variability increases the measurement errors and introduces low-frequency spurious peaks in the power spectra.’ They propose a reduction procedure based on continuously varying extinction coefficients of the atmosphere.

In the example shown by Fig. 3, we note that the two curves are parallel for airmasses larger than 1.4. This suggests that the extinction coefficients are constant and that the astronomer should look for instrumental problems. However, our example is unusual because of the very large number of extinction-

star measurements. In more typical observations, fewer points are available and interpretations are more difficult.

Most of the errors introduced by an incorrect extinction treatment cancel if the comparison stars observed are very close to the pulsating star. However, the remaining small errors are still systematic and very complex. An incorrect choice of the extinction model leads to low-frequency peaks in the power spectrum.

2.2. Mixing different detectors and linking of observatories

Let us now turn to the potential problem of effective-wavelength shifts between different observing sites. Many of the photometric studies of pulsating stars are now multisite with telescopes spaced around the globe. The instruments at the different sites are not identical. Consequently, even if the filters are similar, the effective wavelengths may differ from site to site.

For the study of variable stars, it is essential to combine only measurements with the same effective wavelength, since the amplitudes are strongly variable with wavelength and there exist small phase shifts at different wavelengths. In fact, these small phase shifts of a few degrees and the amplitude ratios between different colors are a strong tool used for mode identification.

Consider a multisite campaign with one of the observatories producing an amplitude 5% higher than the other sites. This would introduce a modulation of each pulsation amplitude with a period of 1 day or some multiple, depending on the distribution of clear nights. Assumption of constant amplitudes would add low frequency peaks to the power spectrum.

A similar effect may occur if both photomultiplier and CCD detectors are used during an observing campaign, since these detectors have very different spectral sensitivities. Fortunately, these errors can be tested for by calculating separate amplitudes for each site. We refer to a more detailed discussion of actual tests (Breger 2001).

Finally, even if the effective wavelengths of the different observing sites are identical, the zero-points of the different sites still need to be determined. If there is no overlap between different sites, the zero-points are usually chosen to give the best overall multifrequency fits to the data. The effect is to usually reduce the power at low frequencies. For the Delta Scuti Network campaigns, these uncertainties are on the level of .0001 mag and can usually be neglected.

How can one determine whether or not a low-frequency peak in the power spectrum is caused by observational effects? For multisite campaigns and a high signal/noise detection, the following test has proven to be useful: does the frequency show up in separate frequency solutions carried out for all (or almost all) of the different observing sites and observing runs?

3. Combination frequencies

Combination frequencies are well known for large-amplitude pulsators with at least two modes. However, small-amplitude pulsators exhibit the same phenomenon, albeit at smaller amplitudes. An example is the star 4 CVn (Breger et al. 1999), which is shown in Figures 4 and 5.

Combination frequencies are easily recognized: their frequency values correspond exactly to numerical predictions, at least for the mode combinations with

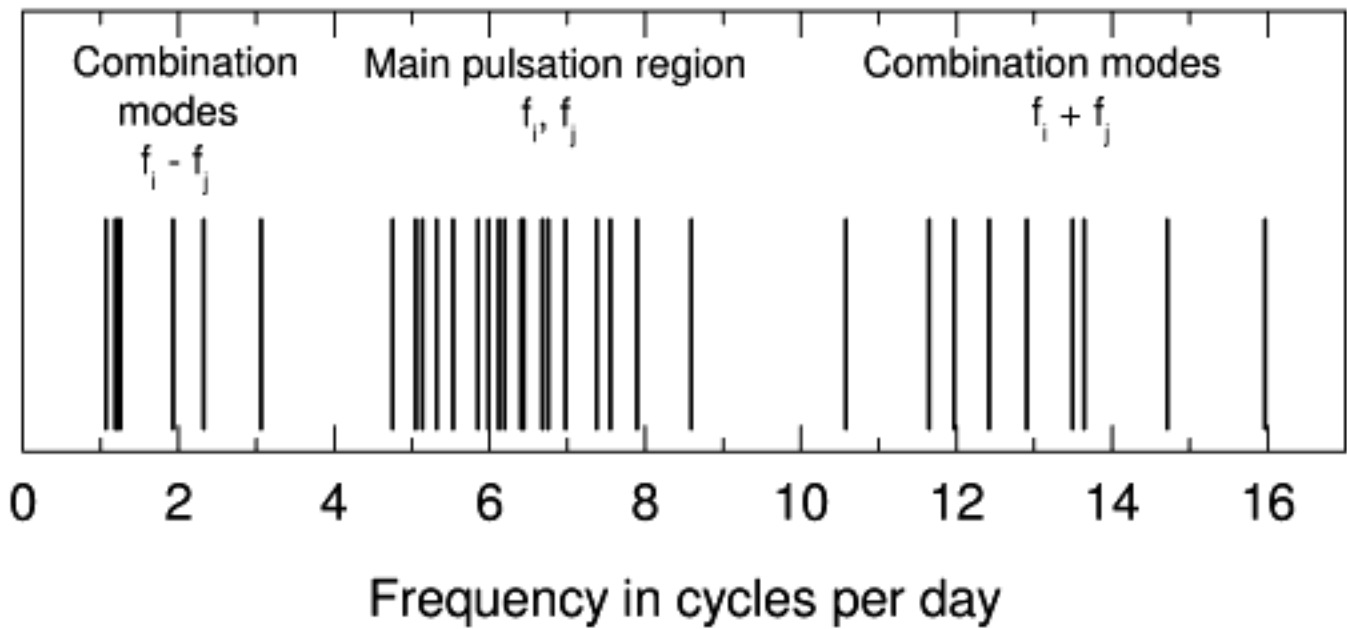


Figure 4. Pulsation structure of the δ Scuti star 4 CVn in the frequency domain. The diagram shows that for this star the very low and the very high frequencies are combination frequencies.

the same nonradial m value. (Otherwise, there may be a problem, since the observer's frame of reference is not identical to the frame of reference rotating with the star.) Furthermore, the data need to have excellent frequency resolution and contain low noise. Finally, the low-frequency combinations, $f_i - f_j$, are accompanied by the other possible combinations, $f_i + f_j$. The latter can be found at high frequencies, where the observational noise level is lower and the peaks are easier to detect. The detection of high-frequency combinations should serve as a warning that low-frequency combination peaks may also be present.

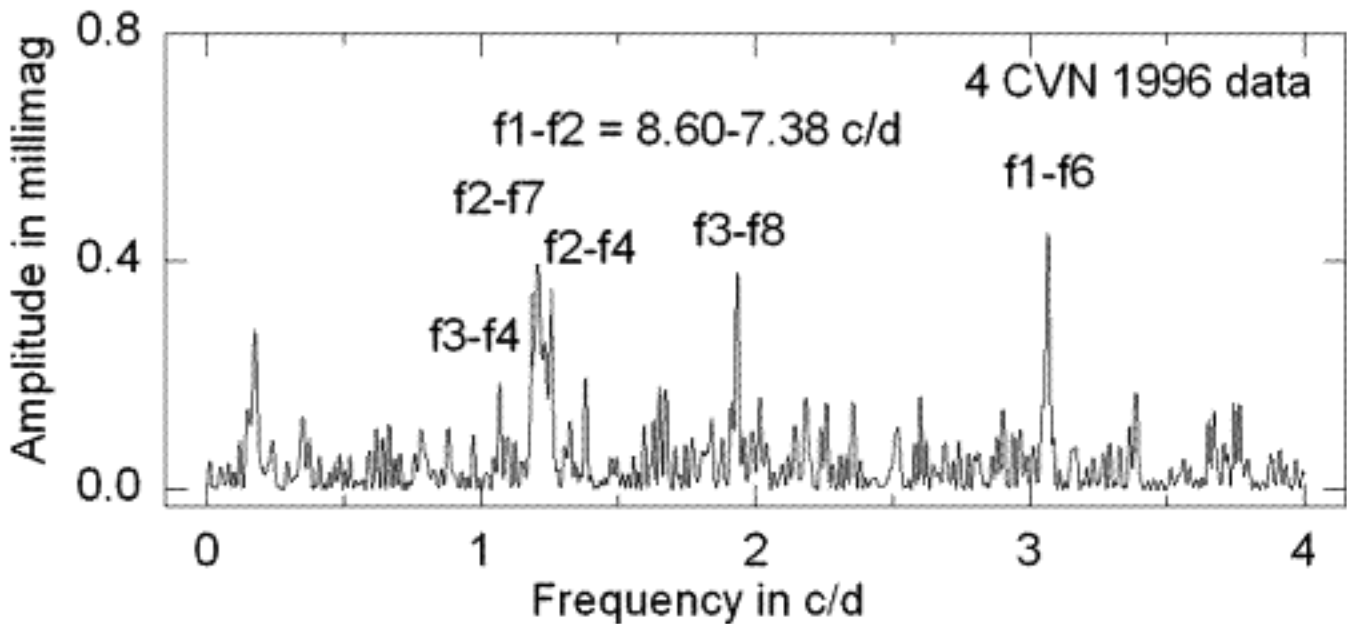


Figure 5. Low-frequency peaks caused by combinations, $f_i - f_j$, of higher pulsation frequencies f_i and f_j . As an example, the peak at 1.22 c/d is actually a combination of the 7.38 and 8.60 c/d modes.

4. Stellar Rotation

The timescale associated with the low-frequency peaks corresponds to that expected for stellar rotation. Inhomogeneities on the stellar surface can lead to light variations as the star rotates. A famous example is provided by the magnetic Ap stars.

An excellent method to determine whether a low-frequency peak in the power spectrum corresponds to the rotational frequency is to measure the $v \sin i$ value spectroscopically and to determine the angle of inclination of the rotation axis to the line of sight, i , from pulsation modelling of observed line-profile variations. Unfortunately, this method is time-consuming. Among the δ Scuti stars, FG Vir has been solved this way by the Delta Scuti Network.

It is sometimes possible to eliminate this explanation by plausibility arguments. Consider the 1.662 c/d peak (see Fig. 6) for BI CMi (F2IIIp SrEuCr). The main pulsation region lies between 4.8 and 10.4 c/d (see Breger et al. 2002). The peak at 1.662 c/d does not fit any expected frequency combination, $f_i - f_j$. Furthermore, the use of two comparison stars can rule out an instrumental/observational origin including the variability of one of the comparison stars.

Suppose abundance spots exist on the surface. The size of the star can be calculated from the known position in the H-R Diagram. A large spot would require a rotational speed of $v = 310$ km/s, which is improbably high. (With the observed $v \sin i$ value is 76 ± 1 km/s, we derive a required angle of incidence, i of 14 degrees.)

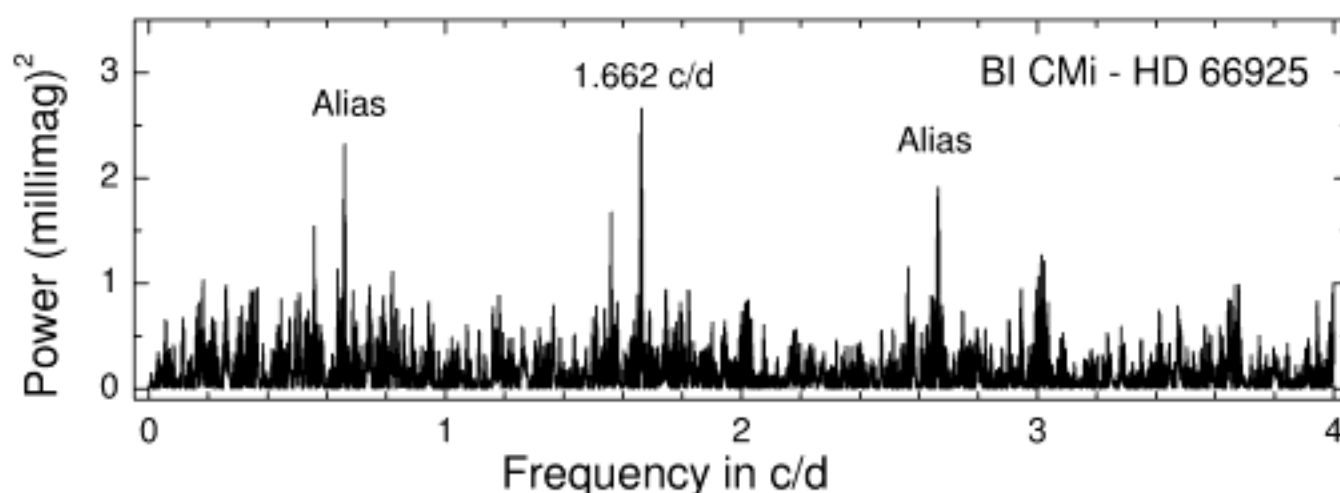


Figure 6. Power spectrum of the cool δ Scuti star BI CMi in the low-frequency region. The origin of the peak at 1.662 c/d is unclear and could be interpreted in a variety of ways such as stellar rotation in a double-wave peculiar star or a nonradial gravity mode.

However, some Ap stars show a double wave. This would halve the rotational velocity, giving $v = 155$ km/s and $i = 29$ degrees. This possibility cannot be rejected, so that an interpretation in terms of rotation cannot be excluded for BI CMi.

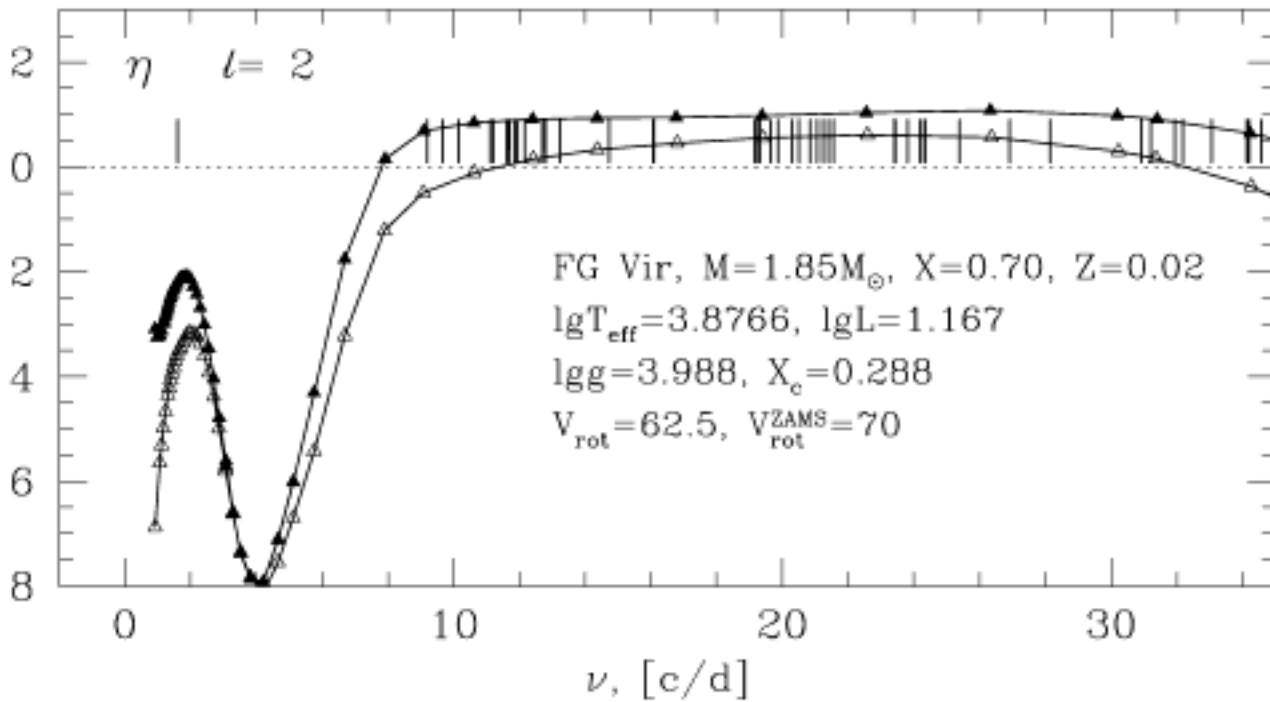


Figure 7. Pulsation excitation models calculated by A. A. Pamyatnykh for a typical evolved δ Scuti star. The parameter η denotes the amount of instability. The two curves were calculated with α values of 0.5 (bottom) and 2.0 (top). Instability occurs above the horizontal line and is in agreement with the observed frequencies of FG Vir. The local maximum at low frequencies may point towards an explanation of the observed low-frequency peaks in FG Vir and other δ Scuti variables.

5. Gravity modes excited in an unstable star

We have already noted in the previous section that some δ Scuti variables show one or more low-frequency peaks, which have not yet been explained. Although these pulsators are usually p(pressure)-mode pulsators with higher frequencies, there exists some theoretical evidence that a few low-order g(gravity) modes may also be excited. This is demonstrated in Fig. 7, where the amount of instability is calculated for a model of FG Vir. The instability parameter, η , shows a second peak in the low-frequency region, viz., near 1.7 c/d. The peak remains negative, but varies with the convection treatment adopted. It is attractive to speculate that with improvements in the stellar models, the peak might actually become positive. Gravity modes would then be predicted within a very limited frequency region.

In this regard, the investigation on convective blocking as an excitation mechanism needs to be mentioned (Guzik et al. 2000, Dupret et al. 2004). Although the details still need to be worked out, the mechanism could also be responsible

for low-frequency g-mode pulsation in the cooler γ Doradus as well δ Scuti stars near the cool instability strip border.

To summarize, some low-frequency peaks may be due to self-excited nonradial pulsation, not requiring a close binary companion.

6. Gravity modes induced by a close companion

Close companions in a binary system can lead to low frequencies, even by indirect means. An excellent example is the star HD 209295. This F0V single-lined 3.1d binary was announced by Handler et al. (2002) to be the first member of both the δ Scuti and γ Doradus groups. This means that both p modes and low-order g modes are excited in this star. In addition to the δ Scuti p mode near 26.0 c/d, the star also shows a number of pulsation modes with low frequencies: 5 of these were found to be exact multiples of the orbital frequency. The remarkable study suggests that these gravity modes are tidally excited by the companion.

7. Tidal distortions from a close companion

An excellent example of tidal distortions in an otherwise regularly pulsating star without mass exchange is θ Tuc. In this star the 0.14 c/d peak is matched by the orbital period (Paparó, Sterken, Spoon & Birch 1996; De Mey, Daems & Sterken 1998) and corresponds to tidal distortions in a close binary system, rather than high-order g modes.

8. Conclusion

We have seen that there exist a number of different explanations for the presence of low-frequency peaks in stars with expected pulsation at higher frequencies. Some of these origins have no connection with stellar binarity, while others point towards close companions.

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Discussion

S. Meibom : Can you detect resonances between tidally induced modes and stellar eigenmodes in stars in binary systems?

M. Breger : Yes, for gravity modes, but not yet for pressure modes.

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