

METHODOLOGICAL ASPECTS OF DELTA SCUTI STAR SEISMOLOGY

Gerald Handler

*Institut für Astronomie, Universität Wien, Türkenschanzstrasse 17,
A-1180 Wien, Austria*

Received September 1, 1997.

Abstract. I present a personally biased view of the present status of seismology of δ Scuti stars. While much thought has been given to develop new tools for mode identification, the required cross-calibrations between them are difficult. I suggest to pay more attention to target selection, since the objects which have the best chances to be successfully modeled – unevolved, slowly rotating δ Scuti stars – are poorly observed.

In the light of an upcoming large multi-site campaign on the only well investigated representative of this class, WET 0856 = CD-24°7599 = XX Pyx, I estimate the size of some spurious results which can affect data analysis, in particular those caused by passband mismatches of inhomogeneous equipment used in worldwide observing campaigns. I find that they hardly influence the results for δ Scuti and roAp stars, but they can become dangerous for high-amplitude DA pulsators.

Key words: stars: variable, oscillations, δ Scuti type – asteroseismology

1. WHAT IS THE POINT OF THIS ARTICLE?

Breger (1998, hereafter B98) comprehensively reviewed the status of our attempts to make seismology of δ Scuti stars possible. The present article is to be understood as a personally biased supplement to the discussions given by B98. I will focus on some methodological points which are rarely mentioned in the literature, but seem of considerable importance to me. I will evaluate some limitations of ground-based network observations as well.

2. TARGET SELECTION

The main difficulties for a successful application of seismological tools to δ Scuti stars have been discussed by various authors, e.g. Handler (1997). Since they are also summarized by B98, I do not repeat them here. We can state the problem in a simple way as follows.

A large amount of high-quality data is available (e.g. Breger et al. 1997). Much effort has been put into model calculations (e.g. Pikall et al. 1997). Regrettably, we are not yet able to match observations and theory because of a lack of definite observational mode identifications¹.

As noted by B98, much thought has been given to develop new tools to obtain these definite mode identifications. However, most methods only yield a determination of ℓ and because of potential pitfalls (the photometric phase shift method is, e.g., sensitive to the treatment of convection in the models used – Dziembowski, private communication), cross-calibration is required.

As we learned during the years, only large data sets with high temporal resolution are capable of detecting a sufficiently large number of modes allowing to attempt an asteroseismological interpretation of the pulsations exhibited by δ Scuti stars. Since there is only one photometric method to determine ℓ , spectroscopic information is needed. This requires at least 1-meter class telescopes; time on such telescopes is limited. Therefore cross-calibration can only be achieved for the dominating modes. Moreover, all observing methods are most sensitive to a special set of ℓ (and sometimes also m , cf. B98), making cross-calibration only possible between a few techniques. Finally, spectroscopic studies are naturally biased towards observations of bright and/or slowly pulsating stars. Slowly pulsating δ Scuti stars are evolved; our current models are not well suited for a comparison to the observations of these stars (see also B98).

For a definite mode identification it is most important to know more than the ℓ value of some modes of some star. (A number of spectroscopic techniques also provide constraints on m , but it is difficult to estimate the credibility of the results.) We would need to know ℓ and m for (almost) all modes detected (k then follows from inference by using ratios and differences of the pulsation frequencies),

¹ This is similar to the situation for DAV asteroseismology, see Bradley, these proceedings.

and we need to detect as many of the theoretically predicted modes as possible.

Is there a way to overcome this dilemma? I think so, and the answer is simple: we need to provide mode identifications for multimode δ Scuti pulsators, whose theoretical frequency spectra are simplest. These objects are unevolved, slowly rotating stars. For these stars, if carefully selected, we have the best chances to identify most of the theoretically predicted unstable pulsation modes.

Models of δ Scuti stars in the first stages of main-sequence evolution only show unstable p -modes. If a sufficient amount of these modes is detected in a real star, and if several consecutive radial overtones are excited, obvious patterns within the mode frequencies will appear, even if rotationally split multiplets of different k or ℓ overlapped. These patterns will allow an assignment of ℓ and m to the modes. Of course, these assignments can be tested (cross-calibrated) with mode identifications from color photometry and spectroscopy.

Following a suggestion by Pawel Moskalik, Holger Pikall and me performed hare-and-hound exercises to evaluate the feasibility of this idea. Holger gave me lists of frequencies of several of his main-sequence models. Some models had all possible modes excited, some had not. Without knowledge about the input parameters I had to come up with mode identifications. In cases where 80 % or more of all possible modes were present, my identifications were correct.

The conclusion from this experiment is: if the real star believes in the same physics than our models do and if we can detect a sufficient number of the modes theoretically predicted, a definite mode identification for unevolved δ Scuti stars can be achieved.

It should also be noted that unevolved stars cannot provide us with such an amount of information like (main sequence) objects with denser mode spectra may, but they are the key to our understanding of the pulsational behavior of δ Scuti stars. Modeling unevolved stars will also show us where the weaknesses of our current models are, and these weaknesses can then be removed.

Where can we find the targets we need? At the time of this writing, more than 300 δ Scuti stars are known (Rodriguez et al. 1994, Zechner 1997). Only a handful appear to be unevolved, and most of these have projected rotational velocities in excess of 100 km/s. For most of the unevolved stars, only discovery observations are available in the literature. Therefore it is hard to assess the asteroseismological potential of these objects.

Fortunately, there is one unevolved slowly rotating δ Scuti star, whose pulsations are well studied. This star is not unknown to the Whole Earth Telescope: WET 0856 = CD-24°7599 = XX Pyx.

3. WET 0856 = CD-24°7599 = XX PYX

No article written by the present author concerning δ Scuti stars can exist without a discussion of this object. We only know about its scientific interest because it was accidentally discovered as a variable comparison star during XCOV7.

The discovery WET observations (Handler et al. 1996) and subsequent follow-up WET (Handler et al. 1997a) plus single-, two- and three-site (Handler et al. 1997b) measurements revealed an enormous amount of information.

Seismologically, XX Pyx² was the first δ Scuti star, whose pulsation information was sufficient to constrain its location in the HR diagram tightly. The first, and so far the only, seismological distance to a δ Scuti star could be derived (Handler et al. 1997a).

Moreover, XX Pyx is just sufficiently evolved to have one (and only one!) g -mode of $\ell = 2$ excited. This particular mode can be used to determine the star's interior rotation rate and to measure the amount of convective core overshooting (Dziembowski & Pamyatnykh 1991), since a large fraction of this mode's kinetic energy originates from the outer part of the convective core.

XX Pyx was also the first low-amplitude δ Scuti star, for which harmonic and linear combination frequencies were detected in the power spectra. Such frequencies have now also been found in other δ Scuti stars (cf. B98). For DA white dwarfs, linear combination frequencies could provide information about the physics going on in the convection zone, since the linear combinations may be generated in the deeper layers of the hydrogen ionization zone (Brickhill 1992). Does this also happen in the ionization zones in δ Scuti stars (Winget, private communication)?

XX Pyx shows amplitude variability on very short time scales (detectable within a month) and large period changes. Both can at this point only be explained by resonances between the different modes (Handler et al. 1997b) and they may provide a hint on the

² I like this name for the star most, because it is easy to remember and nicely ambiguous.

nature of these resonances. They may as well be used to constrain present nonlinear theory.

As stated by Pikall et al. (1997), the game is not over yet. We have evidence that more than the 13 previously detected pulsation modes are excited in the star (Fig. 1). We just need to find them.

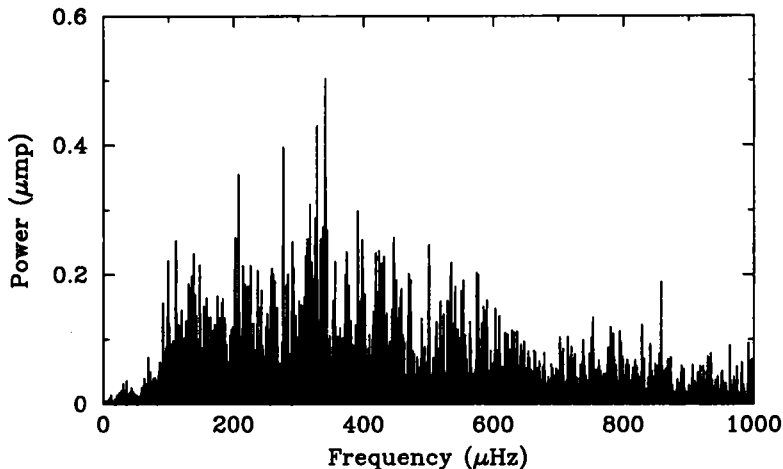


Fig. 1. Power spectrum of the combined XCOV7 and XCOV10 data of XX Pyx after prewhitening of the 13 presently known frequencies. Note the non-white noise near 350 μHz , where all pulsation frequencies have been found. This plot strongly suggests that more low-amplitude modes are excited in the star. Note also the increase in “noise” near 800 μHz . It is due to further linear combination frequencies.

What do we require to do so? Model calculations predict that about 30–35 pulsation frequencies of $\ell \leq 2$ are excited in the pulsationally unstable frequency range of XX Pyx. Experience with previous large observing campaigns devoted to δ Scuti stars suggests that the number of modes with amplitudes below about 1 mmag is almost in 1:1 correspondence with the amount of observing time invested.

We detected 13 pulsation frequencies for XX Pyx so far; all of them had amplitudes larger than 1 mmag. By extrapolation we can estimate that 80–90% of all possible modes $\ell \leq 2$ can be detected with a data set comprising about 400–500 hours of measurement.

This will push the detection level down to amplitudes of 0.3–0.4 mmag.

The Delta Scuti Network (see Zima 1997 for a summary of previous campaigns) has recently provided such large data sets (B98). Therefore, a large campaign devoted to XX Pyx will be undertaken from January – March, 1998. At the time of this writing, we have obtained or applied for 150 nights at 9 sites and we will apply for approximately 50–100 nights more.

We will not only acquire high-speed aperture photometry during this campaign; about half of the data will be taken with CCDs. The latter detectors have been shown to be capable of yielding high-precision time-series photometric measurements for δ Scuti stars (e.g. Frandsen et al. 1996, Stankov et al. 1997).

We will make advantage of the different wavelength sensitivities of the detectors used to obtain the lowest possible error sizes for the phase shifts to be measured. We will cross-calibrate the ℓ identifications by the photometric phase-shift method since we expect to be able to identify the pulsation modes of XX Pyx via pattern recognition. We will then be able to model the star's interior in detail.

However, when going to such low detection levels as stated above, some potential misinterpretations caused by artifacts must be evaluated. I will do this in the next section, including discussions for pulsating white dwarfs and rapidly oscillating Ap (roAp) stars as well.

4. LIMITATIONS OF GROUND-BASED NETWORK OBSERVATIONS

4.1. *Significance criteria*

One not generally accepted, but often applied, technique to analyze power spectra is prewhitening. The danger exists that prewhitened power spectra are overinterpreted. Furthermore, noise-free signals are subtracted from noisy data, resulting in an increase of “effective noise” (Clemens 1994).

The Vienna group adopted a conservative signal-to-noise criterion (Breger et al. 1993) to judge the significance of peaks in power spectra. The noise level is calculated as a moving mean over the region of interest in the amplitude spectrum. This includes noise

peaks as well as possible further intrinsic frequencies and is therefore a measure of effective noise; it does not assume white noise.

We consider a peak to be significant if it exceeds the noise level by a factor of four in amplitude. All frequencies we detected with this method so far have been confirmed by subsequent studies, if undertaken. We are therefore convinced that our criterion is reliable³. Fig. 2 illustrates how strict our signal-to-noise criterion is.

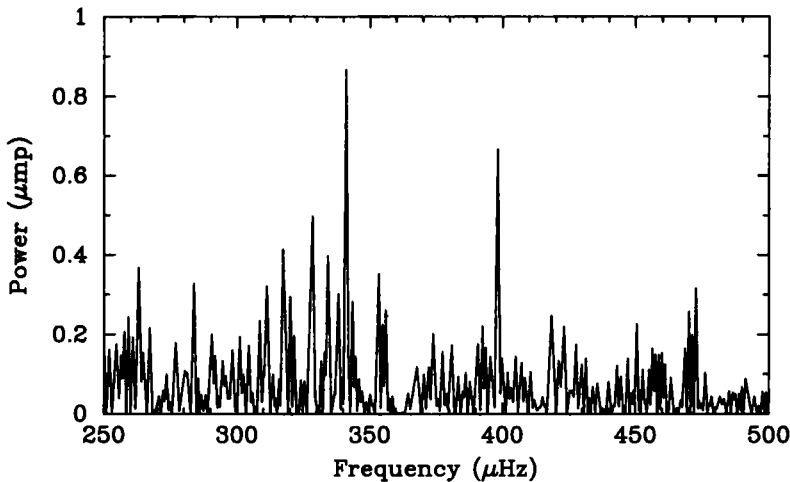


Fig. 2. Power spectrum of the XCOV7 data of XX Pyx prewhitened by 13 frequencies. Two peaks near 340 and 400 μHz clearly exceed the noise level. Our signal-to-noise criterion suggests they are not significant.

4.2. Wavelength dependence of pulsation amplitudes and phases

One potential problem for the search for very-low amplitude variations in the light curves acquired during multi-site campaigns lies in inhomogeneous equipment used. Most of the operating worldwide telescope networks, such as the Whole Earth Telescope and the Delta

³ In fact, we suspect that it may be too conservative. However, we prefer to detect too little frequencies to supplying spurious results to the unsuspecting theorist.

Scuti Network, are informal collaborations of researchers interested in the same field of science.

Financial resources are limited. Therefore existing equipment at the different observatories is mainly used. (Even when a homogenous set of detectors and filters is adopted, manufacturing uncertainties will result in inhomogeneity.) Below, I will discuss some problems caused by inhomogeneous equipment which are of particular interest for WET and DSN to derive limits on what can be done and at what point we should pay close attention.

Pulsation amplitudes and phases are functions of wavelength; they are also dependent on the ℓ value of the pulsation and they are therefore used for mode identification. Slightly different bandpasses at different observatories will hence yield slightly different amplitudes and phases (the latter is also known as "phase smearing"), and by analyzing a combined inhomogeneous data set spurious peaks will appear in power spectra. What size can these peaks reach?

The effects of the wavelength dependence of pulsation amplitudes and phases are not independent. With a little trigonometry, their combined influence can be estimated (Fig. 3).

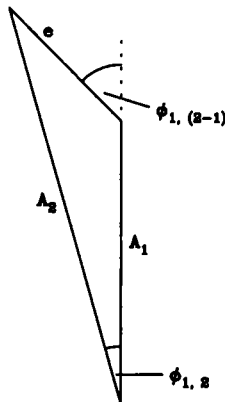


Fig. 3. Pulsation amplitudes and phases at different effective wavelengths. A_1 and A_2 are the amplitudes at wavelengths λ_1 and λ_2 , e represents the color amplitude or the error by passband mismatches. $\phi_{1,2}$ denotes the phase shift of the pulsations between the different wavelengths and $\phi_{1,(2-1)}$ is the phase of the color variations.

To simplify calculations, I will make the following first-order approximations: $dA_\lambda/A_\lambda d\lambda$ (the “pulsation amplitude gradient”) and $d\phi_{1,2}/d\lambda$ are assumed to be constant over the wavelength region of interest. Two further hidden assumptions are present: we obtain data from two different observatories spaced by exactly 12 hours, and the run lengths are short. This will enable us to calculate upper limits to amplitudes of spurious peaks appearing in power spectra. In reality, the spurious signals will be of lower amplitude (with the first-order effects being dominant; these peaks will be separated by about 1 cycle/day from the intrinsic frequencies), but they will be distributed over all frequencies.

In the next subsections I will estimate the relative size of spurious peaks from pulsation amplitudes and phase shifts in the literature and from (hopefully realistic) assumptions of possible differences in effective wavelengths of detectors and filters used. I will apply the results to some objects, for which these peaks may be expected to influence the analysis. It should be noted that due to measurement uncertainties in published data, different behavior of different stars and because of the assumptions above the results should only be considered to be accurate within a factor of 2.

4.2.1. δ Scuti stars

Breger et al. (1989) obtained time-series Strömgren b and y photometry for the δ Scuti star θ^2 Tauri. From their $(b-y)/y$ amplitude ratios one can estimate an upper limit of the pulsation amplitude gradient of about $-2.3 \times 10^{-4} \text{ \AA}^{-1}$.

Assuming a “typical” mismatch of 20 Å in effective wavelength between different observatories using Strömgren filters, the amplitude of spurious peaks will at worst reach 0.23 % of the amplitudes of intrinsic pulsation modes. The largest pulsation amplitude of θ^2 Tauri as determined by Breger et al. (1989) is 6.6 mmag. In power spectra, spurious peaks due to passband mismatches will have amplitudes smaller than 0.015 mmag, which is lower than the best detection level ever achieved with ground-based observations (Gilliland et al. 1993).

FG Vir has a dominating mode with an amplitude of 21.1 mmag in Johnson V and Strömgren y . This mode reaches 31.2 mmag in Strömgren v (Breger et al. 1997). Spurious peaks in v filter power spectra will then be smaller than 0.07 mmag. Assuming a mismatch

of 50 Å in the effective wavelengths of Johnson filters, spurious peaks in V could appear up to amplitudes of 0.12 mmag. The highest “noise” peaks in Fig. 1 of B98 have amplitudes of 0.35–0.4 mmag. This suggests some caution (remember the factor of 2 mentioned above), but it cannot be the cause for the excess power near 300 μHz , since the dominating mode has a frequency of 147 μHz .

The largest amplitudes ever measured for XX Pyx were 16 mmag in Johnson B (Handler et al. 1997a, b). During the large campaign to be undertaken early 1998, we prefer Johnson filters to Strömgren filters because of the faintness of the star. Spurious peaks can therefore be expected to reach amplitudes of 0.09 mmag in B and 0.07 mmag in V . This cannot be responsible for the excess power seen in Fig. 1. It may become dangerous if the star decides to increase the amplitude of one or more of its modes to about 40 mmag. On the other hand, we will then have very accurate phase shifts for these modes.

4.2.2. roAp stars

These objects show much steeper amplitude gradients compared to δ Scuti stars, which have been attributed to a steeper dependence of temperature on optical depth in their atmospheres compared to “normal” stars (Matthews, Wehlau & Walker 1990). This hypothesis may also explain that phase shifts measured for roAp stars can as well be much larger than for δ Scuti stars.

As a “worst case” example, I adopt the results by Kurtz (1982) for HR 3831. From his B , V and $B - V$ amplitudes one can estimate $dA_\lambda/A_\lambda d\lambda \approx -7 \times 10^{-4} \text{ Å}^{-1}$ between the effective wavelengths of the Johnson B and V filters he used.

The highest peaks in amplitude spectra of HR 3831 are about 2.1 mmag in B . Spurious peaks caused by passband mismatches in multi-site campaigns would therefore be expected to show amplitudes of about 0.04 mmag. This is not too far from detection limits of large campaigns (e.g. Kurtz et al. 1989); caution is warranted. Such non-intrinsic peaks can change the amplitudes of rotational sidelobes and can therefore influence inferences about the geometry of distorted modes (Kurtz 1992).

4.2.3. Pulsating white dwarfs

Pulsations detected for white dwarfs are caused by g -modes. These modes have the same phase in all colors since they solely reflect temperature variations (Robinson, Kepler & Nather 1982). Therefore phase smearing will not occur.

The “worst cases” with respect to spurious peaks caused by pass-band mismatches would be high-amplitude DAVs. The wavelength dependence of their amplitudes is larger than for DOVs and DBVs, and their high amplitudes will generate the largest artifacts.

I adopt the UBV amplitudes of Robinson et al. (1995) for the DAV G 117-B15A as a starting point for my estimates. They yield a pulsation amplitude gradient of $-1.5 \times 10^{-4} \text{ \AA}^{-1}$. The high-amplitude DAV G 29-38 can show single modes with amplitudes larger than 60 mmag, and modes with amplitudes down to 0.3 mmag have been detected (Kleinman 1995). For multi-site measurements without filters I assume the effective wavelengths to vary by 200 Å. This can generate non-intrinsic peaks with amplitudes up to 0.9 mmag, a factor of three larger than the lowest amplitude modes found for this star. Multi-site measurements of high-amplitude DAVs should therefore be scrutinized.

4.3. Uncertainties in sky subtraction

For high-speed photometric measurements with two-channel photometers sky background is not continuously monitored, since a comparison star is simultaneously observed to monitor sky transparency. Transparency variations are usually larger than sky background variations. Variations in sky background occurring between consecutive sky measurements cannot be compensated. This introduces artifacts.

If we examine the case of XX Pyx, for which we have large amounts of high-speed photometry available, we find that the count rates for the star are typically 15–20 times higher than that for sky. To generate spurious signals with amplitudes of 0.1 mmag, the background would need to vary by about 20 % between the measurements. This does not occur very often, and a careful observer should notice. In any case it is important to measure sky in intervals shorter than the star’s period.

Taking G 29-38 as a second example, digging in the WET archives allows to estimate that the count rates for sky are about

4–5 times smaller than that for (star + sky). A spurious signal in the amplitude spectrum with an amplitude of 1 mmag can therefore be generated by sky variations of about 10 %. Clearly, the problem becomes more severe, the fainter the target star is.

The discussion above did of course again rely on worst case assumptions (e.g. on periodic background variations). Three-channel photometers used by WET considerably improved the situation (Kleinman, Nather & Phillips 1996). However, a new problem appears with the use of autoguiders (we have experienced that during a recent multi-site campaign of the pulsating “hybrid” PG 1159 star HS 2324+3944, see Handler et al., 1998, these proceedings):

The light beam going to Channel 2 is split using a dichroic, directing the red “component” to the CCD used for autoguiding, while the blue portion of the spectrum goes to the Channel 2 tube. This means that the effective wavelength of the signal measured in Channel 2 is different from that in Channels 1 and 3. If cross-calibration of the sky counts in all three channels is done during dawn or dusk, the real sky counts in Channel 2 will be different from the count rates calculated from the Channel 3 counts when the sky is “dark”, since the color of sky changes during dawn and dusk. This must be taken into account when one wants to make use of the Channel 2 data, e.g. to correct for transparency variations in Channel 1.

5. TWO INTERESTING UNEVOLVED DELTA SCUTI STARS

After this rather technical excursion, let’s go back to seismology of δ Scuti stars. As I pointed out in Sect. 3, most stars offering the best chances to best successfully modeled – unevolved objects – are sparsely observed. I did, however, find two stars in the literature, which seem to be of asteroseismological interest.

Both objects are located in well-known Northern Hemisphere open clusters (the Pleiades and the α Persei cluster). The main interest in these two objects does not arise from their membership in these clusters. They are rather interesting stars which happen to be located in clusters.

5.1. *HD 23567 = V534 Tau*

Variability of this star was discovered by Breger (1972). He noticed very strong beating in his light curves. I Fourier-analyzed Breger’s 3.5-hour light curve and found that at least three frequencies

are present. This is unusually much for such a small data set of a δ Scuti star.

Intrigued by this result, I obtained one differential and three high-speed photometric runs of the star in August and October, 1995. The amplitude spectrum of my longest run is displayed in Fig. 4.

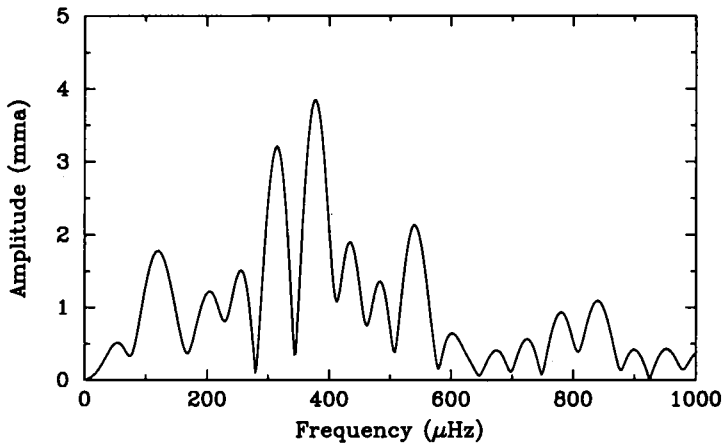


Fig. 4. Amplitude spectrum of a 5.7-hour high-speed photometric run on HD 23567. Multiperiodicity of the star is clearly evident.

Analyzing all data for the star, a number of conclusions can be drawn. The star has definitely a rich pulsation frequency spectrum. Compared to XX Pyx, HD 23567 pulsates with somewhat lower frequencies, but the excited frequency range seems larger. Both points to a slightly more evolved evolutionary stage of HD 23567. Furthermore, there is evidence for linear combination frequencies.

All the findings above suggest that HD 23567 is a potentially highly interesting star. Comparing it again to XX Pyx, it has the advantage of being more than three magnitudes brighter ($V = 8.40$), but its amplitudes are lower, and its $v \sin i$ (90 km/s) is higher. Nevertheless, I strongly suggest to obtain more data on the star. It can be observed with high-speed and differential photometry and also with CCDs. A two-site campaign or low-priority WET observations would be sufficient for the beginning.

5.2. *HD 21553 = V465 Per*

This main-sequence star was discovered to be variable by Slovak (1978) and reobserved by Slovak & Africano (1978). They found two periods near 50 minutes and 2 hours, respectively, in their light curves. Handler (1994) reanalyzed their data and arrived at the same two periods with weak evidence for at least a third one. He suggested from the evolutionary stage of the star that the longer period mode could correspond to the special *g*-mode allowing to determine the amount of convective core overshooting (Dziembowski & Pamyatnykh 1991).

Kim & Lee (1997) obtained thirteen nights of single-site CCD photometry of the star. They detected four frequencies in their light curves, three of them near 1.7 h and the fourth near 43 min.

Now what's so exciting about HD 21553? The answer is: from calibrations of Strömgren photometry and from the star's proven membership to the α Persei cluster (Prosser 1992), one can infer that HD 21553 is a lower main sequence object. Theoretical models do not predict pulsationally unstable modes near 1.7 h for such stars. However, the real star has such modes excited.

This clearly represents a challenge for δ Scuti star model calculations, similar to the probable presence of a mode selection mechanism for evolved objects (cf. B98). Could fast rotation of the star ($v \sin i = 150$ km/s) play a role?

6. CONCLUDING REMARKS

I think that asteroseismological investigations of the interior structure of δ Scuti stars will begin soon. Both models and observations are available in great variety. We just need to approach the problem as careful as possible, with close collaboration between observers and theorists.

I suggest to proceed in small steps. It is not likely that we will be able to model evolved, rapidly rotating stars first. If XX Pyx turns out to become the Rosetta Stone for δ Scuti asteroseismology, the next logical objects to investigate would be (ordered by time) HD 23567 (if it shows a sufficient number of detectable modes), BN Cnc (Frandsen, Kjeldsen & Breger 1997) and/or FG Vir. Then we should be able to solve problems main sequence stars like HD 21553 provide, and in the end we should also be able to explore the inner structure of evolved stars, such as 4 CVn and θ^2 Tauri.

ACKNOWLEDGMENTS. Observations presented in this paper were partially supported by the Austrian Fonds zur Förderung der wissenschaftlichen Forschung under grant S-7304. Steve Kawaler and Darragh O'Donoghue pointed out some potential observational problems discussed in this article. Don Winget, Scot Kleinman and Jiang Xiao-jun provided important information. I am grateful to Holger Pikall for valuable comments on a draft version of this paper. It is a pleasure to thank the LOC for making this such an extremely enjoyable workshop, both scientifically and socially. Most participants (including the present author) gained weight...

REFERENCES

- Breger M. 1972, *ApJ*, 176, 367
Breger M., Garrido R., Huang L. et al. 1989, *A&A*, 214, 209
Breger M., Stich J., Garrido R. et al. 1993, *A&A*, 271, 482
Breger M., Zima W., Handler G. et al. 1997, *A&A*, in press
Brickhill A. J. 1992, *MNRAS*, 259, 519
Clemens J. C. 1994, Ph. D. Thesis, University of Texas
Dziembowski W. A., Pamyatnykh A. A. 1991, *A&A*, 248, L11
Frandsen S., Balona L. A., Viskum M., Koen C., Kjeldsen H. 1996, *A&A*, 308, 132
Frandsen S., Kjeldsen H., Breger M. 1997, *Delta Scuti Star Newsletter*, University of Vienna, No. 11, 6
Gilliland R. L., Brown T. M., Kjeldsen H. et al. 1993, *AJ*, 106, 2441
Handler, G. 1994, Master's Thesis, University of Vienna
Handler G. 1997, *Delta Scuti Star Newsletter*, University of Vienna, No. 11, 10
Handler G., Breger M., Sullivan D. J. et al. 1996, *A&A* 307, 529
Handler G., Pikall H., O'Donoghue D. et al. 1997a, *MNRAS*, 286, 303
Handler G., Pamyatnykh A. A., Zima W. et al. 1997b, *MNRAS*, in press
Kim S.-L., Lee S.-W. 1997, *A&A*, in press
Kleinman S. J. 1995, Ph. D. Thesis, University of Texas
Kleinman S. J., Nather R. E., Phillips T. 1996, *PASP*, 108, 356
Kurtz D. W. 1982, *MNRAS*, 200, 807
Kurtz D. W. 1992, *MNRAS*, 259, 701
Kurtz D. W., Matthews J. M., Martinez P. et al. 1989, *MNRAS*, 240, 881
Matthews J. M., Wehlau W. H., Walker G. A. H. 1990, *ApJ*, 365, L81
Pikall H., Handler G., Pamyatnykh A. A., Dziembowski W. A. 1997, in *A Half Century of Stellar Pulsation Interpretations: A Tribute to A. N. Cox*, eds. P. A. Bradley & J. A. Guzik, in press

- Prosser C. F. 1992, *AJ*, 103, 488
Robinson E. L., Kepler S. O., Nather R. E. 1982, *ApJ*, 259, 219
Robinson E. L., Mailloux T. M., Zhang E. et al. 1995, *ApJ*, 438, 908
Rodriguez E., Lopez de Coca P., Rolland A., Garrido R., Costa V. 1994, *A&AS*, 106, 21
Slovak M. H. 1978, *ApJ*, 223, 192
Slovak M. H., Africano, J. 1978, *IBVS*, No. 1445
Stankov A., Ashley M. C. B., Breger M., Prouton O. 1997, *MNRAS*, to be submitted
Zechner R. 1997, in preparation
Zima W. 1997, *Delta Scuti Star Newsletter*, University of Vienna, No. 11, 37