RADIAL AND NONRADIAL OSCILLATIONS IN DELTA SCUTI STARS

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Mode identifications from the phase shift between the B-V color curves and the V light curves of Delta Scuti stars are discussed. For five Delta Scuti stars the frequency of highest amplitude is due to pulsation in a radial mode with one or more frequencies due to nonradial modes lying nearby. Thus there may be a resonance between the frequencies of radial and nonradial modes. This behavior has only been found in subgiant and giant stars so far, but this could easily be a selection effect. Theoretical predictions of frequencies for different l-modes of the same overtone for main sequence, subgiant, and giant stars are needed to compare with these observations. Theoretical predictions of the strength of resonance coupling between radial and nonradial modes as a function of frequency separation are also needed.

Recent theoretical work by Balona and Stobie (1980a) has shown that mode discrimination can be made in Delta Scuti stars by examining the relative phases of the B-V (temperature) and V (flux) variations in these stars (see Balona and Stobie, this colloquium). We are presently engaged in a program of applying this theory to a number of Delta Scuti stars and some interesting correlations are noted here.

Mode identifications have now been made for five Delta Scuti stars. For all five of these stars the frequency of highest amplitude is due to pulsation in a radial mode with lower amplitude frequencies due to nonradial modes lying nearby. Figure 1 and Table 1 give the data and mode identifications for these stars. For four of these stars for which rotational velocities have been measured, the rotational velocity predicted from the frequency splitting is similar to the measured v sin i.

This leads to the suggestion that in each of these stars

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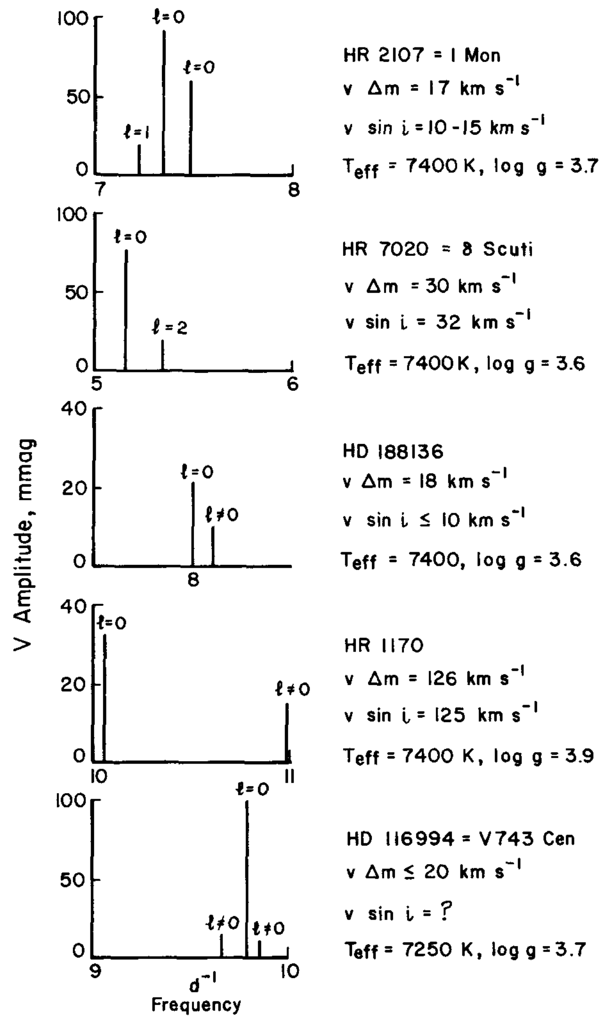
TABLE 1

	f d^{-1}	A m mag	mode	$v\Delta m$ (km s^{-1}) T_{eff} (K)	$v\sin i$ (km s^{-1}) log g	Reference
1 Mon	7.346146	93.7	ℓ=0	17	10 - 15	Balona and Stobie
	7.475268	59.2	ℓ=1	7400	3.7	1980b
	7.217139	18.4	ℓ=1			
δ Scuti	5.16078	78.3	ℓ=0	30	32	Balona *et al.*
	5.35401	17.6	ℓ=2	7400	3.6	1980
HD 188136	8.0062	21.8	ℓ=0	18	10	Kurtz 1980b
	8.11	9.8	ℓ≠0	7400	3.6	
	12.5736	7.2	?			
HR 1170	10.0638	32.6	ℓ=0	126	125	Kurtz 1980c
	10.9913	14.5	ℓ≠0	7400	3.9	
HD 116994	9.79	102.1	ℓ=0	<20	?	McAlary & Wehlau
	9.66	13.9	ℓ≠0	7250	3.7	1979
	9.85	10.6	ℓ≠0			Kurtz 1980d



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the high amplitude radial mode may be in resonance with an unresolved nonradial mode of nearly identical frequency from which the resolved nonradial mode or modes are rotationally perturbed. An examination of the frequencies predicted for radial and nonradial quadrupole p-modes of the same overtone for polytropes (Cox 1976) indicates that those frequencies cross over between polytropic index n=3.5 and n=4.0. We would thus expect that resonances between radial and nonradial modes will only occur for somewhat evolved stars. This is consistent with the subgiant to giant gravities of the five stars under discussion here.

This raises several questions.

1) How close due frequencies need to be in order for a resonance to occur?
2) For what area of the HR diagram can we expect to find radial and nonradial frequencies in resonance?

A theoretical discussion of these two related questions would be most welcome. Our frequency and mode identification program should map out the observational limits in the HR diagram of stars undergoing such resonances.

3) Do nonradial modes occur in Delta Scuti stars in the absence of any radial pulstation? Or, perhaps easier to answer, do Delta Scuti stars occur for which the frequency of highest amplitude is due to nonradial pulsation?

The answers to these questions probably lie with the lower amplitude Delta Scuti stars which we are currently examining. The frequency of highest amplitude in the peculiar magnetic Ap star, HD 101065, is due to quadrupole pulsation (Kurtz 1980a), but because of the strong magnetic field, that may be a special case.

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DISCUSSION

J. COX: One should be careful about drawing conclusions from the polytropic models.

KURTZ: I am not really wanting to draw conclusions from your polytropic models. I would like to get a lot more sophisticated, but at the moment I don't have anything else to go to. I am hoping that something will come from this.

STELLINGWERF: You say that as the polytropic index changes the frequencies change?

KURTZ: As you go toward more condensed models, say from $n = 3.5$ to 4.0, for $\ell = 2$, $k = 1$, $\ell = 0$, $k = 1$ you find that they pass through one for these two models. Does that happen for more sophisticated models?

FITCH: I did a number of evolutionary models from the main sequence across the strip and there is practically no variation for any period ratio you choose.

KURTZ: I am talking about going up in luminosity.

FITCH: The only time you see a change is whether or not you still have hydrogen burning in the core. If there is no more hydrogen burning, then at the low frequencies you can get significance.

BREGER: If you have rotational splitting you may possibly see three frequencies. For example in 1 Mon you were postulating three, one hidden - the radial one and two on the side. For δ Scuti you would just have one. What happened to the other one?

KURTZ: The amplitudes for these different frequencies do come out different and at the moment none of the theories predict anything about what the amplitudes should be. For a lot of these stars we are working at very low amplitude levels. Something just below the noise level might be there or it might not.

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