Peculiar Versus Normal Phenomena in A-Type and Related Stars
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DETERMINATION OF LUMINOSITY, ATMOSPHERIC STRUCTURE, AND MAGNETIC GEOMETRY FROM STUDIES OF THE PULSATION IN roAp STARS

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ABSTRACT For several of the rapidly oscillating Ap stars the best luminosity estimates available come from the asteroseismological interpretation of their pulsational frequency spectra. We give a list of the 23 currently known roAp stars along with their Strömgren photometric indices, T_{eff} estimated from the Hβ index, and luminosity estimated asteroseismologically. In one case, γ Equ, we have an asteroseismological luminosity and a parallax luminosity which are in good agreement. Some of the roAp stars pulsate with frequencies greater than the critical frequency calculated for standard A-star models. This plus multi-colour high-speed photometry of HR 3831 indicate that the temperature gradients in the atmospheres of these stars are substantially steeper than in standard A-star models. We advocate a fine analysis of HR 3831 to see if there is consistency with the pulsational conclusions about T-τ in this star. Further fine analyses and multi-colour pulsational analyses on other roAp stars are then called for. The pulsation mode in HR 3831 can be decomposed into primarily an axisymmetric dipole mode with small radial, quadrupole and octupole perturbations. If the magnetic field is governing the distortion of this mode from a purely dipole mode, then the pulsation can be used to infer the magnetic field geometry. Comments on our current knowledge of all 23 roAp stars are made.

INTRODUCTION

The rapidly oscillating Ap (roAp) stars are high-overtone ($n >> \ell$), low-degree ($\ell \leq 3$) *p*-mode oblique pulsators: Their oscillation axes are aligned with their magnetic axes both of which are oblique to their rotation axes. They are the only non-degenerate stars other than the sun which are unequivocally known to pulsate in such modes. The asymptotic spacing for a star undergoing high-overtone *p*-mode pulsation is given by the relation $\Delta\nu = (n + \ell/2 + \epsilon) + \delta\nu$ (Tassoul 1980, 1990) where ϵ is a constant dependant on the surface layers of the star. Two of the quantities in this relation are observable:

1) $\Delta\nu$, the frequency spacing of consecutive overtones for *p*-modes. This corresponds to the reciprocal of the sound crossing time of the star.
2) $\delta\nu$, a second order term which lifts the degeneracy of modes (n, ℓ) and ($n+1$, ℓ-2) and is a measure of the sound speed gradient inside the star - essentially an age indicator.

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Christiansen-Dalsgaard (1987) has used these parameters to construct a mass-age grid on an asteroseismological HR diagram. Ultimately, our goal is to specify temperature, luminosity, radius, mass, and age from the study of the pulsation frequencies. At present we can derive luminosities for some of the roAp stars under the assumption that spectroscopically and photometrically derived temperatures are reasonably accurate. For some of these stars we think that these are the best luminosity estimates available.

Because the pulsation modes are aligned with the magnetic axes of the roAp stars, it is possible to see non-radial modes from differing aspects as the stars rotate. This potentially allows an accurate determination of the order and degree of each mode, as well as any distortion from a pure spherical harmonic. It allows information to be extracted about the geometry and of the magnetic field, and it may allow information to be extracted about the internal magnetic field structure (see Kurtz 1990a). HR 3831 is particularly interesting in this regard and is discussed further below.

The short pulsation periods in the roAp stars imply that they are pulsating in high-overtone ($10 \le n \le 40$) p-modes. High-overtone modes have short radial wavelengths. To satisfy the outer boundary conditions for a standing wave, the temperature gradient must be steep in the atmosphere so that the sound speed changes significantly over a radial distance which is short compared to the wavelength of the pulsation. This is a simple requirement for reflective phase coherence in a standing wave. The frequency (and hence overtone, n) for which this condition breaks down, *i.e.* where the wavelength of the pulsation becomes comparable to the depth of the reflection layer, is known as the *critical frequency*. Shibahashi & Saio (1985) found that for standard A-star model atmospheres many of the roAp stars pulsate with frequencies larger than the critical frequency. They concluded from this that the temperature gradient in those stars must be substantially steeper than that of the standard models, hence producing a steeper sound speed gradient, a sharper reflection boundary, and a higher critical frequency.

Recently, Matthews *et al.* (these proceedings) have observed the roAp star HR 3831 through 8 filters ranging from the blue to the infrared. HR 3831 is known to be pulsating primarily in a dipole mode, so they were able to argue from simple considerations of limb-darkening as a function of wavelength that the temperature gradient is steeper than expected from standard models. Their gradient is even steeper than that suggested by Shibahashi & Saio.

The suspicion is that the abnormal abundances in the atmospheres of the roAp stars increase the temperature gradient as required by these pulsation observations. The important result of this is that model atmospheres, and hence abundance analyses of these stars must take this into account. The effect of the increased gradient will be to reduce the calculated abundance anomalies. It would be most interesting to have a detailed fine analysis of HR 3831 to complement the pulsation studies. Similar pulsation studies and fine analyses of other roAp stars should follow.

THE CAPE ROAP STAR SURVEY

To improve our understanding of the asteroseismology of the roAp stars we are conducting a survey of all Ap SrCrEu stars in the southern sky. The scope and goals of the survey have been described in detail by Martinez, Kurtz & Kauffman *et al.* (1991). Briefly, we are obtaining Strömgren $uvby\beta$ photometry of all the southern Ap SrCrEu stars. We then search for rapid oscillation in the subset of stars with indices similar to those of the known roAp stars. The currently observed limits of the roAp phenomenon are:

$$0.08 \leq b\text{-}y \leq 0.29$$
$$0.20 \leq m_1 \leq 0.32$$
$$\delta m_1 \leq 0.00$$
$$0.49 \leq c_1 \leq 0.85$$
$$\delta c_1 \leq 0.04$$
$$2.70 \leq \beta \leq 2.88$$

Indices in these ranges are not an unambiguous indicator of the roAp phenomenon. Nonetheless, since the start of the survey in May 1990, eight new roAp stars have been discovered. These are HD 19918, HD 84041, HD 119027, HD 161459, HD 190290, HD 196470, HD 193756 and HD 218495 which are individually discussed below.

Table I is an updated list of the confirmed roAp stars as of June 1992. So far we have searched for rapid oscillations in 129 stars. This includes a number of stars selected because they lie well outside the ranges above. We have not yet published lists of 'constant' stars because it is a lot easier to establish that a star pulsates than that it does not. A single observation of constancy entitles us only to claim that the star was constant during the time-span of the observations. Thus far, $\Delta\nu$ has been determined for 11 roAp stars (Table I). We caution that not all of these values of $\Delta\nu$ are secure. We assess our knowledge of the frequencies in each of these stars below.

ASTEROSEISMOLOGICAL DETERMINATIONS OF THE LUMINOSITIES OF roAp STARS

The luminosities of the roAp stars are not well known because the normal photometric calibrations of temperature and luminosity are not valid for the heavily blanketed flux distributions in the cool Ap stars. A naïve application of the δc_1 index implies that the roAp stars are well below the ZAMS, a result not confirmed for two roAp stars with parallax luminosities. This effect is most pronounced in stars with extreme abundance anomalies and in the cooler Ap stars. Thus the possibility of obtaining asteroseismological luminosities for the roAp stars is particularly interesting.

As an exercise, we used the observed frequency spacings and T_{eff} estimated from the photometry to derive tentative luminosities for the roAp stars (Table I). The Hβ index was used to estimate T_{eff} using the T_{eff} - $\log g$ grids of Moon & Dworetsky (1985). The effective temperatures thus determined for the roAp stars range from 6800 K to 8400 K. These temperatures are less well determined than for normal stars because in the Ap stars the continuum flux distributions differ substantially from those of the normal stars. An extreme example of this is Przybylski's star, HD 101065, where the continuum is not seen in the visible part of

TABLE I. Fundamental parameters for the roAp stars

HD	HR	Name	V	b-y	m_1	c_1	β	δm_1	δc_1	Teff K	$\Delta\nu$ μHz	$\Delta M_V(\Delta\nu)$	$M_V(\Delta\nu)$
6532			8.45	0.084	0.237	0.846	2.884	-0.032	-0.050	8400			
12932			10.2	0.169	0.235	0.761	2.806	-0.031	-0.031	7800			
19918			9.336	0.169	0.216	0.821	2.855	-0.010	-0.059	8200			
24712	1217		5.99	0.183	0.212	0.634	2.744	-0.029	-0.034	7400	68	0.7	2.4
60435			8.889	0.132	0.234	0.843	2.855	+0.002	+0.035	8200	52	1.1	1.4
80316			7.808	0.122	0.295	0.657	2.856	-0.089	-0.169	8300			
83368	3831		6.174	0.146	0.203	0.796	2.827	+0.004	-0.035	7950			
84041			9.330	0.177	0.233	0.797	2.844	-0.026	-0.061	8100			
101065		Przbylski's star	8.004	0.448	0.368	-0.014	2.641	-0.185	-0.386	7400	57.8	1.0	2.1
119027			10.027	0.262	0.198	0.575	2.734	-0.017	-0.067	7100	52	1.2	2.1
128898	5643	α Cir	3.198	0.152	0.195	0.760	2.831	+0.012	-0.077	8000			
134214			7.479	0.211	0.288	0.597	2.766	-0.098	-0.115	7550			
137949		33 Lib	6.674	0.188	0.321	0.584	2.833	-0.114	-0.256	8000	40	1.4	1.2
161459			10.32	0.248	0.240	0.693	2.824	-0.034	-0.133	7950			
166473			7.953	0.213	0.311	0.538	2.804	-0.131	-0.101	7850	68	0.6	2.1
176232	7167	10 Aql	5.89	0.150	0.208	0.829	2.809	-0.004	+0.031	7800	50.6	1.1	1.7
190290			9.91	0.295	0.299	0.447	2.791	-0.099	-0.315	7900	40	1.4	1.2
193756			9.19	0.179	0.217	0.760	2.808	-0.013	-0.036	7800			
196470			9.72	0.22	0.25	0.65	2.80	-0.05	-0.13	7850			
201601	8097	γ Equ	4.68	0.147	0.238	0.760	2.819	-0.032	-0.058	7900	58	0.8	1.8
203932			8.820	0.169	0.196	0.736	2.814	+0.009	-0.072	7650	66	0.6	2.2
217522			7.520	0.289	0.215	0.487	2.701	-0.043	-0.046	6800	31	2.3	1.4
218495			9.35	0.115	0.251	0.816	2.866	-0.047	-0.086	8350			

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the spectrum because of severe line blanketing. For HD 101065, we have adopted T_{eff} = 7400 K based on the arguments presented by Martinez & Kurtz (1990).

Wolff (1983) has discussed the difficulties of obtaining reliable effective temperatures for the Ap stars. Ultimately, it may be possible to determine the T_{eff} of Ap stars by working backwards from the asteroseismology and a HIPPARCOS parallax.

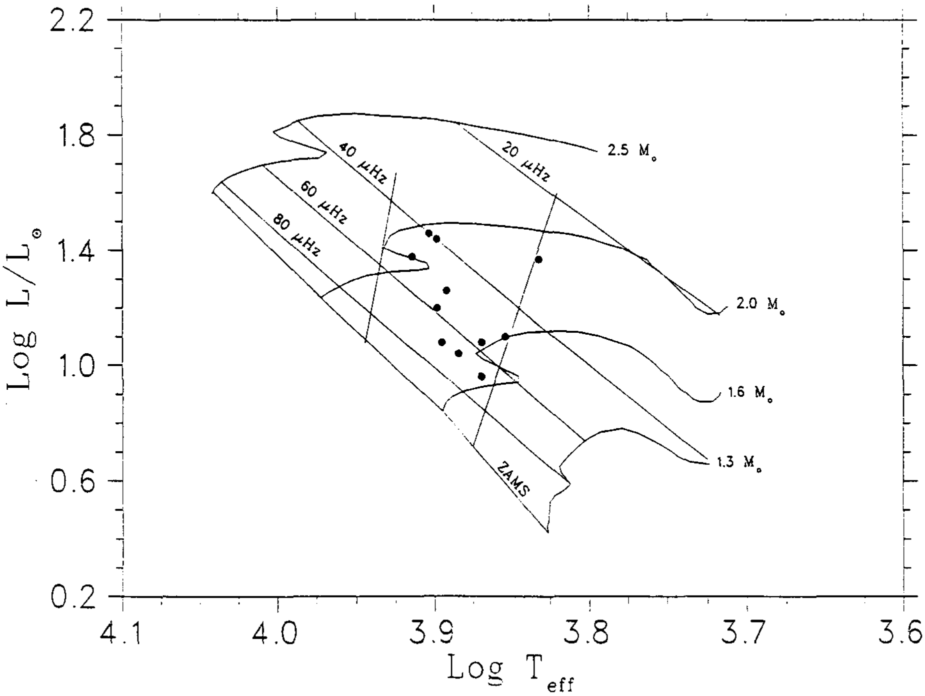

Fig. 1. A theoretical HR diagram showing the roAp stars for which $\Delta\nu$ is known. The evolutionary tracks of Heller and Kawaler (1988) are shown for a range of masses appropriate to the roAp stars. Also shown are the observed borders of the δ Scuti instability strip.

Fig. 1 shows an HR diagram with the evolutionary tracks of the normal A star models of Heller & Kawaler (1988). On this diagram we have plotted the roAp stars for which we have $\Delta\nu$ values, no matter how tentative. The borders of the lower instability strip determined from observations of δ Scuti stars (Breger 1979) are also indicated. The results are interesting.

Firstly, the diagram indicates that the roAp stars all lie within the instability strip. It is unlikely that this is a selection effect; we have searched for rapid oscillations in many stars outside the instability strip without success. Thus we suspect that the κ-mechanism operating on He II in the He II ionization zone is the probable driving mechanism.

Invoking the κ-mechanism has substantial implications for the diffusion theory but is not necessarily inconsistent with it. In the roAp stars the pulsation

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velocities are not big enough to be a problem for the diffusion hypothesis. Surface pulsation velocities are 20 - 200 m/s for HR 1217 (Matthews *et al.* 1988) and γ Equ (Libbrecht 1988). Since velocity amplitude falls off rapidly with depth in the atmosphere there is no turbulent mixing of the surface layers with lower layers. Recent models of He abundance variations in the Ap stars by Vauclair, Dolez & Gough (1991) which incorporate the effects of stellar winds suggest that He is underabundant at the magnetic equator but slightly enhanced in the second He ionization zone at the magnetic poles. Further work is required to show whether there is sufficient He enhancement to drive the oscillations observed in the roAp stars.

The discovery of rapid oscillations in a star well outside the instability strip would present a problem for this hypothesis. We have searched for rapid oscillations in many such stars and have only null results. The detection of non-pulsating Ap stars inside the roAp instability strip is also problematic although the same problem arises for the δ Scuti stars.

Secondly, the roAp stars all appear to be 1 to 2 mag above the ZAMS. At present, we can check our asteroseismological luminosity for only one star. γ Equ (HD 201601) has a parallax luminosity $M_V(\pi) = 1.9$ that agrees with its asteroseismological luminosity of $M_V(\Delta\nu) = 1.8$. Our value of $\Delta\nu = 58\,\mu$Hz for this star is not secure and needs to be confirmed. For HD 128898, we do not have an asteroseismological luminosity, but the available parallax luminosity $M_V(\pi) = 1.9$ and $T_{eff} = 8000$ K place it inside the instability strip. When the HIPPARCOS parallaxes for the roAp stars become available, we will be able to confirm or refute more of these asteroseismological luminosities.

COMMENTS ON THE INDIVIDUAL STARS

HD 6532

HD 6532 pulsates basically in a single oblique distorted dipole mode with a rotation period of 1.9455 days (Kurtz & Cropper 1987). The principal pulsation period is a little less than 7 min; at this period the photometric noise is essentially scintillation limited, so observations through large aperture telescopes can reduce the noise level in the amplitude spectrum. However, with the rotation period so close to 2 days, only multi-site observations are of use because of confusion of the rotational sidelobes and their aliases in single-site data.

HD 6532 has a detectable harmonic near 3.5 min and other pulsation frequencies may be present. No second mode has yet been detected. This star deserves a new, thorough multi-site study with 1-m, or larger, telescopes. It is of interest to compare the distorted dipole mode in this star with the much better studied HD 83368.

No magnetic study of HD 6532 had been made, not is there any detailed spectroscopic study. Both of these are of interest to compare with the pulsational studies.

HD 12932

HD 12932 was discovered to be a roAp star Schneider, Kreidl & Weiss (1992) who have 35 hours of observations obtained on 12 nights. We, also have additional (unpublished; in preparation) observations obtained on 21 nights. Although there is clear evidence of amplitude modulation, both groups have only been able to determine a single frequency; other frequencies which may account for the amplitude modulation are then lost in the noise of the amplitude spectrum. At V = 10.2 this star could benefit from observations made with 1.5-m telescopes, or larger, to improve the photon statistics.

HD 19918

Martinez & Kurtz (unpublished) have observed this star for 14 nights and find that it has a principal period near 11 min which shows amplitude modulation. With the data available they cannot determine any of the secondary frequencies which account for this modulation. An intensive, single-site, exploratory study of this star would be useful.

HD 24712 (HR 1217)

From an asteroseismological point of view HD 24712 is the most interesting roAp star yet studied. A major multi-site observing campaign by 15 astronomers (Kurtz *et al.* 1989) has shown this star to have an amplitude spectrum reminiscent of that of the sun. It is still uncertain whether the frequencies should be ascribed to consecutive overtones of dipole modes, or alternating even and odd ℓ-modes. The inherent interest and complexity of this star make a new study desirable.

That study should take into account the following: 1) The separation of the pulsation frequencies is close to 3 d^{-1}, so multi-site observations are required. 2) Although the star is bright, the pulsation periods are near 6 min where larger aperture telescopes can reduce scintillation noise. 3) Past studies of this star and other roAp stars suggest that the amplitudes and/or phases of the individual modes in HD 24712 may not be stable on times scales longer than a few weeks. The rotation period is 12.4572 days, however, so that a new study must last longer than the rotation period; a three-week multi-site observing run is probably ideal.

HD 60435

HD 60435 has the richest *p*-mode spectrum of any of the roAp stars (Matthews, Kurtz & Wehlau 1987). This star at times also has the largest amplitude of any roAp star (16 mmag peak-to-peak in B). These two characteristics should make it an extremely promising object to study, but it has been neglected since the above-mentioned paper.

The reason for this is that the pulsation modes seem to suffer stochastic amplitude and/or phase modulation on a time scale as short as days. It is now known that the rotation period is 7.6793 days (Kurtz, van Wyk & Marang 1990). A new observing campaign with intensive multi-site observations over about 10 days would be very interesting for this star. Telescopes of 1-m aperture are needed for photon statistics with V = 8.889. Larger telescopes would help substantially with the study of the 6-min harmonics. The periods in this star are mostly around 12 min which means that observations must be made at the very best photometric sites to avoid contamination of the signal caused by sky transparency variations.

HD 80316

HD 80316 pulsates with a period near 7.4 min and a semi-amplitude less than 1 mmag (Kurtz 1990b). It appears that it may be a dipole pulsator and hence is of interest like HD 6532 and HD 83368. The rotation period may be near 2 days, however, so a campaign from two observing sites is desirable. This star has been neglected because its right ascension is close to the much-studied HD 83368; any new observations would be of interest.

HD 83368 (HR 3831)

HD 83368 is the most observed roAp star. It pulsates is a single distorted dipole mode which can be modelled with a linear sum of axisymmetric ℓ = 0, 1, 2 and 3 spherical harmonics (Kurtz 1992a). There is some stochastic phase variation on a time-scale of months to years. Either the frequency and/or the phase of the pulsation are not stable. We are obtaining high-speed photometric observations through a Johnson B filter for 1 hour per night, or more, on every possible night for this star. Any such (high quality) observations are of use; prospective observers should contact me for details.

The π-radian phase reversal and the amplitude modulation curves in figure show that HR 3831 pulsates primarily in a dipole mode, but that this mode is distorted and requires small contributions from radial, quadrupole and octupole spherical harmonics to describe it. Shibahashi (1992) has shown theoretically that an axisymmetric, centered dipole mode will give rise to octupole components, but not radial and quadrupole components. The latter therefore imply that the pulsation mode is not centered. New, high-quality magnetic observations are needed to see if the distortion of the pulsation mode is entirely caused by the magnetic field configuration. If so, it will be possible to infer magnetic field geometry from the pulsation modes in other roAp stars which may be too faint for accurate magnetic studies.

Fig. 2 plots the pulsation phase and amplitude as a function of the rotation phase for the all of the 1981 to 1991 data. To produce this figure each week of high-speed B photometric data from 1981 to 1990 was adjusted for the (as yet unexplained) phase variations. The rotation phase is calculated from the time of magnetic maximum using the ephemeris given by Kurtz *et al.* (1992) with the rotation period P_{rot} = 2.851982 day. Two rotation cycles are plotted. Each point in the diagram has been calculated by fitting the frequency ν = 1.4280128 mHz to 4 cycles (46.685 min) of the high-speed photometric data by linear least-squares. There are 632 points plotted here representing 492 hours of observations. The heavy theoretical line shows the best fit assuming a pulsation mode which can be described by the sum of ℓ = 0, 1, 2 and 3 spherical harmonics. The individual ℓ = 0, 1, 2 and 3 components are shown with thin lines for a rotational inclination of i = 89° and a magnetic obliquity of β = 57°. These angles give the minimum contribution from ℓ = 0 and 2. The thin line which almost follows the heavy line is ℓ = 1; the straight line at amplitude = 0.3 mmag is ℓ = 0; the double-wave thin line

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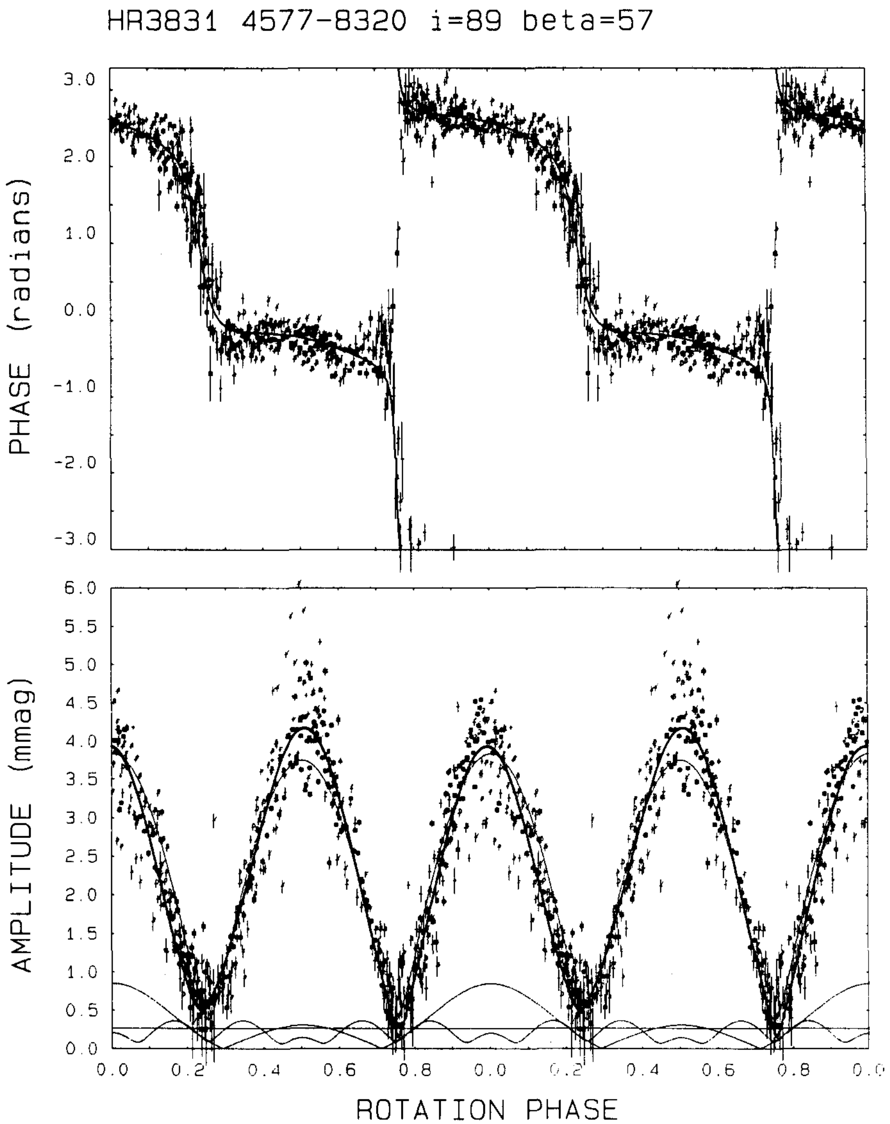

Fig. 2. See text for a description of this figure.

almost reaching amplitude 0.8 mmag at rotation phase zero is $\ell = 2$; the other line is $\ell = 3$. See Kurtz (1992a) and Kurtz, Kanaan & Martinez (1992) for complete descriptions of the theory and techniques for producing this kind of figure.

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HD 84041

Martinez *et al.* (1992) have analysed 131 hours of high-speed *B* photometric observations of this star. They find that it pulsated in several modes with periods near 15 minutes with frequency separations of about 28 μHz, although this latter conclusion needs confirmation. They also find that the rotation period is P_{rot} = 3.69 days. Studies of this star are complicated by apparently stochastic amplitude modulation on a short time-scale similar to the behavior of HD 60435.

HD 101065 (PRZYBYLSKI'S STAR)

HD 101065 was the first discovered of the roAp stars and has one of the highest amplitudes (13 mmag peak-to-peak in B). Martinez & Kurtz (1990) have made an intensive study of this star. They find two frequencies separated by $\Delta\nu_0$ = 58 μHz, hence giving an asteroseismological luminosity for the star, assuming that the problematical temperature is known. This is the best luminosity measure for this spectroscopically most peculiar star.

The principal frequency in HD 101065 is amplitude modulated and secondary frequencies are found close to it in any data set analysed. Whether they represent pulsation modes, or stochastic amplitude and/or phase modulation is not yet certain. There is evidence for a large dP/dt term to the principal period.

HD 101065 has been studied intensively in relatively short bursts to try to decipher the frequency spectrum. It would be useful to monitor this star on a regular basis over a long time to watch the phase behaviour of the principal frequency. This would require a full night of observation (> 6 hr to resolve the two pulsation modes which are separated by 58 μHz) on a regular basis (say once per week) over an entire observing season. The relatively large amplitude would allow this to be done on a 50-cm telescope in a good site.

HD 119027

HD 119027 has a rich *p*-mode spectrum similar to that of HD 24712 and HD 60435. Martinez, Kurtz & Meintjies (1992) have studied 18 nights of observations of this star which show at least 5 frequencies separated by about 26 μHz. They interpret these frequencies as arising from alternating even and odd ℓ-modes and use their separation for an asteroseismological luminosity determination. The amplitudes of the frequencies are modulated in complex ways which are not yet understood. Inequality in the frequency spacing, when better determined, may measure $\delta\nu$. For observers interested in asteroseismology: This star deserves an intensive multi-site observational campaign.

HD 128898 (HR 5463; α CIR)

HD 128898 is the brightest roAp star at V = 3.198. Kurtz & Balona (1984) found two frequencies separated by about 2.5 μHz which they suggested might be caused by modes of (n, ℓ) and ($n+1$, ℓ-2) thus determining the second-order asteroseismological parameter $\delta\nu$. We have obtained higher accuracy observations recently and confirm the two frequencies found by Kurtz & Balona. Observations of this star are continuing at the time of this writing; we are attempting to get enough data to look for period changes.

During our recent observing campaign on this star we obtained simultaneous two-channel photometry through *B* and *I* filters using a beam-splitter. The 6.8-minute, 3 mmag peak-to-peak variation in *B-I* can be detected with good signal-to-noise even through light to moderate cirrus cloud. The low amplitude of the light variation in *I* and the correlation of the noise in the *B* and *I* channels allows some of the sky transparency variations and scintillation noise to be removed while preserving the signal. This technique will be most useful at observatories with relatively poor photometric conditions. See Kurtz (1992b) for a detailed discussion of this two-channel technique of using a star as its own comparison.

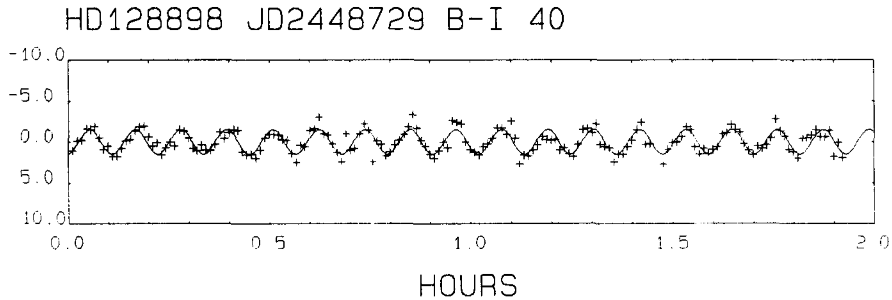

Fig. 3. A light curve of α Cir showing the 3-mmag peak-to-peak *B-I* variations for 2 hours of observations. These observations were made through moderate cirrus cloud which was absorbing up to 1.5 mag of the light in the individual *B* and *I* channels. The gray nature of the cirrus absorption allowed this tiny signal to be recovered with good signal-to-noise. The ordinate scale is in mmag, hence the total range is only 0.02 mag.

HD 134214

HD 134214 is a singly periodic roAp star with the shortest known principal period of 5.65 min and a semi-amplitude of 3.3 mmag. The phase of the pulsation does not seem to be stable, however (Kurtz *et al.* 1991). This star has little asteroseismological potential, but a study of its long-term phase behaviour could help us understand stochastic processes in roAp stars. One hour of high-speed photometry per night to determine the pulsation phase on a regular basis over a complete observing season would be very instructive. This star is bright (V = 7.479) and accessible to observers in both hemispheres (δ = -14°).

HD 137949 (33 LIB)

HD 137949 is another roAp star which appears to be singly periodic, although the presence of a second period with an amplitude of 0.15 mmag is suspected (Kurtz 1991). The principal frequency seems to have changed significantly between two sets of observations made in 1981 and 1987. As for HD 134214 above, HD 137949

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has little asteroseismological potential, but is an excellent star in which to study stochastic phase variations and changes of frequency. This star is bright (V = 6.674) and accessible to observers in both hemispheres (δ = -17°).

HD 161459

HD 161459 is the faintest of the known roAp stars at V = 10.32. It oscillates with several periods near 12 min (Martinez, Kurtz & Kauffman 1991), but complexity of the amplitude spectrum exacerbated by aliases in a meagre 23-hr data set has precluded understanding it. Almost certainly HD 161459 is a multi-mode pulsator which deserves an intensive study with at least a 1-m telescope (because of the faintness) from a good photometric site (because the periods are relatively long at 12 min where sky transparency variations strongly affect the noise).

HD 166473

HD 166473 is a multi-periodic roAp star with low amplitude oscillations, <0.5 mmag per mode semi-amplitude (Kurtz & Martinez 1987); possibly $\Delta\nu_0$ = 68 μHz. This star is difficult to study; often the amplitude is undetectable. It would be interesting to understand it better, but only observations made under the best of conditions with the best equipment are likely to yield new information.

HD 176232 (HR 7167; 10 AQL)

Rapid oscillations in HD 176232 were discovered and studied by Heller & Kramer (1990) who found three periods near 12 min; possibly $\Delta\nu_0$ = 51 μHz. The amplitudes per mode are low, <0.5 mmag, as in HD 166473. But HD 176232 has the advantage that it is bright (V = 5.89); it is also one of only two known roAp stars which are in the northern hemisphere. New observations would be useful to try to determine $\Delta\nu_0$ with certainty, but should only be made from excellent photometric sites because of the low amplitudes and relatively long periods which make sky transparency variations the limiting factor in the accuracy of the observations.

HD 190290

HD 190290 is definitely of asteroseismological interest. Martinez, Kurtz & Kauffman (1991) were able to resolve two frequencies with a separation of 40 μHz with a single night of observation. They interpreted this as $\Delta\nu_0$ = 40 μHz, although they could not rule out the possibility that this might be $\frac{1}{2}\Delta\nu_0$. New observations of this star are desirable. It can easily be observed from a single site for long times because of its far southerly position (δ = -79°) and winter observing season. The disadvantage of the declination is, however, that it can only be observed at relatively high airmass, and hence only on excellent photometric nights. A 14-hr light curve obtained on a rare perfect winter night with the 1-m telescope of Mt. John in New Zealand would be very interesting for this star; somewhat shorter light curves from less southerly observatories would be nearly as useful.

HD 193756

HD 193756 has been observed on only five nights and appears to have a single period near 13 min with a semi-amplitude of about 0.9 mmag (Martinez, Kurtz & Kauffman 1991). The noise level in the available data is relatively high (0.3 mmag), so little can be concluded. More observations are needed.

HD 196470

HD 196470 has been observed on only three nights and appears to have a single period near 11 min (Martinez, Kurtz & Kauffman 1991). As with HD 193756 above, the noise level in the available data is relatively high (0.3 mmag). More observations are needed; this star at a declination of $\delta = -18^{o}$ is accessible to northern hemisphere observers.

HD 201601 (HR 8097; γ EQU)

HD 201601 is a bright (V = 4.68) northern ($\delta = +10^{o}$) roAp star for which both photometric (Kurtz 1983) and spectroscopic radial velocity observations (Libbrecht 1988) show rapid oscillations with periods near 12.5 min, but with very small semi-amplitudes: about 20 m s^{-1} in radial velocity and around 1 mmag in brightness. It is thought that $\Delta\nu_0 = 58\ \mu$Hz which yields an asteroseismological absolute magnitude of $M_V(\Delta\nu_0) = 1.8$ which agrees well with the parallax absolute magnitude of $M_V(\pi) = 1.9$. This star has a magnetic field which has decreased steadily since its discovery in the late 1940s from +500 G to about -800 G at present.

No thorough study of this star has been done. Kurtz's original observations consisted of 36 hr spread over 11 nights in three months. Libbrecht's radial velocity measurements were made on only four nights. This star can be observed from both hemispheres, is well-studied magnetically (and is an enigma), and is a multi-mode pulsator with great asteroseismological potential. It demands a thorough photometric study.

HD 203932

HD 203932 oscillates with a single period near 5.94 min with a semi-amplitude of about 0.5 mmag. From 3 weeks of data obtained at both the SAAO and CTIO Martinez, Kurtz & Heller (1990) concluded that transient modes are present in this star. It is not certain whether that is the correct interpretation, or whether stochastic amplitude and/or phase variations may account for the apparently non-periodic amplitude variations. This star is probably not of interest asteroseismologically, but it remains of considerable interest to those who wish to study non-periodic phenomena in the roAp stars.

HD 217522

HD 217522 presents the best case of a roAp star which seems to have switched modes (Kreidl *et al.* 1991). Its principal oscillation frequency changed from 1.21529 mHz in 1982 to 1.1999 mHz in 1989. In the 1989 data a frequency is present at 2.0174 mHz which is entirely absent from the 1982 data. This star is relatively bright at V = 7.520 and is the best object to monitor for studies of non-periodic processes in roAp stars.

HD 218495

HD 218495 is, with HD 6532, the hottest of the roAp stars with a spectral type around A3. It has only been observed for 7 hr on three nights (Martinez, Kurtz & Kauffman 1991) and has a principal period near 7.4 min. Little is known about this star so any new observations will be useful.

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DISCUSSION (Hensberge; Kurtz & Martinez)

JARZEBOWSKI: (To Hensberge) The seven-year period in HD 187474 has already been suggested 30 years ago by Babcock on the basis of his magnetic observations. Babcock's suggestion has now been confirmed by your photometric data. My question is whether the relationship between magnetic and light variations, mentioned in your paper, is based on Babcock's data only or were there some new magnetic measurements?
HENSBERGE: The measurements of Babcock have been confirmed by Mathys (A&A Suppl, 89, 121, 1991). There are small differences in the numerical scale but these can easily be accounted for by the differences in the instrumentation.
MATHYS: In HD 187474, my quadratic field determinations, which were performed at phases different from those of the field modulus measurements, seem to confirm that Δa is smaller when we see the strongest magnetic pole of the star. Also, you suggested that a number of long-period stars might have very small spectroscopic or magnetic variations and that photometric variations might be more easily detected. I believe that, among the stars of your sample, HD 94660 and HD 116458 are two examples of such behaviour.
HENSBERGE: I agree.
MICHAUD: (To Kurtz) The temperature gradients you mention, do you have evidence that they are not spherically symmetric?
KURTZ: The study of HR 3831 (Matthews et al., poster paper) was done only near pulsation maximum, which is also magnetic maximum, so it gives a measure of the temperature gradient at only one rotational phase. Although it would be impossible to use the technique of Matthews et al. at magnetic quadrature when the amplitude of the pulsation goes to zero, it would be possible to look at other rotation phases when the amplitude is non-zero to see if there is any aspect dependence on the temperature gradient. Do you have theoretical expectations that the temperature gradient should vary as a function of latitude and longitude?
MICHAUD: Yes.

KURTZ: We will make the observations and have a look.
CORBALLY: Richard Gray tells me that he has seen slightly peculiar hydrogen line profiles in a few Ap stars. Your evidence that roAp stars have abnormal atmospheres makes me ask if you have observed any λ Boo stars for rapid oscillation, particularly those with the "Peculiar Hydrogen Line" profiles.
KURTZ: I haven't. I have had a prejudice that the roAp phenomenon is to be found among the coolest SrCrEu stars and have mostly looked there. I have searched some hotter stars, even up to the He-weak and -strong stars, but not thoroughly or systematically - it has been more like a bit of part-time fishing. We'll have a look at a couple of PHL λ Boo stars and let you know the results.
SHORE: You mentioned nonlinearity may be present in HR 3831. Are there any indications of close modal splitting or low-level wings in your power spectra, possibly signatures of incipient chaos?
KURTZ: For HR 3831 in the amplitude spectra shown, the answer is no. The entire spectrum is adequately modelled with a frequency septuplet and appropriate harmonics; there is no indication of broadening for the two-week 1991 multi-site observations. On the other hand, the kind of signature you are asking about appears in an analysis of the entire 1981 - 1991 data set for HR 3831; the frequency peaks break into multiple, closely spaced peaks which indicate frequency and/or phase instability. We are getting long-term, frequent observations of HR 3831 now for a few years to monitor this effect. HR 1217 shows that same behavior: for a three-week data set the peaks are as wide as the spectral window; for longer runs they broaden, indicating amplitude, phase or frequency modulation on a longer time scale. That modulation doesn't appear to be periodic, but non-periodicity is hard to prove.
POLOSUKHINA: How many stars have measurements of radial velocity oscillations? And what agreements between power spectrum?
KURTZ: Only two: HR 1217 and γ Equ. The radial velocity observations on HR 1217 are too short to analyse for the component frequencies. The observed amplitude is a few hundreds of m s^{-1}. Radial velocities of γ Equ give frequencies which agree with the photometrically derived ones in $\Delta\nu_0$, but the same frequencies were not excited in both types of observations. However, the observations were separated in time, the photometric amplitude is very low, and the radial velocity amplitude was only a few tens of m s^{-1}.
POLOSUKHINA: What spectrum power of comparison star for oscillating stars?
KURTZ: We CAN find constant stars! Everything we look at is not variable. At the frequencies of interest for the roAp stars the highest peaks in the amplitude spectrum of a "constant" star on a good night at Sutherland are usually in the range of 0.2 to 0.3 mmag for a few hours of observation with the 1-m telescope on an 8th magnitude, or brighter, star.
POLOSUKHINA:Your opinion about connection between oscillation and spottiness of Ap stars.
KURTZ: As we've seen at this meeting, for many of the Ap stars the surface distributions of the elements is not symmetrical about the magnetic poles. In the case of HR 3831 we have shown that the time of rotational light variation extremum differs from the time of magnetic extremum, but the magnetic extremum and pulsation maximum coincide. This is a greater than 3 sigma result. In the case of HR 1217 the situation is the same, but the result is just on 3 sigma. So the pulsation pattern coincides with the magnetic field, not with the surface element distribution.

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