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The δ Scuti variability of the high metallicity δ Del star, rho Pavonis

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Summary. The δ Del star, ρ Pav, is announced to be a δ Scuti variable ($\Delta y \leqslant$ 0.03 mag). Thirty-nine hours of observations in both b and y colours are presented. It appears that ρ Pav pulsates with more than one frequency, but the present data are inadequate to derive a definitive frequency solution. A frequency analysis of both the b and y data indicates that $f_1 = 8.761 \pm 0.014\ \mathrm{day}^{-1}$ is the frequency of highest amplitude. Simultaneous light and radial velocity observations were obtained on one night which yield $(\Delta R/R)/\Delta M_{\mathrm{bol}} = 0.11$, a value typical of δ Scuti stars. The δ Del spectral classification of ρ Pav and its metallicity index, $\delta m_0 = -0.092$, both indicate that it is probably a metallic line star.

1 Introduction

HR 7859, ρ Pavonis, is a δ Del star (Houk & Cowley 1975; Malaroda 1975) which is announced to be a δ Scuti variable ($\Delta y \leqslant 0.03$ mag). The δ Del stars are thought to be evolved Am stars (Kurtz 1976) in which, in some cases, metallicism and pulsation can coexist in the same star. In Section 2 of this paper differential photometric observations in Strömgren b and y colours are presented which show that ρ Pav is a δ Scuti star. In Section 3, simultaneous light and radial velocity curves are presented. In Section 4 it is argued that ρ Pav has a strong metallic line spectrum on the basis of its spectral classification and metallicity index. This is important to theories which attempt to explain the pulsating metallic line stars.

A discussion of the position of ρ Pav in the $[(b-y)_0, M_V]$ plane is given in Section 5. The absolute magnitude of ρ Pav computed from calibrations of the δc_1 index indicates that it is cooler than the previously observed red edge of the instability strip. Kurtz (1979b), however, has shown that the δc_1 index frequently underestimates the luminosity of δ Del stars. The parallax of ρ Pav and the application of a period–luminosity–colour relation for δ Scuti stars both argue for a higher luminosity, placing the star in the perviously observed instability strip at an approximately equivalent spectral type of F0 III.

Finally in Section 6 preliminary frequency analyses of the b and y light curves of ρ Pav are presented. It is argued that the data available are insufficient for a definitive frequency solution.

2 Differential photometry

Differential photometric observations of ρ Pav were obtained on one night in 1977 June through a Johnson V filter and on seven nights in 1977 July–October through Strömgren b and y filters. All observations were carried out with the University of Cape Town Photometer attached to the South African Astronomical Observatory (SAAO) 0.75-m telescope at Sutherland. Initially two comparison stars were used, HD 196265 (B9/9.5 V, m_{pg} = 7.3) and HD 196517 (A6 V, m_{pg} = 8.6). The spectral types are from the *Michigan Spectral Catalogue* (Houk & Cowley 1975). HD 196517 proved to be a δ Scuti star and has been reported elsewhere (Kurtz 1977).

Observations consisted of 10 consecutive 10-s integrations on ρ Pav and HD 196265 alternately. Table 1 lists the nights on which observations were obtained, the number of b and y magnitudes measured, the duration of the observations in hours, and the standard deviation of one measured magnitude for both the b and y colours. The standard deviations were computed each night by breaking the HD 196265 observations into two data sets alternating in time and normalizing one set by the other as a function of time.

Table 1. Standard deviations for each night of observation of ρ Pav

Date	JD	n	t	σ_b	σ_y
1977	2440000.+		hr	(mag)	(mag)
June 17/18	3312.				0.0052 (σ_V)
July 27/28	3352.	35	5.68	0.0009	0.0016
July 30/31	3355.	59	9.14	0.0015	0.0016
August 12/13	3368.	54	7.99	0.0024	0.0019
September 27/28	3414.	33	4.70	0.0023	0.0010
September 28/29	3415.	27	4.08	0.0020	0.0016
October 3/4	3420.	20	3.53	0.0048	0.0051
October 5/6	3422.	29	4.10	0.0018	0.0020
Total		256	39.23	⟨0.0021⟩	⟨0.0019⟩

Table 2 gives the Heliocentric Julian Date and computed differential b and y magnitudes for ρ Pav. Given that ρ Pav ≡ V and HD 196265 ≡ C the magnitudes were computed from the relation $\Delta m = V - \langle C \rangle$ where $\langle C \rangle$ is the average of the value of C immediately preceding and following V in time. In Figs 1 and 2 the data from Table 2 have been plotted. They show ρ Pav to be variable in a manner typical of δ Scuti stars with an amplitude of $\Delta y \leqslant$ 0.03 mag.

3 Simultaneous light and radial velocity observations

The variability of ρ Pav reported in the last section was initially discovered on 1977 June 17/18. Although Kukarkin, Efremov & Kholopov (1958) list ρ Pav as a suspected variable (number 101991), the original source (Zinner 1929) suggests a range of 0.6 mag which is most probably incorrect and is certainly irrelevant to the δ Scuti variability reported here. Observations on 1977 June 17/18 were made through a Johnson V filter using the same technique reported in the last section. After 2.5 hr of observation, when the variability of this star was obvious, Dr L. Balona generously agreed to obtain simultaneous radial velocities with the speedometer attached to the SAAO 1.88-m telescope. The magnitudes and radial velocities obtained on that night are given in Table 3. These data are plotted in Fig. 3 where

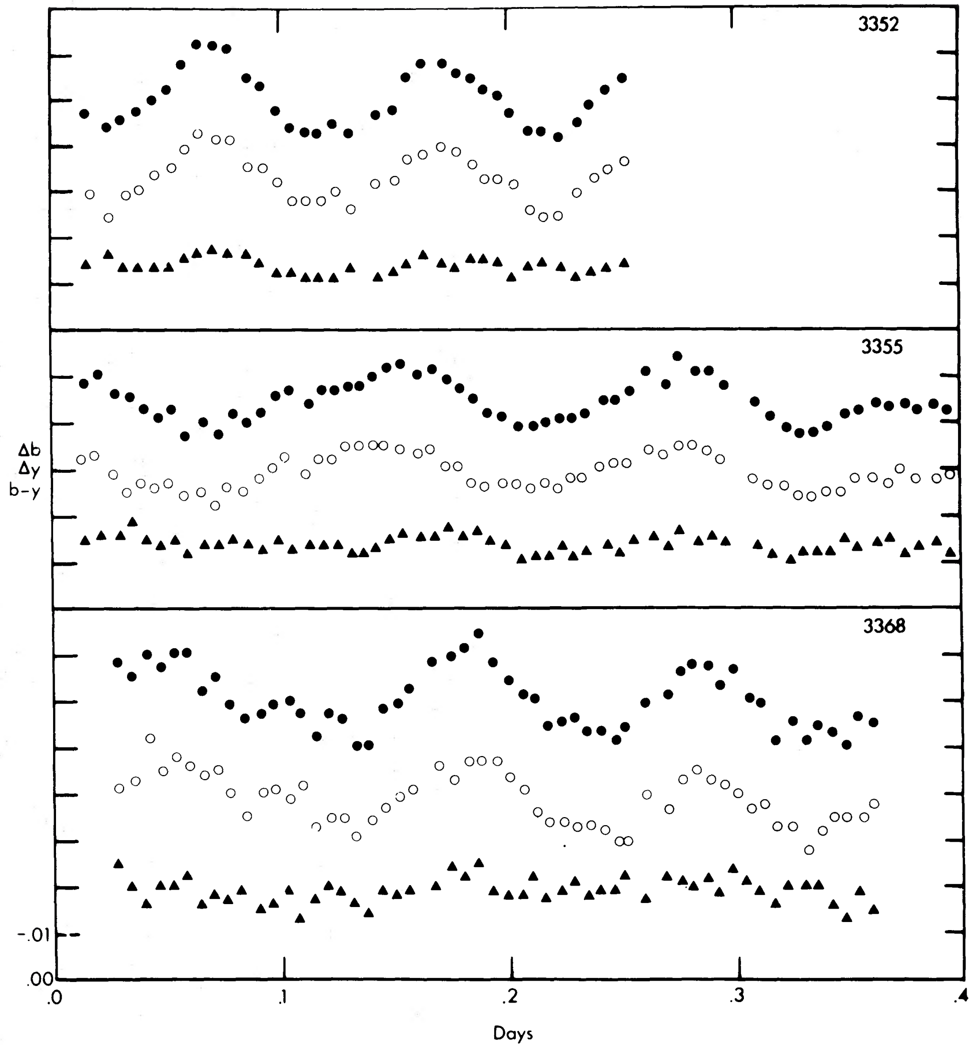

Figure 1. The observed light curves of ρ Pav. The closed circles are Strömgren b, the open circles Strömgren y, and the triangles $b-y$. The tick marks on the ordinate scale are in units of 0.01 mag. The numbers in the upper right corner of each box are the Julian Date $-$ 2440000 of those observations.

one can see that the radial velocity curve is roughly a mirror image of the light curve which is typical of δ Scuti stars.

If we compare the velocity amplitude to the light amplitude in ρ Pav we find $2K/\Delta m_V$ = 130 km s^{-1} mag^{-1} using $2K$ = 4.0 km s^{-1} and Δm_V = 0.03 mag from Fig. 2. This is at the upper end of the range of values typically found for δ Scuti stars of 93 ± 26 km s^{-1} mag^{-1} (Breger, Hutchins & Kuhi 1976–BHK). Watson (1971) has pointed out that another parameter, $(\Delta R/R)/\Delta M_{\rm bol}$, is nearly constant for Cepheids and Miras. BHK extend this conclusion to δ Scuti stars. They give

$$\frac{\Delta R/R}{\Delta M_{\rm bol}} = 1.34 \, \frac{P}{2\pi R} \, \frac{2K}{(\Delta M_V + \Delta \mathrm{BC})} \tag{1}$$

and $P/R \propto P^{0.46}$. Taking the differential bolometric correction to be ΔBC = 0.005 (Harris 1963), we find from equation (1) that $(\Delta R/R)/\Delta M_{\rm bol}$ = 0.11 mag^{-1}. This is identical with the average value found by BHK for their seven δ Scuti stars.

Table 2. Differential Strömgren Δb and Δy magnitudes for ρ Pav.

HJD	DB	HJD	DB	HJD	DB	HJD	DB
3352.345	.883	3355.298	.883	3355.594	.881	3368.495	.875
3352.354	.886	3355.305	.885	3355.600	.882	3368.500	.879
3352.360	.884	3355.311	.883	3355.608	.881	3368.506	.876
3352.367	.883	3355.318	.879	3355.614	.882	3368.512	.882
3352.374	.880	3355.324	.878	3368.235	.874	3368.518	.883
3352.380	.878	3355.332	.881	3368.241	.877	3368.524	.891
3352.387	.872	3355.338	.878	3368.248	.872	3368.530	.887
3352.393	.868	3355.344	.878	3368.254	.875	3368.538	.891
3352.400	.868	3355.350	.877	3368.260	.872	3368.543	.888
3352.406	.869	3355.355	.877	3368.266	.872	3368.549	.889
3352.415	.875	3355.361	.875	3368.272	.880	3368.555	.892
3352.420	.877	3355.367	.873	3368.278	.877	3368.561	.886
3352.428	.882	3355.373	.873	3368.284	.883	3368.567	.887
3352.434	.886	3355.381	.875	3368.290	.886	3414.237	.875
3352.440	.887	3355.387	.874	3368.298	.885	3414.243	.883
3352.446	.887	3355.393	.876	3368.303	.883	3414.250	.886
3352.453	.885	3355.399	.878	3368.310	.882	3414.256	.890
3352.460	.887	3355.405	.880	3368.315	.885	3414.262	.890
3352.472	.883	3355.411	.883	3368.322	.890	3414.268	.890
3352.479	.882	3355.418	.883	3368.328	.885	3414.275	.891
3352.485	.875	3355.425	.886	3368.333	.886	3414.281	.886
3352.492	.872	3355.431	.886	3368.339	.892	3414.287	.890
3352.500	.872	3355.437	.885	3368.345	.892	3414.293	.891
3352.506	.874	3355.443	.884	3368.352	.884	3414.299	.895
3352.513	.875	3355.448	.884	3368.358	.883	3414.305	.896
3352.519	.878	3355.454	.883	3368.363	.880	3414.311	.893
3352.525	.879	3355.462	.880	3368.375	.874	3414.317	.893
3352.531	.883	3355.468	.880	3368.382	.873	3414.323	.897
3352.539	.887	3355.474	.878	3368.388	.871	3414.329	.887
3352.545	.887	3355.483	.874	3368.394	.868	3414.335	.886
3352.552	.888	3355.490	.877	3368.400	.874	3414.342	.883
3352.560	.885	3355.495	.872	3368.407	.878	3414.347	.884
3352.566	.881	3355.503	.874	3368.413	.881	3414.353	.879
3352.573	.878	3355.509	.874	3368.418	.882	3414.359	.876
3352.581	.875	3355.515	.877	3368.424	.888	3414.365	.875
3355.234	.877	3355.529	.882	3368.430	.887	3414.371	.872
3355.240	.875	3355.535	.884	3368.436	.886	3414.377	.874
3355.248	.879	3355.543	.886	3368.442	.889	3414.383	.872
3355.254	.880	3355.549	.887	3368.448	.889	3414.389	.874
3355.260	.882	3355.555	.887	3368.454	.891	3414.395	.877
3355.266	.884	3355.561	.886	3368.458	.888	3414.402	.880
3355.272	.882	3355.568	.883	3368.467	.883	3414.409	.888
3355.278	.888	3355.574	.882	3368.477	.881	3414.415	.891
3355.286	.885	3355.582	.881	3368.483	.876	3414.420	.897
3355.292	.888	3355.588	.881	3368.488	.875	3414.426	.900
3414.432	.903	3415.363	.888	3420.339	.877	3422.316	.904
3415.239	.892	3415.370	.889	3420.346	.881	3422.322	.902
3415.246	.892	3415.377	.887	3420.352	.888	3422.327	.898
3415.253	.887	3415.383	.886	3420.357	.888	3422.333	.896
3415.260	.886	3415.389	.887	3420.363	.888	3422.339	.890
3415.267	.886	3415.395	.888	3420.369	.892	3422.346	.886
3415.274	.883	3415.402	.885	3420.375	.891	3422.352	.880
3415.280	.882	3415.407	.884	3420.381	.891	3422.357	.874
3415.287	.877	3420.235	.876	3422.241	.864	3422.363	.871
3415.295	.883	3420.242	.885	3422.247	.866	3422.369	.868
3415.301	.881	3420.249	.893	3422.255	.863	3422.376	.871
3415.307	.884	3420.256	.897	3422.261	.864	3422.381	.872
3415.313	.885	3420.273	.902	3422.267	.870	3422.387	.874
3415.319	.885	3420.279	.904	3422.273	.873	3422.393	.876
3415.325	.890	3420.298	.883	3422.279	.879	3422.399	.882
3415.332	.888	3420.304	.879	3422.286	.887	3422.405	.884
3415.338	.888	3420.310	.878	3422.292	.892	3422.411	.886
3415.345	.886	3420.317	.875	3422.297	.899	.000	.000
3415.351	.886	3420.323	.874	3422.304	.904	.000	.000
3415.357	.888	3420.334	.876	3422.310	.904	.000	.000

Table 2 – *continued*

HJD	DY	HJD	DY	HJD	DY	HJD	DY
3352.347	.674	3355.299	.674	3355.595	.670	3368.496	.667
3352.355	.679	3355.306	.675	3355.602	.672	3368.502	.668
3352.362	.674	3355.313	.672	3355.610	.672	3368.508	.670
3352.368	.673	3355.319	.670	3355.615	.671	3368.514	.673
3352.375	.670	3355.325	.667	3368.236	.669	3368.520	.672
3352.382	.668	3355.333	.671	3368.243	.667	3368.526	.677
3352.388	.664	3355.339	.668	3368.249	.658	3368.532	.677
3352.394	.661	3355.345	.668	3368.255	.665	3368.539	.682
3352.402	.662	3355.351	.665	3368.261	.662	3368.545	.678
3352.408	.662	3355.357	.665	3368.267	.664	3368.556	.675
3352.416	.668	3355.363	.665	3368.273	.666	3368.550	.675
3352.422	.668	3355.368	.665	3368.280	.665	3368.563	.675
3352.429	.671	3355.375	.666	3368.285	.670	3368.568	.672
3352.435	.675	3355.382	.667	3368.292	.675	3414.241	.669
3352.441	.675	3355.388	.666	3368.299	.670	3414.245	.672
3352.448	.675	3355.394	.670	3368.305	.669	3414.251	.675
3352.454	.673	3355.400	.670	3368.311	.671	3414.257	.677
3352.461	.677	3355.406	.673	3368.317	.668	3414.263	.677
3352.473	.671	3355.412	.674	3368.323	.677	3414.270	.676
3352.480	.671	3355.420	.673	3368.329	.675	3414.277	.678
3352.486	.666	3355.426	.673	3368.335	.675	3414.282	.674
3352.493	.665	3355.432	.674	3368.340	.679	3414.288	.677
3352.501	.663	3355.438	.673	3368.347	.676	3414.294	.678
3352.508	.664	3355.444	.674	3368.353	.673	3414.300	.677
3352.514	.667	3355.450	.672	3368.359	.671	3414.307	.678
3352.520	.670	3355.455	.672	3368.365	.669	3414.312	.680
3352.526	.670	3355.463	.670	3368.377	.664	3414.319	.679
3352.533	.671	3355.469	.669	3368.383	.667	3414.325	.679
3352.540	.677	3355.475	.669	3368.390	.663	3414.330	.676
3352.546	.678	3355.485	.666	3368.395	.663	3414.336	.673
3352.553	.678	3355.491	.667	3368.402	.663	3414.343	.671
3352.561	.673	3355.497	.665	3368.408	.666	3414.349	.672
3352.568	.670	3355.504	.665	3368.414	.669	3414.355	.668
3352.574	.668	3355.510	.666	3368.420	.674	3414.360	.665
3352.582	.666	3355.516	.668	3368.425	.676	3414.366	.662
3355.235	.668	3355.530	.672	3368.431	.676	3414.372	.662
3355.241	.667	3355.537	.673	3368.437	.677	3414.379	.662
3355.249	.671	3355.544	.674	3368.443	.677	3414.385	.663
3355.255	.675	3355.550	.676	3368.450	.678	3414.391	.664
3355.261	.673	3355.556	.676	3368.455	.680	3414.397	.666
3355.267	.674	3355.563	.675	3368.459	.680	3414.403	.671
3355.273	.673	3355.569	.675	3368.468	.670	3414.410	.674
3355.280	.676	3355.575	.672	3368.478	.673	3414.416	.678
3355.287	.675	3355.583	.672	3368.484	.667	3414.422	.682
3355.293	.678	3355.590	.673	3368.490	.665	3414.427	.686
3414.433	.688	3415.365	.675	3420.341	.669	3422.317	.686
3415.240	.677	3415.372	.674	3420.347	.671	3422.323	.685
3415.247	.680	3415.378	.674	3420.353	.674	3422.329	.683
3415.255	.675	3415.385	.674	3420.359	.676	3422.334	.682
3415.261	.673	3415.390	.675	3420.364	.678	3422.340	.679
3415.268	.670	3415.396	.675	3420.371	.675	3422.347	.670
3415.275	.672	3415.403	.672	3420.377	.678	3422.353	.668
3415.282	.669	3415.409	.672	3420.382	.678	3422.359	.664
3415.289	.665	3420.236	.668	3422.242	.655	3422.364	.663
3415.296	.669	3420.244	.679	3422.249	.658	3422.370	.661
3415.302	.669	3420.251	.682	3422.256	.655	3422.377	.663
3415.308	.673	3420.257	.685	3422.262	.657	3422.382	.662
3415.315	.674	3420.274	.685	3422.268	.661	3422.388	.663
3415.320	.674	3420.280	.687	3422.274	.666	3422.394	.666
3415.326	.677	3420.300	.665	3422.280	.669	3422.400	.667
3415.333	.676	3420.306	.668	3422.287	.674	3422.407	.671
3415.340	.678	3420.312	.662	3422.293	.679	3422.412	.674
3415.347	.678	3420.318	.662	3422.299	.684	.000	.000
3415.353	.673	3420.325	.665	3422.305	.685	.000	.000
3415.359	.675	3420.335	.667	3422.311	.688	.000	.000

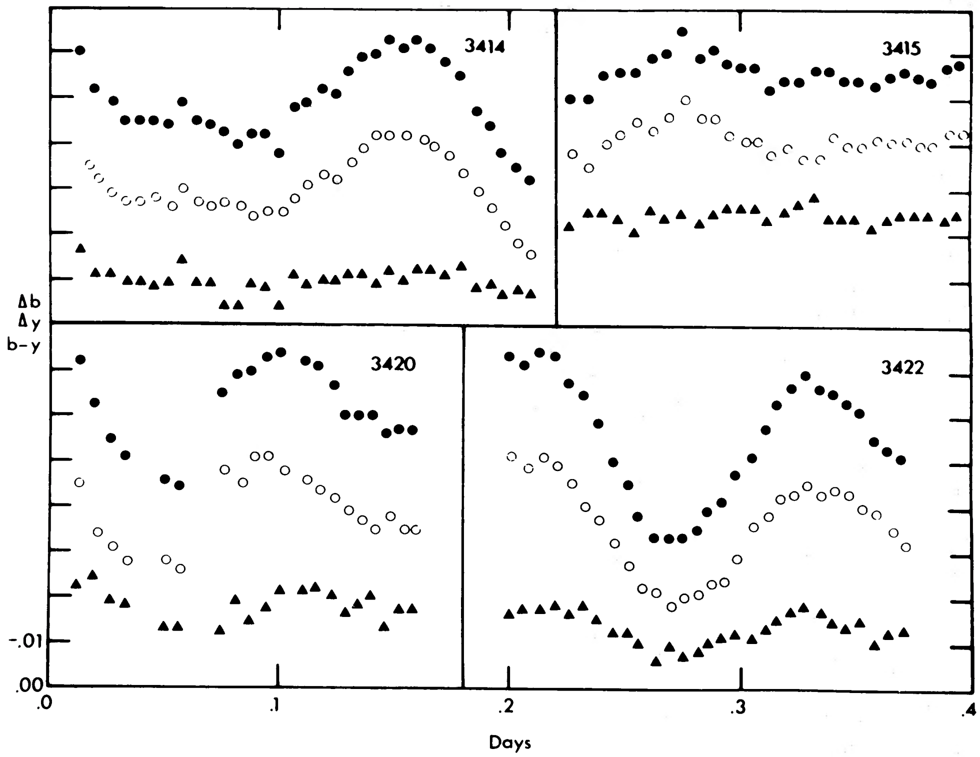

Figure 2. The observed light curves of ρ Pav. The symbols and coordinates are the same as in Fig. 1.

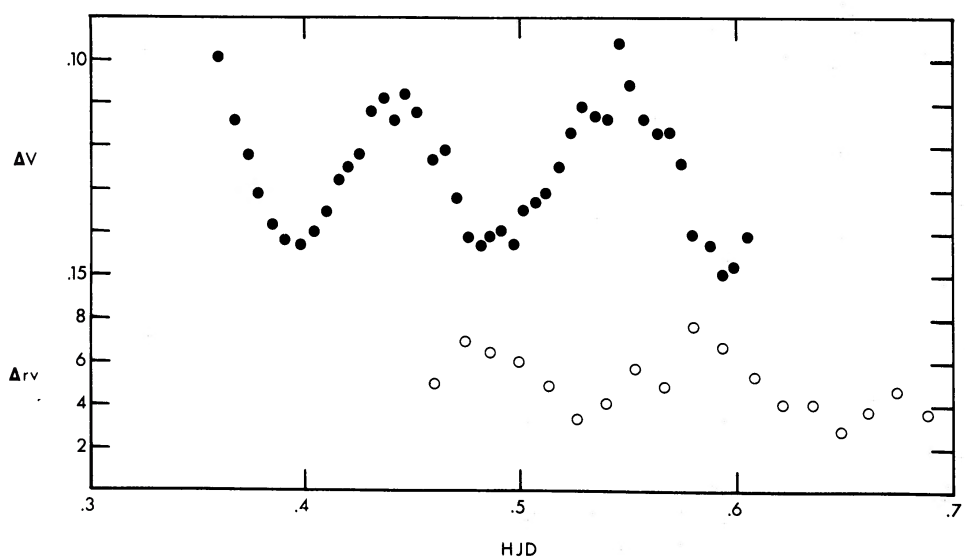

Figure 3. Simultaneous light and radial velocity curves for ρ Pav. The ordinate scale tick marks represent 0.01 mag for the light curve and 2 km s^{-1} for the radial velocity curve.

4 Metallicism, pulsation and ρ Pav

It is well known that most metallic-line stars do not pulsate (Breger 1970, 1972, 1979; Kurtz *et al.* 1976). One of the strengths of the diffusion hypothesis for the origin of Am stars is that it neatly explains this general metallicism–pulsation exclusion by the depletion of He in the He II ionization zone. However, in some metallic-line stars or metallic-line

Table 3. Differential magnitudes and radial velocities of ρ Pav on 1977 June 17/18.

HJD 2443312.+	ΔV (mag)	HJD 2443312.+	ΔV (mag)	HJD 2443312.+	rv (km s^{-1})
.359	0.099	.486	0.141	.460	4.9
.367	0.114	.491	0.140	.474	6.9
.373	0.122	.497	0.143	.486	6.3
.378	0.131	.502	0.135	.499	5.9
.385	0.138	.507	0.133	.513	4.8
.390	0.142	.512	0.131	.526	3.3
.398	0.143	.518	0.125	.540	4.0
.404	0.140	.523	0.117	.553	5.6
.410	0.135	.528	0.111	.567	4.8
.415	0.128	.535	0.113	.580	7.6
.420	0.125	.540	0.114	.593	6.6
.425	0.122	.546	0.096	.608	5.3
.431	0.112	.551	0.106	.621	4.0
.436	0.109	.557	0.114	.635	4.0
.441	0.114	.563	0.117	.648	2.7
.446	0.108	.569	0.117	.661	3.6
.452	0.112	.575	0.124	.674	4.6
.459	0.123	.580	0.141	.688	3.5
.465	0.121	.588	0.143		
.470	0.132	.593	0.150		
.475	0.141	.599	0.148		
.481	0.143	.605	0.141		

related stars, pulsation and metallicism appear to coexist in the same object (Kurtz 1976, 1978). A great deal of interest has been focused recently on the theoretical explanation of such objects within the diffusion hypothesis (Vauclair 1976, 1977; Valtier, Baglin & Auvergne 1979; Cox, King & Hodson 1979). All of these studies deal with less than 10 well-established cases of metallicism and pulsation occurring in the same star. The discovery of pulsation in ρ Pav is, therefore, an important addition to the observational evidence available.

It was pointed out by Kurtz (1976) that ρ Pav might be an interesting object based on its Strömgren indices. Those indices have been remeasured for ρ Pav (Kurtz 1979b) and are given in Table 4. They are in excellent agreement with the observations of Grønbech & Olsen (1976, 1977). Quite striking is the metallicity parameter $\delta m_0 = -0.092$. This is indicative of metal line blocking equal to that in the most extreme Am stars. While an abundance analysis will be necessary to prove the metallic line nature of ρ Pav, the independent δ Del classifications of Malaroda (1975) and Houk & Cowley (1975) along with the very strong metallicity index give good confidence that this is a case of a pulsating metallic-line star.

Table 4. Strömgren indices for ρ Pav.

V =	4.869		
$b-y$ =	0.253	$(b-y)_0$ =	0.236
m_1 =	0.262	δm_0 =	-0.092
c_1 =	0.667	δc_0 =	0.070
β =	2.718	(ΔM_V =	0.56)
		(M_V =	2.60)*

* Arguments given in the text indicate that $M_V = 1.75$.

5 The position of ρ Pav in the $[(b-y)_0, M_V]$ plane

Using the data in Table 4, ρ Pav can be plotted in the $[(b-y)_0, M_V]$ plane along with other δ Scuti stars (see Breger 1979, Fig. 2). In this plot ρ Pav seems to be cooler than the otherwise observed boundary of the δ Scuti instability strip. The $(b-y)_0$ temperature parameter has been calculated from Crawford's (1975) calibration which is in reasonable agreement with the β index and thus seems secure. The luminosity, however, has been calculated from the relation $M_V = M_V(\mathrm{ZAMS}) - 8\,\delta c_1$ and Kurtz (1979b) has shown that the δc_1 index in many cases underestimates the luminosity of δ Del stars.

There are other reasons to believe that the luminosity of ρ Pav determined from the δc_1 index has been underestimated. The parallax of ρ Pav is $\pi = -0.002 \pm 0.010$ arcsec. Thus, at the 3σ level of confidence we can state that $\pi \leqslant 0.028$ arcsec or $d \geqslant 36$ pc. For $m_V = 4.87$ this yields $M_V \leqslant 2.11$. Breger & Bregman (1975) and Breger (1979) have shown that statistically the δ Scuti stars can be fit with a reasonable Period–Luminosity–Colour (PLC) relation. If we make the assumption that ρ Pav also fits Breger's (1979) δ Scuti PLC relation, then for the frequency of highest amplitude derived for ρ Pav in the next section of $f_1 = 8.761\ \mathrm{day}^{-1}$, we derive $M_V = 1.75 \pm 0.31$. This value is dependent on the Q-value of the pulsation mode associated with $f_1 = 8.761\ \mathrm{day}^{-1}$ being near to the mean Q-value of the δ Scuti stars from which Breger's PLC relation was derived.

This absolute magnitude for ρ Pav of $M_V = 1.75 \pm 0.31$ is hereby adopted since it is consistent with the parallax of ρ Pav, the PLC relation for δ Scuti stars, the δ Del classification of ρ Pav which is indicative of a luminosity class of III or IV (Kurtz 1979b), and it places ρ Pav in the previously determined δ Scuti instability strip. The absolute magnitude of $M_V = 2.60$ (see Table 4) derived directly from calibrations of the δc_1 index is inconsistent with all four of the above criteria.

6 Frequency analysis

The light curves of ρ Pav were frequency analysed using the technique of Fourier analysis of unequally spaced data (Deeming 1975). The data were repetitively pre-whitened by the frequency with the highest peak in the power spectrum until the noise level was reached. A multivariate least squares fit of the determined frequencies to the data was then performed to obtain optimum amplitudes and phases.

Table 5 gives the results of the frequency analyses performed on ρ Pav. The components given are for the equation

$$\Delta m = \sum_i A_i \cos(2\pi f_i t + \phi_i), \qquad t_0 = \mathrm{JD}\,2440000. \tag{2}$$

Table 5. Preliminary frequencies derived for ρ Pav.

N	f (day^{-1})	A (mag)	ϕ	σ (mag)
b data	±.014	0.0004		
1	8.761	0.0088	−0.81 ± 0.04	
2	8.842	0.0044	−0.79 ± 0.09	
3	6.202	0.0032	−2.20 ± 0.11	0.0038
y data		± 0.0003		
1	8.761	0.0069	−0.82 ± 0.05	
2	8.842	0.0031	−0.83 ± 0.10	
3	6.202	0.0029	−2.20 ± 0.10	0.0031

The error in frequency given is $1.5/\Delta T$ where ΔT is the time span of the data set. This represents the separation two frequencies must have to be completely resolved (Loumos & Deeming 1978).

Long-period variations occur in the brightness of ρ Pav on a time-scale of days which results in some power at frequencies near 0.04 day^{-1}. This low frequency power is often found in frequency analyses of low-amplitude δ Scuti stars (Kurtz 1979a) and remains unexplained. The data under examination here, however, are insufficient for examining this low frequency behaviour. All of the ρ Pav observations were therefore normalized in the mean to zero on a night-by-night basis in order to suppress the low frequency peaks for further analysis.

Frequency analyses were performed separately on the b and y data to obtain the three frequencies given in Table 5. The amplitudes and phases given were computed by a multivariate least squares fit. These frequencies are considered preliminary as there are not enough data to derive them independently from smaller subsets of the data given in Table 2. Fig. 4 shows the three-frequency fit to the y data. The fit is satisfactory for the basic shape of the light curves, but there are systematic deviations. The rms scatter of the residuals to that fit of $\sigma_y = 0.0031$ mag can be compared with the actual data error of $\langle\sigma_y\rangle = 0.0019$ mag (Table 1).

Recently, Balona & Stobie (1979) have shown that the phasing between the $B-V$ colour curve and the V light curve in an oscillating star depends on the pulsation mode, assuming linear pulsation, a direct relation between $B-V$ and surface brightness, and a phase lag

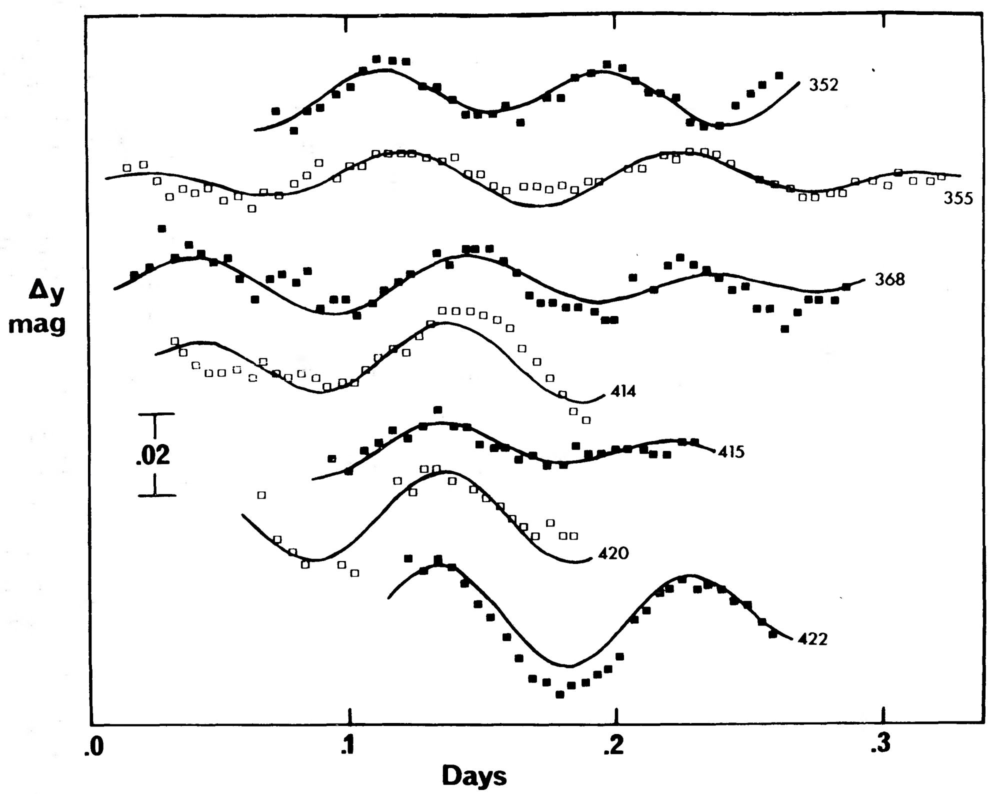

Figure 4. The y light curves of ρ Pav. The solid line is the predicted light curve from the three frequencies given in Table 5. Each curve is for JD 2443000.+ the number next to the curve. The zero points for each night are arbitrary in this figure. Filled and open squares have been used alternately only to keep from confusing adjacent data strings. The size of the data points is approximately one standard deviation.

between the flux and radius variations of $\psi \sim 90^\circ$ within a wide latitude. These assumptions should hold for ρ Pav where we use $b-y$ and y instead of $B-V$ and V.

For the frequency of highest amplitude in ρ Pav of $f_1 = 8.761\ \mathrm{day}^{-1}$, we can compute $A_{b-y} = 0.0019$ mag and $\phi_{b-y} = 0.77$ from the b and y amplitudes and phases given in Table 5. We thus calculate the phase shift between the y light curve and the $b-y$ colour curve to the $\Delta\phi(y, b-y) = +2.7 \pm 3^\circ.7$. From Balona & Stobie's theory we expect a phase shift of $\Delta\phi(y, b-y) = -11^\circ$ for radial pulsation, 0° for odd non-radial pulsation, $+16^\circ$ for $l=2$ non-radial pulsation, and $\Delta\phi(y, b-y) > 126^\circ$ for $l \geqslant 4$ and even assuming a ratio of flux to radius variation of $f = 10$ and $\psi = 90^\circ$. Thus for $f_1 = 8.761\ \mathrm{day}^{-1}$ in ρ Pav we can certainly rule out $l \geqslant 4$ and even.

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