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THE NATURE OF V829 Aql – A TRIPLE-MODE RADIALLY PULSATING POST-MAIN-SEQUENCE DELTA SCUTI STAR

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Diethelm (1997, hereafter D97) obtained time-resolved CCD photometry of V829 Aql during 25 nights in 1995 and 1997 (see his paper for more information). He suggested that this star is a multimode radial pulsator.

These observations have been analysed with respect to the underlying pulsational frequencies. Starting with his 1997 measurements (which are of better quality and more numerous than the 1995 data), we computed amplitude spectra and performed multifrequency sine-wave fits using the program package Period 98 (Sperl 1998). Our resulting amplitude spectra before and after successive prewhitening of simultaneously optimized frequencies are shown in Figure 1.

From Figure 1 it can be seen clearly that (at least) four frequencies are present in the light variations of V829 Aql. Furthermore, some harmonics of these frequencies ($2f_1$, $2f_2$, $3f_2$) can be discerned after prewhitening the four dominant peaks. Because of the small amount of data we did not attempt to fit these frequencies to push the analysis further.

With that knowledge, we attempted a frequency analysis of the 1995 measurements. The frequencies f_1, f_2 and f_3 are present in these data as well, but because of severe aliasing and the higher noise level, they do not dominate the amplitude spectra. After prewhitening these three frequencies, the first harmonics of them can be seen as well ($2f_1$, $2f_2$, $2f_3$). Again, we did not try to calculate a higher order fit at this point.

The results of our frequency analysis are summarized in Table 1. The error bars have been determined following Kovács (1981) and should be taken only as formal values; the real errors may be higher by up to a factor of 2.

Table 1. Frequencies detected in the light curves of V829 Aql

Ident.	Freq. (1995) (cycles/day)	Ampl. (1995) (mmag)	Freq. (1997) (cycles/day)	Ampl. (1997) (mmag)
f_1	4.529 ± 0.006	83 ± 20	4.5260 ± 0.0008	85 ± 4
f_2	3.415 ± 0.006	75 ± 20	3.4196 ± 0.0008	82 ± 4
f_3	5.664 ± 0.006	64 ± 21	5.6597 ± 0.0025	29 ± 4
$f_4=f_1+f_2$	–	–	7.9498 ± 0.0022	26 ± 4

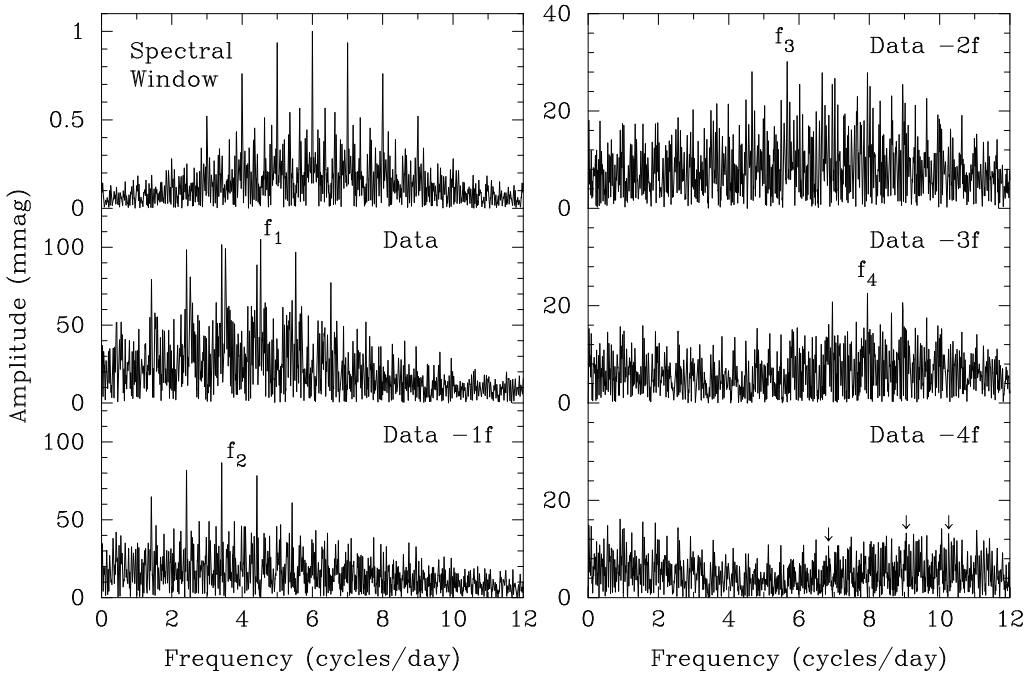

Figure 1. Amplitude spectra for the 1997 measurements of D97. Four frequencies can be identified and some further linear combinations of them (indicated with arrows) may be present

From Table 1 it may be suspected that the amplitude of f_3 was different between the two seasons, which is supported by the presence of its first harmonic in the 1995 data. However, keeping the error sizes in mind, this statement is only preliminary. Because of the significantly different quality of the two yearly subsets of data and because of the large gap between them, we did not attempt to calculate multifrequency fits for the whole data set. We rather base the following discussion on the 1997 data only.

What is the cause of variability of V829 Aql? The frequency ratios $f_2/f_1=0.7555\pm0.0002$ and $f_1/f_3=0.7997\pm0.0004$ together with the presence of linear combinations and harmonic frequencies strongly point towards the excitation of radial pulsations in the fundamental mode (F) plus the first and second overtones (1H and 2H, respectively).

In a first approach to unravel the nature of V829 Aql, we can state that it is either an RR Lyrae star or an evolved δ Scuti star. Unfortunately, we have no spectroscopic information on this object. Garcia-Melendo & Clement (1997) compiled the periods for field and cluster double-mode RR Lyrae (RRd) stars. The radial fundamental mode periods for these stars are between 0.46–0.58 days, much longer than the 0.292 days we determined for V829 Aql. The F/1H frequency ratios for RRd variables are confined to a narrow range between 0.742 and 0.747, smaller than the value we derived for V829 Aql. Moreover, if we determine the location of the star in the $(P_1/P_0 - P_2/P_0)$ vs. P_0 diagram of Kovács & Buchler (1994, hereafter KB94), we see that it cannot be represented with any of their RR Lyrae star models. All this, together with the low galactic latitude ($b = -10\overset{\mathrm{d}}{.}7$) of the star, strongly suggests that V829 Aql is not an unusual RRd variable, but rather an evolved δ Scuti star.

To verify this suspicion, we computed a number of post-main-sequence δ Scuti star model sequences with the Warsaw-New Jersey stellar evolution and pulsation code (see Pamyatnykh et al. 1998 for more details). Since we do not have any information on the

metallicity of the star, we assumed solar abundances.

We followed the work by KB94 and evaluated the behaviour of their parameter Δ, the "period ratio distance", which is a measure of the deviation of the theoretical 1H/F and 2H/F period ratios from the corresponding observed period ratios. The "best" models are then characterized by a minimum of Δ at the radial fundamental mode period. This was done along several evolutionary tracks for different masses, and the results of this investigation are displayed in Figure 2.

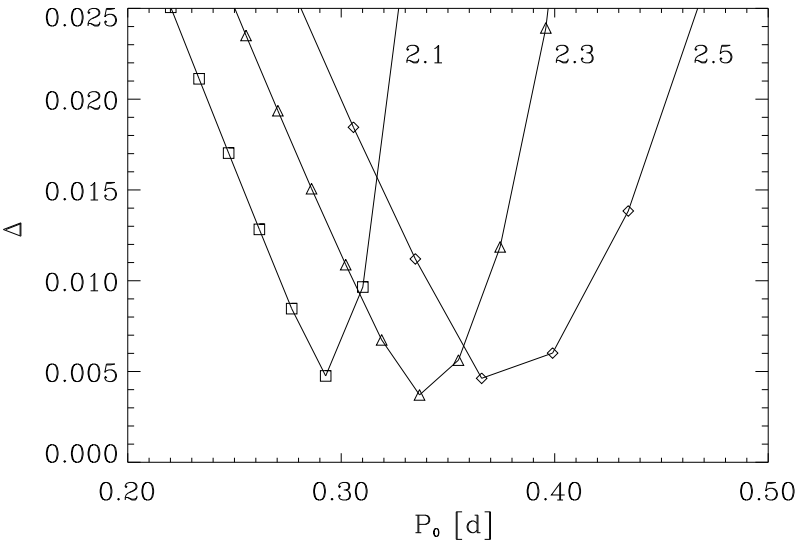

Figure 2. The period ratio distance Δ vs. the radial fundamental mode period along post main sequence evolutionary tracks of 2.1 $M_\odot$ (squares), 2.3 $M_\odot$ (triangles) and 2.5 $M_\odot$ (diamonds). The 2.1 $M_\odot$ model resembles the observed quantities for V829 Aql very well

As one can see, the 2.1 $M_\odot$ model is an excellent match to the observed quantities. Intriguingly, this model has the radial fundamental mode at a frequency of 3.4162 cycles/day, while this mode has a frequency of 3.4196 cycles/day in the real star. However, we are unable to reach $\Delta = 0$, and this best model is slightly outside the red edge of the instability strip. Both problems may be resolved by varying the metallicity of the models. From the work of KB94 and from this example it is clear that stars like V829 Aql can considerably contribute to the evaluation of the reliability of pulsational model calculations: if a sufficient amount of information on these stars is available to constrain their position in the HR diagram (i.e. $T_{\rm eff}$, $\log g$, $[M/H]$), the models must be able to reproduce their pulsational behaviour. This will also have impact on the model calculations presently used for asteroseismology of multimode nonradial δ Scuti pulsators.

At this date, only two (or three) δ Scuti stars simultaneously pulsating in the radial fundamental as well as the first and second radial overtone modes are known besides V829 Aql. These are AC And (Fitch & Szeidl 1976, KB94), GSC 4018.1807 (Antipin 1997) and perhaps HR 6434 (Scheck 1990 and references therein).

Regrettably, at best only low-resolution spectroscopy is available for AC And, GSC 4018.1807 and V829 Aql and only single-color broad-band photometric observations have been analysed in the literature. While the faintness of the three stars ($V > 10$ mag) requires a fairly large telescope to obtain high-resolution spectra, multicolor narrow and/or

broad-band photometry can be obtained by photometrists with a large amount of available telescope time, an APT or well-equipped amateur astronomers.

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