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γ Dor CANDIDATES IN THE OPEN CLUSTER M34

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The γ Dor stars are early F-type stars located on or near the main sequence in the HR diagram, either at or just redward of the cool (red) edge of the δ Scuti instability strip. γ Dor variables, as a class, are non-radial, gravity-mode pulsators (Krisciunas 1998). In 1997, Krisciunas & Crowe suggested that six early F-type stars in the open cluster M34 (NGC 1039) showed evidence for photometric variability over the course of a given night or from night to night. From 27 September to 5 October 1997 (UT) we obtained CCD time-series photometry for four of these six stars in two overlapping 11.5×11.5 arcmin fields (which we call A and B) in the central region of M34. The data were taken with the USNO 1-m reflector, located near Flagstaff, Arizona, using a 1024×1024 CCD and broad-band filters with effective wavelengths of 4825 Å and 6161 Å. These filters, designated g' and r', are identical to those being used for the Sloan Digital Sky Survey (Fukugita et al. 1996). In this paper, we shall refer to the M34 stars by their "UVa" numbers (Ianna & Schlemmer 1993).

The primary goal of our time-series survey was to characterize the relative levels of variability amongst M34 member stars, not to measure absolute photometry. To that end, we elected to use an ensemble averaging technique where the mean magnitude of a set of demonstrably constant stars at each of the sky positions was used as the reference magnitude for differential photometry. In order to select a set of constant stars for each position, we used an iterative approach where we started by using all of our program stars in each position for the ensemble average (39 stars in position A and and 65 stars in position B) and then rejecting those stars with the largest variations with respect to the reference magnitude. In the end we selected 9 stars in position A and 12 stars in position B for the ensemble average determinations. These stars show variations of ± 5.5 mmag with respect to the ensemble average in their positions and thus set the limit for the amplitude of variations we are able to detect in the remaining program stars.

We note that two previously suspected variable stars, UVa 161 and UVa 162 (Krisciunas & Crowe 1997), are now believed to be constant. In fact, both of these stars are used as a part of the reference ensemble for position A in M34. Welch & Stetson (1993) have devised a simple index for determining whether a star is variable. If the variability is due to a temperature effect (e.g., pulsations or rotational modulation due to star spots), the variations observed in one broad-band filter should be correlated with the variations in another filter. For noiseless photometry of an ideal temperature-variable star using two wavelength-adjacent filters (such as g' and r'), the Welch-Stetson variability index would be +1.00. If two-filter photometry gives a Welch-Stetson index of 0.00 for a given star, then it is not temperature-variable. For our two ensemble average stars and former suspected variables, UVa 161 and 162, we derive Welch-Stetson variability indices of +0.11 and +0.20. This result, when combined with a visual inspection of the light curves and a lack of any strong peaks in their Fourier power spectra show that these stars are demonstrably constant.

Our time-series campaign revealed a number of new variable stars. The γ Dor candidates are discussed here while the cooler variables (likely spotted stars) will be the subject of a separate paper (Patten & Krisciunas 1999). The two γ Dor candidates are UVa 144 (located in position A of the survey) and UVa 224 (located in position B of the survey).

UVa 144 has a Welch-Stetson variability index of +0.69 and shows evidence for two periods, $P_1 = 0.6587$ and $P_2 = 0.7812$ days, with false alarm probabilities of 0.0012 and 0.060, respectively. The 1997 g' data are characterized by sinusoids with amplitudes (i.e. half of peak-to-peak) of 12.3 $\pm$ 1.5 and 6.7 $\pm$ 1.4 mmag, respectively. We have combined the V-band data of 1996 with the g' data of 1997, normalizing each to the mean values of the two observing runs. In Figure 1 we show the combined data for the two observing seasons, folded by P_1, but *without* pre-whitening by P_2. For those γ Dor stars which have been well-characterized, it has been found that while the photometric *amplitudes* of individual stars may be variable, the periods are often quite stable. Figure 1 shows that this holds true for UVa 144. That the combined photometry folds well strongly suggests that we have measured the true principal period and not settled on an alias of this period.

UVa 224 was our best γ Dor candidate in M34 from scanty observations made in September 1996. The two-filter photometry of 1997 yields a Welch-Stetson variability index of +0.45, not a particularly large value. However, we believe part of the explanation for this value lies in the low amplitude of variability of this star in 1997, as compared to the 1996 light curve. The photometric amplitude from the 1997 g' data is 6.5 $\pm$ 1.2 mmag. The 1996 data indicate a V-band amplitude of 25 $\pm$ 6 mmag. Since the photometric amplitude of γ Dor stars diminishes from 4400Å to 5500Å, and presumably continues to diminish at even longer wavelengths, the combination of photometric noise with low amplitudes might reasonably give a smaller Welch-Stetson index. The biggest peak in the power spectrum of UVa 224 yields a period of 0.9295 days, with a false-alarm probability of 0.0076. If we assume the period determined from the 1997 data is close to the true period and we also assume that period is stable, we find that the 1996 data also fold reasonably well to the 1997 period.

It is possible that the true second period of UVa 144 is the one day alias of the value given above, or $(1 + 1/P_2)^{-1} \approx 0.439$ d. Similarly, for UVa 224 the one day alias of the period given above ($\approx$ 0.482 d) might be its true principal period. These values are not unheard of for γ Dor stars (e.g. BS 8799; Zerbi et al. 1999). Only a multi-longitude photometric campaign or extensive single-site photometry over the course of a full season could decide the matter.

We feel confident that we have identified two γ Dor candidates in M34. We call these stars *candidates*, not *bona fide* γ Dor stars, because we have no spectroscopic evidence (i.e. radial velocity and/or line profile variations) to prove conclusively that these two stars are non-radial pulsators. The evidence to date suggests that the γ Dor phenomenon occurs in young stars (Krisciunas et al. 1995 and references therein). While no γ Dor variables have been found in the Hyades (age about 625 Myr; Perryman et al. 1998), the much younger (100 Myr) open cluster NGC 2516 has several γ Dor candidates (Zerbi et al. 1998). M34 has an age of about 250 Myr (Ianna & Schlemmer 1993). Under the assumption that

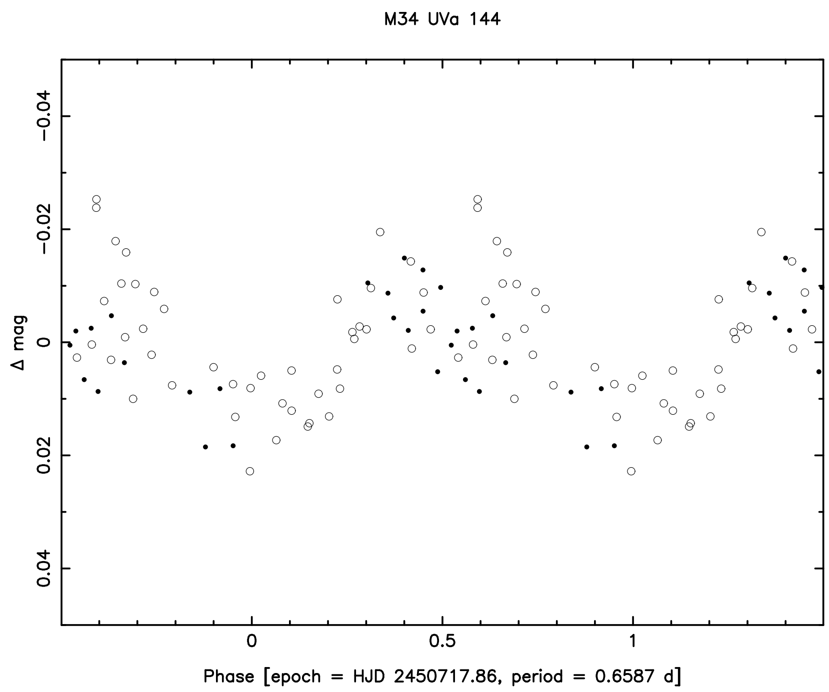

Figure 1. Folded light curve of the M34 star UVa 144. The V-band data of 1996 (dots) and the g'-band data of 1997 (open circles) have been folded with a period of $P_1 = 0.6587$ days. The data have *not* been pre-whitened by the sinusoid with $P_2 = 0.7812$ days.

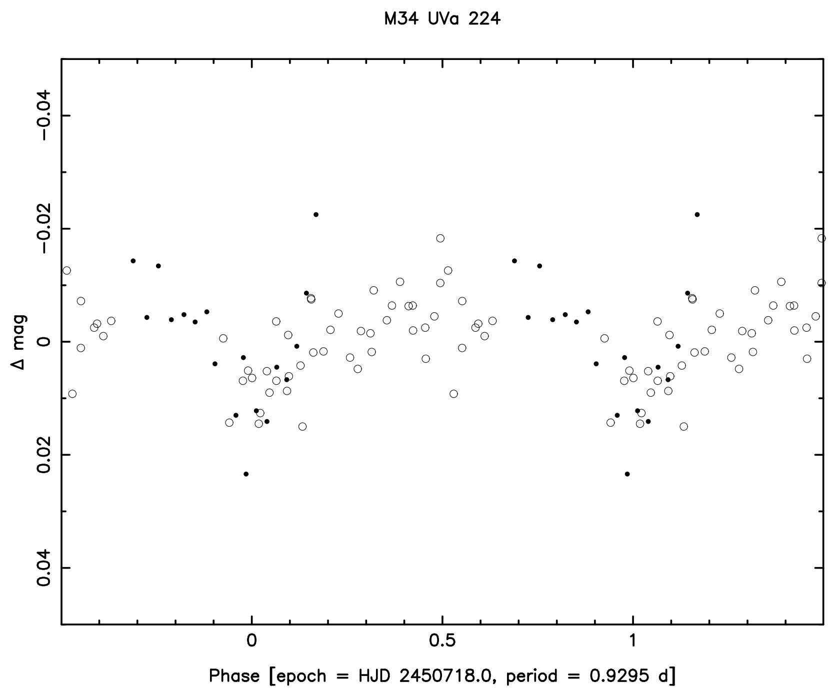

Figure 2. Folded light curve of the M34 star UVa 224. The V-band data of 1996 (dots) and the g'-band data of 1997 (open circles) have been folded with a period of 0.9295 days.

γ Dor-type variability is just a phase in the life of an early F-type star which ends when its thin convection zone develops, we have shown that the γ Dor phenomenon can persist at least until such a star is 250 Myr old.

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