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Photometric data by the Delta Scuti Network II. EE Cam, FG Vir, 44 Tau

M. Breger[1] and P. Lenz[2]

[1] Department of Astronomy, University of Texas, Austin, TX 78712, USA
[2] Ronin Institute, Montclair, NJ 07043, USA

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Abstract

The three δ Scuti pulsators EE Cam, FG Vir and 44 Tau are of special interest because their pulsation properties are different from those expected from the low rotational velocities indicated by spectroscopic measurements. This paper presents the previously unpublished high-precision photometric data obtained by the Delta Scuti Network during 780 nights.

Keywords: technique: photometric – stars: individual: EE Cam, FG Vir, 44 Tau – variable stars: δ Scuti stars

1 Introduction

From 1983 to 2012, the Delta Scuti Network (DSN) at the University of Vienna organized observing campaigns of short-period variable stars using telescopes on different continents. This minimized the effects of frequency aliasing caused by regular day-light observing gaps. Usually, two or more comparison stars were used, leading to a precision of 2 to 3 millimag per single observation every five minutes. These campaigns with observing sequences of one variable and two comparison stars are called three-star DSN campaigns.

The present series of papers presents the photometric data obtained by the network. Additional information about the observational details and astrophysical results can be found in the previous publications discussing the individual pulsators studied during the DSN campaigns. The first paper of the data series covered the δ Scuti star 4 CVn, for which about 1000 nights of photometric data were presented (Breger & Lenz , 2018).

The δ Scuti stars are short-period pulsators of spectral type A and F with most stars situated on or slightly above the main sequence. They can generally be divided into two subgroups: high-amplitude δ Scuti stars (HADS) with peak-to-peak amplitudes ≥ 0.3 mag in the photometric V passband, and the very common low-amplitude pulsators. The HADS stars generally have dominant radial pulsation, while the low-amplitude variables show dominant nonradial pulsation. Furthermore, the HADS stars show rather slow rotation in comparison with the average value of the projected rotational velocity ($v \sin i$ = 96 km s^{-1}) of the low-amplitude δ Scuti stars (Solano & Fernley , 1997).

However, not all δ Scuti stars can be clearly assigned to one of these two subgroups. A number of stars show low values of *projected* rotational velocities as well as low amplitudes. These stars, therefore, show some behavior typical of both groups. Three of these stars were selected for detailed study by the Delta Scuti Network: EE Cam, FG Vir and 44 Tau. The results of these studies can be found in the references presented below. This paper presents the photometry for these stars.

2 The star EE Cam

The δ Scuti pulsator EE Cam (HD 37857, spectral type F0) is a slightly evolved main-sequence star. Koen (2001) analyzed the Hipparcos data for this star and detected two pulsation frequencies of 4.93 and 5.21 cd^{-1}. This star is of special astrophysical interest because of its rotational velocity. The measured values of $v \sin i = 40 \pm 3$ km s^{-1} (Breger *et al.* , 2007) and 51 $\pm$ 8 km s^{-1} (Bush & Hintz , 2008) place the star between the high-amplitude pulsating stars (HADS) with generally dominant radial pulsation and the low-amplitude nonradial pulsators on the main sequence. This assumes that the low $v \sin i$ value is not caused by the inclination. More extensive photometric data became available when the star was observed with the Vienna Automatic Photoelectric Telescope in Arizona (Breger & Hiesberger , 1999) from 2006 to 2010 for 300+ nights. The two comparison stars used were HD 35606 (F8) and HD 37420 (F5). 275 nights were found to contain high-quality data, as judged by the scatter of the two comparison stars. 40 frequencies of pulsation were detected, of which 37 were independent (Breger et al. 2015). We also note a more recent paper on asteroseismic modeling of EE Cam by Chen & Li (2017).

Table 1: Three-star DSN campaigns of EE Cam

Observing season	Nights used	Data discussion
2005/2006	9	Breger *et al.* (2015)
2006/2007	81	Breger *et al.* (2015)
2007/2008	43	Breger *et al.* (2015)
2008/2009	66	Breger *et al.* (2015)
2009/2010	76	Breger *et al.* (2015)

Here we present the high-quality data obtained during the 2005–2010 campaigns (see Table 1). The zero-points of the data in magnitudes presented here were calculated relative to the comparison stars and adjusted to zero for each observing season. Additional nightly adjustments to provide the best fit to the 40-frequency solution were not applied.

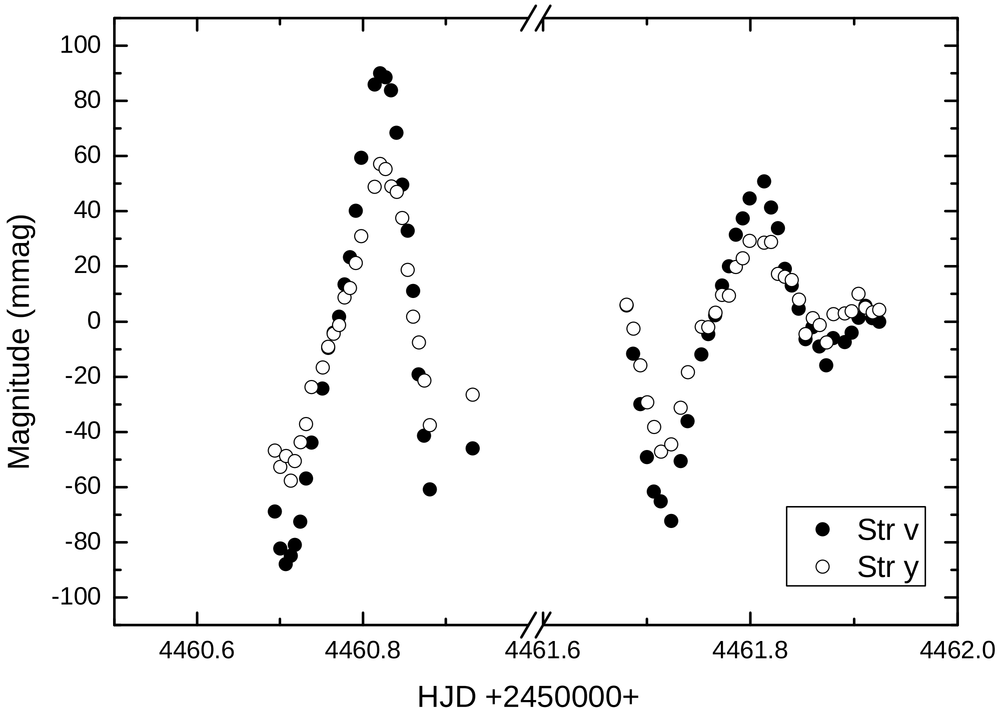

Figure 1: Brightness change of EE Cam in the Strömgren *y* and *v* passbands during two nights in December, 2007.

An example of Strömgren *y* and *v* measurements covering two nights in December, 2007 is shown in Fig. 1.

Online Table **jad25_1_1.dat** presents the brightness variations in the Johnson *V* or Strömgren *y* passbands, while online Table **jad25_1_2.dat** presents the measurements in the Strömgren *v* passband.

3 The star FG Vir

The multiperiodic δ Scuti variable FG Vir (HD 106384, spectral type A8V) is at the end of its main-sequence evolution. Despite its small projected rotational velocity of $v \sin i$ = 21.3 $\pm$ 1.0 km s^{-1} (Mittermayer & Weiss , 2003), the dominant frequency is a nonradial ℓ = 1 mode with a peak-to-peak amplitude of $\sim$ 0.04 mag in the *V* passband. Mantegazza & Poretti (2010) present arguments that the actual rotational velocity (corrected for the projection factor) is $\sim$ 80 km s^{-1}. This would put FG Vir outside the HADS domain and be consistent with a dominant nonradial ℓ = 1 mode.

In this paper we are listing the photometric data from the DSN campaigns carried out in 1995 as well as from 2002 to 2004 (Table 2). The comparison stars used were HD 106952 and HD 105912. We note that within a specific 24-hour time period, there may be data

Table 2: Three-star DSN campaigns of FG Vir

Observing season	Nights used	Data discussion
1995	54	Breger *et al.* (1998)
2002	91	Breger *et al.* (2004)
2003	123	Breger *et al.* (2005)
2004	95	Breger *et al.* (2005)

sets from, say, two observatories situated on two continents: they would be counted as two separate nights in the table. During these campaigns the narrowband Strömgren y and v filters were used. These measurement are presented in Online Tables **`jad25_1_3.dat`** and **`jad25_1_4.dat`**.

A discussion of the data and the summary of astrophysical results can be found in Breger *et al.* (2005), which also lists references to additional measurements of FG Vir obtained with different passbands as well as those obtained with different observational techniques.

4 44 Tau

44 Tau (HD 26322, spectral type F2 IV) exhibits characteristics of both groups: radial as well as nonradial modes are excited to observable amplitudes and its projected rotational velocity is very small ($v \sin i = 2 \pm 1$ km s^{-1}). As discussed by Antoci *et al.* (2007), this indicates either a pole-on view and/or intrinsic slow rotation. Zima *et al.* (2007) confirmed that 44 Tau is an intrinsic slow rotator. This makes 44 Tau particulary interesting for asteroseismology.

On the basis of additional data from 2002 to 2006, Breger & Lenz (2008) determined that the dominant mode at 6.90 cd^{-1} is a radial mode. This is typical for such a slow rotator, but the amplitude is considerably smaller than the typical amplitude of a HADS. The next dominant modes of 44 Tau are $\ell = 1$ modes, which are typical of fast rotating δ Scuti stars. In 44 Tau, the nonradial modes show modulated amplitudes. We refer to Breger & Lenz (2008) for more detailed discussions.

44 Tau is also interesting because the detected frequencies are arranged in specific frequency patterns separated by approximately one radial order. This effect is demonstrated in Fig. 2. This frequency distribution together with previous mode identifications allowed for deriving a precise asteroseismic model that showed that 44 Tau is in the contraction phase after its main sequence evolution (Lenz *et al.* , 2010).

The available two-color DSN photometry of 44 Tau is summarized in Table 3 and presented in Online Tables **`jad25_1_5.dat`** and **`jad25_1_6.dat`**. The comparison stars used were HD 25867 and 25768 for the 2000–2003 measurements and HD 23626 and HD 24301 for the 2004–2006 data.

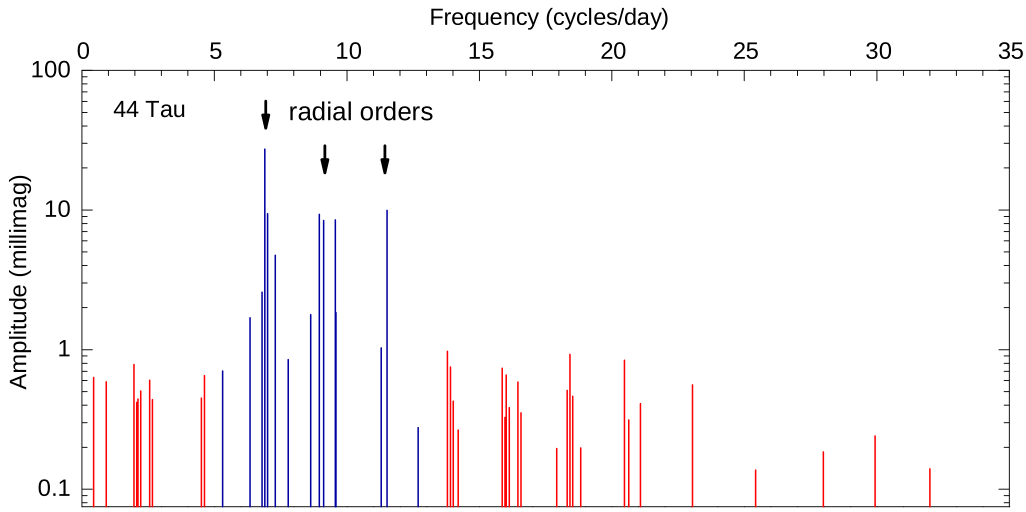

Figure 2: Frequency distribution of the detected modes of 44 Tau. The figure shows that the detected frequencies form patterns separated by approximately one radial order. This holds for the detected radial modes, nonradial modes as well as their combination modes ($f_i \pm f_j$) outside the main pulsation region (5–13 cd^{-1}, frequencies marked in blue). The observed pattern can be explained by the detected nonradial modes being trapped modes.

Table 3: Three-star DSN campaigns of 44 Tau

Observing season	Nights used	Data discussion
2000/2001	42	Antoci *et al.* (2007)
2001/2002	31	Antoci *et al.* (2007)
2002/2003	17	Antoci *et al.* (2007)
2004/2005	26	Breger & Lenz (2008)
2005/2006	26	Breger & Lenz (2008)

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