# Chapter 9. Surface magnetic fields of the Sun and stars

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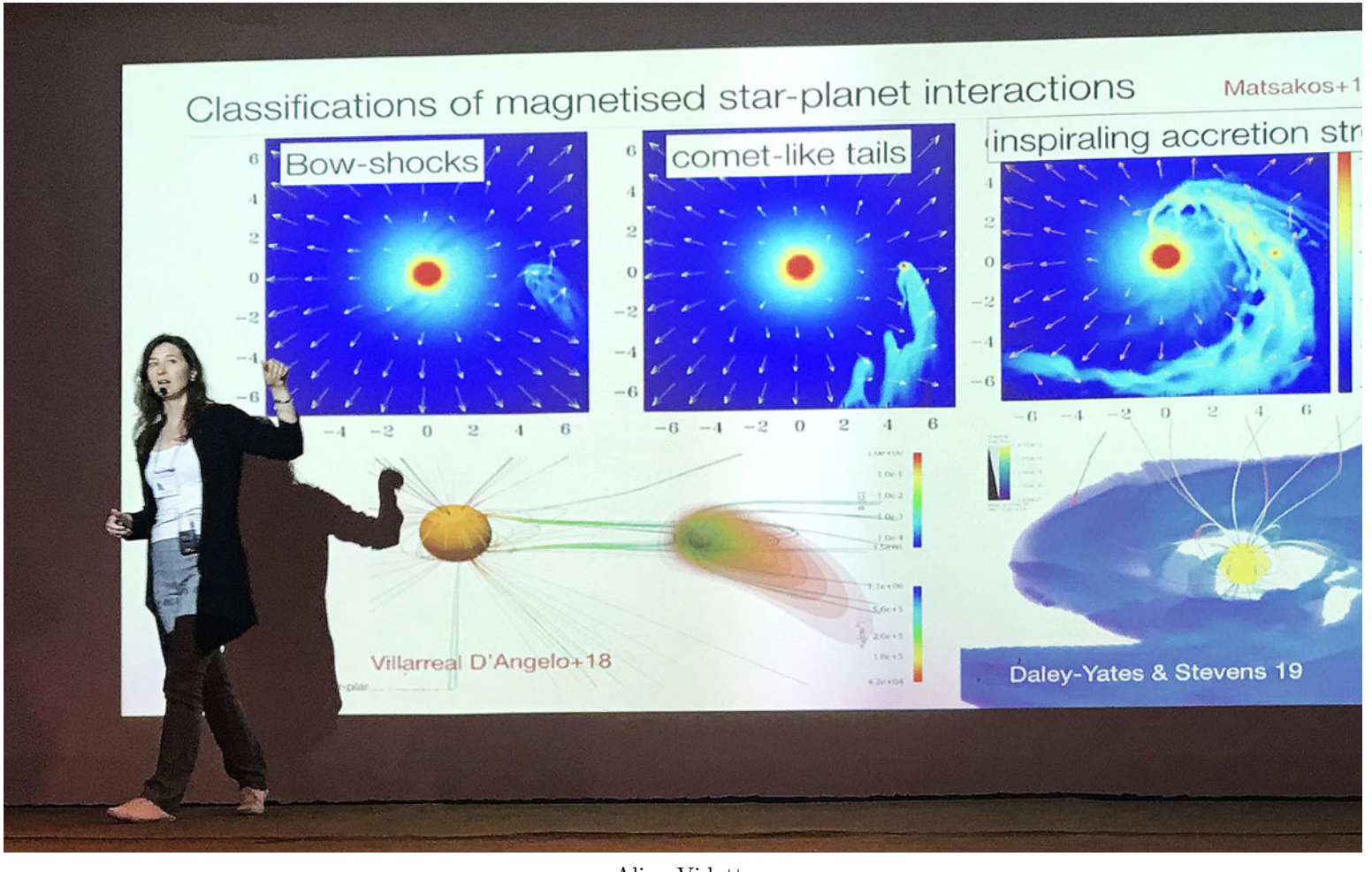


Aline Vidotto

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# On the properties of the magnetic Chemically Peculiar B, A, and F-type stars

**Kutluay Yüce[1], Saul J. Adelman[2], Diane M. Pyper[3] and Robert J. Dukes[4]**

[1]Dept. of Astronomy and Space Sciences, Faculty of Science, University of Ankara, TR-06100 Tandoğan, Ankara, Turkey
email: Kutluay.Yuce@ankara.edu.tr

[2]Dept. of Physics, The Citadel, 171 Moultrie Street, Charleston, U.S.A.

[3]Dept. of Physics/Astronomy, University of Nevada, Las Vegas, U.S.A.

[4]Dept. of Physics and Astronomy, The College of Charleston, Charleston, U.S.A.

**Abstract.** We present a preliminary analysis of the Strömgren *uvby* photometry of the magnetic CP stars obtained using the Four College Automated Photometric Telescope for its 21.5 years of operation ending in Fall 2012. We summarize the photometry for all the FCAPT mCP stars that have been published to date. We do not find any significant correlation between the amplitudes of variation in the *uvby* filters and the periods. A small number of stars show anomalous behaviour of the *v* filter which will be discussed in a future study.

**Keywords.** stars: magnetic chemically peculiar, photometry

## 1. Introduction

If magnetic fields cause elemental abundances to change in the stellar photosphere, then all magnetic Chemically Peculiar (mCP) stars should exhibit signatures of this effect in both their spectra and flux distributions. Given that all stars rotate, these stars should be magnetic, spectrum, and photometric variables, albeit sometimes of low amplitude. The generally accepted explanation for the light variations of magnetic stars is inhomogenous brightness distribution on the surface of the rotating star. This explanation was given earlier by the discoveries of this effect (Guthnik & Prager 1918). The magnetic fields and light curves vary periodically with a range from about one-half day to decades (e.g., Preston 1971, Adelman & Woodrow 2007, Mathys 2017). Adelman (2002) found some evidence for the expectation that as mCP stars move away from the ZAMS their rotational velocities decrease. He noticed that many, but not all, of the most rapidly rotating mCP stars are close to the ZAMS and some of the least rapidly rotatings are the furthest from the ZAMS. Recently, Hümmerich *et al.* (2018) detect observed periods ranging from 0.84 d to 9.6 d, and effective amplitudes ranging from 0.6 mmag to 90.5 mmag based on Kepler data.

The differential Strömgren *uvby* photometric studies from the Four College Automated Photometric Telescope (FCAPT, Fairborn Observatory in Southern Arizona) for the magnetic CP stars have both improved periods and better defined the shapes of their light curves (e.g. Pyper & Adelman 2017, Dukes & Adelman 2018). In the literature a series of papers entitled "The FCAPT *uvby* Photometry of the mCP Stars" by Adelman & others (e.g. see Dukes & Adelman 2018) discuss mCP stars that have spectral types between B2 and A2 on or near the Main Sequence of the HR diagram. The long-term FCAPT observation program was completed in 2012, after 21.5 years of operation. In

**Table 1.** Descriptive statistics in Periods and in *uvby* of FCAPT magnetic CP stars.

| | **0.5<P<7850 d** | **0.5<P<18 d** | ***u*** | ***v*** | ***b*** | ***y*** |
|---|---|---|---|---|---|---|
| Mean | 166.339 | 5.140 | 0.050 | 0.037 | 0.033 | 0.029 |
| Stand.dev. | 931.487 | 5.071 | 0.035 | 0.033 | 0.024 | 0.026 |
| Median | 3.873 | 3.093 | 0.045 | 0.030 | 0.028 | 0.024 |
| Sample Variance | 867668.651 | 25.719 | 0.00124 | 0.00106 | 0.00057 | 0.00070 |
| Range | 7849.481 | 17.969 | 0.180 | 0.155 | 0.120 | 0.140 |
| Min. | 0.519 | 0.519 | 0.000 | 0.000 | 0.000 | 0.000 |
| Max. | 7850 | 18.488 | 0.180 | 0.155 | 0.120 | 0.140 |
| Count | 76 | 63 (83 %) | 81 | 81 | 81 | 81 |

this work we present a preliminary study of the photometric properties of 81 FCAPT mCP stars, that have been published so far, focusing on their amplitudes of variation as a function of period for each of the *uvby* filters.

## 2. Findings

Observationally, the shortest known period for our mCP stars was found to be about 1/2 day for CU Vir (Adelman *et al.* 1999, Pyper *et al.* 2013) while HD 15980 (Ap Si) appears to be minimally variable, with a period of at least 5 yr (Adelman & Woodrow 2007) and HD 9996 (B9pCrEu) has a period of 21.5 yr (Pyper & Adelman 2017) in the FCAPT program. Since the majority of these stars of Pyper & Adelman (2017) have unusual light curves that cannot be easily explained by the oblique rotator theory, they will be discussed in more detail in a future study.

Most of the stars (83 %) have periods between 0.51899 and 18.4877 days. Because of that the distribution of 76 mCP stars as a function of period were investigated for two different groups: $0.51899 < P < 18.4877$ d and $0.51899 < P < 7850$ d. Descriptive statistics are given in Table 1. The mean and median values are measures of central tendency. The median is a robust to outstanding observations and it indicates that the period is about 3.873 days.

We did not observe a significant relationship between photometric periods and amplitudes for our mCP stars. Correlation coefficients between period and *u*,*v*, *b*, *y* bandpasses of 75 stars are -0.118, 0.395, 0.161, and 0.461, respectively.

For the *uvby* bands of mCP stars the descriptive statistics are as in Table 1. The mean and median for each band are nearly equal. The amplitudes from the highest to lowest value of our data are from the *u* to the *y* band. The means of these distribution are 0.050 $\pm$ 0.035 mag for *u*, 0.037 $\pm$ 0.033 mag for *v*, 0.033 $\pm$ 0.024 mag for *b*, and 0.029 $\pm$ 0.026 mag for the *y* band.

The mean amplitudes and their standard deviations decreases with increasing wavelength. These values are nearly equal for *v* and *b*. They are slightly smaller than those of Adelman & Woodrow (2007).

Figure 1 shows the dependence of the light amplitudes on the wavelength. The observed amplitudes of our mCP stars in the four bandpasses tend to change the same manner. However, the structure of the amplitude-wavelength relation for the various stars is not simple. For example, we note for a few stars (the SrCrEu stars HD 86592, HR 7575, HD 81009), larger amplitudes have been observed in the *v* band compared to the other bands. HD 32966 has the largest amplitudes in each band in the group of 81 magnetic CP stars.

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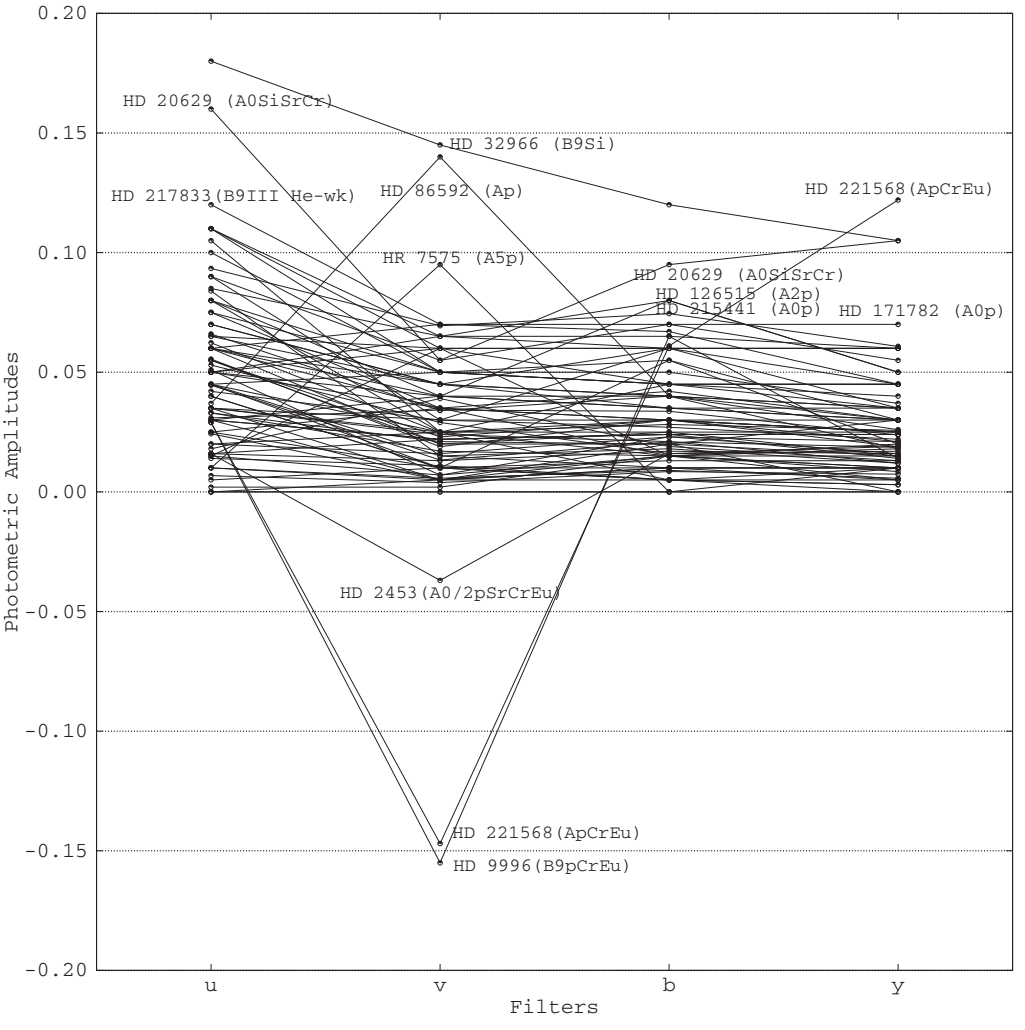


**Figure 1.** Amplitudes of light variations in stellar magnitudes vs. wavelength relation.

## 3. Conclusion

We investigated the distribution of periods and amplitudes of magnetic chemically peculiar stars in *uvby*. We did not observe a significant relationship between photometric periods and amplitudes for these stars. The amplitudes have a Gaussian distribution, but each band has a slight skewness to large amplitudes.

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