Chemically peculiar stars identified in large photometric surveys

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Abstract. The chemically peculiar (CP) stars of the upper main sequence are mainly characterized by strong overabundances of heavy elements. Two subgroups (CP2 and CP4) have strong local magnetic fields which make them interesting targets for astrophysical studies. This star group, in general, is often used for the analysis of stellar formation and evolution in the context of diffusion as well as meridional circulation. The overabundant elements in CP2/4 star atmospheres are concentrated into large spot regions that persist for decades to centuries. Periodic variations of the brightness, spectrum, and magnetic field are observed. The stars are slow rotators and it is believed that the slow rotation is owed to the strong magnetic field. Recent and future surveys that aim to obtain photometric time series are ideally suited to provide a detailed view of the stars' rotational behaviour. We present our efforts to analyze the rotational periods of CP stars and to identify new candidates in the Kepler, SuperWASP, and ASAS-3 surveys, but also in the photometric data that were extracted as valuable by-product of the STEREO satellite mission.

Key words: Binaries: eclipsing – stars: chemically peculiar – variables: general – techniques: photometric

Introduction

Chemically peculiar (CP) stars are upper main sequence objects (spectral types early B to early F) whose spectra are characterized by abnormally strong (or weak) absorption lines that indicate peculiar surface elemental abundances. The observed chemical peculiarities are thought to arise from the diffusion of chemical elements due to the competition between radiative pressure and gravitational settling. CP stars constitute about 10% of upper main sequence stars and are commonly subdivided into four classes (Preston, 1974): metallic line (or Am) stars (CP1), magnetic Ap stars (CP2), HgMn stars (CP3), and He-weak stars (CP4). The CP2 and the CP4 objects are notorious for exhibiting strong, globally organized magnetic fields of up to several tens of kiloGauss. Their atmospheres are enriched in elements such as Si, Cr, Sr, or Eu and usually present surface abundance patches or spots, leading to photometric variability, which is considered to be caused by rotational modulation and explained in terms of the oblique rotator model (Stibbs, 1950). As a result, the observed photometric period is the rotational period of the star. CP stars that exhibit this phenomenon are normally classified as α^2 Canum Venaticorum (ACV) variables. It is important to increase the sample of known rotational periods among CP stars by discovering new ACV variables. An increased sample size will contribute to the understanding of the CP stars' evolution in time.

We present our efforts towards a better understanding of the CP star phenomenon. We made use of several data sources to derive the rotational periods of the stars. The next step will include a statistical analysis to provide constraints for the rotational evolution of CP stars.

CP stars with ASAS-3

The All Sky Automated Survey (ASAS) is a project that aims at continuous photometric monitoring of the whole sky, with the ultimate goal of detecting and investigating any kind of photometric variability. The typical exposure time for ASAS-3 V-filter observations was three minutes, which resulted in reasonable photometry for stars in the magnitude range $7 < V < 14$ mag (about 10^7 objects). The all-sky character of the survey necessitated sparse sampling. In general, a field was observed each one, two, or three days (Pigulski, 2014) resulting in strong daily aliases in the corresponding Fourier spectra. Bernhard et al. (2015a) presented a sample of 323 photometrically variable CP stars or CP star candidates, 246 of which were described as variable stars for the first time. An example is given in Fig. 1. A part of the sample (31 stars) is made up of late B to early A-type variables lacking confirmation of their chemical peculiarity. They were included as ACV candidates because of their typical photometric variability but need spectroscopic confirmation.

CP stars with STEREO data

The Solar TErrestrial RElations Observatory (STEREO) is a satellite mission that consists of two spacecrafts and aims to study the solar corona in three dimensions and image coronal mass ejections along the Sun-Earth line (Kaiser et al., 2008). However, the images cover also numerous stars along the orbit and the data were already used for some variability studies. The data have a cadence of about 40 min and cover in total four and half years, where each data block from each spacecraft covers about 20 d with gaps of about 1 yr. Wraight et al. (2012) analysed the light curves of 337 CP stars that are covered by the STEREO spacecraft. Using a matched filter algorithm, they produced the light curve, phase folded on the best-fitting period, for each star and extracted from the whole sample the objects which appeared clearly constant, or are too badly affected by systematic effects to allow any reliable analysis. They detected relevant photometric variability and measured its period for 82 CP stars. For 48 of them, the first measurement of their rotation period was presented.

CP stars in the SuperWASP archive

The SuperWASP survey started in 2004 and offers long-term photometric time series. It covers both hemispheres and provides photometry in a broadband filter (400-700 nm) with an accuracy better than 1% for objects in the magnitude range $8 < V < 11.5$ mag (Pollacco et al., 2006). Observations consist in general of two consecutive 30s integrations followed by a 10 minute gap. The main aim of this survey is the detection of exoplanet transits, but the dataset covers numerous CP stars as well. Bernhard et al. (2015b) analysed 3 850 000 individual photometric WASP measurements of 579 CP stars and candidates selected from the Catalogue of Ap, HgMn, and Am stars (Renson & Manfroid, 2009). In total, they found 80 variables, from which 74 were reported for the first time (see Fig. 1 for an exemplary light curve). The data also allowed to establish variability for 23 stars which had been reported as probably constant in the literature before. In addition, light curve parameters were obtained for all stars by a least-squares fit with the fundamental sine wave and its first harmonic.

CP stars with the Kepler satellite mission

The Kepler mission is designed to detect Earth-like planets around solar-type stars by the transit method (Koch et al., 2010). Kepler continuously monitored the brightness of about 150 000 stars for 4.5 yr in a 105 square degree fixed field of view. In the course of the mission, extremely accurate photometry was obtained. The mean top-of-the-noise level in the periodogram for a star of 10th magnitude is about 3 ppm for an observing run of 30 d, dropping to about 1 ppm after one year. For a star of 12-th magnitude, the corresponding noise level is about 6 ppm for one month and 3 ppm after one year (Murphy, 2015). These values apply to a frequency range 0-20 c/d, the noise level dropping slowly towards higher frequencies. This unprecedented level of precision allows to discover several new CP stars and to study their behaviour in detail (cf. Fig. 1). We have just started to investigate the huge amount of publicly available data and found about 50 new ACV variables, so far.

Conclusion

The (magnetic) chemically peculiar stars of the upper main sequence are well-suited laboratories for investigating the influence of magnetic fields on the stellar surface as they produce abundance inhomogeneities (spots), which results in photometric variability that is explained in terms of the oblique rotator model.

The group of CP stars is an excellent laboratory to test astrophysical mechanism like (microscopic and turbulent) diffusion, convection, meridional circulation, mass loss, and accretion in the absence/presence of an organized stellar magnetic field. For this, it is important to increase the sample of known rotational periods among known CP stars, but also to discover new ACV variables. An increased sample size will contribute to the understanding of the CP stars' evolution in time.

We presented our efforts in this respect using ground-based as well as spaced-based photometric data.

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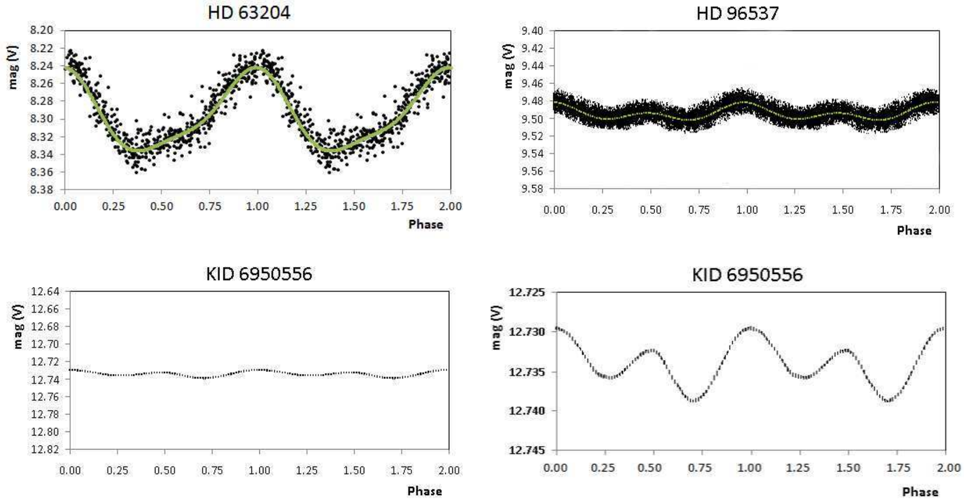

Fig. 1. Exemplary light curves of new ACV variables discovered in ASAS-3 (upper left panel), SuperWASP (upper right panel), and Kepler (lower left panel) data. In order to allow for comparison between the different surveys' data, the ordinate scale is identical for all plots. An enlarged version of the Kepler light curve is shown in the lower panel, right side.

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