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# CP Stars - probing stellar surface structure with BRITE Constellation

T. Lüftinger[1], W.W. Weiss[1]

[1] Institut für Astronomie, Türkenschanzstrasse 17, 1180 Vienna, Austria

## Abstract

More than 170 chemically peculiar (CP) stars will be observable by BRITE Constellation. These stars host a complex interplay of phenomena like strong magnetic fields, chemical diffusion, pulsation and rotation in the same object. Thus they serve as unique stellar laboratories where we can observe the correlation and interaction of these fundamental physical processes.

We present here a summary of the unique potentials BRITE Constellation offers to obtain new insights in the atmospheric structure formation and the complex interplay of abundance variations, pulsation and magnetic fields under conditions that could never be reproduced on Earth.

## Introduction

About $10-20\%$ of the stars found on or close to the mid-main sequence, covering effective temperatures $T_{\rm eff}$ of about 6500 K up to 30 000 K, reveal stunning anomalies in their spectra and light curves, which translate into remarkable differences in the stellar atmospheric composition from the sun's photosphere and from stars of similar spectral type and luminosity.

Modelling interior structures of these F-, A- and B-type stars was originally expected to be simple as they do not exhibit extensive surface convection zones, hydrogen is their primary source of opacity, and they do not reveal turbulent line broadening or irregular short-period variability. Luminosity and colour variations are sometimes seen to vary periodically at timescales of hours or days to decades, with the same period as their magnetic fields and the shapes and strengths of their spectral line profiles.

However, a wide variety of spectroscopic peculiarities has been observed and classified for these stars and they are generally referred to as chemically peculiar (*CP*) stars. Preston (1974) divided the CP stars into four main subclasses. We would like to focus on the CP2 (magnetic chemically peculiar, described in the following) and the CP3 stars, the mercury-manganese (HgMn) stars, in which

Hg and Mn are enhanced. Recent investigations by Kochukhov et al. (2007) revealed evidence for dynamical structure formation on their surface.

The CP2 stars, the *magnetic* chemically peculiar A and B (ApBp) stars, exhibit depleted abundances of light elements and normal to stongly enhanced iron-peak elements. The heavy elements and especially the rare earths (REEs) can be overabundant by orders of magnitudes over the solar composition.

A very important subgroup of the CP2 stars are the rapidly oscillating Ap (roAp) stars, which were discovered by Kurtz in 1982. Exhibiting effective temperatures between about 6400 K and 8100 K (Ryabchikova et al. 2004) they occur at the cool end of the ApBp range and show moderate to (sometimes) very strong magnetic fields and various outstanding abundance peculiarities. They pulsate with periods of about 6 to 21 min, consistent with nonradial acoustic (p-mode) pulsations of low degree and high radial order. As the observed pulsational amplitude of a roAp star is modulated with the magnetic (thus, rotation) period, such that the maximum coincides with the peak field strength, there is likely a close connection between the geometries of the magnetic field and the pulsation modes.

Thus Ap and Bp stars with their subgroup of roAp stars serve as unique stellar laboratories where we can observe the correlation and interaction of rotation, strong magnetic fields, chemical diffusion, and pulsation in the same object and explore the origins and the evolution of these fundamental physical processes with conditions that could never be reproduced on Earth.

## The oblique rotator model

The hitherto most successful model to explain the extreme abundance anomalies observed for Ap and Bp stars is the so-called oblique rotator concept, which was first proposed by Michaud in 1970. In a stellar atmosphere stabilised by a global magnetic field with only weak turbulent motion, convection or rotational mixing, a sensitive interplay between gravitational settling and radiatively driven diffusion is possible. Atoms and ions can be lifted higher into the atmosphere or sink, causing enhanced or depleted chemical abundances. As these processes are not homogeneous over the stellar surface (influenced by magnetic field geometries, winds, and other processes) the star can develop vertical and horizontal chemical inhomogeneities. The chemical diffusion concept is discussed in detail by Babel (1992) and Vauclair et al. (1991), also considering the possible influence of weak, magnetically confined winds.

The resulting inhomogeneous stellar surface structures lead to variable opacities, temperatures and fluxes, resulting in modulated light curves and spectral line signatures linked to the rotation of the star.

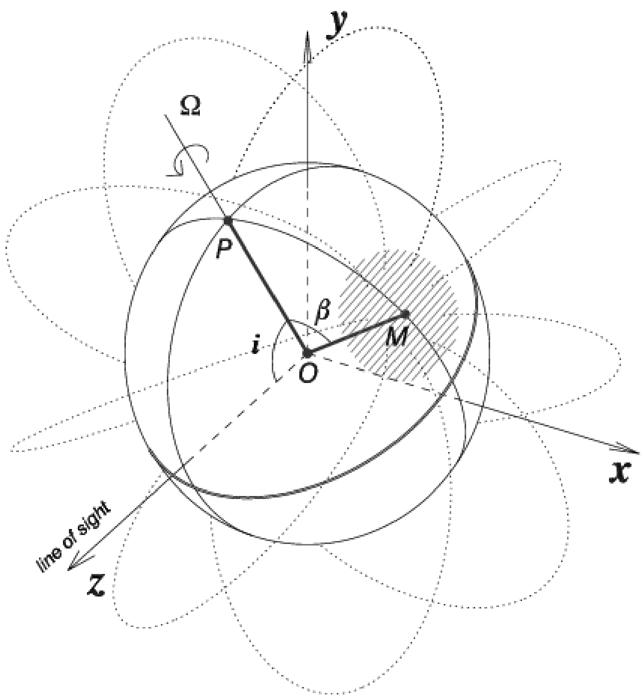


Figure 1: Geometry of an oblique rotator: the line of sight ($z$-axis) and the stellar rotational axis *OP* enclose the inclination angle $i$. *OM*, the axis of the dipolar magnetic field is inclined by an angle $\beta$ with respect to the stellar rotation axis *OP*. The rotational equator is presented by a thick line. In such a configuration, chemical elements may diffuse upwards through the stellar atmosphere and e.g. accumulate in the area around the magnetic pole M. Figure taken from Kochukhov (2003).

## Spot Modelling

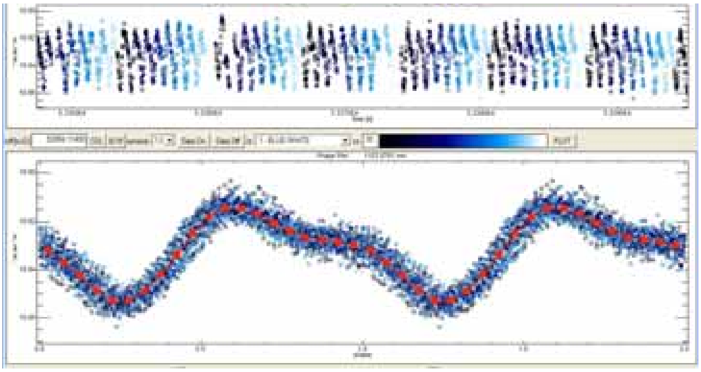

Figure 2: MOST light curve and phase diagram of an Ap star, showing rotational modulation with a period of 0.8 d.

A very successful tool for gaining information on inhomogeneities on the surface of a rotating star caused by changing temperature, abundance and/or magnetic field structure is the technique of Doppler imaging (DI), where time series of photometric, spectroscopic and/or spectropolarimetric observations of rotating stars based on complex mathematical procedures are inverted into temperature structures (cool, active stars) or elemental surface abundances (ApBp stars).

With the MOST space photometer (Walker, Matthews et al. 2003; Matthews et al. 2004) it was already possible to monitor the rotationally modulated light curves of a number of ApBp stars, as presented in Figure 2. For the cool active star $\kappa^1$ Ceti photometric observations from different observing seasons could even be used to trace the differential rotation of various spots (see Figure 3) on the surface of this star using StarSpotz (Croll 2006), a program developed specifically to analyse space photometry.

With BRITE Constellation we will be able to obtain space-quality *light* and *color curve variations* of more than 100 CP2 (and CP3 stars) and thus have the possibility to derive surface abundance inhomogeneities (in combination with ground-based spectroscopy) of numerous stars. This will considerably increase the sample of mapped ApBp and HgMn stars, which is indispensable when trying to explore and understand the physics and interaction of diffusion, magnetic fields and rotation.

According to recent investigations (Kaiser et al. 2007, this workshop), we will have access to more than 170 ApBp and HgMn stars spanning the whole

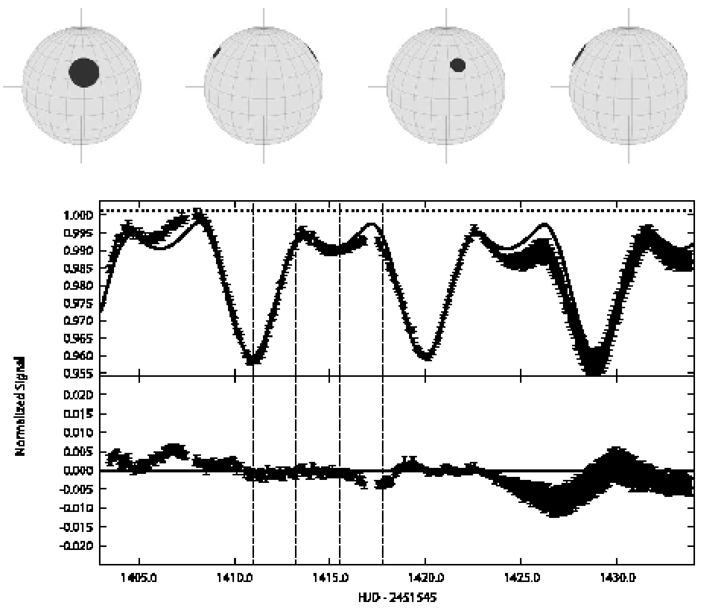


Figure 3: The best fitting two-spot solution for $\kappa^1$ Ceti in 2003, seen at phase 0.00, 0.25, 0.50, and 0.75, rotating counterclockwise from left (top panel). In the middle, the corresponding MOST light curve (with errors) is presented and below, the residuals from the model on the same scale are plotted. Figure taken from Walker et al. 2007;

temperature range from 6500 K (and below) up to 30 000 K. Apart from the possibility to cover this huge temperature domain, the region around 6500 K and cooler will be of special interest as exactly there the global magnetic fields of ApBp stars 'switch' into locally strong fields of cool, active stars, resulting in temperature (rather than abundance) inhomogeneities, as e.g. observed for the sun.

## Outstanding candidates

At this stage we would like to mention already a few by now outstandingly interesting candidates for our investigations:

### CU Virginis

CU Vir (HD 124224, HR 5313) is a bright (V=5.01 mag), very fast rotating B9pSi star ($\mathrm{v_e} \sin i$=160km s$^{-1}$) exhibiting photometric, spectrum and magnetic variations. CU Vir shows also one of the shortest known rotational periods for Ap stars and Pyper et al. (1998) found evidence for an abrupt period decrease from 0.5206778 d to 0.5207031 d, most likely due to a breaking mechanism associated with the star's magnetic field ('magnetic breaking').

In Figure 4 O-C diagrams (U+u and B+b light curves) for CU Vir are presented, where panels a and b present the data plotted with *one* constant period of P1=0.5206778 d, which best fits the observations before 1985 (2446000), and in b and c two constant periods, P1 and P2=0.5206778 d, were applied. It is obvious from the graphs, that with the combination of two different values the observational data obtained over a time span of more than 40 y can be fit best.

In addition, CU Vir was detected as a radio source in 1994 (Leone et al. 1994) and recent investigations give evidence (Kellet et al. 2007) for pulsar-like emission of a highly collimated coherent polarised radiation from one of the stellar magnetic poles.

Observations with BRITE Constellation will facilitate to enable crucial investigations, if the change of the rotational period of CU Vir continues. Spectrosopic DI studies of CU Vir have already been carried out by Kuschnig et al. (1999) and we will be able to test and calibrate our photometric investigations on the necessary (already obtained) ground based spectroscopic results.

Moreover it will be possible to carry out similar, pioneering investigations of potential rotational period changes for numerous other ApBp stars. So far only two more stars of this type, 56 Ari (Adelman et al. 2001) and HD 37776, were detected to show a period decrease linked to the stellar magnetic field.

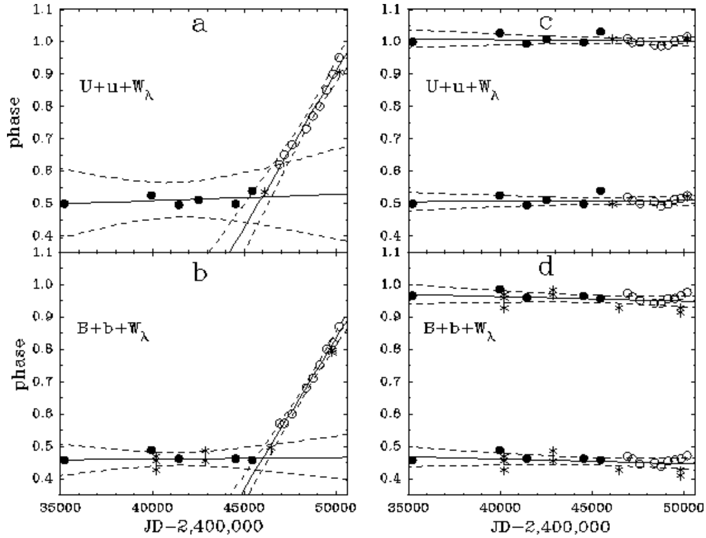


Figure 4: O-C diagrams of CU Vir; a and b: one constant period was used; c, d: fit with two periods. Filled circles indicate photometric observations obtained before 1985 (2446000), open circles those obtained after 1985 (2446000). In a and b the dashed lines mark the 99% confidence level, while in c and d the upper and lower lines represent light and spectrum minima and maxima, respectively. Spectroscopic observations are represented by asterisks, where in (a,c) $W_\lambda$(Si II 6347) and in (b,d) $W_\lambda$(Si II 4128-31, 4201) are plotted. Figure taken from Pyper et al. 1998;

### $\alpha$ Circini

$\alpha$ Cir (HD 128898, HR 5463) is a very bright (V=3.19 mag) member of the pulsating subgroup of the Ap stars (roAp) and was discovered to have a period of 6.83 min in 1987 by Kurtz & Cropper.

With a $\mathrm{v_e} \sin i$=12.5km s$^{-1}$ and a rotational period of P=4.4790(1) d this star is an ideal candidate to determine the stellar surface structure and probe the influence of the magnetic field on pulsation.

Another prominent member of the roAp stars, HD 24172 (HR 1217) has been observed and analysed spectroscopically (Ryabchikova et al. 2006, Lüftinger et al. 2007) and photometrically (by the MOST space photometer, Cameron et al. 2006). The MOST-campaign revealed, in addition to pulsational frequencies detected already during ground based observing campaigns additional frequencies that are shifted due to the influence of the magnetic field.

Similar investigations for $\alpha$ Cir with BRITE Constellation have the potential to reveal comparable effects of another prototypical member of this group of stars and to test observational and recent theoretical investigations (Cunha et al. 2006, Saio et. al. 2005) that try to explain the correlation and interaction of the various astrophysically crucial processes present in these stars.

### $\alpha$ Andromedae

HgMn (CP3) stars and their prominent member $\alpha$ Andromedae have recently come into the focus of scientific interest, as a seven-year monitoring (Kochukhov et al. 2007) of this non-magnetic star revelaed a secular evolution of its mercury cloud cover. It is the first time that we observe such a dynamical structure formation processs, where possibly the heavy-element clouds created by atomic diffusion (Michaud et al. 1974) are affected by a non-equilibrium dynamical evolution, possibly based on the same physical processes as weather patterns on giant planets and the earth (Kochukhov et al. 2007). With BRITE Constellation we will be able to further monitor the evolution of 'stellar weather' in $\alpha$ And (and its timescale) and possibly similar effects in other HgMn stars.

## Summary

The unique potentials of data obtained with BRITE Constellation are:

- the ability to obtain long-term, continuous space-quality light curves, which is crucial to perform spot modeling from photometric data. In the context of DI we benefit from the fact that light curves are particularly sensitive to structure in equatorial and low-latitude bands (Unruh et al. 1995)

- besides analysing inhomogeneous stellar surface structures, we will be able to obtain precise, hitherto unknown, rotational periods for a number of stars
- the possibility to find evidence for a breaking mechanism associated with stellar magnetic fields, as already observed for e.g. the Ap star CU Vir.
- we will have the opportunity to find pulsational frequencies not detectable via ground based observations (due to a much lower noise level) and to trace the influence of magnetic fields on the frequency pattern of magnetic pulsatig stars.

Thus, we will be able to provide, with the further development of theoretical aspects, new information for diffusion properties within stellar atmospheres and to obtain new insights in the atmospheric structure formation and the complex interplay of abundance variations, pulsation and magnetic fields in CP stars.

Hence, these stars provide unique access to otherwise invisible stellar interior processes and structures, making them extremely useful as stellar laboratories to explore and understand the physics of many complex, interacting phenomena, presumably also present in other types of stars.

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