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Spectrum variability of CP stars (Review)

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Abstract. The significant steps which have contributed to our current understanding of the peculiarity of A- and B-type stars phenomenon are reviewed. This presentation is framed in terms of the rotational variability of the spectra of A- and B-type stars. Continuing attempts to detect the light and spectrum variability, and the occurrence of magnetic field in Am and HgMn-stars are both addressed. CP stars as radio and X-ray emitters are also mentioned.

Key words: CP stars – spectrum variability – photometric variability – magnetic fields – oblique rotator – radio emission – X-ray emission

1 Introduction

The first variable peculiar A star (Ap star) discussed has usually been α^2 CVn. The variability of lines in its spectrum was first noted by Luddendorf (1907). He noted variability in the relative intensity of lines Fe, Cr and Mg on 12 photographic plates though was not able to find any regularity in the phenomenon. Luddendorf did call attention to a paper by Lockyer & Baxandall (1906) in which they noted that

"... investigation of various spectra of α Andromedae, taken between the years 1900 – 1904 at Kensington, appeared to indicate slight changes in the relative intensities, position and definitions of some of the lines in various photographs".

α Andromedae is known to be a spectroscopic binary and so the *changes* in the position of spectral lines are visible. A more detailed description of the *changes* in the relative intensity and definition (line profile?) of some of the lines is lacking. The latter can hardly be related to the variability of Hg II 3984, recently discovered by Adelman et al. (2002). Lockyer & Baxandall (1906) included α Andromedae in a group of *Markabian stars*[1]. Even though the classification was a temperature one, associating α Andromedae with the now well known Ap stars, α^2 CVn and θ Aur is yet another interesting point in their work.

They also mentioned *"... the chemical classification of stars ..."* which resembles the currently used Preston's "CP" designation.

2 The cool, magnetic CP stars

The first systematic study of the spectrum variability of Ap stars was published by Deutsch (1947). He compiled the first catalogue of spectrum variables containing 20 B8 – F0 stars with variable absorption lines. Deutsch observed that the line strengths of various metals in magnetic Ap stars varied with periods typically of days, some in phase (as He I, Ca II–K and Mg II 4481 in HD 34452, Sr II and Ca II–K in ι Cas, Eu II, Cr II and Ca II–K in α^2 CVn), some in anti-phase or out of phase (as Eu II and Cr II in HD 125248, He I and Fe II in HD 34452, Sr II and Ca II–K in HD 140160, Ca II–K and Cr II in γ Ari, Eu II, Cr II and Fe II in α^2 CVn). These phase relationships differ from star to star. The variability of the silicon lines is less pronounced. Deutsch noted that *"... in each star lines originating from atoms or ions having ionization*

[1] Markab = α Pegasi, B9.5 III, var?, varRV

potentials within certain limits vary together, while lines originating from atoms or ions of lower or higher ionization potential vary in the opposite sense", thus he indicated the physical roots of this behaviour of the spectral features.

Stibbs (1950) examined the relationship between the variability in line intensity, radial velocity, magnetic field and luminosity of HD 125248. He found a radial velocity variation of an amplitude 13 km s^{-1} with zero velocity when Eu II lines had their maximum strength, and the magnetic field had its extreme values. The light variations were symmetrical about the maximum which occurred when Cr II lines had their greatest intensity. He then deduced that the amplitude of the light variations at the effective wavelength 4000 Å were consistent with a colour temperature change from a maximum to a minimum of about 250 K, thus he introduced *temperature oscillations* into the concept of the phenomenon. Stibbs first calculated the integrated Zeeman effect for a star viewed at any angle to the magnetic axis and realized the possibility that this magnetic axis may also be inclined to the axis of rotation as is observed in the cases of the Earth and Sun. Babcock (1951) named this concept the *oblique rotator*. He studied the magnetically variable star HD 125248 in detail and discovered that the variations of spectral lines were not only remarkable in terms of their line strengths but also in their line profiles. In certain phases, the lines in one circular polarization are sharper and deeper than in the other circular polarization. He called this a *cross over effect* because the effect was usually greatest close to those phases when the mean longitudinal field reverses its sign, 'crosses over' from one polarity to the other. Babcock noted that: *"the positive extreme +7000 G is reached near the zero phase when the lines of the rare earths are at a maximum intensity and lines of Cr are at a minimum. The negative extreme –6200 G is reached at a mid-period when Eu* II *is weak and Cr is at a maximum intensity."* He concluded the *"oblique rotator"* model did not satisfactorily represent the observations and preferred the *magnetic oscillator* model.

When investigating the magnetic variable CP star HD 71866, Deutsch (1956) concluded that *"To account for the spectral variations that are observed to accompany the magnetic changes, it is necessary to assume in both of these models — the oblique rotator and magnetic oscillator — that there is a separation of elements according to the intensity of the magnetic field, and possibly even according to its sign"*. In subsequent, work Deutsch (1958) did favour the oblique rotator model stating that *"It has been proposed that the atmosphere of such a star as HD 125248 is spectroscopically non-homogeneous, and it is in rigid rotation around an axis that is not a symmetry axis of the abundance irregularities or of the associated general magnetic field. The observed variations would then be attributed to the changing aspect of the star as it rotates; the observed period would be simply the period of rotation. ... a satisfactorily representation — of the observations — may be possible by a more general kind of rigid rotator"*.

When evaluating the observed variability of lines of various ions, Durrant (1964) concluded that the atmosphere af a peculiar star is spatially non-uniform in abundances and probably in its *atmospheric structure* also. Having excluded temperature oscillations as the origin of the line intensity variations, repeated diffusion and circulation which would smear up the inhomogeneities, Durrant attributed the spectrum variability to the rotation of a star with an inhomogeneous atmosphere.

North et al. (1998) discovered a variable line of Li I 6708 in the spectrum of the roAp star HD 83368. The variability was attributed to two almost diametrically opposed spots of lithium or the elements responsible for the 'Li' blend. The discovery however, gave birth to a new challenge: how to explain the occurrence of such a fragile element in a Population I star.

3 The hot magnetic CP stars

3.1 He-strong stars

Berger (1956) discovered unusually strong He lines and even the helium discontinuity in the spectrum of σ Ori E. The light, photospheric He lines and strong H_α emission vary in a period of 1.19 d. Two eclipse-like drops in light occur during each cycle and variable shell lines appear in the Balmer spectrum at the time of these drops. The character of the variability of the helium lines suggests that σ Ori E can be interpreted in terms of the rigid oblique rotator model. This was directly confirmed by Landstreet & Borra (1978), who discovered a magnetic field of -2.3 and $+3.1$ kG varying with the period 1.19 d, and later by numerous positive observations of the magnetic field in other He-strong-stars (Borra & Landstreet 1979). The variations of the helium lines strength, H_α emission and light seemed to be closely correlated in all cases while no variations were detected in the non-magnetic He-strong stars.

3.2 He-weak stars

Garrison (1967) noticed weak and diffuse helium lines in a few B0–B9 stars in the upper Scorpius Complex. Using polarimetric observations, Borra et al. (1983) detected magnetic field in 12 out of 30 He-weak (7 of them of Si- and SrTi-subclasses) B stars. Their spectrum and magnetic field variability was consistent with the oblique rotator model. Typical representatives of the He-weak stars are HD 125823 (a Cen, Si-type) and HR 7129 (Sr-type), which vary with periods of 8.82 d and 3.67 d, respectively.

4 The Am – metallic line stars

The term *metallic-line stars* was introduced by Titus & Morgan (1940) for stars with the K-line considerably weaker than would be expected for the average metallic line type. Many searches of the photometric and spectral variability in Am stars yielded negative results in the sense that no variability on a given time scales within a given limit was detected. Due to their high percentage of occurrence in double systems the detected photometric variability of some A stars could be explained as a consequence of the binarity: the observed photometric variability in HR 976 was attributed to the ellipsoidal shape of the components of the binary (Abt & Levy 1976). The considerable departures from a smooth light curve of AN And were supposed to be due to the presence of light-absorbing and light-emitting clouds present in the binary system (Bakos & Tremko 1978).

Lane & Lester (1980) observed that some of the Am stars have variable energy distributions. While τ UMa and 15 Vul change over a long time period, the energy distribution of 81 Tau possibly varied over five nights. Based on spectrophotometry and *B, V* photometry Boehm-Vitense & Johnson (1978) concluded that all Am stars were probably variable over a long time period.

In an analogy with the cool Ap stars, where the spectrum and photometric variability was related to the existence of magnetic field, searches for the magnetic field in the Am stars were conducted. Thus, using an indirect method based on a comparison of the equivalent widths of selected spectral lines, Mathys & Lanz (1990) discovered a strong magnetic field of about 2 kG of a complex structure in the Am star o Peg. However, Shorlin et al. (2002) in their high sensitive search found *"... absolutely no evidence for magnetic fields in the ... Am stars"*. Monin et al. (2002) did not detect a magnetic field greater than 30–60 G in 3 Am stars, α^2 Gem, ζ^2 UMa and ϵ Ser, while in θ Leo, the star *"with distinct features of chemical anomalies of the Am-type"* they suspected a positive detection.

Mikulášek et al. (at this meeting) discussed the possibility of a variable magnetic field in the evolved Am component of the binary HR 6611.

5 The HgMn stars

The mercury-manganese stars were first recognized by Morgan (1933). Wolff (1983) in her review concluded that the HgMn stars *"Do not vary in luminosity or radial velocity apart from orbital motion in binaries, the visible spectrum does not change in time. Repeated attempts to detect magnetic fields have been unsuccessful. Occasional reports ... need confirmation."*

Later however, Takeda et al. (1979) using high dispersion spectra of the eclipsing binary AR Aur revealed that just before the mid-secondary minimum, the line Hg II 3984 Å suddenly became stronger showing a double-line structure. Takada (1981) suggested, that the primary star had some inhomogeneities such as a cloud, a spot or a stratification. Zverko et al. (1997) found the line was definitely present during the most of the orbital period, however, it seemed to display a variable profile.

Rajamohan (1990) in his survey found 5 out of 6 HgMn stars to probably be spectrum variable. His observational material comprised photographic spectra of 30 Å mm^{-1} reciprocal dispersion. He noted that of 52 HgMn stars listed in the Catalogue of Bright Stars were 13 light variables, 4 spectrum variables and one (HR 5049) was a magnetic star. In the Bertaud & Floquet (1974) Catalogue, however, HR 5049 is classified as SrEu. Rajamohan hypothesized that *"... high resolution spectroscopic observations of such stars would exhibit Zeeman broadening in lines that vary in strength and are also sensitive to the magnetic field"*.

Hubrig et al. (1999) searched for magnetic fields in HgMn stars by using relative strengths of the multiplet 74 Fe II lines. They found three HgMn stars, HD 175640, HD 178065 and HD 186122, are very likely to possess a magnetic field of 2 kG. Again Shorlin et al. (2002) in their high sensitive search found *"...absolutely no evidence for magnetic fields in the ... HgMn stars"*.

Adelman et al. (2002), examining high dispersion S/N $>$ 500 spectra, discovered a variability of the Hg II 3984 line in the primary of the binary star α And. They showed that the variability is produced by the combination of the 2.38 d rotational period of the primary and a nonuniform surface distribution of mercury that is concentrated in its equatorial region. Wade et al. (2004, this proceedings), however, did not detect any measurable magnetic field on α And and thus the variability cannot be attributed to magnetic structures.

6 Radio and X-ray emission from CP stars

Magnetic CP stars are known to be radio emitters with high radio luminosities, moderate circular polarization and fairly flat microwave spectra. Drake et al. (1987) observed 34 magnetic CP stars with the VLA at 6 cm wavelength. Five were found to be continuum radio sources of which three were of the He-strong type. The latter are variable nonthermal sources. Leone & Umana (1993) showed that the radio emission from the He-strong type stars HD 37017 and σ Ori varies with their rotational periods. Leone et al. (1994) combining previous surveys and their new one, performed with the VLA at 6 cm, found out that 35% of all He-strong, 26% of He-weak, 23% of Si and 0% of cool magnetic CP stars observed are radio emitters. Based on the VLA 3.6 cm observations, Drake et al. (1994) stated that none of 23 Am and HgMn stars were detected as radio sources. The predicted radio luminosities of α And and Sirius were more than an order of magnitude larger than the observed upper limit, indicating that *"these stars lack magnetospheres, and, by inference, surface magnetic fields"*. To summarize, out of 120 magnetic CP stars observed in the radio frequencies 25% have detectable radio emission. No radio emissions, however, was found among the SrCrEu-type stars (Drake et al. 2002).

Drake et al. (1994) searched the ROSAT All-Sky Survey at the positions of $\approx$ 100 Bp and Ap stars. At least three of them were found to be X-ray sources. The He-strong star has $\log L_{\rm X}/L_{\rm bol} \approx -7$, the He-weak and Si ones have $\log L_{\rm X}/L_{\rm bol} \approx -6$.

The radio and X-ray observations of the CP stars are worth to be added to the challenges enumerated in the opening lecture by John Landstreet.

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