A SPECTRAL ANALYSIS OF $\varkappa$ PISCIUM, I

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RIASSUNTO. — Dall'esame di 9 spettri di dispersione 34 Å/mm ad H_γ abbiamo determinato le variazioni spettroscopiche e di velocità radiale della stella magnetica A2p, $\varkappa$ Piscium. Le grandezze misurate sono state messe in relazione con i 2 periodi fotometrici dati dalla bibliografia, e si è ottenuto un accordo con il periodo $P = 0,5805$ giorni.

I profili medi osservati di H_γ ci hanno permesso di ottenere una stima della temperatura effettiva e della gravità. In certe fasi c'è evidenza di uno sdoppiamento delle righe. È stato osservato uno sfasamento tra la curva di luce e la curva di velocità radiali che si accorda bene con l'ipotesi del rotatore obliquo.

RÉSUMÉ. — En analysant neuf spectres avec dispersion 34 Å/mm de l'étoile magnétique A2p K Piscium, nous en avons calculé les variations spectroscopiques et les vitesses radiales. Parmi les deux différentes périodes photométriques qui ont été proposées pour l'étoile: $P = 0.5853$ J et $P = 0.5805$ J, nos résultats sont en accord avec la seconde période.

Les profiles moyens observés de H_γ ont permis d'obtenir une évaluation de la température effective et de la gravité. Dans quelques phases nous avons rencontrés des raies dédoublées. On a aussì observé un dephasage parmi la courbe de lumière et la courbe des vitesses radiales qui est en accord avec l'hypothèse du rotateur oblique.

1. - INTRODUCTION

$\varkappa$ Piscium (HD 220825) is a spectrovariable magnetic star of spectral class A2p, belonging to the Cr, Eu, Sr subgroup. Since all Ap stars with sufficiently sharp lines for Zeeman measurements show variable magnetic fields, the study of these stars is connected with the general problem of magnetic stars.

A convenient model of Ap stars must explain both the spectral anomalies and the peculiar variations of light, spectrum and magnetic field. According to various authors, among which recently PIKEL'NER and KHOKHLOVA (1971), the best model is the oblique rotator; hence the inhomogeneous distribution of elements on the surface, and not the variation in excitation conditions, is responsible for the observed variations.

The stellar nucleosinthesis and the binary hypothesis are two possible promising ways to interpret the abundance anomalies. But the first hypothesis runs up against the difficulty that Ap stars are in a phase earlier than He-burning, as they belong to the main sequence, since their anomalies seem to be concentrated in spots and not diffused over the surface. The binary hypothesis is supported by the existence of some double systems. Furthermore, the rare earths overabundance and the presence of some heavy elements, that can be synthesized in *r*-processes only, seem to agree with the supernova hypothesis, so that some Ap stars were once secondaries in binary systems in which the primaries exploded as supernovae. Nevertheless other pieces of evidence pose serious difficulties to the supernova hypothesis; for example the He-deficiency and the mechanism that originates the magnetic field.

Among the many other theories proposed to interpret the abundance anomalies in Ap stars, we recall that by MICHAUD (1970): according to him, the cause of the anomalies is a mechanism of selective diffusion that, however, may occur only when convective motions are quite absent.

The concentration in spots of the peculiarities was observed with certainty in α^2 C Vn (PYPER 1969) and in 56 Ari (BONSACK and WALLACE 1970) (ASLANOV and KHOKHLOVA 1972). Superheavy elements such as Au, Os, Pt, Pm, U, were recently observed in many Ap stars (JASCHEK and MALARODA 1970; DWORETSKY 1969; BRANDI and JASCHEK 1970; ALLER and COWLEY 1970; GUTHRIE 1969; GUTHRIE 1972; DAVIS 1971) among which 73 Draconis, whose sharp spectral lines make it very suitable for this study.

Nevertheless, other Ap stars with the same anomaly do not give evidence for the existence of such superheavy elements. So it is interesting to study the spectrum of $\varkappa$ Piscium, because this star belong to the same group as 73 Draconis furthermore both stars are magnetic and spectrovariable and they differ only for the period (0.5 d for $\varkappa$ Psc, 20.3 d for 73 Dra).

The magnetic field of $\varkappa$ Piscium cannot be measured because the lines are too broad; but BABCOCK (1958) could observe visually the polarity inversion, without determining the period.

Some indications of variability were obtained by PROVIN (1953). Later on, RAKOS (1962) gave a photometric period of 0.5805 d and a very small amplitude of light variations: 0.011 m in yellow and 0.007 in blue. Recently, VAN GENDEREN (1971) studied the light variations of several Ap stars, among which $\varkappa$ Piscium, and while he confirmed the variability, his results are different from those of Rakos: he observed a period of 0.5853 d and a range of light variation $\Delta V = 0.006$, $\Delta B = 0.002$, $\Delta U = 0.010$, $\Delta W = 0.018$. Van Genderen claimed that the new period does not agree with Rakos' estimate because one of the comparison stars chosen by Rakos (HD 22.0858) presents light variations; however his measurements hardly cover half a period and recent observations by BLANCO et al. (1972) at the Observatory of Catania seem to agree with the period given by Rakos.

Several authors (BASCHEK 1965; SARGENT 1962; SARGENT 1964; SEARLE 1966; WOLFF 1967) analyzed the spectral features of K Psc examining a limited number of lines of some elements in order to obtain abundance ratios, or hydrogen lines in order to obtain its atmospheric physical parameters. Some small variations in line intensity were already observed by BABCOCK (1958), particularly for the overabundant elements; the line Ca II K too shows intensity variations although it always is typically faint.

A complete study of the spectrum of $\varkappa$ Piscium is still lacking; in the present paper we report some results of the spectral analysis from moderate dispersion plates.

2. - OBSERVATIONS AND RESULTS

We obtained at the Astronomical Observatory of Merate, 9 plates of 34 Å/mm dispersion at H_γ during August-September 1969. The observing epochs were such that the phases cover the whole photometric period available at that time (RAKOS 1962); but according to the period of VAN GENDEREN (1971), some plates have nearly the same phase. Table I gives the observing epochs and the phases computed from the ephemerides given by Rakos and by Van Genderen.

TABLE I - Julian Days and phases of the observations according to both photometric periods.

Plate n.	J.D.	Phase Rakos	Phase Van Genderen
2789	2440453.482	0.239	0.254
2790	453.528	318	333
2797	461.401	880	783
2799	461.474	006	909
2801	461.553	142	044
2802	461.589	204	105
2803	487.364	606	142
2804	487.430	719	255
2808	488.436	452	974

Table II gives the radial velocities, with probable errors, and the equivalent widths of H_γ and H_δ.

In each plate we measured the central intensities R_c and the equivalent widths W_λ of the metallic lines reported in Table III together with the mean values of W_λ. Fig. 1 shows the observed profiles of H_γ and H_δ, averaged over all the plates.

Some lines appeared double during some phases, this is much evident for Ca K (cfr. Fig. 2) in the plate n. 2799. A doubling of lines in $\varkappa$ Piscium was earlier observed by BABCOCK (1958) who quoted as an example the lines 4254 and 4242 of Cr. Furthermore a doubling of Ca II K has already been observed in another Ap star: α And.

TABLE II - Radial velocities with probable errors, and equivalent widths of H_γ and H_δ for each plate.

Plate n.	Rad. Vel.	P.E.	W_λ (H_γ)	W_λ (H_δ)
2789	− 1.76	±3.34	15.70	17.02
2790	−18.07	4.18	16.90	15.81
2797	+13.57	3.41	14.48	14.56
2799	+ 8.56	2.99	14.51	14.98
2801	− 1.00	1.86	13.95	14.53
2802	+ 5.06	3.58	14.35	15.95
2803	+11.57	2.51	16.14	16.75
2804	+13.66	3.36	15.20	16.19
2808	− 1.33	2.44	16.76	16.95

TABLE III - List of the lines used to compute the radial velocities and their averaged equivalent widths.

Element, Mult.	λ	W_λ
Fe I, 45	3815.84	0.17
Fe I, 20	3820.43	0.15
Fe I, 20	3825.88	0.25
Fe I, 4	3859.91	0.19
Cr II, 167	3865.59	0.23
Ca II, 1	3933.66	0.70
Ti II, 11 Ce II, 206	4012.38	0.17
Fe I, 527	4017.16	0.13
Mn I, 2	4034.49	0.12
Fe I, 43	4045.82	0.16
Sr II, 1	4077.71	0.41
Sr II, 3	4161.80	0.19
Eu II, 1	4205.05	0.21
Sr II, 1	4215.52	0.29
Fe II, 27	4233.17	0.27
Sc II, 7	4246.84	0.20
Ti II, 41	4290.22	0.21
Ti II, 41	4300.05	0.26
Fe II, 27	4351.76	0.22
Fe II, 41	4383.56	0.27
Ti II, 19	4395.03	0.21
Eu II, 4	4435.58	0.21
Ti II, 31 Fe II, 201	4444.56	0.29
Mg II, 4	4481.23	0.59
Ti II, 31	4501.27	0.27
Cr II, 44	4558.66	0.36
Ti II, 82	4571.97	0.23
Cr II, 44	4588.22	0.32

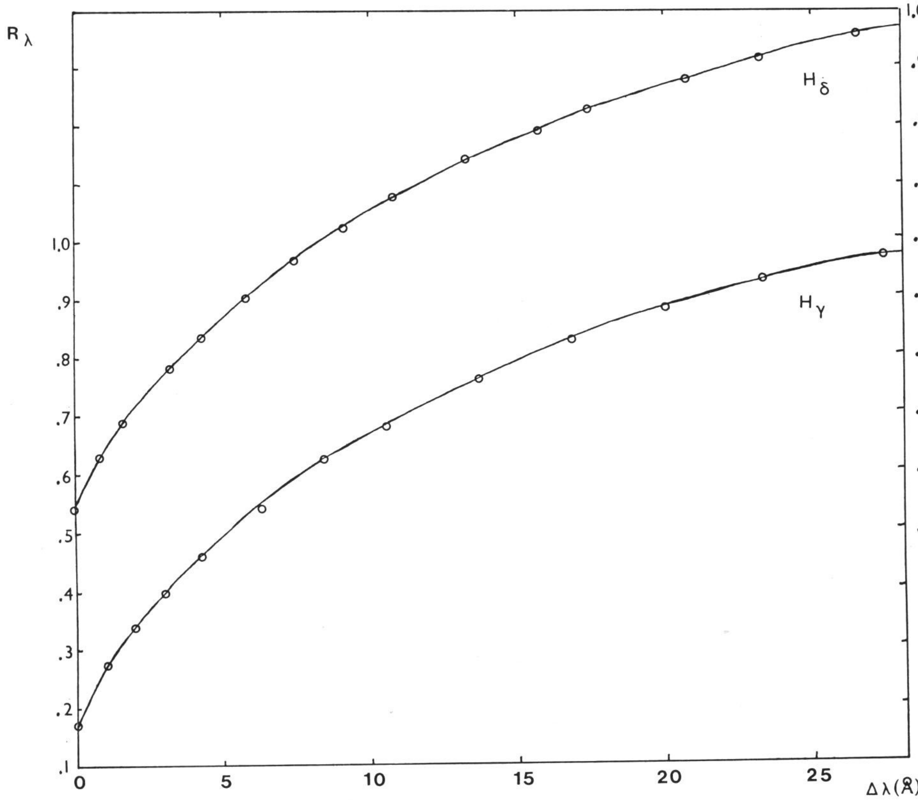

FIG. 1

Averaged profiles of H_γ and H_δ.

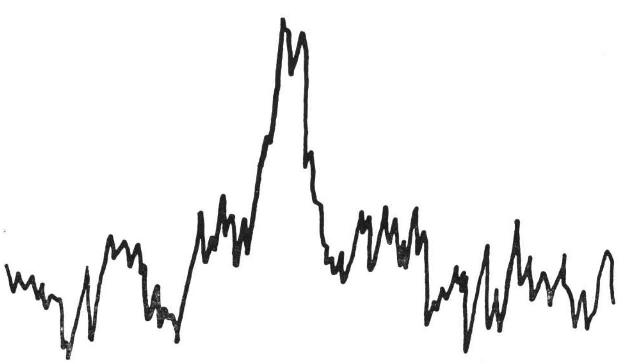

FIG. 2

Doubling of Ca II K in the plate n. 2799.

3. - Discussion

The observed radial velocities, central intensities and equivalent widths of hydrogen and metals were plotted against the phases computed from both periods available. The R_c and W_λ of the metallic lines show a very short range of variation

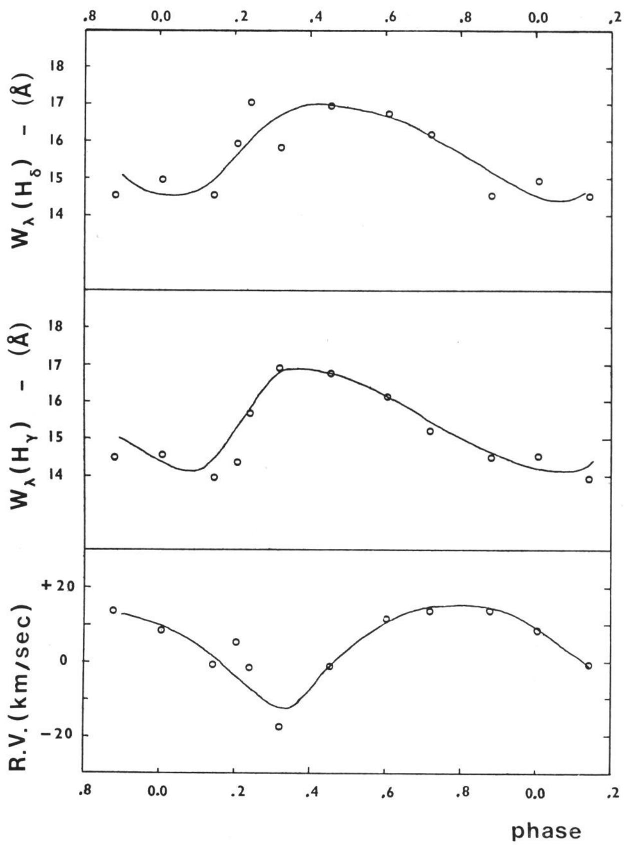

Fig. 3

Variations of radial velocities and equivalent widths of H_γ and H_δ, against the phase computed with period $P = 0.5805$ d. Phase 0.00 corresponds to minimum light according to Rakos' ephemeris.

and we cannot see (at this dispersion) a definitely periodic trend. On the contrary, the equivalent widths of H_γ and H_δ and the radial velocities show undoubtedly a periodic variability with $P = 0.5805$ days, as can be seen from Fig. 3.

The W_λ of H_γ was previously measured by Petrie (1948) who obtained a value of 17.7 A and by Wolff (1967) who obtained 14.2 A; this apparent disagreement may be explained as due to a real variation of this parameter. We notice that the equivalent widths of hydrogen lines vary in phase with the light variations (see Fig. 3); we shall look for a variation of the metallic lines by analyzing the high dispersion plates, in order to test the oblique rotator theory.

The observed variations of the radial velocities show a periodic behaviour of very small amplitude that can be explained on the basis of the oblique rotator model, as the phase shift between our radial velocities curve and the light curve given by Rakos is of about 1/4 of a period, in accord with the theory of the oblique rotator.

Finally, we compared the observed profile of H_γ (Fig. 1) with those computed by MIHALAS (1965) and by CARBON et al. (1969); the best agreement gives an effective temperature, $T_e = 9.500 \div 10.000$ ($\vartheta_e = 0.50 \div 0.53$) and gravity log $g = 4$. These values are in fact in good agreement with the previous measurements (SARGENT 1964; SEARLE 1966; WOLF 1967), with the only exception of the gravity estimate by Wolf (log $g = 3.2$) from photometric observations. The profiles of the hydrogen lines are slightly different from plate to plate.

We are now doing a detailed analysis from some high dispersion plates (4.5 Å/mm) that we had from prof. Babcock, to whom we want to express our warm tanks. From a preliminary analysis we can till now state that some lines of superheavy elements (expecially U II) are present in the atmosphere of this star.

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