THE SPECTRUM OF $a^2$ CANUM VENATICORUM

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Received July 25, 1943

ABSTRACT

A new list of wave lengths containing 3107 absorption lines between $\lambda$ 3087.9 and $\lambda$ 4740.6 has been obtained from 28 spectrograms taken at the Mount Wilson and the McDonald observatories. Of these plates, 18 were obtained with a dispersion of around 3 A/mm, while the other plates, used in the ultraviolet region, had 20 A/mm. The identifications are based upon all available laboratory material and show that all singly ionized rare earths which have been measured in the laboratory and which have a sufficient number of lines in the region covered by the stellar spectrograms are present. One doubly ionized rare earth, Ce III, is almost certainly present, and others may contribute to blends. The intensities of all rare-earth lines are variable in a period of 5.5 days and follow the pattern of the Eu II lines (designated as group A). The lines of Cr II and some other elements vary in the opposite sense (group B), while certain other lines—Si II, Mg II, etc.—do not appreciably change in intensity (group C). The radial velocities as measured from the lines of different elements also fall into three groups, designated as a, b, and c, which roughly correspond to the intensity groups A, B, and C. Group a, consisting of the rare earths and some other elements predominantly of low ionization potential, shows a shallow minimum of velocity at phase 4.5 days after maximum Eu II intensity and a sharp maximum of velocity at phase 1.5 days. Group b, represented by Cr II and some other elements, shows a velocity-curve with a double wave. The highest maximum is at phase 5.0 days and the deepest minimum at phase 0.7 day. Group c, consisting of Mg II, Si II, H, and Ca II, shows no appreciable variation.

A recent review of the problem presented by the variable line-intensities in $a^2$ Canum Venaticorum has shown that several important conclusions rested upon somewhat inadequate observational data. In particular, there exists as yet no satisfactory list of the absorption lines in this remarkable spectrum. The most complete previous set of measurements was obtained by W. W. Morgan on Yerkes single-prism spectrograms and covers the region $\lambda\lambda$ 3913–4572, with a linear dispersion of 30 A/mm at $\lambda$ 4500. The more recent work by Tai contains fewer lines and therefore adds relatively little to Morgan's identifications. The spectrum is exceedingly rich in lines. With small, or even with moderately large, dispersion the great majority of the lines are blends—many of which have never before been identified or even measured. Since Baxandall's discovery in 1910 of five strong absorption lines, measured by Belopolsky and found by the latter to have variable intensities, were due to the rare earth europium, several other ionized rare-earth atoms have been identified in $a^2$ CVn, though until recently there existed little agreement among different observers.

The purpose of this investigation is to present as complete a list of wave lengths and identifications as can be obtained at the present time and to study the variations in radial velocities presented by lines of different atoms. There has been some controversy concerning the reality of the changes in radial velocity first observed by Belopolsky for Eu II; and for a number of years the opinion appeared justified that, in some of these lines at least, the observed variations were caused by disturbing blends near minimum intensity of Eu II. The reality of the changes in velocity was definitely established by our preliminary measurements of McDonald Observatory coudé spectrograms.

* Contributions from the McDonald Observatory, University of Texas, No. 78.

1 Struve, Proc. Amer. Phil. Soc., 85, 349, 1942; Struve and Swings, Observatory, 64, 291, 1942. Since these reviews were written, Nikonov and Brodskaja (Bull. Acad. Sci. Georgian S.S.R., 3, No. 7, 657, 1942) have found that the star changes in color-temperature by about 2000°, being bluest when the total light is at minimum.


3 M.N., 100, 94, 1939.

4 Observatory, 36, 440, 1913.
The tables presented in this paper are based upon a number of spectrograms obtained at the Mount Wilson and McDonald observatories. The nine McDonald coudé plates have already been used in part. They extend from about $\lambda$ 3900 to $\lambda$ 4800. The dispersing system consists of two large prisms of Chance glass, figured by Hilger and giving excellent definition over the entire range. The emulsion used was Eastman Ia0. The dispersion varies from 1.9 A/mm at $\lambda$ 3933 to 4.5 A/mm at $\lambda$ 5000.

We are greatly indebted to Dr. W. S. Adams, director of the Mount Wilson Observatory, for extending to us the use of his exquisite coudé spectrograms, also nine in number, which were taken with various adjustments of a large plane grating ruled on aluminum on glass. These spectrograms extend over a very large range in wave lengths and are uniformly of excellent quality. The dispersion is 3 A/mm. We have reproduced in Plates XXIII–XXX a number of the best spectrograms of each observatory. The changes in the line-intensities with phase are very conspicuous. The McDonald plates were taken through the glass (a practice which was necessitated by the large amount of curvature of our plateholders and which has since been abandoned because of a new technique which permits us to bend the plates sufficiently without breaking them), and this accounts for some of the irregular spots on the reproductions. The extreme ultraviolet region, from $\lambda$ 3087.9 to $\lambda$ 3408.0, has been measured on McDonald Observatory Cassegrain quartz spectrograms, having a dispersion of 20 A/mm at $\lambda$ 3250 or 40 A/mm at $\lambda$ 3933. These plates were obtained on Eastman Process emulsion and are of fine quality, but the dispersion was insufficient to resolve many of the blends. The Cassegrain quartz plates ($CQ$) were measured by Swings. All high-dispersion plates were measured by Struve. The identifications were made by Swings and were later in part re-examined by Struve. Because of the unusually large amount of work involved in these measurements, Struve measured all eighteen coudé plates in one direction and later remeasured two of them, Cd 81 and MtW 1992, in the reverse direction. The reductions were made quite independently, and the comparisons of direct and reverse measures furnish a valuable indication of the precision and of the essential absence of systematic differences in the two sets. Although a small tendency exists in each plate for strong and weak lines to differ slightly in the direct and the reverse measurements, the trend of the two spectrograms is opposite in sense. Hence it may be concluded that for the relatively broad lines of $\alpha^2$ CVn no systematic errors in excess of 0.01 A have been introduced into the results. The actual precision of the faintest lines should be of the order of 0.02 A, and of the stronger lines it should be more nearly of the order of 0.01 A.

The phases used in this paper were computed with the formula established by Miss G. Farnsworth.\footnote{\textit{Ap. J.}, 75, 364, 1932.}

$$\text{Maximum intensity of } Eu\, \Pi = JD\ 2419869.720 + 5.46939 E.$$  

This formula satisfactorily predicts the phase of the maximum $Eu\, \Pi$ intensity, but it is possible that there are small departures from one cycle to another in the curve of intensity plotted against time. Hence the combination of observations made in different years may not be rigorously correct; unfortunately, the high-dispersion material is not sufficient to study possible departures from the mean curves.

Table 1 covers the region $\lambda\lambda$ 3088–3315 and is based upon only one spectrogram at phase 3$^{d}7$, where the rare-earth lines should be weak. The contributions of these lines to blends, which should become important at other phases, are indicated in a separate column.

Table 2 gives the region $\lambda\lambda$ 3317–3408 and is based upon three spectrograms at phases 0$^{d}47$, 1$^{d}46$, and 4$^{d}93$, which were measured from $\lambda$ 3317 to $\lambda$ 3369, and upon six spectrograms, which were measured from $\lambda$ 3369 to $\lambda$ 3408.
Table 3 is based upon nine Mount Wilson coudé plates and one McDonald coudé plate. The manner in which the phases of some of the plates were combined for the forming of average wave lengths and intensities is shown in Table 7.

All wave lengths have been corrected to the sun in the usual manner. The curvature correction was applied to the McDonald plates but was, of course, neglected for the Mount Wilson plates, which were taken with a grating.

The intensities of the star lines are rough estimates and are not intended for a study of the variations of the intensities, because they are affected by underexposure or overexposure of the region in question. The illustrations give a far better idea of the variations. Intensities greater than 9 are shown by the symbol $x$ in the tables. An intensity of 0 does not mean that the line is absent, but a single measure of such a line is rather doubtful and may not be real.

The work of identification was especially difficult for the following reasons:

a) The variation of $\lambda$ with phase. This variation may be so different for two atoms, A and B, that a line may be single at one phase and become double at another phase.

b) The unsatisfactory state of laboratory data for certain rare earths.

c) Considerable differences which may exist between the laboratory and the stellar intensities. Let us adopt $T_{exc} = 10,000^\circ$ for $a^2\mathrm{CVn}$ and $T_{exc} = 5,000^\circ$ for an arc. Table 8 gives the ratio $(I_1/I_2)_{arc}/(I_1/I_2)_{a^2\mathrm{CVn}}$ for various differences in excitation potential of the two lines. Hence high-level lines may be considerably enhanced in $a^2\mathrm{CVn}$ relative to their laboratory intensities. The criterion of "arc intensity" (as applied by Tai, for example) is not reliable, although it may still be the best one could use in many cases when a term classification is not available. Whenever a term classification is known, the identifications have been discussed on the basis of multiplet intensity relations.

d) A contribution of minor importance at a specific phase may become important at some other phase (at least as far as $v_{rad}$ is concerned). Hence many minor contributions have been included in the tables.

The list of identifications gives the probable major contributors first. These are followed by minor, but appreciable, contributors. Less important contributors and uncertain contributors are given in parentheses.

The laboratory material used for identifications consisted of the following:

a) Miss Moore's original multiplet table, combined with new M.I.T. wave lengths wherever advisable.

b) New material on Ne II, A II, P II, Fe I, etc.

c) Considerable unpublished material generously supplied by Mrs. Sitterly (parts of her revised multiplet table) and by Dr. A. S. King for: Fe II, Cr II, Ti II, Mn II, Co II, Ni II, Sc II, Cu II, Ce II, Pr II, Nd II, Sm II, Eu II, Gd II, Dy II, Tm II, Yb II, Lu II.

d) Meggers' and Moore's analysis of V II.

e) No term analysis is available for Tb II, Dy II, Ho II, Er II. For Dy II, a temperature classification by A. S. King is available over the whole astronomical region, but it seems to concern only the strong lines. A summarized copy belonging to Mrs. Sitterly was used.

For Ho II and Tb II, King's temperature classification covers only the region $\lambda\lambda 3836$–4680. Hence the M.I.T. table had to be used for $\lambda<3836$. Only the Ho and Tb lines have been entered, which are observed in the spark (the separation of Ho I–II and Tb I–II is not known for $\lambda<3836$). The corresponding identifications are marked Ho (I?) and Tb (II?), and the intensities denoted by $S$ are taken from the spark column of the M.I.T. table.

A recent temperature classification of Gd II extending over the whole astronomical region was received from Dr. A. S. King prior to publication; it was used with considerable success.

For erbium, only the old work of Exner and Hascheck and of Eder is available. This does not separate Er I and Er II. Over the whole astronomical region the wave lengths

were taken from the M.I.T. table, for the lines only which appear in the spark. These wave lengths may be less satisfactory than for most other elements.  

Generally speaking, the term analyses are still very incomplete for the rare earths. Hence the temperature classifications were used extensively.  

f) Nothing has been published on the doubly ionized rare earths, except Ce III. Yet it is very probable that a number of unidentified lines are due to Eu II, Gd III, Dy III, etc.  

g) Each wave length of a² CVn was compared with the neighboring wave lengths in the M.I.T. table.  

With regard to the elements represented in a² CVn the following notes are pertinent:  

a) Ne II and A II. Probably pure chance coincidences or minor contributions.  

b) Sc II. Extremely weak compared with a Cygni.  

c) Singly ionized rare earths. The evidence is probably satisfactory for all singly ionized rare earths, except Yb II and Er II. Yb II is very faint, yet almost certainly present. The uncertainty of Er II is due to the lack of reliable laboratory data.  

d) Doubly ionized rare earths. These identifications were made with the help of unpublished data kindly supplied by Dr. A. S. King.  

Ce III.—The stellar evidence is summarized in Table 9. The following multiplets are present: 

\[ \text{fsF}^9 - \text{fpF}^9, \text{fsF}^9 - \text{fpG}^9, \text{fsF}^9 - \text{fpF}^9, \text{fsF}^9 - \text{dG}^9, \text{fsF}^9 - \text{fG}^9, \text{fsF}^9 - \text{fG}^9, \text{fsF}^9 - \text{dG}^9. \]

Eu III (\(\lambda 2900-3194\)).—The region covered by King's list was taken only on CQ spectrograms and cannot provide reliable identifications. The Eu III line \(\lambda 3183.7(100)\) may contribute, but it is badly blended by Cr II.  

Gd III (\(\lambda 2900-3177\)).—\(\lambda 3118.0 (1000)\) may contribute. This region was taken only on CQ spectrograms.  

Sm III (\(\lambda 2903-3398.4\)).—No definite evidence; Sm III contributes probably in a number of blends, but the region is too crowded.  

Nd III (\(\lambda 2899-3431\)).—Contributions by Nd III probably improve the identifications of blends.  

Pr III (\(\lambda 3147-3568\)).—Most lines are blended; but their contributions improve the identification of the blends; \(\lambda 3397.5(600)\) cannot be appreciably blended and is probably present.  

La III.—\(\lambda 3517.14\) may be present.  

Table 4 contains the best lines for a number of atoms and ions, selected for lack of seriously disturbing blends. The selection was made without regard to any changes in wave length. The radial velocities determined from the individual lines are, of course, corrected to the sun and represent in each case the true velocity as determined from each individual line on each plate. These velocities are arranged in order of phase and are given individually, not only for the ten plates used in Table 3, but also for the remaining eight McDonald coude spectrograms. For each atom or ion the mean radial velocity has been derived individually for each plate, together with the number of measures used in forming each mean. The mean velocities are plotted in Figures 1–5 as functions of the phase. The value of the period, 5.5 days, is indicated along the abscissae, so that the amount of repetition of each set of points can be clearly seen in all diagrams.  

The velocity-curves fall into three distinct groups:  

a) Lines which show a large range in velocity, with a pronounced minimum at phase 4.5 days after the epoch of maximum of Eu II intensity. Maximum velocity occurs at phase 1.5 days, and the curve is characterized by a sharp maximum and a shallow minimum. This type of variation is best determined for Eu II and Dy II. Probably all rare earths share in this type of variation, with the exception of Ho II, for which the material is inadequate. The following elements belong to group a: Al II, Ca I, Mn I, Ni I, Ce II, Pr II, Nd II, Sm II, Eu II, Gd II, Dy II, and perhaps Sr II. The range of the

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The Spectrum of α² Canum Venaticorum
PLATE XXV

The Spectrum of α² Canum Venaticorum
PLATE XXIX

THE SPECTRUM OF α² CANUM VENATICORUM
PLATE XXX

The Spectrum of α² Canum Venaticorum

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© American Astronomical Society • Provided by the NASA Astrophysics Data System
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**NOTES TO TABLE 3**

λ 3865.6 and λ 3865.9 form two distinct lines on MtW 1995, while MtW 2544 shows only one broadened line. The assignment of the components to Cr II + Fe I and to Cr II + Nd II is not certain. λ 3903.8 main contributor unknown. The line is of class B.

λλ 3905.7 and 3906.0 are clearly divided on MtW 1995 but are blended on MtW 2544.

λ 3919.4 is a fairly strong unidentified line of class A.

λ 3920.6 is a strong, unidentified line of class B.

λ 3930.3 of Fe I and λ 3930.5 of Eu II are clearly double on MtW 1995 but are blended on MtW 2544.

λ 4012.3 and λ 4012.4 are single on MtW 1995, but double on MtW 2544. It is difficult to disentangle the blends contributing to these lines.

λ 4034.2 is a strong line not satisfactorily identified.

λ 4050.5 is of class B and is probably not all due to Dy II.

Lines Ti II 4053.84 and Cr II 4054.18 are not resolved on all plates. For phase 3.042 the two entries are two separate measures of the same blended line.

λ 4060.6 is of class B and cannot be due to Eu II and Nd II alone.

λ 4161.8 is of class B and is mostly unidentified.

λλ 4177.6 and 4177.9 are not satisfactorily identified. The latter line is of class A or is completely blended with λ 4177.6 on some plates.

λλ 4200.5 and 4200.8 are not satisfactorily identified.

λ 4288.4 is not satisfactorily identified.

λ 4289.9 is one of the most remarkable lines of class A. It is probably due to Ce II.

λ 4356.4 is a strong unidentified line.

λ 4371.9 is a strong unidentified line.

The line Fe I 4383.6 is the violet component of a double line. The red component, whose shift is not the same on all plates, has not been satisfactorily identified.

λ 4384.2 is not satisfactorily identified. Class B, very strong.

λ 4393.0, strong unidentified line.

λ 4393.7, strong unidentified line.

λ 4410.0, strong unidentified line.

λ 4410.8, strong unidentified line.

λ 4419.6, not satisfactorily identified, class B.

λ 4447.3, strong unidentified line, class A.

λ 4448.4, not satisfactorily identified.

λ 4502.9, not satisfactorily identified.

λ 4511.9, not satisfactorily identified.

λ 4514.1, very strong unidentified line of class B.

λ 4515.6, strong unidentified line.

λ 4540.8, strong unidentified line.

λ 4618.0, strong unidentified line.

λ 4621.1, strong unidentified line.

λ 4621.6, strong unidentified line.

λ 4660.6, strong unidentified line.

λ 4673.3, strong unidentified line.

λ 4722.9, strong unidentified line.
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|          | +2.3(5)| + 0.5(6)| + 2.9(3)| + 5.8(3)| +10.8(2)| + 8.9(1)| - 0.9(0)| + 1.3(1m)|        |        |
| 4000.45(800)| + 2.3(3)| - 0.3(2)| + 4.7(1)| + 6.8(2)| + 6.1(1)| +15.4(0)|        |        |        |        |
| 4077.75(30)| + 5.6(2)| + 7.7(3)| + 6.8(2)| + 7.9(1)| + 8.8(1)| +11.9(1)| - 7.5(0)| -11.5(1)|        |        |
| 4050.58(100)| - 4.3(3)| - 2.9(3)| - 2.6(3)| - 0.9(1)| + 1.5(2)| + 3.2(2)| - 0.5(1)|        |        |        |
| 4141.10(150)| - 1.3(5)| + 3.2(3)| + 3.3(3)| + 9.3(2)| +10.4(2)| +15.4(2)| +16.0(1)| + 2.9(1)| - 3.0(1)|        |
| 4099.38(200)| - 1.4(1)| + 5.2(5)| + 2.3(3)| + 1.4(1)| + 4.9(3)| +11.0(2)| +10.6(1)| + 9.3(1)| + 8.4(2)| + 2.6(1)|

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### TABLE 5

**Observations of \( \alpha^2 \) Canum Venaticorum**

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### TABLE 6

**Cd 81—Comparison between Direct and Reverse Measurements**

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**MtW 1992—Comparison between Direct and Reverse Measurements**

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velocity-curves is not the same: it is 30 km/sec for Eu II, 25 km/sec for Dy II and Pr II, 20 km/sec for Ce II and Ni I, 15 km/sec for Sm II, 10 km/sec for Gd II, and less than 5 km/sec for Sr II. The reality of this effect is attested by the small range shown by Gd II, of which there are many strong unblended lines.

b) Lines which show a remarkable double wave, with principal maximum at phase 5°0, secondary maximum at phase 24°0, principal minimum at phase 0°7, and secondary minimum at phase 34°5. This type of variation is best shown by Cr II, where the total range is 15 km/sec. It is conspicuously present for Cr I, where the range is even larger, though the scatter is also larger. The same type is shown by Fe II and Fe I, though the range is only 10 km/sec, and by Mn II, where the range is also about 10 km/sec. The variation of Ti II seems to be intermediate between types a and b. Considering the large number of excellent lines of Ti II used in forming this curve, the observed maximum velocity at phase 1.5 days probably reflects a superposition of the principal maximum of type a and the secondary maximum of type b.

c) Lines which show no variation. Conspicuous in this group is Mg II with a very small range, in spite of the fact that the curve is based upon one line only, λ 4481. Other representatives are Si II, H, and Ca II.

TABLE 7

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<tr>
<td></td>
<td></td>
<td>MtW 1669</td>
<td>1.642</td>
<td></td>
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<tr>
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<td>4601.279</td>
<td>MtW 1669</td>
<td>1.642</td>
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<tr>
<td>3606.724</td>
<td>3677.920</td>
<td>MtW 2580</td>
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<td>MtW 1992</td>
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<td>MtW 1992</td>
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<td>4.490</td>
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<td>4647.340</td>
<td>MtW 2229</td>
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<td>Cd 81</td>
<td>4.520</td>
<td></td>
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<tr>
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<td>Cd 81</td>
<td>4.520</td>
<td>0.756</td>
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<td>4740.785</td>
<td>MtW 1995</td>
<td>0.691</td>
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TABLE 8

<table>
<thead>
<tr>
<th>Diff. in Exc. Pot.*</th>
<th>( \frac{I_1}{I_2} ) arc</th>
<th>( \frac{I_1}{I_2} ) aSCvA</th>
<th>Diff. in Exc. Pot.*</th>
<th>( \frac{I_1}{I_2} ) arc</th>
<th>( \frac{I_1}{I_2} ) aSCvA</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 volt</td>
<td>0.31</td>
<td></td>
<td>4 volt</td>
<td>0.010</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.10</td>
<td></td>
<td>5</td>
<td>0.003</td>
<td></td>
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<tr>
<td>3</td>
<td>0.031</td>
<td></td>
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</table>

* Two lines of same spectral region.
Attention may be drawn to the fact that some of the curves are systematically displaced from one another. $H$ and $Si\ \Pi$ cluster around 0 km/sec; $Mg\ \Pi$ gives, in the mean, about $-9\ km/sec$, while $Sr\ \Pi$ gives $+7\ km/sec$. These differences are much too large to be caused by errors of measurement. They may be attributable to blends; but in the case of $Mg\ \Pi$ no blend is known that would be strong enough to produce the observed displacement, while in the case of $Sr\ \Pi$ a weak line of $Cr\ \Pi$ may possibly influence the measured wave length to a slight extent. It is entirely possible, though by no means certain, that we are dealing here with an effect of relative motion similar to that observed by Adams in several other stars.

### TABLE 9

**Observed Intensities of Ce III Lines**

<table>
<thead>
<tr>
<th></th>
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<th></th>
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<th></th>
<th></th>
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<tbody>
<tr>
<td>3353.26</td>
<td>150</td>
<td>3</td>
<td>4</td>
<td>$Cr\ \Pi$</td>
<td>$Fe^3F^0 - fp^6F^0$</td>
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<tr>
<td>3395.73</td>
<td>50</td>
<td>1-2</td>
<td>1-2</td>
<td>$Cr\ \Pi$, $Fe\ \Pi$</td>
<td>$Fe^3F^0 - fp^6F^0$</td>
</tr>
<tr>
<td>3427.332</td>
<td>125</td>
<td>2</td>
<td>1</td>
<td>$Cr\ \Pi$, $Fe\ \Pi$, $Fe^3F^0$</td>
<td>$Fe^6F^3 - fp^6F^0$</td>
</tr>
<tr>
<td>3443.609</td>
<td>150</td>
<td>2</td>
<td>2</td>
<td>Weak $Nd\ \Pi$, $Zr\ \Pi$</td>
<td>$Fe^3F^0 - fp^6F^0$</td>
</tr>
<tr>
<td>3454.368</td>
<td>150</td>
<td>2</td>
<td>2</td>
<td>Very weak $Nd\ \Pi + Dy\ \Pi$</td>
<td>$Fe^3F^0 - fp^6F^0$</td>
</tr>
<tr>
<td>3459.374</td>
<td>200</td>
<td>3</td>
<td>2</td>
<td>$Cr\ \Pi$</td>
<td>$Fe^3F^0 - fp^6F^0$</td>
</tr>
<tr>
<td>3470.894</td>
<td>300</td>
<td>1+</td>
<td>1-2</td>
<td>$Cr\ \Pi$</td>
<td>$Fe^3F^0 - fp^6F^0$</td>
</tr>
<tr>
<td>3497.755</td>
<td>60</td>
<td>2</td>
<td>3</td>
<td>Very weak $Nd\ \Pi + Dy\ \Pi$</td>
<td>$Fe^3F^0 - fp^6F^0$</td>
</tr>
<tr>
<td>3504.596</td>
<td>100</td>
<td>3</td>
<td>3</td>
<td>$Fe\ \Pi$, $Fe\ \Pi$, $Zr\ \Pi$, $Dy\ \Pi$</td>
<td>$Fe^3F^0 - dp^2G^4$</td>
</tr>
<tr>
<td>3543 999</td>
<td>80</td>
<td>1</td>
<td>1</td>
<td>Weak $Eu\ \Pi$, $Dy\ \Pi$</td>
<td>$Fe^3F^0 - dp^2G^4$</td>
</tr>
</tbody>
</table>

It will be noticed that in a general way our groups a, b, and c coincide with the groups A, B, and C first established by Belopolsky, which represent lines varying in intensity, like $Eu\ \Pi$; lines varying in the opposite sense, like $Cr\ \Pi$; and lines which remain constant in intensity, like $Mg\ \Pi$. There are appreciable differences in the results of different observers who have attempted to classify the lines into groups A, B, and C. For example, Belopolsky considers $H$, $Mg\ \Pi$, $Ca\ \Pi$, and $Fe\ \Pi$ to belong to class C. Tai attributes $Fe\ \Pi$ to group B and $Fe\ \Pi$ to group A, while for $H$, $Mg\ \Pi$, and $Si\ \Pi$ the group may be either B or C. But it is undoubtedly significant that all rare earths belong simultaneously to groups A and a, while $Cr\ \Pi$, the most conspicuous representative of group B, is also the most characteristic representative of group b.

Although it was not the primary purpose of this investigation to provide extensive data concerning the variations in the intensities, we have estimated on an arbitrary scale the intensities of a number of lines of different elements, in order to verify Tai's conclusion that the rare earths all belong to group A. These estimates are independent of those made during the measurements. Their advantage consists in the fact that they were made by comparing the enlargements of three McDonald coude spectrograms, Cd 77, Cd 81, and Cd 86. The corresponding phases are $3^{4530}$, $4^{4520}$, and $5^{4530}$. The estimates in Table 10 are given in this order. The last phase is, of course, very close to
Fig. 1.—Radial velocities of α² Canum Venaticorum
Fig. 3.—Radial velocities of α² Canum Venaticorum
Fig. 4.—Radial velocities of α² Canum Venaticorum
Fig. 5.—Radial velocities of $\alpha^2$ Canum Venaticorum
### Table 10

**Estimates of Line Intensities**

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<thead>
<tr>
<th>Line</th>
<th>Phases</th>
<th>Line</th>
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</thead>
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<tr>
<td></td>
<td>3.530</td>
<td>4.520</td>
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<tr>
<td>Ni II (14)</td>
<td>16.3 v.</td>
<td>(C)</td>
</tr>
<tr>
<td>4128.0</td>
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<td>6</td>
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<tr>
<td>Ti II (22)</td>
<td>13.6 v.</td>
<td>(A)</td>
</tr>
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<td>4163.6</td>
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<tr>
<td>4171.9</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>4300.0</td>
<td>0</td>
<td>4</td>
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<tr>
<td>4301.9</td>
<td>0</td>
<td>3</td>
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<tr>
<td>4312.9</td>
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<td>3</td>
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<td>4314.9</td>
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<td>4488.3</td>
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<td>3</td>
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<tr>
<td>4501.3</td>
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<td>3</td>
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<tr>
<td>Cr I (24)</td>
<td>6.7 v.</td>
<td>(C-A)</td>
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<td>4254.4</td>
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<td>3</td>
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<tr>
<td>Cr II (24)</td>
<td>16.6 v.</td>
<td>(B)</td>
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<tr>
<td>4052.0</td>
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<td>3</td>
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<tr>
<td>4070.9</td>
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<td>4076.9</td>
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<td>4242.4</td>
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<td>4269.3</td>
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<td>3</td>
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<td>Mn II (25)</td>
<td>15.7 v.</td>
<td>(A)</td>
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<td>4259.3</td>
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<td>Fe I (26)</td>
<td>7.8 v.</td>
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<tr>
<td>4468.4</td>
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</table>
the predicted maximum of intensity of $Eu$ II. The elements are arranged in order of atomic weight. The ionization potential and the intensity group are given at the head of each element. It is certain that all rare earths included in Table 10 belong to group A, and it is probable that the range in intensity is largest for $Eu$ II, and somewhat smaller for $Gd$ II. But this conclusion may be related to the fact that at maximum the lines of $Eu$ II are the strongest among the rare-earth lines.

**TABLE 11**

<table>
<thead>
<tr>
<th>Phase in Days</th>
<th>Diffuseness of Lines</th>
<th>Phase in Days</th>
<th>Diffuseness of Lines</th>
</tr>
</thead>
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<tr>
<td>5.050</td>
<td>4</td>
<td>2.363</td>
<td>10</td>
</tr>
<tr>
<td>0.691</td>
<td>3</td>
<td>3.721</td>
<td>8</td>
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<tr>
<td>0.822</td>
<td>1</td>
<td>4.460</td>
<td>2</td>
</tr>
<tr>
<td>1.323</td>
<td>3</td>
<td>4.956</td>
<td>5</td>
</tr>
<tr>
<td>1.642</td>
<td>2</td>
<td>5.050</td>
<td>4</td>
</tr>
</tbody>
</table>

It has already been pointed out\(^1\) that the contours of the lines of groups C and B are somewhat broader when the $Eu$ II lines are weak. Estimates of diffuseness were made on the Mount Wilson coudé plates for the region near $Ca$ II K. If 10 designates the broadest lines and 1 the narrowest (on any arbitrary scale), we obtain the relation with phase shown in Table 11. The lines were broadest at phases 2.3 and 3.7 days. They were narrow at phase 0.8 and again at phase 4.5 days. Possibly the double wave shown in these estimates is related to the double wave in the radial velocities of group b and to the peculiar changes in line contours observed in ε Ursae Majoris.\(^6\)

We are indebted to Mrs. Martha B. Carlson and Mrs. Gladys Rezek for much help in the computations, to Miss Alice Johnson for the reproductions of the spectrum, and to Miss J. Ringstad and Mrs. T. Belland for the typing of the tables reproduced by planography.