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THE *Ba* II STARS*

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ABSTRACT

The spectroscopic characteristics of a newly discovered group of peculiar G- and K-type stars are described. All the stars discussed show abnormally strong lines of ionized barium, as well as *CH*, C_2, and probably also *CN* bands of anomalous intensity. The strength of the lines of *Ba* II is not due to high luminosity but appears rather to be associated with an atmospheric carbon abundance intermediate between that of normal stars and that of members of the presently accepted carbon-star group. The possible connection between the *Ba* II stars and the stars of type S is briefly discussed.

INTRODUCTION

The extraordinary strength of one of the resonance lines of ionized barium, λ 4554, has long been known as one of the distinctive characteristics of the spectra of stars of type S.[1] This line is also well marked in the cooler carbon stars, being very strong indeed in some objects such as HD 59643, class $C6_2$, and the star V CrB, class $C6_3$. Furthermore, it has been noted to be somewhat enhanced in the *CH* stars.[2] Among the normal stars of earlier type, the line λ 4554 was shown by Morgan[3] to increase greatly in strength with increasing luminosity after spectral type F5, while Miss Burwell stated that it was stronger in the spectra of δ CMa and ρ Cas, both type F8 I*a*, than in any other star of known absolute magnitude, aside from stars of classes S and N.[4] Since the neutral barium atom has an ionization potential of only 5.2 e.v., a positive absolute-magnitude effect of the resonance lines of the ionized atom in the late-type stars is to be expected. It is conceivable that the great enhancement of the λ 4554 line in the spectra of the S-type stars and in some of the carbon stars is a natural consequence of the low temperatures and low pressures in these stellar atmospheres.

The stars to be discussed in this paper are a group of G- and K-type stars which show very strong lines of *Ba* II but which, however, do not appear to be supergiant stars. These stars appear to be related to the carbon stars. The existence of this heretofore unstudied group of stars casts considerable doubt on the hypothesis that the strength of λ 4554 in the stars of classes S and N is purely a consequence of ionization and excitation processes taking place in stellar atmospheres in thermodynamic equilibrium.

THE *Ba* II STARS

The objects which we now consider as members of the *Ba* II star group are given in Table 1. Low-dispersion spectra (76 A/mm at $H\gamma$) of the photographic region of these stars are reproduced in Figure 1, together with spectra of a G5 II star, β Scuti, and a K0 III star, ν Ophiuchi. All the *Ba* II stars show, in addition to an abnormally strong line at λ 4554, a definite enhancement of the G band (due to *CH*) and also, probably, of the violet bands of *CN* as well. The lines of *Sr* II at λ 4077 and at λ 4215 [the latter blended with the head of the (0, 1) *CN* band] are also strengthened, the case of ζ Capri-

* *Contributions from the McDonald Observatory, University of Texas*, No. 203.

[1] P. W. Merrill, *Mt. W. Contr.*, No. 306; *Ap. J.*, **63**, 13, 1926.

[2] P. C. Keenan, *Ap. J.*, **96**, 101, 1942.

[3] *Ap. J.*, **77**, 291, 1933.

[4] *Mt. W. Contr.*, No. 598; *Ap. J.*, **88**, 278, 1938.

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corni being notable. In normal stars the increased intensities of the lines of *Ba* II, of *Sr* II, and of the *CN* band would indicate a very high luminosity for these objects; however, the hydrogen lines are not strong enough to permit us to consider these stars as normal supergiants. It is significant in this connection that HR 5058 was classified as a subgiant at the Mount Wilson Observatory.[5] This conclusion concerning the weakness of the hydrogen lines is not quite so certain in the case of ζ Capricorni, which, to judge by the weakness of *Ca* I λ 4226, is the earliest in type; but the correct spectral type of ζ Capricorni is in any case difficult to assess. In short, the stars of this group cannot be fitted into the spectral-class–luminosity-class array defined by the normal stars.

We have obtained higher-dispersion spectra (27 A/mm at $H\gamma$) of the photographic and visual region of all the stars of Table 1 except HD 211594. In their peculiarities these spectra are closely similar. An inspection reveals the following facts in all cases:

A. The lines of ionized barium arising from the first excited levels (e.p. 0.7 and 0.6

TABLE 1

Name	m_v	(1900) α	(1900) δ	λ	β	μ	RV (Km/Sec)	Trig. π	Remarks
HR 774.....	5.92	2^h33^m4	+81° 1′	95°	+20°	0″.070	+24	.....	1
HR 2392.....	6.38	6 28.1	−11 6	188	− 8	.009	.....	.....	2
HR 5058.....	5.25	13 20.3	−39 14	278	+22	.193	+68	0″.007	3
ζ Cap.....	3.86	21 21.0	−22 51	355	−45	.024	+ 3	−0.015	4
HD 211594...	8.3	22 13.1	− 6 21	25	−49	0.024	.....	.....	5

NOTES TO TABLE 1

1. Strong λ 4554 was noted at the David Dunlap Observatory (*Pub. David Dunlap Obs.*, **1**, 311, 1945).
2. The *Henry Draper Catalogue* suggests that this star may be intermediate between classes K and R.
3. Strong λ 4554 was noted at the Mount Wilson Observatory (*Mt. W. Contr.*, No. 511; *Ap. J.*, **81**, 187, 1935).
4. Strong lines of *Sr* II and *Ba* II were noted by Miss Maury (*Harvard Ann.*, **28**, 97, remark 111, 1897).
5. The *Henry Draper Catalogue* suggests that the *CN* absorption is abnormally strong.

volts) are greatly enhanced, as well as those from the ground level; consequently, we are not dealing with a mechanism affecting only the resonance lines.

B. The head of the (0, 0) band of the Swan system of C_2 at λ 5165 shows clearly in the *Ba* II stars, whereas it does not appear at all on similar spectrograms of the many normal stars investigated in this region. The star ζ Capricorni is thus the star of greatest apparent brightness known to show the C_2 bands in appreciable strength.

C. The abnormal strength of the bands of *CH* is very apparent on the higher-dispersion spectrograms. This strengthening is most clearly shown by the increased intensity of a linelike feature at $\lambda\lambda$ 4323–4324, which is almost entirely due to the closely packed heads of the *Q* branches of the (2, 2) band of the $^2\Delta-{}^2\Pi$ system of *CH*.[6] A great many differences between the spectra of the *Ba* II stars and normal stars can be accounted for by the increased *CH* absorption in these objects. Also noteworthy is the weakening of many atomic lines in the violet region of the spectra of the *Ba* II stars, though the effect is not so conspicuous as in the *CH* stars.[2]

In Figure 2 we have reproduced portions of the higher-dispersion spectra of the *Ba* II star HR 774 and of a normal K0 giant, λ Hydrae. In the reproduction of the region of the *CH* bands, the upper spectrum is that of the peculiar star HR 885, in which

[5] *Mt. W. Contr.*, No. 511; *Ap. J.*, **81**, 187, 1935.

[6] L. Gerö, *Zs. f. Phys.*, **118**, 27, 1941.

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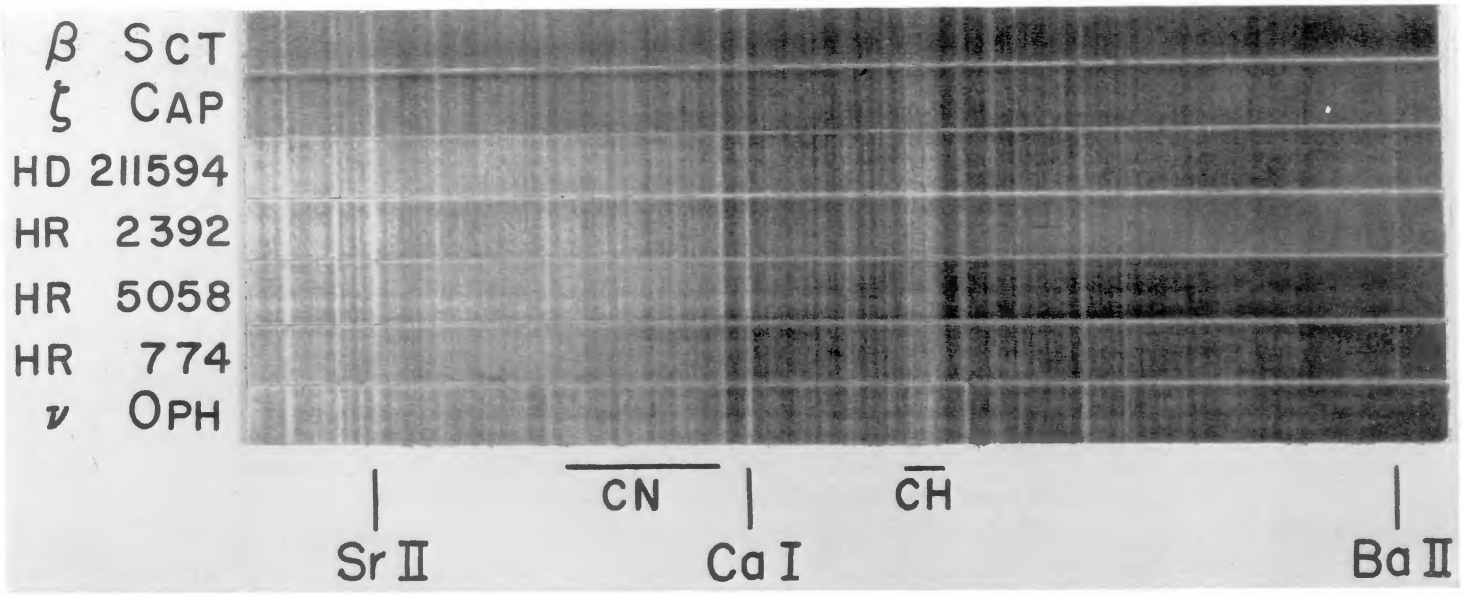


FIG. 1.—The photographic region of the spectra of the *Ba* II stars and of the normal stars, β Scuti, G5 II, and ν Ophiuchi, K0 III

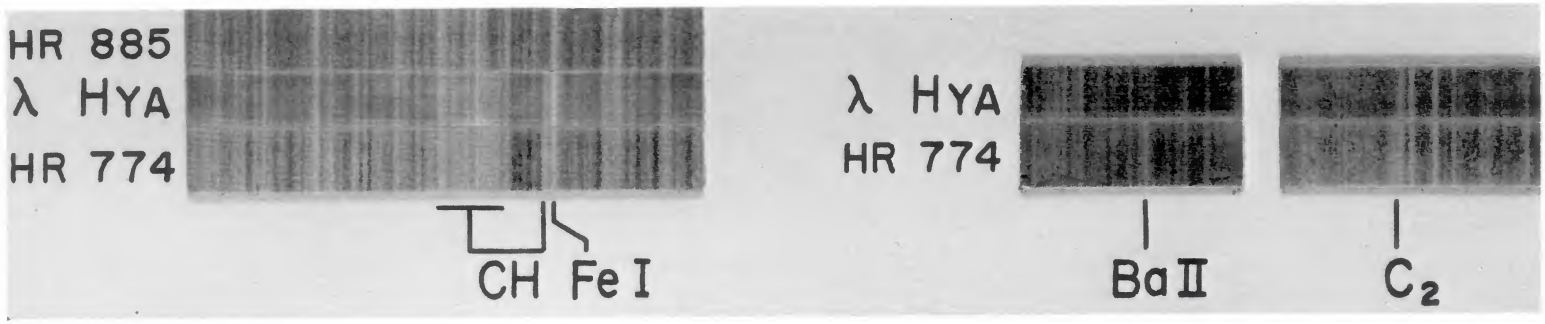


FIG. 2.—Details in the spectrum of the *Ba* II star HR 774. The spectrum of the normal K0 giant star λ Hydrae is shown for comparison, as is also that of the peculiar star showing no *CH* absorption, HR 885. The *Ba* II line reproduced is λ 4554, the C_2 absorption is that of the (0, 0) band at λ 5165.

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no *CH* or *CN* absorption is evident, although the other spectral features would indicate a spectral type of about G5 III.[7] The remarkable absence of *CH* in HR 885 thus represents a departure from a normal spectrum in the opposite sense from that shown by the *Ba* II and the *CH* stars.

For one of the *Ba* II stars, HR 774, the region from λ 7000 to λ 8600 has been photographed with grating dispersion of 48 A/mm. In this part of the spectrum the intensity distribution is about that of a normal G8 or K0 giant, in agreement with the appearance of the blue and yellow regions. The infrared *CN* bands, which belong to the $^2\Pi-^2\Sigma$ system, are strengthened to about the same degree as the blue bands.

The atomic lines in the infrared which are most sensitive to luminosity are the *Fe* I lines and the ultimate doublet of *K* I.[8] In HR 774 the strength of these features is not great and suggests a luminosity not exceeding that of an ordinary giant. Actually, the *Fe* lines may be a little weak even for a giant, for the type assigned on the basis of their absolute intensity would be one or two subdivisions earlier than that given by the *Ti* I lines. A few other infrared lines appear slightly stronger in HR 774 than in a typical K0 giant. Their approximate wave lengths are as follows:

λ		λ	
7484	*La* II ?	7909	Possibly atmospheric H_2O
7895	.....	8511–8512	Blend

THE GENERAL PROBLEM OF THE *Ba* II STARS

1. Two other stars are known which are probably related to the *Ba* II group. The eighth-magnitude high-velocity star HD 26, recently discussed by Keenan and Kellar,[9] is rather similar to the *Ba* II stars. The C_2 and *CH* bands are stronger in HD 26, however, and the suppression of the metallic lines in the violet region of the spectrum is somewhat greater. These facts led to the suggestion that HD 26 may be intermediate in character between the stars of the *Ba* II and *CH* groups. In any case, the resemblance of HD 26 to the *Ba* II stars is of considerable importance, since the very high proper motion of HD 26 ($\mu = 0''.258$ per year) suggests an upper limit of its luminosity near visual absolute magnitude zero. This fact offers rather conclusive proof that the enhancement of the *Sr* II and *Ba* II lines in that star is not due to normal ionization effects, and it strengthens our similar conclusion in the case of the *Ba* II stars. On the other hand, it must be kept in mind that HD 26 is a star of very high velocity, while the data of Table 1 suggest that the space motions of the *Ba* II stars are more moderate.

Another related star is the cooler object, HD 121447, which has generally been considered an S-type star, although the *ZrO* bands do not appear on recent spectrograms of low dispersion. HD 121447 does show *CH* and *CN* bands which are abnormally strong for its equivalent spectral type, which may be estimated at about M0. The line λ 4554 of *Ba* II is extremely intense in this star. Thus HD 121447 could be considered a cooler member of the *Ba* II group and perhaps a connecting link between these and the S-type stars.

2. The abnormal strength of the bands of C_2, *CH*, and *CN* in the *Ba* II stars appears to imply a carbon abundance in their atmospheres intermediate between that of the normal stars and that of the carbon-star group. Because the C_2 sequence starting at λ 4737 is not strong in the *Ba* II stars, it is not surprising that objects of this sort have not hitherto been found. The reason why an abnormal strength of the lines of *Sr* II and *Ba* II should be associated with an intermediate carbon abundance is obscure. This relationship may be connected with the properties of the *BaO* and *SrO* molecules, the

[7] W. P. Bidelman, *Ap. J.*, **113**, 304, 1951.

[8] P. C. Keenan and J. A. Hynek, *Ap. J.*, **101**, 265, 1945.

[9] *Ap. J.*, **113**, 700, 1951.

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formation of which would certainly be affected by an abnormal carbon abundance. In any case the connection between the *Ba* II stars and the carbon stars is a direct inference from observation. Reasons for thinking that the S-type stars may also be cases of intermediate carbon abundance have been sketched previously by one of us.[10] If this be correct, it would follow that the *Ba* II stars and the S-type stars could be regarded as manifestations of the same abundance anomaly at considerably different temperatures. The essential question is whether the same relative abundances could give the observed *Ba* II star features at the temperature of early K-type stars and also the observed S-type star features at the temperature of the M-type stars. On the theoretical side this question requires further computations of the dissociation equilibria in late-type stars with varying atomic abundances, while on the observational side the next step is the comparative study of the spectra of the *Ba* II stars and the S stars with the highest practicable dispersion.

[10] W. P. Bidelman, *Ap. J.*, **112**, 219, 1950.

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