

POLYATOMIC MOLECULES IN LATE-TYPE STARS*

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ABSTRACT

Some general problems connected with the presence of polyatomic molecules in stellar atmospheres are noted, and, in particular, reasons are advanced in favor of attributing at least part of the intensity drop and fluctuations in the spectra of the N-type stars violetward of λ 4100 to the triatomic molecule CH_2 .

INTRODUCTION

Absorption by polyatomic molecules is detected in the atmosphere of the earth (O_3 , H_2O , CO_2 , CH_4 , N_2O) and of planets (CO_2 , CH_4 , NH_3), while emission bands of the triatomic molecules CH_2 and NH_2 are found in cometary spectra. No polyatomic molecule has heretofore been identified in a stellar atmosphere. Yet triatomic molecules may be abundant in the coolest stars, even under the assumption of thermodynamical equilibrium. H. N. Russell¹ has estimated the abundances of H_2O and CO_2 in giant and dwarf stars of the K-M branch of the spectral sequence and has concluded that in those of latest type the abundance of H_2O is of the same order as that of oxygen or nitrogen atoms. On the other hand, the abundance of CO_2 in a stellar atmosphere is always very small compared with that of oxygen atoms. The greater calculated abundance of H_2O compared with CO_2 is due to the high abundance of hydrogen compared with oxygen and carbon. In actual stellar atmospheres of very late type we may expect H_2O molecules to be even more abundant than would be indicated by Russell's theoretical estimates, since the photodissociating radiation may be absorbed in the lower layers before reaching the coolest outer layers, where the presence of polyatomic molecules would be favored.² The possible presence of another triatomic molecule, HCN , has been suggested by B. Lindblad and E. Stenquist³ in order to explain certain absolute-magnitude effects on the CN bands.

Probably high-dispersion spectrograms would be required in any attempt to detect H_2O in a stellar atmosphere of very late type. The problem is not perfectly straightforward, since, of course, telluric H_2O lines would be present. The effect of radial velocity could be used in separating telluric and stellar lines. Also, on account of the higher stellar temperature, the bands would have an entirely different intensity distribution, and some bands not present in the spectrum of the earth's atmosphere would appear, for which radial-velocity effects need not be invoked. However, on the other hand, the absolute intensities of the additional bands are very small, and it does not seem likely that they would suffice for the detection of H_2O in stellar atmospheres. Two other triatomic molecules containing two hydrogen atoms are CH_2 and NH_2 . Their stellar bands would not be blended by telluric lines, since the amounts of CH_2 and NH_2 in the earth's atmosphere must be very low. Because of the absence of data on the essential physical constants of CH_2 and NH_2 , a calculation of the abundances of these two compounds in the atmospheres of late-type stars is at present impossible. Moreover, as mentioned above,

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¹ *Ap. J.*, **79**, 317, 1934.² P. Swings, *Pub. A.S.P.*, **54**, 232, 1942.³ *Astr. iakt. och und. Stockholm Obs.*, Vol. **11**, No. 12, 1934.

conditions of thermodynamical equilibrium assumed in calculations do not necessarily prevail in the stellar regions of highest molecular abundance.

While any detailed calculation of the abundances of CH_2 cannot be made at present, we may expect it in late carbon stars to reach abundances of the same order as those of H_2O in late-type oxygen stars. Moreover, from the high intensity of the CH_2 emission in comets at large heliocentric distances, one could justifiably assume that the oscillator strength of the band near λ 4050 is not small. Hence the existence of CH_2 in late carbon stars appears to be fairly probable.

THE OBSERVATIONAL DATA AND THEIR DISCUSSION

A recent paper by G. Shajn and O. Struve⁴ brings new observational information on the violet region of the late carbon stars, in addition to that contained in C. D. Shane's pioneering work.⁵ From Shajn and Struve's paper it appears reasonably certain that the sudden intensity drop of the continuous background of the late N-type stars violetward of λ 4100 is due to the effect of molecular bands rather than (or in addition) to a purely continuous absorption. The presence of an absorption band with structure could explain more reasonably why the spaces between absorption lines near λ 4036 and λ 4009 could look like emission lines in the spectrum of the N-type star, UU Aurigae, while the background near λ 4052, which is also free from absorption in M-type stars, does not appear in the N types. It could also explain why the intensity of λ 4072, Fe I, is reduced to a lesser extent than is the neighboring line λ 4063, Fe I. Atomic negative ions or quasi-molecules giving rise to continuous absorption would not be likely to produce the observed structure.

In trying to identify the molecule responsible for the intensity drop and fluctuations in the spectrum of UU Aurigae as described by Shajn and Struve, the following considerations present themselves:

1. The permitted spectra of neutral diatomic molecules, composed of the cosmically abundant atoms, hydrogen, carbon, nitrogen, and oxygen, have been studied extensively in the laboratory, and no known band explains the observed phenomenon. The spectra of the oxides of all abundant elements are well known, and none explains the observed absorption. Moreover, oxides are not likely to be abundant in a late carbon star. Compounds of hydrogen, carbon, or nitrogen with an abundant element may possibly provide the explanation, but no such compound is known to have its strongest absorption system around λ 4050.

2. Forbidden bands (such as the Vegard-Kaplan system) or bands of positive molecular ions (such as N_2^+ or CO^+), which appear in this region, should not be expected to reach any appreciable intensity in a stellar atmosphere.

3. The molecular band responsible for the absorption has no sharply defined head, which otherwise would appear on the stellar spectrograms.

4. The identification problem presents some similarity with that encountered in cometary spectra, where many fruitless attempts were made to attribute the so-called " λ 4050 group" to a hypothetical diatomic molecule.

It seems probable that the absorption in the N stars in the λ 4050 region is due to a polyatomic molecule, just as the " λ 4050 group" of cometary spectra was finally identified with CH_2 . In fact, this same molecule may be at least partly responsible for the depression in the N stars. The absence of a segment of continuous background of the N spectra near λ 4052 could be due to absorption by the strongest CH_2 feature at this wave length. The absence of CH_2 in M stars is, of course, readily understood.

McKellar's investigation of the spectrum of Y Canum Venaticorum in the $\lambda\lambda$ 4100-3950 region⁶ has brought additional and more specific observational information on this

⁴ *A p. J.*, 106, 86, 1947.

⁵ *Lick Obs. Bull.*, 13, 123, 1928.

⁶ *A p. J.*, 108, 453, 1948.

matter. The absorption features which he has observed in Y Canum Venaticorum, the strongest of which is located at λ 4053, appear to coincide in wave length with the CH_2 maxima observed in cometary spectra. The correspondence between the relative intensities of the stellar absorption features and those of the CH_2 emissions in comets is also about as good as may be expected. There are, indeed, numerous reasons why the intensity distribution within the CH_2 absorption bands of an N star could differ from that of the CH_2 emission bands in a comet, e.g., the different rotational temperatures, the different excitation mechanisms (especially the effect of the solar absorption lines on the profile of the CH_2 emission in comets, assuming that the emission bands are produced by the resonance phenomenon), and the differences in relative abundances of C^{12} and C^{13} . A detailed argument must await a more or less complete laboratory analysis of the CH_2 spectrum.

While the identification of CH_2 in late N-type stellar atmospheres, if correct, provides satisfactory solutions to most of the questions raised by the observations in the violet spectral region, there remain one or two apparent difficulties which may be resolved by further observations and by laboratory work on CH_2 . For example, whereas the maximum intensity of the CH_2 bands is in the $\lambda\lambda$ 4070–4000 interval, Shajn and Struve found that for UU Aurigae the H and K lines of Ca II, λ 3968 and λ 3934, exhibited the effects of stronger superposed absorption than did the Fe I and other lines from λ 4078 to λ 4032. Examination of the spectrum of CH_2 as produced in the laboratory by Herzberg⁷ reveals that a fairly diffuse feature of moderate intensity appears about λ 3970, very near the position of the H line of Ca II; but nothing is shown near the K line. In cometary spectra CH_2 emission cannot give information on this point, since, being a resonance phenomenon, it would not be expected to show anything very near λ 3968 or λ 3933 because of the wide and strong Ca II absorption lines in the spectrum of the exciting solar radiation. Hence the greater weakening of the H and K lines compared to the lines from λ 4070 to λ 4000, if firmly established by further observations, does not seem explicable on the basis of CH_2 absorption alone. It would appear necessary to invoke an additional source of opacity.

The presence of a CH_2 feature in the laboratory spectrum at λ 3970 and not at λ 3933 brings forward a further item of interest. If CH_2 absorption is important and if it occurs in the same levels of the atmosphere as the Ca II lines, there should be found a greater weakening of the H line than of the K line. A very slight effect in this direction (reduction of the intensity of H compared to the comparison M-type spectrum by a factor of 6.8 and of K by a factor of 6.5) is shown in the measurements of Shajn and Struve for UU Aurigae. However, the difference probably does not exceed their errors of measurement. More precise and extensive data will be required to provide a positive answer.

It might be noted that the amount by which Shajn and Struve found the intensities of the spectral lines of UU Aurigae decreased in the violet indicated that the weakening of the continuous background of the N-type star compared to its M-type counterpart should have been about 1.6 mag. However, the observed difference in the $\lambda\lambda$ 4100–3900 region was about 4 mag. The question as to whether this large discrepancy arose either from inadequacies in the simple theory of blended lines or in the assumption that it could be applied to the observations in this case was left unanswered. Effects of possible stratification in the atmospheres, especially of the N-type star, and of the choice of the comparison star enter into the problem. Again, more complete and, if possible, more accurate observational material is required before all aspects of the role of CH_2 can be discussed.

As noted earlier, it would be interesting to search for the presence of absorptions arising from NH_2 . The spectrum attributed to this molecule is of the "many-line" type and extends through the yellow and red regions. It has been photographed in the laboratory in emission by various investigators⁸ but, unfortunately, has not been analyzed. There-

⁷ *Ap. J.*, **96**, 314, 1942.

⁸ See, e.g., W. B. Rimmer, *Proc. R. Soc., London, A*, **103**, 696, 1923.

fore, the lines which should appear strongest in absorption cannot be designated with certainty. The strongest group of emission lines appears at $\lambda\lambda$ 5705–5708, 5972–5977, 6295–6302, and 6332. Grating spectrograms (dispersion, 15 Å/mm) covering the red region were available at Victoria for twenty-five N-type stars, including those discussed in the preceding paper. Examination of the plates at λ 6300 and λ 6332 did not show any notable differences between early and late N-type spectra. While, among the multitude of lines present, there are some corresponding closely in wave length to strong NH_2 lines, they cannot be safely identified as NH_2 . We conclude that, to settle the question of the presence or absence of NH_2 band lines, a full and separate investigation, covering various regions of strong NH_2 emission, would be necessary. It would be desirable to include late M-type as well as N-type stars.

From the blue-green down into the violet region of the spectra of some late N-type stars, a number of unidentified molecular absorption bands are found. In some stars (e.g., RY Draconis) they are very strong. McKellar⁹ in a recent study of the bands suggested, among possible carriers of the bands, the molecules TiH or FeH , but attempts to produce TiH bands in the laboratory have not yet been successful. The suggested identification of CH_2 bands for Y Canum Venaticorum brings forward the possibility that the blue-green systems may arise from a polyatomic molecule. It would be interesting to extend present observational material to investigate whether there are any similarities in the behaviors of the blue-green bands and λ 4053 absorption, from star to star. It may be significant that in the spectrum of Y Canum Venaticorum the blue-green bands are present but weak, while the λ 4050 group is of considerable strength, and for RY Draconis the blue-green bands are very strong and the whole region to the violet of λ 4135 is almost completely absorbed.¹⁰

⁹ *J.R.A.S. Canada*, **41**, 147, 1947; *Contr. Dom. Ap. Obs.*, No. 7, 1947.

¹⁰ *Ap. J.*, **108**, 453, 1948.