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 CH₃.

INTRODUCTION

Absorption by polyatomic molecules is detected in the atmosphere of the earth (O₃, H₂O, CO₂, CH₄, N₂O) and of planets (CO₂, CH₄, NH₃), while emission bands of the triatomic molecules CH₃ and NH₃ 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 H₂O and CO₂ 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 H₂O is of the same order as that of oxygen or nitrogen atoms. On the other hand, the abundance of CO₂ in a stellar atmosphere is always very small compared with that of oxygen atoms. The greater calculated abundance of H₂O compared with CO₂ is due to the high abundance of hydrogen compared with oxygen and carbon. In actual stellar atmospheres of very late type we may expect H₂O molecules to be even more abundant than would be indicated by Russell's theoretical estimates, since the photodissociating radiations 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 H₂O in a stellar atmosphere of very late type. The problem is not perfectly straightforward, since, of course, telluric H₂O 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 H₂O in stellar atmospheres. Two other triatomic molecules containing two hydrogen atoms are CH₃ and NH₃. Their stellar bands would not be blended by telluric lines, since the amounts of CH₃ and NH₃ in the earth's atmosphere must be very low. Because of the absence of data on the essential physical constants of CH₃ and NH₃, 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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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 CH₂ cannot be made at present, we may expect it in late carbon stars to reach abundances of the same order as those of H₂O in late-type oxygen stars. Moreover, from the high intensity of the CH₂ 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 CH₂ 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 N₇⁺ 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 CH₂. 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 CH₂ feature at this wave length. The absence of CH₂ in M stars is, of course, readily understood.

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

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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 CH₂ maxima observed in cometary spectra. The correspondence between the relative intensities of the stellar absorption features and those of the CH₂ emissions in comets is also about as good as may be expected. There are, indeed, numerous reasons why the intensity distribution within the CH₂ absorption bands of an N star could differ from that of the CH₂ 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 CH₂ emission in comets, assuming that the emission bands are produced by the resonance phenomenon), and the differences in relative abundances of C₁² and C₁³. A detailed argument must await a more or less complete laboratory analysis of the CH₂ spectrum.

While the identification of CH₂ 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 CH₂. For example, whereas the maximum intensity of the CH₂ bands is in the λλ 4070–4000 interval, Shahj 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 CH₂ 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 CH₂ 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 CH₂ absorption alone. It would appear necessary to invoke an additional source of opacity.

The presence of a CH₂ feature in the laboratory spectrum at λ 3970 and not at λ 3933 brings forward a further item of interest. If CH₂ 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 0.8 and of K by a factor of 6.5) is shown in the measurements of Shahj 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 Shahj 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 λλ 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 CH₂ can be discussed.

As noted earlier, it would be interesting to search for the presence of absorptions arising from NH₂. 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-

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 \AA/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 \( \lambda 6300 \) and \( \lambda 6332 \) 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 wavelength 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. McKellar\(^9\) 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 \( \lambda 4053 \) 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 \( \lambda 4050 \) group is of considerable strength, and for RY Draconis the blue-green bands are very strong and the whole region to the violet of \( \lambda 4135 \) is almost completely absorbed.\(^10\)
