SPECTRA OF THE LATE N-TYPE STARS IN THE ULTRA-VIOLET, VIOLET AND BLUE-GREEN REGIONS

P. Swings, A. McKellar and K. Narahari Rao†*

(Received 1953 June 12)

Summary

Spectrograms of several late N-type stars have been obtained covering the far violet spectral region from λ 4100 to λ 3900. One plate of Y CVn extends the observations into the ultra-violet, radiation being detectable below λ 3500. A list of the wave-lengths of the absorption features and the emission-like spaces between them is given for the interval λ 3400 to λ 4100.

The ultra-violet spectrum of Y CVn is dominated by a series of newly discovered broad absorption bands centred about λλ 3790, 3700, 3595 and 3480, for which no identification is found.

The λ 4100–λ 3900 region of the several late N-type stars exhibits the series of absorption bands previously found for Y CVn, these bands being separated by comparatively sharp regions of background radiation. The λ 4050 group of bands as found in the laboratory and in cometary spectra, currently provisionally ascribed to C_3, is discussed. Comparison of the stellar absorptions with the laboratory and cometary bands is made. While the stellar bands cannot be identified with the others for certain, the previous tentative identification is believed strengthened.

The unidentified blue-green bands characteristic of late N-type spectra, as photographed with moderately high resolution, are found to reveal no rotational structure. Hence the suggestion that they might arise from a diatomic hydride must be abandoned. It is noted that the spectrum of the irregular variable, U Hya, sometimes shows the blue-green bands and, when it does, the λ 4050 group and high opacity in the far violet, associated with late N-type spectra, are also present. When the blue-green bands are absent, the violet bands are also absent and the spectrum is of early N-type. Various considerations are believed to favour a polyatomic molecular origin for the blue-green bands; as for the high opacity in the far violet, it is related to the formation of the molecules responsible for the λ 4050 absorption.

Introduction

The violet and ultra-violet regions of the spectra of the cool carbon stars are notoriously difficult to photograph. This is so particularly for the late N-type stars with which the present paper deals. The spectra of R-type and early N-type stars can be photographed down to λ 3500 by exposures several times as long as for M-type stars of comparable class. However, the later N-type spectra (which are *quite* distinct from the early N-type) fall so rapidly in intensity from λ 4400 and even more extremely from λ 4100 to shorter wave-lengths that the spectra of the brightest stars had not been recorded below λ 3900.

The earlier investigators, for example Shane (1), were well aware that the extreme decrease in intensity toward the violet was much more than expected

* On leave of absence from Institut d'Astrophysique, Liège, Belgium.
† Present address : National Physical Laboratory of India, New Delhi.

from a source at the temperature indicated for late N-type stars, but the agent giving rise to the opacity was not apparent. In 1947 Shajn and Struve (2) photographed the spectrum of UU Aur (N3) to about λ 3900 and by comparing it with an M-type spectrum advanced reasons for supposing the source of extra opacity in the violet and ultra-violet to be at least partly molecular absorptions. In 1948 McKellar (3) described a survey of the spectra of several N-type stars in the λ 4000 region and noted that a well-marked group of absorption bands occurred in the spectrum of Y CVn. The strongest band was at λ 4053, and the group was tentatively identified with the λ 4050 group, long known in emission in cometary spectra and first produced in the laboratory by Herzberg in 1942. The likelihood of occurrence of polyatomic molecules in the atmospheres of N-type stars and their possible role in causing the far-violet opacity in the stellar atmospheres were discussed briefly by Swings and McKellar (4).

In view of the continuing lack of knowledge of the agent or agents responsible for the high violet and ultra-violet opacity of the late N-type atmospheres, and the provisional nature of the identification of the stellar λ 4053 bands with the laboratory λ 4050 group, it was considered important to secure further spectrographic observations of the late N-type stars. Also, it is possible that observations on stellar spectra may prove of value to the laboratory spectroscopists who are studying the interesting problem of the nature of the emitter of the λ 4050 bands.

Spectrographic observations were therefore undertaken to explore the spectra of the late N-type stars as far into the ultra-violet as possible, and to photograph the already recorded λ 3900–λ 4100 region with the highest practicable resolution. Also, as noted below, certain observations of the unidentified blue-green bands have been obtained and are discussed, since they appear to have some relevance to the general subject under investigation.

Observations and Measurements

The observations were made mainly at the McDonald Observatory in 1949 April and May by P. Swings and K. N. Rao, and at the Dominion Astrophysical Observatory by A. McKellar from 1947 to 1950. The stars observed were the brightest available of type N, the earlier N stars being for comparison with the later types. Spectrograms of several M-type stars were also obtained for comparison purposes. The stars observed included RY Dra (N4p), Y CVn (N3), X Cnc (N3), U Hya (N2), VY UMa (Na), 19 Psc (No), RS Cyg (Nope), Z Psc (No) and UX Dra (No). The dividing line between early N-type and late N-type, judged by marked changes in the far-violet spectrum, and by the occurrence of the blue-green bands, is at N2. As will be discussed later, U Hya (N2) sometimes shows an early and sometimes a late N-type spectrum. The M-type comparison stars, of which spectra in the violet and ultra-violet regions were secured at the McDonald Observatory, included 56 Leo (gM5), BD 15° 2620 (dM3), and BD 9° 1633 (M6).

The spectrograms in the far violet were, of necessity, obtained with low dispersion. One such plate of the star Y CVn (vis. mag. 4·8–6·0) obtained by Swings on 1949 April 22 in an exposure of 6 hours 22 minutes, with a quartz spectrograph and *f*/1 camera at the McDonald Observatory, records the spectrum farther into the ultra-violet than yet reported for a late N-type star.

Upon this plate radiation is detectable as far as about λ 3400 (see Plate 5). In addition, several McDonald spectrograms obtained with somewhat higher dispersion show the λ 3900–λ 4100 region in the spectra of Y CVn and RY Dra with superior resolution (see Plate 6).

Certain spectrograms of the region λ 4800–λ 5200, showing the blue-green unidentified bands, were secured with the three-prism spectrograph at Victoria.

Three of the best plates of Y CVn, two plates of RY Dra and one each of U Hya and X Cnc were measured by P. Swings and K. N. Rao. The results of these measurements, extending from about λ 3400 to λ 4100, are given in Table I. This table is necessarily a rather involved one since, in order to describe the spectrograms, wave-lengths must be recorded not only for the absorption bands or lines, but also for the " apparent emissions " which are actually the spaces between absorption features.

The Ultra-violet Region and the New Wide Bands

The appearance of the ultra-violet spectrum of Y CVn as revealed by spectrogram Q *f*/1, 11931 of the McDonald Observatory, already referred to, is shown in the top strip of Plate 5. From about λ 3880 towards shorter wave-lengths, the intensity is sufficiently depressed to suggest general absorption arising from the λ 3883 sequence of violet CN bands, and, indeed, the CN bands may make a contribution. The structure in the λ 3830–λ 3880 region is, however, certainly not the vibrational structure of the CN system; it is much more irregular and similar in general nature to that in the λ 4100–λ 3900 region of the spectrum of Y CVn. Thus we must conclude that the major contributor to absorption in the λ 3830–λ 3880 region is not CN. The region farther into the ultra-violet seems characterized by a series of wide absorption bands (centred about λλ 3790, 3700, 3595, 3480) separated by groups of radiations having almost the appearance of emission lines. The wave-lengths of some of these features are shown on Plate 5, while all that were measurable are recorded in Table I. Spectrograms of the stars RY Dra and U Hya extending weakly as far as λ 3750 show also the existence of the wide absorption centred about λ 3790 and the brighter region near λ 3750.

Several questions arise regarding the new ultra-violet bands. (1) Are the wide absorption bands, or the " apparent emission " regions between them, detectable as such in the spectra of earlier N-type stars or late M-type stars? (2) Are the " apparent emission " features real emissions or simply regions between absorption bands? (3) Is there any obvious identification for the wide absorption bands? Our conclusions on these questions follow.

(1) Along with the spectrum of Y CVn on Plate 5, reproductions are shown from plates of an M-type star and an early N-type star, all obtained with the same spectrograph. These two comparison spectra exhibit no similarity, either in gross or detailed structure, to the spectrum of Y CVn. Additional careful comparisons in the ultra-violet, involving McDonald and Victoria plates of M-, R- and early N-type spectra, as well as reproductions given in Sanford's atlas of spectra of the cool carbon stars (**5**), have indicated no similarities with the spectrum of Y CVn, with the exception of the few coincidences to be expected on the basis of chance. Therefore we conclude that essentially all the prominent features of the ultra-violet spectrum of Y CVn do not occur in

TABLE I

Wave-length measurements on the spectra of late N-type stars in the λ 3380–λ 4150 *region*

IA. *Region* λ 3380–λ 3900 *in the spectrum of Y CVn*

Spectral feature	Absorption maxima	Bright maxima	Notes
Maximum in wide bright background		3380 (1^{-}nn)	
Centre of wide absorption	3418 (2nn)		
Maximum in wide bright background		3455 (1^{-}nn)	
Maximum of wide absorption	3480 (3nn)		
Bright region extending from λ 3535 to λ 3572 with intensity maxima estimated at		3541 (1^{+}) 3550 (1) 3558 (1) 3568 (1^{-})	
and with absorption maxima estimated at	3546 (2n) 3554 (2n) 3563 (2n)		
Deep and wide absorption (extension 60 A), with maximum at	3595 (4nn)		
Bright region extending from λ 3634 to λ 3673 with intensity maxima at		3635·6 (3) 3642·6 (2) 3654·5 (3n) 3671·2 (2)	1
and with absorption maxima at	3639 (3) 3649 (3n) 3663 (3nn)		
Deep wide absorption centred near	3700 (4nn)		
with bright region at		3689·4 (1^{+})	
and secondary absorption centres at	3681 (4n)		
and near	3710 (4nn)		
Bright region extending from λ 3728 to λ 3756 with intensity maxima at		3730·5 (1^{+}) 3741·7 (2) 3753·6 (4)	2
and with absorption maxima at	3736 (4) 3748 (4)		
Deep wide absorption centred near	3790 (5nn)		
extending from λ 3760 to λ 3815, with bright structure near		3810 (1)	3
and maximum absorption at	3806·7 (6)		
Complex region	3825 (4n) 3840 (4n) 3848 (4n) 3858 (4n) 3870 (4n) 3876 (3n) 3886·8 (4s) 3895·7 (2)	3835·7 (3) 3843·8 (3^{-}) 3851·6 (3) 3865·1 (3) 3874·3 (3^{+}) 3877·9 (2) 3890·7 (3)	

IB. *Region* λ3900–λ4150 *in the spectra of Y CVn, RY Dra, U Hya and X Cnc*

Wave-length				Adopted wave-length		
Y CVn	RY Dra	U Hya	X Cnc	Absorption maxima	Bright maxima	Notes
3900·1 (3^+Sn)	01·0 (0S)				3900·1 (3^+n)	
07 (2A)				3907 (2)		
08·7 (1S ?)					3908·7 (0)	
14·3 (3^+S)	14·8 (1S)	16·3 (1S)			3914·6 (3^+)	
19 (3A)	19 (1A)	19 (1A)		3919 (3)		
23·3 (4S)	26·0 (1S)	24·8 (0S)			3923·9 (4)	4
33·4 (3An)		35·4 (1A)		3934 (3n)		5
40·5 (1S)	39·6 (1S)				3940 (1)	
48·1 (5S)	48·4 (3S)	46·3 (0S)			3948·1 (5)	
54 (2A)	53 (2A)	52 (2A)		3953 (2)		
57·9 (6S)	58·0 (4S)	58·0 (0S)			3957·9 (6)	
65 (2As)	65·4 (1A)	65 (2A)	64·4 (2A)	3965 (2)		
69 (0S)	70·3 (0S)		69·4 (0S)		3969·6 (0)	
76 (3An)	76·8 (2A)		76·3 (2A)	3976 (3n)		
82·4 (8S)	82·5 (6S)	81·3 (1S)	83·8 (1S)		3982·4 (7)	
85 (1A)		84·3 (1A)		3985 (1)		
87 (1S)		87·9 (1S)			3987·5 (1)	
94·1 (5An)	94·7 (1A)	92 (1A)	92 (1A)	3994 (5n)		
3999·6 (1S)					3999·6 (1)	
4002 (1A)				4002 (1)		
04 (1S)		03·7 (0S)			4003·9 (1^-)	
06 (1A)		06·6 (1A)		4006 (1)		
10·1 (7Sn)	09·7 (5S)	09·1 (3S)	09·0 (2S)		4009·6 (6n)	
18 (1S)	16 (0S)	17·2 (0S)			4017·1 (1^-)	
19·8 (5An)	20 (1An)			4019·8 (5n)		6
	25·3 (0S)	24·3 (1S)			4024·7 (1)	
		28·0 (0S)			4028·0 (0)	
		30·8 (0S)			4030·8 (0)	
37·8 (4S)		36·1 (3S)	36·6 (2S)		4036·4 (3)	
40 (2A)				4040 (2)		
	42·4 (0S)		41·8 (1S)		4042·1 (1^-)	
		47·5 (1S)	45·3 (1S)		4046·8 (1)	
53·2 (7A)	52·2 (6A)	52·5 (2A)	53·8 (2A)	4052·8 (6)		
62·1 (0S)	65·4 (1S)		65·9 (1S)		4064·5 (1)	
4075·1 (3A)	75·4 (1A)		75·1 (3A)	4075·2 (3)		7
	89·7 (0A)		87·4 (0A)	4088·6 (0)		
4102·2 (2A)	04·0 (1A)	02·3 (2A)	01·8 (1A)	4103·1 (2)		
		12·2 (0A)		4112 (0)		
		24·7 (0A)		4125 (0)		
		29·4 (0A)		4129 (0)		
	32·4 (0A)	34·9 (0A)		4134 (0)		
	44·8 (0A)			4145 (0)		

NOTES

n, wide. nn, very wide. A, absorption. S, bright region (space between absorptions).

1 : probably double.

2 : possibly with longward emission wing.

3 : accompanied by a sharper absorption feature at 3806·7.

4 : perhaps double.

5 : probably Ca II absorption line.

6 : In the spectrum of X Cnc a double absorption line was measured at λ 4016 (2A) and λ 4027 (2A) with a bright maximum at λ 4021.

7 : In the spectrum of U Hya the absorption line is double at λ 4073·4 (1A) 4076·8 (2A) with a bright maximum at λ 4074·8. For Y CVn a weak absorption appears at 4079·0 (0A).

R-type, early N-type or M-type spectra, but are characteristic of late N-type spectra.

(2) As will be described in more detail in discussing the λ 4050 region, the apparent emissions are undoubtedly only regions of the stellar spectrum showing through between absorption bands and, despite their appearance, are not emission lines.

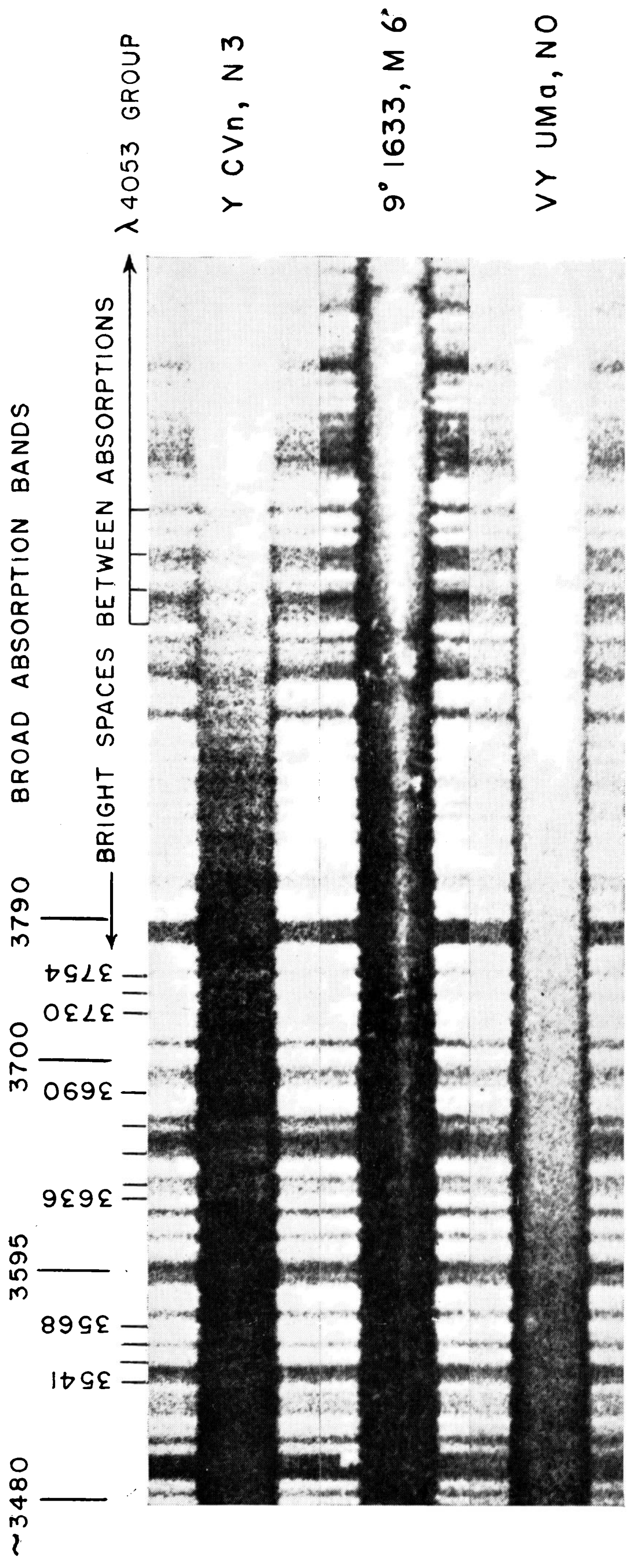
(3) The wide absorption bands, which on the one available plate seem possibly to be slightly shaded toward shorter wave-length, do not correspond, in so far as we can determine, to any set of bands yet produced in the laboratory.

The λ 4050 Wave-length Region

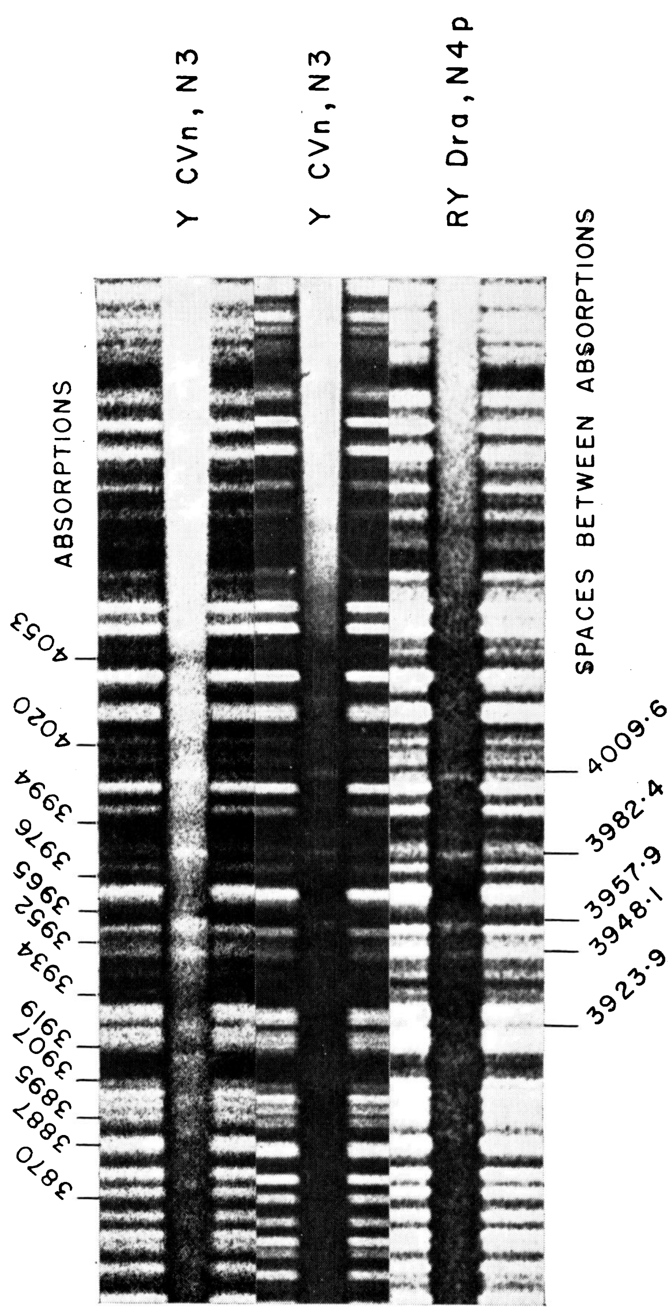
The region of wave-lengths λ 3900 to λ 4100 in the spectra of the late N-type stars will be called the λ 4050 region both for brevity and also because of the possible connection of the absorption bands appearing in this region with the well-known λ 4050 group of cometary bands. Considerable work on the λ 4050 bands has been done in recent years by laboratory spectroscopists. We shall describe briefly the cometary and laboratory bands, then the stellar bands, and examine the question of whether they are the same group or system.

The λ 4050 group of cometary bands.—The λ 4050 group of emission bands in cometary spectra has been known since the beginning of the century. The strongest band is centred at λ 4051 and the other more prominent bands occur at about λλ 3992, 4014, 4020, 4039, 4043, 4069, 4074 and 4100. With the low dispersion required for photographing cometary spectra, the bands show neither well-defined heads nor uniform shading either to red or violet, but rather appear as a group of semi-headless bands, the intensities of the individual bands decreasing with distance from the main band at λ 4051. The extent of the band in space from the cometary nucleus is greater than that of CH, but not as great as CN or C_2. The intensity of the λ 4050 group relative to the CN and C_2 bands is greater at larger heliocentric distances (>1 astronomical unit) than at smaller heliocentric distances. This, on currently accepted ideas of the increase of photo-dissociation and photo-ionization of cometary gases with decreasing heliocentric distance, is suggestive of a polyatomic rather than diatomic origin for the bands. The several attempts by various investigators prior to 1940 to account for the group as CH Raffety bands, CN tail bands, etc. gave unacceptable results.

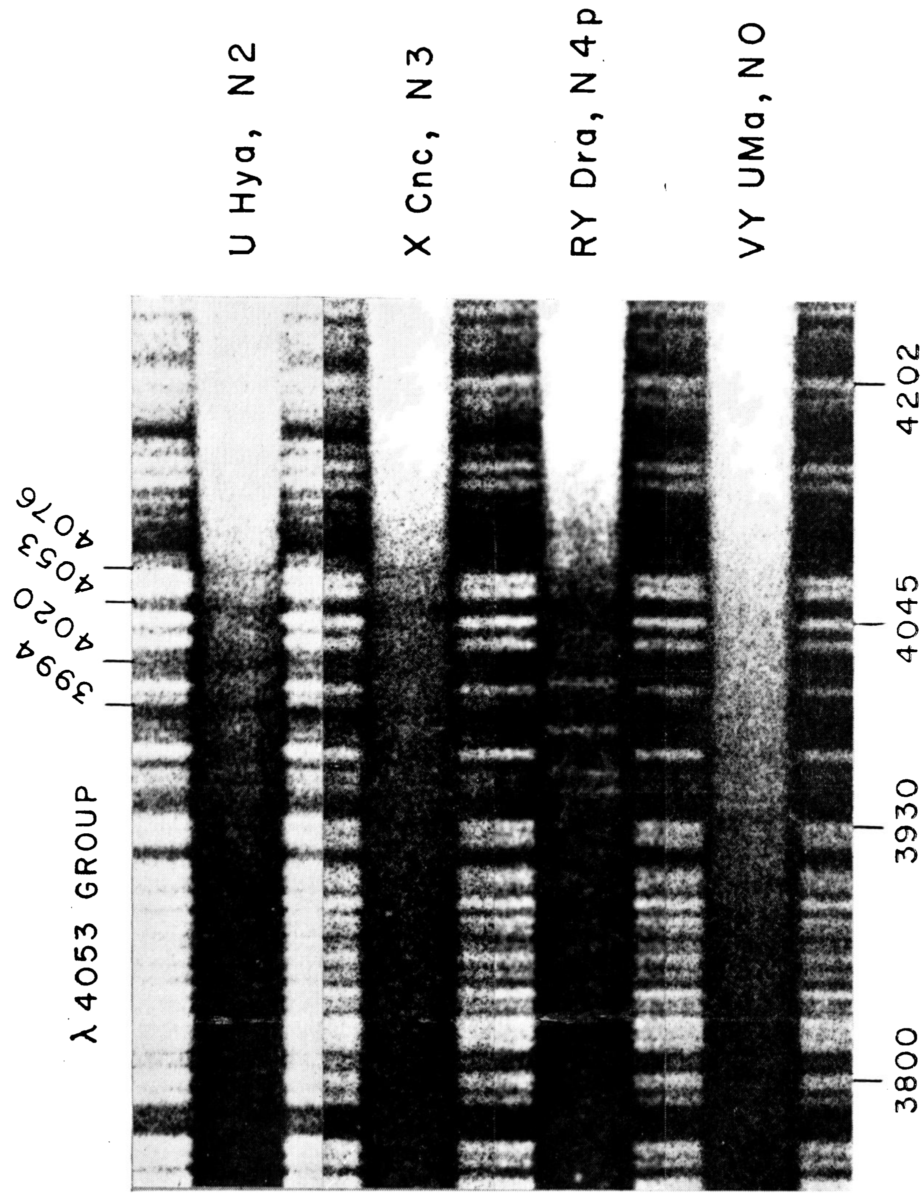
The λ 4050 group of bands in the laboratory.—In 1942, Herzberg (**6**) produced in the laboratory a set of bands undoubtedly identical with the cometary λ 4050 group. These bands were excited by an interrupted discharge in a rapidly moving stream of methane, and what appeared to be good reasons were advanced for attributing the bands to the molecule CH_2. In the years immediately following 1942, while Herzberg did secure spectrograms of the λ 4051 band with a 21-ft. grating and was able to distinguish Q- and R-like branches, attempts to obtain the system in absorption and to analyse it in detail met with little success. From 1946 onward, more intense sources of the λ 4050 bands were developed by Mme Herman (**7**), by Goldfinger, LeGoff and Letort (**8**), by Monfils and Rosen (**9**) and by Etienne (**10**). These sources allowed the bands to be photographed more easily with higher dispersion, but did not enable a vibrational analysis or a complete rotational analysis to be made. The results



P. Swings, A. McKellar and K. Narahari Rao, Spectra of the late N-type stars in the ultra-violet, violet and blue-green regions

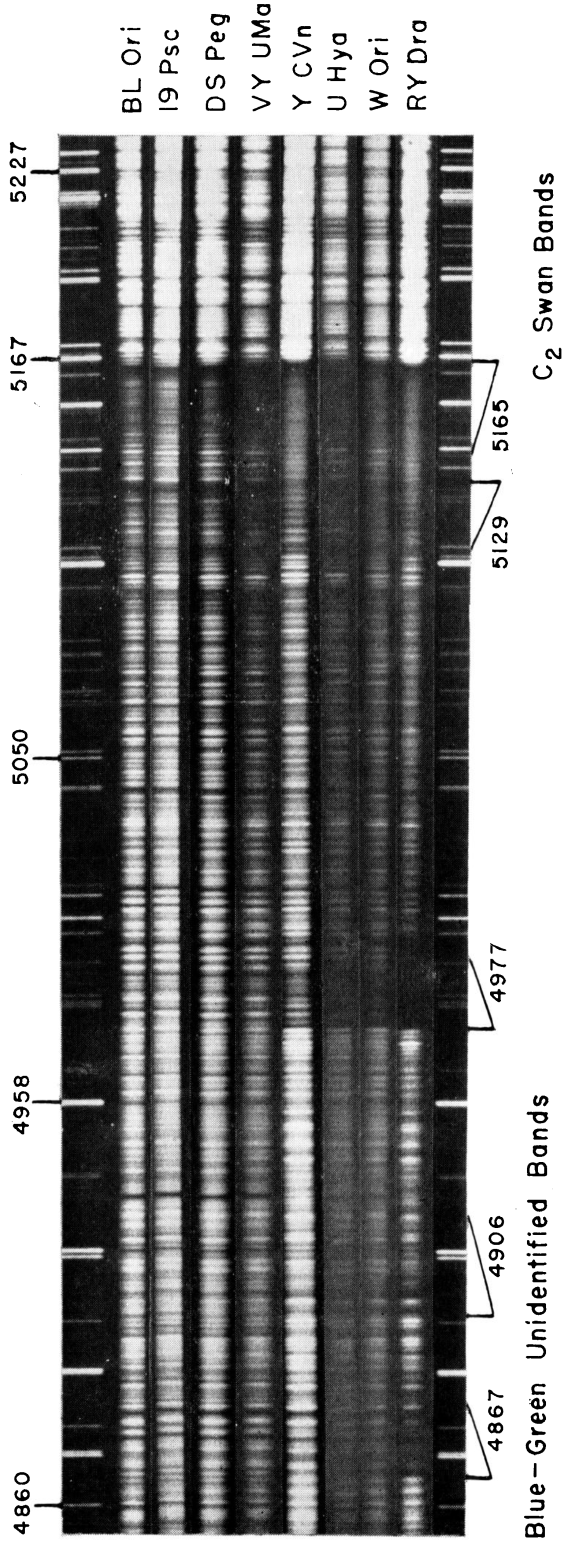


P. Swings, A. McKellar and K. Narahari Rao, Spectra of the late N-type stars in the ultra-violet, violet and blue-green regions

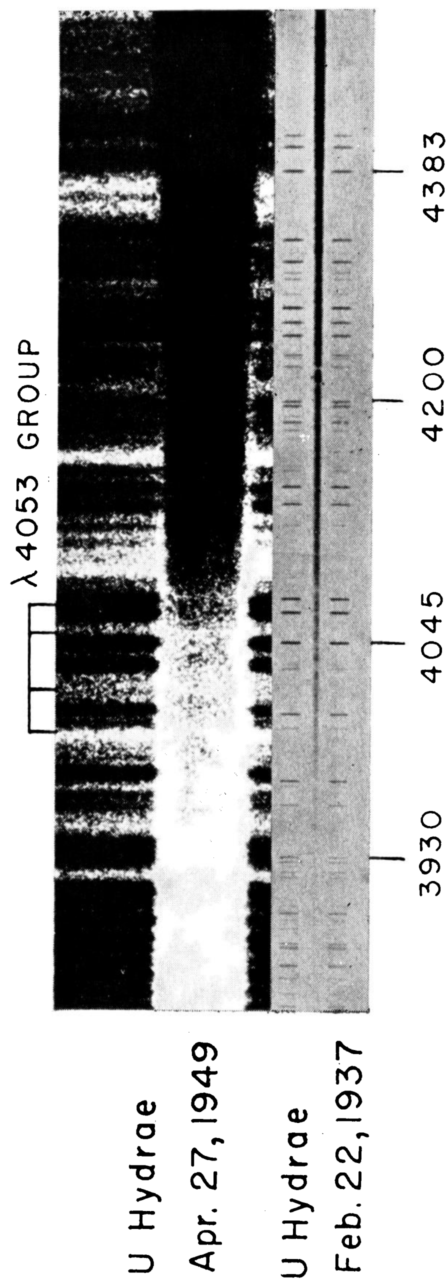


P. Swings, A. McKellar and K. Narahari Rao, Spectra of the late N-type stars in the ultra-violet, violet and blue-green regions

THREE-PRISM SPECTROGRAMS OF EIGHT N-TYPE STARS



P. Swings, A. McKellar and K. Narahari Rao, Spectra of the late N-type stars in the ultra-violet, violet and blue-green regions



P. Swings, A. McKellar and K. Narahari Rao, Spectra of the late N-type stars in the ultra-violet, violet and blue-green regions

of Monfils and Rosen were of particular importance. They found that when deuterium was substituted for hydrogen in their hollow-cathode source, the structure of the λ 4050 band remained unaltered. This showed that the emitting molecule could not contain hydrogen, therefore could not be CH_2. Douglas (**11**), using the type of source developed by Mme Herman, repeated the experiment of Monfils and Rosen and verified their conclusion. He went further by using in the source a mixture of the carbon isotopes ^{12}C and ^{13}C. This caused the structure of the λ 4051 band to become very complicated, the single main head now becoming one of six heads; the emitting molecule thus was shown to contain probably more than one atom of carbon. Douglas was able to suggest a rotational analysis of the λ 4051 band. At this stage, the possibility that the λ 4050 group might arise from the triatomic molecule C_3 was considered by various investigators interested in these bands*; this suggestion was stated in several lectures by Swings (**12**) in 1951 and was recorded also by Douglas (**11**). Probably the most convincing evidence of this identification to date is the occurrence of the six band heads when a mixture of ^{12}C and ^{13}C is used; the bands would correspond to the six possible isotopic species of C_3. Douglas hopes to secure enough pure ^{13}C to test more rigorously whether the emitter is a linear C_3 molecule. The latest development is the production of the $\lambda\lambda$ 4051 and 4074 bands of the group in absorption by Norrish, Porter and Thrush (**13**), who found the bands in the absorption spectrum of the gaseous mixture resulting from an oxygen-acetylene explosion induced by ultra-violet light. The experiment has been repeated at Ottawa by D. A. Ramsay, who has photographed the λ 4051 absorption band using a 21-ft. grating, and has shown (**14**) the band to be the same, line for line, as its emission counterpart. The production of the λ 4050 group in absorption is important astrophysically since it verifies that the group arises from the normal state of its emitting molecule; this is in keeping with the presence of the bands in cometary spectra (resonance-fluorescence) and gives some support to their suggested presence in the spectra of the late N-type stars.

The present status of the λ 4050 group of bands may be summarized as follows: it has been produced and photographed with high dispersion in the laboratory, both in emission and absorption; there is as yet no vibrational and only an incomplete rotational analysis; the most likely assignment is to an electronic transition from the ground state of a linear or nearly linear C_3 molecule; there is no doubt that the laboratory and the cometary bands are the same.

After describing the absorption bands in the λ 4100–λ 3900 region of the spectra of the late N-type stars, we shall try to decide whether they are actually the λ 4050 group described above.

The λ 4050 group of bands in late N-type stellar spectra.—The appearance of the λ 4100–λ 3900 region in the spectra of the late N-type stars is shown in Plates 6 and 7. Plate 7 illustrates in particular how the three late N-types differ from the early N-type spectrum of VY UMa. Here, as well as in the ultra-violet, the regions between some of the absorptions are so narrow, and so

* One of the authors (A. McK.) was in a particularly favourable position to know the history of the proposed assignment of the λ 4050 bands to C_3. He visited Drs G. Herzberg and A. E. Douglas in Ottawa in 1950 June, at which time the possibility of the C_3 identification was discussed, He also, during 1950, was in correspondence with Dr P. Swings who, with his group in Liège. had independently, on both astronomical and laboratory grounds, considered the same identification, and who suggested, in analogy to oxygen, the descriptive name " carbozone " for C_3.

resemble emission lines, that it seems necessary to establish whether they are, in fact, emission lines or merely narrow zones of radiation escaping between absorption features. The whole spectrum from λ 4100 to the ultra-violet was carefully examined. It was verified that the bright regions did not correspond to known permitted or forbidden atomic or molecular transitions. To examine whether they might arise as some molecular fluorescence pattern, a search was made among their frequencies for coincidences in wave-number interval; only three coincidences were found and were more directly explained as spaces between absorptions of similar band groups. Furthermore, comparison of the late N-spectra with M-, R- and early N-types showed that those bright regions did not, to any significant extent, correspond to wave-lengths between absorption lines or bands characteristic of these types. Therefore all the evidence pointed toward the bright lines being primarily narrow regions of radiation escaping between absorption features characteristic of the late N-type spectra.

The absorption bands in the λ 4050 region in the spectra of Y CVn, RY Dra and U Hya were compared with the λ 4050 bands as measured in cometary spectra. The positions of the emissions of the λ 4050 group in cometary spectra were plotted on enlarged prints of the stellar spectra, and it was found that all such emissions fell in the regions of N-type absorption. Furthermore, there was an overall similarity in the appearance of the bands for the two sources, which might not even be anticipated in view of the different means of excitation in the two cases. From the wave-length measurements there is an apparent tendency for the cometary bands to fall at slightly shorter wave-lengths than the stellar bands; this might be expected since the excitation in the comet corresponds probably to a few hundred degrees while that in the stellar atmosphere to 1 000°–1 500 °K. The present data seem, therefore, to strengthen the case for the identity of stellar and cometary λ 4050 groups.

The absorption in the λ 4050 region of the late N-type stars was next compared with the laboratory bands. The average wave-length of the main band in the stellar spectra, λ 4052·8, falls between one and two angstroms to the violet of the maximum of intensity in the Q-branch of the laboratory band, which extends from the P-branch head at λ 4049·77 to about λ 4065. (See reproduction by Douglas (**11**).) This measured stellar wave-length, when suitable cognizance is taken of the probably lower excitation temperature of the stellar compared to laboratory bands, and of the ^{13}C isotopic shift to shorter wave-lengths, demonstrated by Douglas, together with the presence of bands involving ^{13}C in the spectra of the N stars, seems to be about where the maximum of the band should occur. Similarly for comparison with cometary spectra, the wave-lengths of the other laboratory bands were plotted on enlargements of the stellar spectra. Again the general agreement was good, the only apparent inconsistency being that a group of laboratory lines near λ 4036·2 falls near a bright region in the stellar spectrum at λ 4036. Perhaps this one apparent difficulty may arise because of the different excitation conditions; this cannot be checked until an analysis of the λ 4050 group is available.

Taken altogether, the evidence in favour of the identity of the stellar and laboratory λ 4050 group is fairly strong. Therefore, while our conclusion cannot yet be taken as certain, we are of the opinion that the stellar bands are the same as the laboratory λ 4050 group. If so, and if the currently favoured identification of the bands is correct, the C_3 molecule occurs in the atmospheres of the late N-type stars, as well as in the comets and in laboratory sources.

The Unidentified Blue-Green Bands

The blue-green unidentified bands present in the spectra of certain of the coolest carbon stars were brought into the present investigation because of their possible relation to the violet and ultra-violet bands.

It has long been known that the presence of the blue-green bands distinguished late N-type stars from the earlier subtypes. At the time of the discovery of the λ 4977 band by Merrill (**15**) in 1926, a study of the bands in the λ 4800–λ 5000 region was made by Sanford (**16**). Two years later a similar and related group of bands was found by Shane (**1**) in the λ 4540 to λ 4640 region. The most recent investigation of the bands, in which further members were found in the λ 4260–λ 4350 region, was carried out by McKellar (**17**) in 1947. The molecule responsible for the bands is still not known. A provisional vibrational analysis given indicated that the bands could be assigned to two systems, one strong and the other weaker. The vibrational constants found were in some respects suggestive of a hydride origin, which would mean that the bands should have an open rotational structure. To investigate this point, three-prism spectrograms of several stars, of early and later N-type, were secured at Victoria with dispersion 20 A/mm at λ 5000. Examples of these spectrograms are shown in Plate 8, where the reproductions are arranged in order of increasing strength of the unidentified bands. On the lower spectrograms the heads of the bands at $\lambda\lambda$ 4977 and 4867 are clearly seen.

Careful comparison of the spectra showing the unidentified bands with the earlier N-types, where the bands do not occur, failed to show any differences that could be ascribed to rotational structure of the bands. Yet, as may be seen on Plate 8, the Swan band of C_2 at λ 5165 shows resolved structure at some distance from its head. The conclusion is that the unidentified bands do not have as open a structure as the C_2 bands. Thus they almost certainly do not arise from a diatomic hydride molecule. If their source is a diatomic molecule, it must be a heavy one. There are arguments against a diatomic molecule as the source, one being that the longer wave-length bands of the pairs are the more intense, which is difficult to understand. In view of the polyatomic origin of the λ 4050 group of bands, we favour a polyatomic molecule as the source of the unidentified blue-green bands.

Probable Relation between New Ultra-violet, λ 4050 and Blue-Green Bands

In considering possible identifications for the new ultra-violet, the λ 4053 and the blue-green bands, an interesting set of wave-number coincidences was found. When the λ 4053 band was taken as a central fixed point, and the wave-numbers of the blue-green and of the ultra-violet bands considered with respect to it, five fairly equal intervals were found, varying between that from the λ4053 to the λ4352 and λ3790 bands ($\sim$1700 cm^{-1}) and that from the λ4053 to the λ4977 and λ3418 bands ($\sim$4580 cm^{-1}). At first we were inclined to think that these coincidences might have some significance, such as being suggestive of a common origin for all three groups of bands. Various difficulties in this interpretation, both theoretical and observational (such as the non-occurrence of the other groups along with the λ 4050 bands in the laboratory) led us to abandon it for the present. If, however, the wave-number coincidences are significant, this fact will probably eventually be shown by laboratory results.

An interesting observational fact came to light, however, for the star U Hya (N2). While Sanford's atlas of spectrograms of R- and N-type spectra (5) showed the blue-green unidentified bands not present, the Victoria three-prism plate showed them present with considerable strength (see Plate 8). Therefore a search was made through the available spectrographic material at the McDonald, Mount Wilson and Victoria Observatories, to compare the behaviour in the blue-green and the λ 4050 regions. We are grateful to Dr T. L. Page of the McDonald Observatory, and Dr A. Deutsch of the Mount Wilson and Palomar Observatories for their kind cooperation in obtaining spectrograms of U Hya.

The results of this investigation are summarized in Table II. From this table it can be seen, so far as can be concluded from the rather scattered data, that when the blue-green bands are present in the spectrum, so also are the λ 4050 bands, and the light decreases rapidly toward the violet. The spectrum then is of late N-type. When, however, the blue-green bands are absent, so also are the λ 4050 bands, and the spectrum resembles that of an early N-type star. Spectrograms of U Hya are shown in Plate 9, where the upper reproduction, from a McDonald plate, shows a late N-type spectrum, and the lower, from a Mount Wilson plate, is of early N-type.

TABLE II

Occurrence of the blue-green bands and the λ 4053 group in the spectrum of U Hydrae

Date	Photographic magnitude*	Intensity of blue-green bands	Intensity of λ 4053 group	Observatory
1914 Apr.	8·65	strong		Mt. Wilson
1923 Feb.	8·50	present		Mt. Wilson
1937 Feb.–Apr.	8·90	absent	absent	Mt. Wilson
1939 May	8·25	absent		Mt. Wilson
1941 Mar.–May	8·10–8·50 (7)	absent		Victoria
1943 Apr.	8·65–9·25 (3)	absent		Mt. Wilson
1944 Feb.	8·20	absent		Victoria
1949 Jan.–May	8·30–9·35 (10)	strong	strong	McDonald and Victoria
1950 Apr.	8·45–8·85 (4)	strong		Victoria
1951 Feb.–Mar.	8·30–8·65 (3)	strong	strong	Mt. Wilson and Victoria

* Magnitudes from Dr S. Gaposchkin's estimates. Where there were determinations on several days in the interval, the range is given, and the number of estimates is shown in brackets.

An attempt was made to relate the occurrence of the bands to the varying brightness of U Hya. A series of estimates of the brightness of the star at and near the times of spectrographic observations was provided by Dr S. Gaposchkin of the Harvard College Observatory, to whom we wish to record our thanks. Gaposchkin's estimates show that U Hya is an irregular variable, with a range in photographic magnitude from 8·1 to 9·4. Changes in brightness of several tenths of a magnitude can take place in a day or two. There is no apparent correlation between the brightness of the star and the occurrence of the bands, on the basis of our present data.

We are able to conclude that the occurrence of the blue-green bands and of the λ 4053 group, and the sharp increase in far-violet opacity can be linked together. This does not solve the problem of the identifications of the molecules responsible for any of the bands. It does, however, show that the change occurring in the atmosphere of the star, causing the alteration from early to late N-type spectrum, gives rise to absorption both in the blue-green and λ 4053 bands, and strongly suggests that the increased opacity in the far violet and ultra-violet is closely related to the formation of the molecules responsible for the λ 4050 absorption.

Conclusions

The results of our investigation may be summarized as follows.

(1) A series of wide deep absorption bands was found in the ultra-violet region (λ 3800–λ 3400) of the one spectrogram of Y CVn extending into this region.

(2) The λ 4053 group of bands and the associated drop in intensity shortward of λ 4100 occur together for all of the several late N-type stellar spectra studied.

(3) The likelihood of the identity of the λ 4053 group of bands with the λ 4050 laboratory and cometary bands is strengthened by the new data, but cannot yet be regarded as certain.

(4) It was not possible to identify the molecule responsible for the ultra-violet bands, but it is felt that the two unidentified sets of bands (ultra-violet and blue-green) may arise from polyatomic molecules.

(5) The behaviour in the spectrum of U Hya of the blue-green bands and the λ 4053 group, and the rapid decrease in intensity in the far-violet region, tend to support the idea that the great opacity of the atmospheres of the late N-type stars in the far-violet region is related to the presence of polyatomic molecules.

Note added in proof (1954 *January*).—In a private communication Dr G. Herzberg has informed us that K. Clusius and A. E. Douglas in Ottawa, by obtaining spectrograms of the λ 4050 bands using almost pure ^{13}C, have conclusively proved their emitter to be the C_3 molecule. (See paper by K. Clusius and A. E. Douglas to be published in *Canadian Journal of Physics*, 1954.)

McDonald Observatory,
Fort Davis,
Texas:
1953 *June* 10.

Dominion Astrophysical Observatory,
Victoria,
British Columbia.

References

(1) C. D. Shane, *L.O.B.*, **13**, 123, 1928.
(2) G. A. Shajn and O. Struve, *Ap. J.*, **106**, 86, 1947.
(3) A. McKellar, *Ap. J.*, **108**, 453, 1948; *Contr. Dom. Ap. O.*, No. 15, 1948.
(4) P. Swings and A. McKellar, *Ap. J.*, **108**, 458, 1948; *Contr. Dom. Ap. O.*, No 16, 1948.
(5) R. F. Sanford, *Ap. J.*, **111**, 262, 1950.
(6) G. Herzberg, *Ap. J.*, **96**, 314, 1942.
(7) R. Herman, *C. R. Acad. Sci.*, Paris, **223**, 280, 1946.
(8) P. Goldfinger, P. LeGoff and M. Letort, *C. R. Acad. Sci.*, Paris, **227**, 632, 1948.
(9) A. Monfils and B. Rosen, *Nature, Lond.*, **164**, 713, 1949.
(10) R. Etienne, Thesis, Liège, 1950 (unpublished).
(11) A. E. Douglas, *Ap. J.*, **114**, 466, 1951.
(12) P. Swings, *La Physico-Chimie des Comètes*, Université de Paris, Les Conférences du Palais de la Découverte, 1951.
(13) R. G. W. Norrish, G. Porter and B. A. Thrush, *Nature, Lond.*, **169**, 582, 1952.
(14) Private communication from G. Herzberg.
(15) P. W. Merrill, *P.A.S.P.*, **38**, 175, 1926.
(16) R. F. Sanford, *P.A.S.P.*, **38**, 177, 1926.
(17) A. McKellar, *J.R.A.S. Can.*, **41**, 141, 1947; *Contr. Dom. Ap. O.*, No. 7, 1947.