THE ASTROPHYSICAL JOURNAL 243:204–212, 1981 January 1

OBSERVATIONS OF C III λλ9701–9718 IN EARLY TYPE STARS

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Received 1980 June 16; accepted 1980 July 14

ABSTRACT

Observations of lines of C III in a sample of O- and B-type stars have been obtained with modern Reticon detectors. The multiplet λλ9701–9718 is in emission in all stars with spectral types earlier than O8. The latest spectral type at which emission is seen in supergiants is B0, while the feature is in absorption in the O9.5 V star σ Ori. The variation of equivalent width with spectral type and luminosity class matches closely the behavior previously observed for C III λ5696. In the O stars with λ5696 in emission, the profile of that line is narrow and symmetric, with no trace of broad emission wings. The λ8500 line is always observed to be in absorption, regardless of the behavior of λλ9701–9718 or λ5696. The observations support model calculations which show that the emission at λλ9701–9718 and λ5696 can be produced in static stars in radiative equilibrium.

Subject headings: stars: early-type — stars: emission-line

I. INTRODUCTION

Emission lines of N III λλ4634, 4640, 4641 and of C III λ5696 are seen in many O- and Of-type stars. Detailed calculations based on plane-parallel non–LTE model atmospheres show that the N III emission is the result of dielectronic recombination to the upper level ($3d\ ^3D$) of the relevant transition ($3d$–$3p$) in a compact atmosphere (Mihalas, Hummer, and Conti 1972). The observed emission can be explained without resorting to temperature inversions, extended atmospheres, or dilute radiation fields.

A similarly detailed analysis of the C III emission has been hampered by the lack of observational data to constrain the model. Two crucial transitions fall in relatively inaccessible regions of the near-infrared. Figures 1 and 2 show energy level diagrams for the singlet and triplet lines of C III. The λ5696 line ($3d\ ^1D$–$3p\ ^1P^o$) is known to appear in emission in most O- and Of-type stars, but only after the advent of modern detectors was it possible to show that λ8500 ($3s\ ^1S$–$3p\ ^1P^o$), which follows the λ5696 transition and might have afforded an effective drain of the population of the $3p$ level, in fact appears in absorption (Mihalas, Frost, and Lockwood 1975). Among the triplet series lines, only λλ4647–4651 ($3s\ ^3S$–$3p\ ^3P^o$) is readily observable, and it is known to be in absorption in all but a few O-type stars (Conti 1973). The important transitions at λλ9701–9718 ($3p\ ^3P^o$–$3d\ ^3D$) fall in a spectral region where, under normal observing conditions, absorption by atmospheric water vapor is strong enough to mask their presence (Mihalas, Frost, and Lockwood 1975). The only published measurement of these lines is a low-resolution spectrum of ζ Ori, which shows that the C III multiplet is in emission (Johnson and Wisniewski 1977) in that star.

The present paper reports measurements of the λλ9701–9718 multiplet in a number of O- and B-type stars. Combined with new and existing observations at λ8500 and λ5696, the data show that the behavior of C III is essentially similar to that of N III and that the observed line strengths are primarily a reflection of atomic physics and not of atmospheric structure.

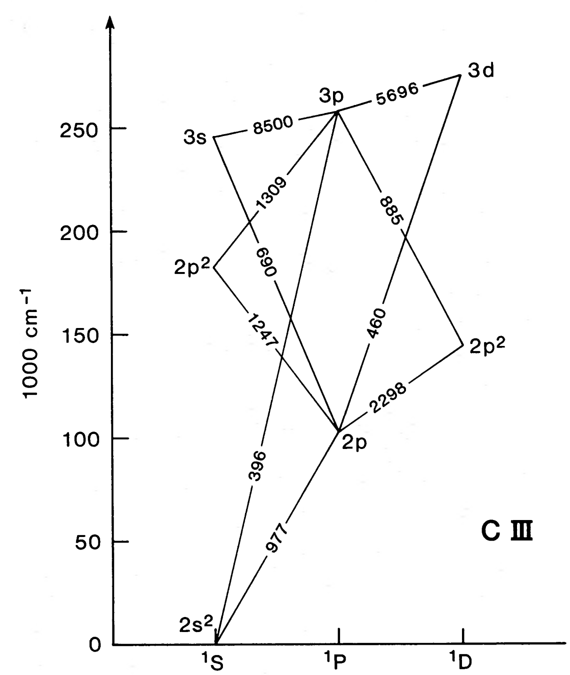

FIG. 1.—Energy level diagram for the singlet series of C III.

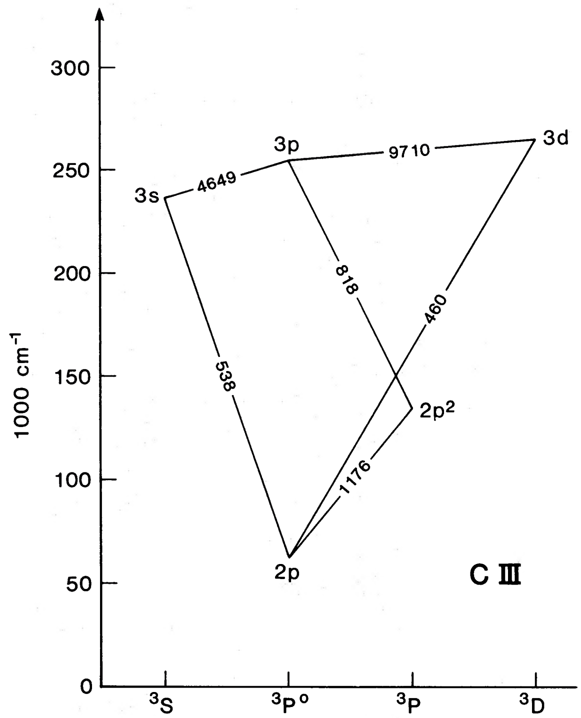

FIG. 2.—Energy level diagram for the triplet series of C III. Note that the multiplet at λ9710 is the analog of the λ5696 singlet line. Also, the λ4649 transition corresponds to the λ8500 singlet feature.

II. OBSERVATIONS

The observations at both Mauna Kea and McDonald were obtained during 1979 September, with Reticon detectors mounted on coudé spectrographs. The Texas observations were made at the 2.1 m telescope, with a grating and entrance slit which gave a spectral resolution of about 0.5 Å. All of the lines in this study, $\lambda\lambda$5696, 8500, 9701–9718, were observed in the first order of the same grating, with a dispersion of 0.14 Å per pixel. The continuous spectrum of a tungsten lamp was used to remove instrumental sensitivity variations, and the wavelength scale was defined by the spectrum of an iron arc. For the λ9700 region, the paucity of iron lines was offset by the abundance of telluric water vapor lines. The Reticon, which was cooled by liquid nitrogen, was maintained at a temperature of $-125°$ C for the λ5696 observations, and at $-100°$ C for the λ8500 and λ9700 exposures. The observations at Mauna Kea were made at the 2.2 m telescope, with a dispersion of 0.067 Å per pixel. The Reticon detector, which was constructed at the University of British Columbia, was also cooled to liquid nitrogen temperature.

In the λ5696 and λ8500 regions, there is no problem with telluric water vapor lines. Rectification and normalization of individual line profiles can thus be accomplished by simply fitting a straight line to the adjacent stellar continuum and dividing the data by this line. The resulting profiles are plotted with a velocity scale for the abscissa, and intensity relative to the continuum as the ordinate. Profiles for several supergiants are shown in Figure 3, and for several main-sequence stars in Figure 4. Equivalent widths were measured with a planimeter and are listed in Table 2. For those stars which were not observed at McDonald, the equivalent widths from Leparskas and Marlborough (1979) or Conti (1974) are listed. The C III line at λ8500 is blended with Paschen 16

TABLE 1

WAVELENGTHS OF LINES OF C III

Multiplet	Transition	λ(Å)	gf
$3p\,^3P^o$–$3d\,^3D$	0–1	9701.10	0.218
	1–1	9706.44	0.163
	1–2	9705.41	0.490
	2–1	9718.79	0.011
	2–2	9717.75	0.163
	2–3	9715.09	0.915
$3s\,^3S$–$3p\,^3P^o$	1–2	4647.42	
	1–1	4650.25	
	1–0	4651.47	
$3s\,^1S$–$3p\,^1P^o$	0–1	8500.32	
$3p\,^1P^o$–$3d\,^1D$	1–2	5695.92	1.03

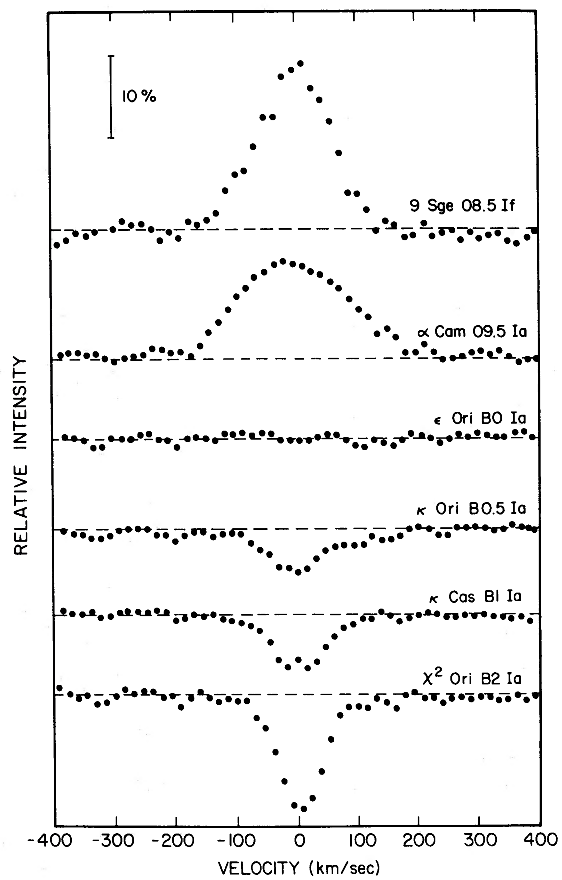

FIG. 3.—The λ5696 line makes an abrupt transition from emission to absorption at spectral type B0 Ia in the supergiants. There are no broad emission wings present in 9 Sge, α Cam, or any of the other stars listed in Table 2.

TABLE 2

SPECTROSCOPIC DATA

HD	Star Name	Spectral Type	$v \sin i$ (km s^{-1})	Equivalent Width (Å)					
				λ9713(MKO)	λ9713(McD)	λ5696	λ8500 (P16 + C III)	λ8467 (P17)	λ8545 (P15)
2905	κ Cas	B1 Ia	62	<0.10	0.45	0.17	0.76	0.31	0.63
24760	ε Per	B0.5 III	153	<0.08		0.17[a]			
24912	ξ Per	O7.5 I	200	0.50E	0.83E	0.30E	0.44	<0.02	0.16
30614	α Cam	O9.5 I	85	0.70E	1.43E	0.48E	0.81	0.27	0.62
36512	υ Ori	B0 V	17	0.45:		0.14[a]			
36861	λ Ori A	O8 IIIf	53	0.69E		0.14E			
37043	ι Ori	O8.5 III	71	0.32E	0.58E	0.13E	0.26	0.06	0.24
37128	ε Ori	B0 Ia	87	0.21E	0.34E	0.00	0.63	0.29	0.52
37468	σ Ori	O9.5 V	94	0.23		0.04[a]			
37742	ζ Ori	O9.5 I	110	0.71E	1.02E	0.26E	0.57	0.23	0.40
38771	κ Ori	B0.5 Ia	82	0.08	0.08	0.13	0.55	0.20	0.42
41117	χ^2 Ori	B2 Ia	36			0.25			
54662		O7 III	70			0.13E			
57682		O9 V	17			0.00			
144217	β Sco	B0.5 V	130	<0.18		0.20[a]			
149438	τ Sco	B0 V	24			0.10			
149757	ζ Oph	O9.5 V(e)	351			0.00			
158296	λ Sco	B1 V	163			0.05			
162978		O8.5 III((f))	50			0.24E			
175191	σ Sgr	B2 V	201			0.02			
188001	9 Sge	O8 If	88		1.25E	0.56E	0.48	0.02	0.29
188209		O9.5 I	70		0.43E	0.25E			
203064	68 Cyg	O8 V	274	0.39E		0.23E			
206267		O6	154			0.11E			
209481	14 Cep	O8.5 III	120	0.57E		0.22E[a,b]			
209975	19 Cep	O9 I	75	0.98E	1.01E	0.25E	0.70	0.15	0.33
210839	λ Cep	O6 f	214	0.48E		0.34E[a]			
214680	10 Lac	O8 III	32	0.41E		0.04			

[a] Data from Leparskas and Marlborough 1979 or Conti 1974.

[b] Double-lined binary.

of hydrogen at λ8502. These lines were never resolved, and the equivalent width in the table is that of the total absorption feature. For reference, the strengths of the adjacent lines in the Paschen series, P15 at λ8545 and P17 at λ8467, are also tabulated.

The observations at λ9700 were made possible by the availability of sensitive electronic detectors and by the extremely dry conditions at both sites. Even with the unusually low humidity, the telluric H_2O lines were still quite strong, especially in the Texas data. Attempts at McDonald to obtain data at this wavelength during several other observing runs were foiled by nearly complete obscuration by the telluric lines, even though the humidity at ground level was not particularly high. The Mauna Kea data show substantially less telluric absorption, even when the local conditions are wetter than average. To facilitate the correction for the lines of H_2O, observations were made of bright standard stars—Vega, Deneb, and Rigel. Every attempt was made to observe the standard and program stars at nearly the same airmass, and at Mauna Kea, the standards were observed both before and after the program stars. The water lines were removed by dividing the spectrum of a program star by that of the corresponding standard. In general, it was necessary to scale the equivalent widths of the lines in the standard star in order to obtain the optimum correction. An example of this procedure is shown in Figure 5.

The shape of the continuous energy distribution in the interval $\lambda\lambda$9600–9800 is very sensitive to the amount of water vapor absorption. Particularly shortward of λ9670 and longward of λ9740 the H_2O lines overlap to such a degree that the continuum level is depressed relative to the intensity in the region of the C III lines. Even in the interval $\lambda\lambda$9710–9717, which includes a portion of the C III multiplet, there appear to be a number of weak lines that distort the energy distribution. Except in those stars for which the total strength of the C III feature is ~ 1 Å or greater, the C III lines are not apparent in the raw spectra of the stars observed here, and this fact accounts for the failure of earlier photographic attempts to detect these lines (Mihalas, Frost, and Lockwood 1975). On dry nights when the atmospheric humidity is stable, the division of the spectrum of the program star by a standard star results in a continuum that is level throughout the observed region ($\lambda\lambda$9653–9775 for the Mauna Kea data), and the C III is then easily measured. Even on nights of variable humidity, for which division of one spectrum by another leaves some variation in the level of the continuum, all but the weakest C III lines are readily detected. Apart from the weak H_2O line at λ9705.6, the region

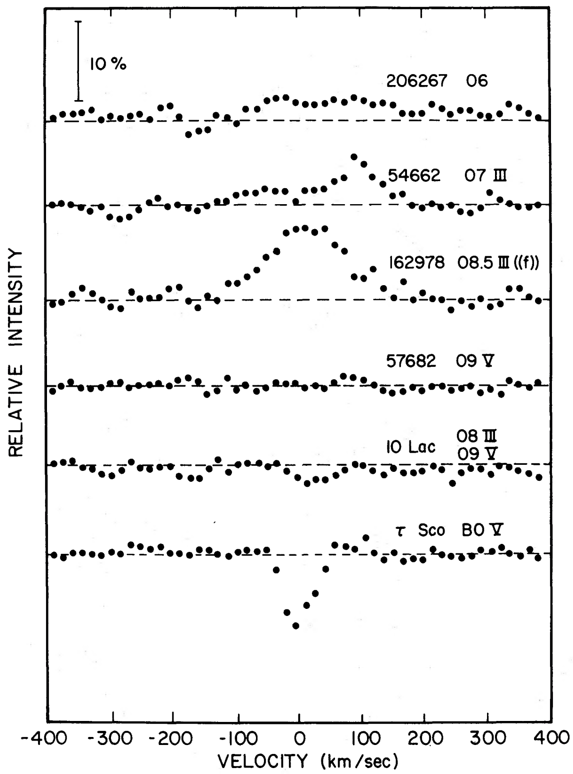

FIG. 4.—Observations of λ5696 in main-sequence and giant stars. Note that the transition from emission to absorption occurs at spectral type O9 V.

λλ9702–9708, which includes two of the transitions in the C III multiplet, appears to be fairly free of water vapor absorption.

To ensure that all of the emission present was measured, the continuum was established at points 250 km s^{-1} (λ9693 and λ9727) from the positions of the extreme members of the multiplet, which fall at λ9701 and λ9718. The equivalent widths measured for the entire multiplet of C III are listed in Table 2. The results from McDonald and Mauna Kea are given separately as an indication of the uncertainty of the measurements. The values of the apparent rotational velocities $v \sin i$ for the O-type stars are from the work of Conti and Ebbets (1977) and for the B-type stars from the catalog prepared by Uesugi (1976).

In most of the stars observed, two components are clearly present in the interval λλ9701–9718. One includes the lines at λλ9701, 9705, and 9706; the other consists of lines at λλ9715, 9718, and 9719. The second is the stronger of the two, as one would expect from the *gf*-values. In 10 Lac, which has the lowest rotational velocity of the stars observed here, three components are observed, with the line at λ9701 being clearly resolved from those at λ9705 and λ9706. Three separate components are also seen in ε Ori, and the line at λ9701 is partially resolved in 19 Cep and λ Ori A. In λ Cep, the two main components of the multiplet are not resolved at all, and the emission intensity is only 1.5% above the level of the continuum. The equivalent width measured for this star is therefore quite uncertain.

The results from the two observatories are in excellent agreement concerning whether the C III multiplet is in emission or absorption, and they also yield the same relative strengths for the lines. There is a systematic disagreement in the absolute line strengths in the sense that the McDonald equivalent widths average 1.4 times larger than the Mauna Kea measurements for the seven stars in common. Two of the differences exceed the uncertainties of measurement by a significant margin. For α Cam the McDonald measurements show strong emission that rises nearly 10% above the continuum, while the Mauna Kea data show a feature that is only 4% above the level of the continuum. In the case of κ Cas, measurements at Mauna Kea on three different nights fail to detect any feature at all, although the McDonald observations show fairly strong absorption. While these differences may reflect real variability, there is no evidence for comparable changes in λ5696 (Leparskas and Marlborough 1979). On the other hand, the Hα emission is known to vary substantially, both in strength and profile, on a time scale of days (Ebbets 1980) in both of these stars. Apart from these two stars, the systematic difference between line strengths obtained at the two observatories probably reflects the difficulty of measuring such broad features. Since the multiplet extends over ~ 20 Å, a 1% error in placing the continuum corresponds to an error of 200 mÅ in equivalent width, a value equal to about 40% of the typical line strengths.

The one previously published measurement of λλ9701–9718 yielded a value of 0.72 for ζ Ori (Johnson and Wisniewski 1977). This result compares favorably with the equivalent widths of 0.71 (Mauna Kea) and 1.02 (McDonald) presented in Table 2.

The equivalent widths of λ5696 are plotted in Figure 6. Similar results have been discussed in some detail by Leparskas and Marlborough (1979) and by Cardona-Nunez (1978), and will be only quickly summarized here. For supergiants, the line is strongly in emission at types O9.5 Ia and earlier. There is a rather abrupt transition to absorption between O9.5 Ia and B0.5 Ia with the feature completely absent at B0 Ia. The absorption strengthens toward later spectral types, although a blend with an Al III line also contributes in the cooler stars. In the main-sequence stars the transition from emission to absorption occurs at a somewhat earlier spectral type. Emission is present earlier than spectral type O9 V, and a weak absorption is seen between B0.5 V and B2 V.

The λ8500 line is always in absorption, regardless of the appearance of λ5696, a result which is in complete agreement with the findings of Mihalas, Frost, and Lockwood (1975). As mentioned earlier, the C III line is inextricably blended with the hydrogen line P16, so we must be sure that the total observed equivalent width is greater than that which would be produced by P16 alone. Several other hydrogen lines were recorded on the same exposure, and their equivalent widths decrease monotonically with increasing upper level quantum number. The exception is the λ8500 feature, whose strength is about 3

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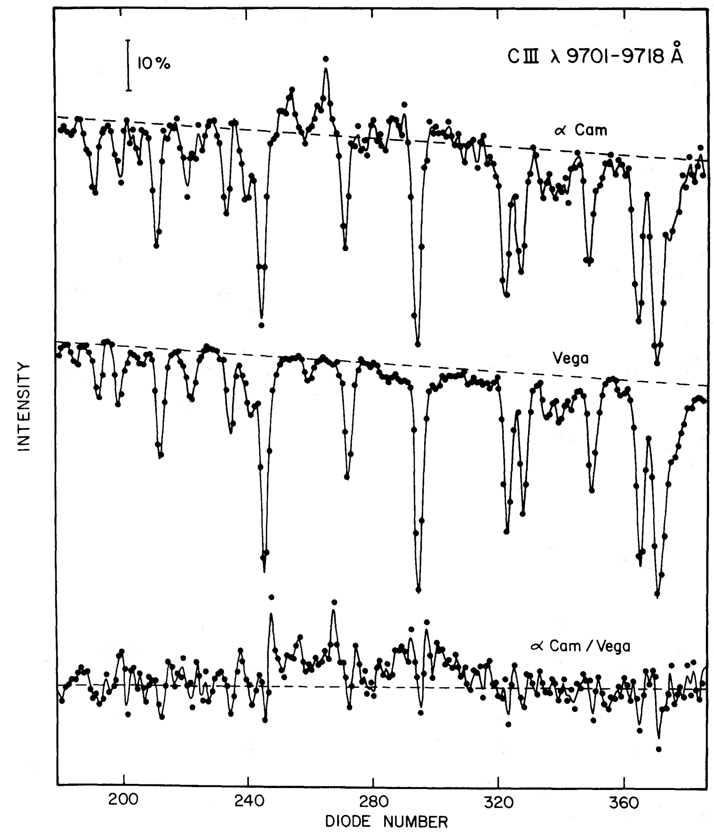

FIG. 5.—The λ9700 region is seriously contaminated by telluric water vapor lines. Division of the program star spectrum by that of a standard star allows most of the interference to be removed. In the bottom panel, two broad emission features, corresponding to blends of the individual transitions in the multiplet, are clearly seen above the continuum level. These observations were made at McDonald.

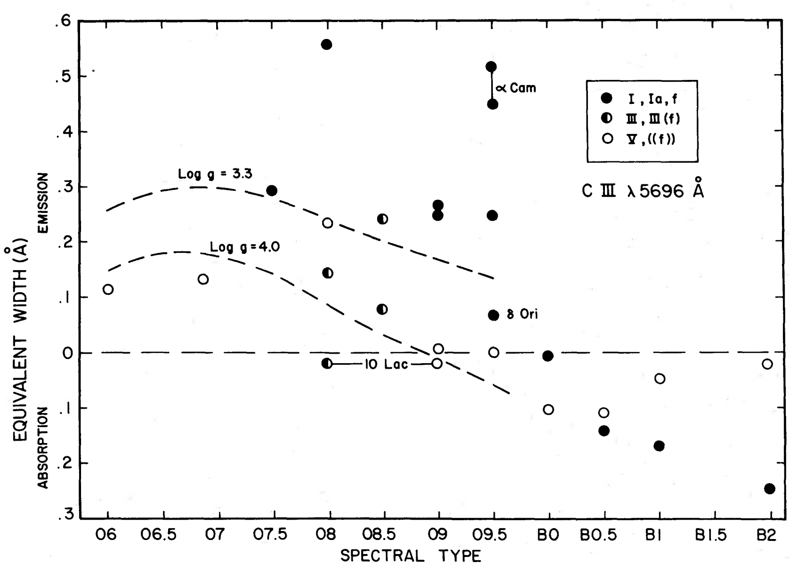

FIG. 6.—The equivalent widths of λ5696 from the McDonald data are plotted as a function of spectral type and luminosity class. α Cam was observed five separate times, and showed a small range of equivalent widths. δ Ori is a binary whose lines are diluted somewhat by the barely visible secondary spectrum. 10 Lac is usually classified O9 V, but Conti and Alschuler (1971) assigned a spectral type O8 III. The dashed lines correspond to two series of models calculated by Cardona-Nunez (1978).

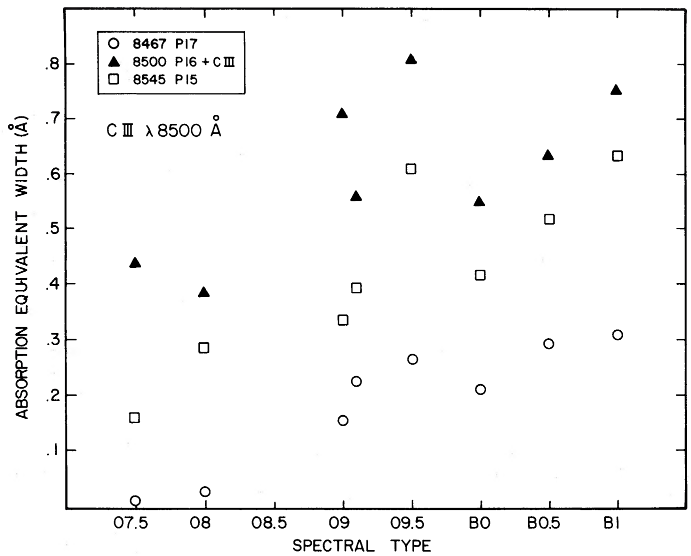

FIG. 7.—Equivalent widths of Paschen 15, 16, and 17 in eight stars which show λ5696 in emission. The blend at λ8500, P16 + C III is more strongly in absorption than the hydrogen line would be. The extra absorption strength indicates that the C III line at λ8500 is contributing additional absorption to the feature.

times the mean value of P15 and P17. In fact it is always stronger than P15, demonstrating the presence of excess absorption. A plot of these equivalent widths is shown in Figure 7.

The equivalent widths of the multiplet C III λλ9701–9718 are plotted as a function of spectral type and luminosity class in Figure 8. The multiplet is in emission in all stars earlier than spectral type O9. The emission is stronger in stars of higher luminosity and persists to later spectral types as well. The latest spectral type at which emission is observed is B0 Ia (ε Ori). Only four stars of luminosity class V were observed. Emission is clearly present in 68 Cyg (O8 V), absorption occurs in σ Ori (O9.5 V) and υ Ori (B0 V), and only an upper limit was obtained for the equivalent width in β Sco (B0.5 V).

In all these respects the behavior of λλ9701–9718 is strikingly similar to that of λ5696. Figure 9 shows a plot of the equivalent width of λ5696 versus the equivalent width of λλ9701–9718. The scatter does not significantly exceed the uncertainty of measurement, and on the average the equivalent width of λλ9701–9718 is about 1.95 times that of λ5696 (and the slope differs by only about 0.05 from

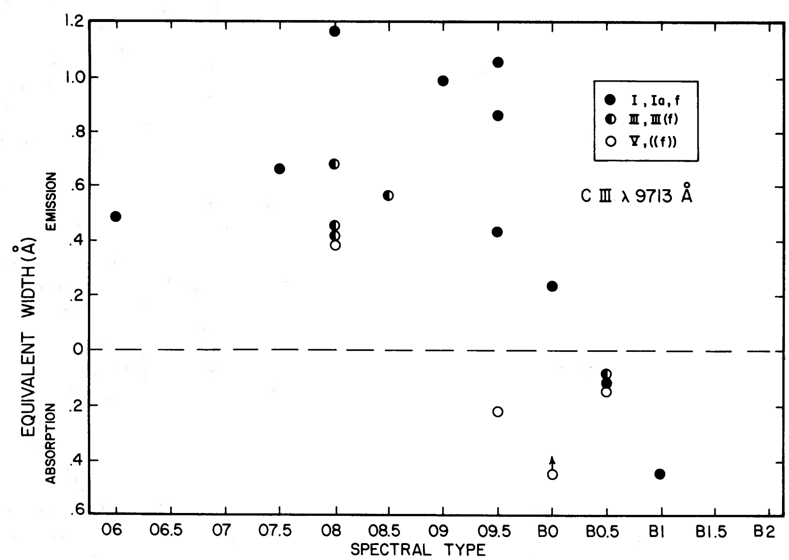

FIG. 8.—The equivalent widths of C III λλ9701–9718 as a function of spectral type and luminosity class. For those stars observed at both McDonald and Mauna Kea, the mean value of the two measurements is plotted.

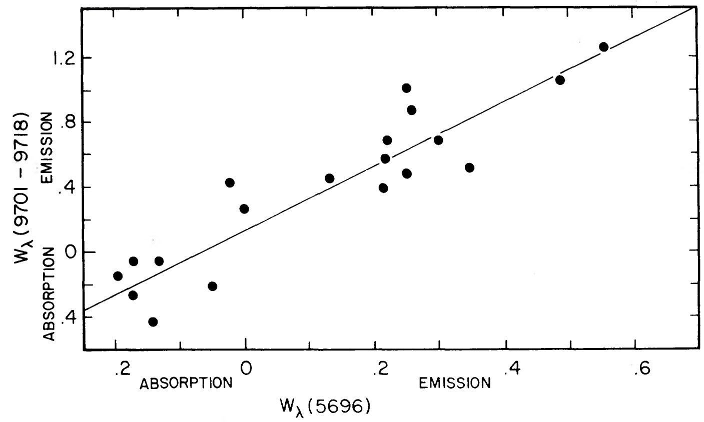

FIG. 9.—The equivalent width W_λ of C III λλ9701–9718 vs. the equivalent width of C III λ5696. The straight line is the best least-squares fit to the data on the assumption that the errors in each coordinate are equal. The line has a slope of 1.95 with a correlation coefficient of 0.91 and an intercept of 0.14. The mean value of the equivalent width was used for those stars measured at both observatories.

this value if the data from Mauna Kea and McDonald are treated separately). It also appears from the figure that the linear regression line does not pass through the origin. In both ε Ori and 10 Lac, λλ9701–9718 is clearly in emission and λ5696 in absorption, while in κ Ori, λλ9701–9718 is barely detected even though λ5696 is a strong absorption line. Observations of λ5696 (Conti 1974) include a significant number of stars earlier than type O6 and show clearly that the strength of the line in these objects decreases sharply relative to the values measured for stars of types O7–O9. Because no stars of very early type are included in the present sample, we do not know if λλ9701–9718 varies in the same way. However, very low resolution observations (228 Å mm^{-1}) by Vreux, Dennefeld, and Andrillat (1980) show strong emission in HD 152408 (O8 If) but none in HD 66811 (O4 ef) or HD 93129A (O3 f), and so it appears likely the strength of λλ9701–9718 does decrease in the hottest O-type stars.

III. DISCUSSION

The general behavior of the λ5696 emission in early-type stars has been known for over 20 years (Wilson 1958), but a satisfactory mechanism to produce this emission has only recently been identified. The upper level ($3d\ ^1D$) of λ5696 cannot be effectively populated by direct radiative transitions from the ground term ($2s^2\ ^1S$). An alternative method of overpopulating the $3d\ ^1D$ level on the basis of selective ionization of C II (Underhill 1957) can be ruled out on the grounds that throughout the temperature range in which λ5696 is in emission the dominant stages of ionization of carbon are either C III or C IV (Nussbaumer 1971; Mihalas, Frost, and Lockwood 1975). A second mechanism (Gauzit 1966) for selective excitation that depends on a coincidence in wavelength between the transition N IV $2s2p\ ^3P_1{}^o \rightarrow 2s3s\ ^3S_1$ and C III $2s^2\ ^1S \rightarrow 2p3s\ ^1P_1{}^o$, with C III $2p3s\ ^1P_1{}^o$ then decaying to $2s3d\ ^1D$, can now be ruled out on observational grounds—namely that the $3d\ ^3D$ must also be overpopulated in order to produce emission at λλ9701–9718. This process already appeared unlikely from theoretical arguments based on the fact that nitrogen is less abundant than carbon and that the transition probability for C III $2p3s\ ^1P_1{}^o \rightarrow 2s3d\ ^1D$ is low (Nussbaumer 1971). Direct recombination-cascade in optically thin lines can be ruled out by the observation that both λ5696 and λλ9701–9718 are in emission while the subsequent transitions at λ8500 and λλ4647–4651 (in most cases) are in absorption (cf. Fig. 10).

The first significant step in the theoretical interpretation of the C III spectrum in O-stars was taken by Nussbaumer (1971), who calculated the intensities of the transitions at λλ5696, 8500, 4647–4651, and 9701–9718 for a single-layer expanding atmosphere. Nussbaumer finds that for temperatures characteristic of O-type stars λλ9701–9718 and λ5696 are both expected to appear in emission while λ8500 should be in absorption. The transitions involved in determining the populations of the upper and lower levels of λλ4647–4651 are more involved, but in most cases the line is predicted to be in absorption. The lower level of λ5696 ($2s3p\ ^1P$) is effectively drained via the λ1309 and λ885 transitions to the doubly excited $2p^2$ states. This keeps $3p$ underpopulated with respect to both $3d$ and $3s$. Thus, λ5696 is in emission, while λ8500 remains in absorption. In this regard, the behavior of C III is essentially similar to that of the N III lines λλ4634–4641 ($3p\ ^2P^o$–$3d\ ^2D$) and λλ4097, 4101 ($3s\ ^2S$–$3p\ ^2P^o$), where two-electron jumps drain the population of the $3p\ ^2P^o$ level (Mihalas and Hummer 1973).

More extensive calculations for the singlet lines λ5696 and λ8500 have been carried out by Cardona-Nunez (1978), who solved the coupled statistical-equilibrium and transfer equations for a multi-level, multi-line, multi-ion ensemble. He finds that the $2s3d\ ^1D$ level is overpopulated by means of direct recombination and cascades from upper states (with dielectronic recombination important in the earliest spectral types) with subsequent cascade to $3p$. In agreement with the earlier work by Nussbaumer, Cardona-Nunez shows that the $3p$ state

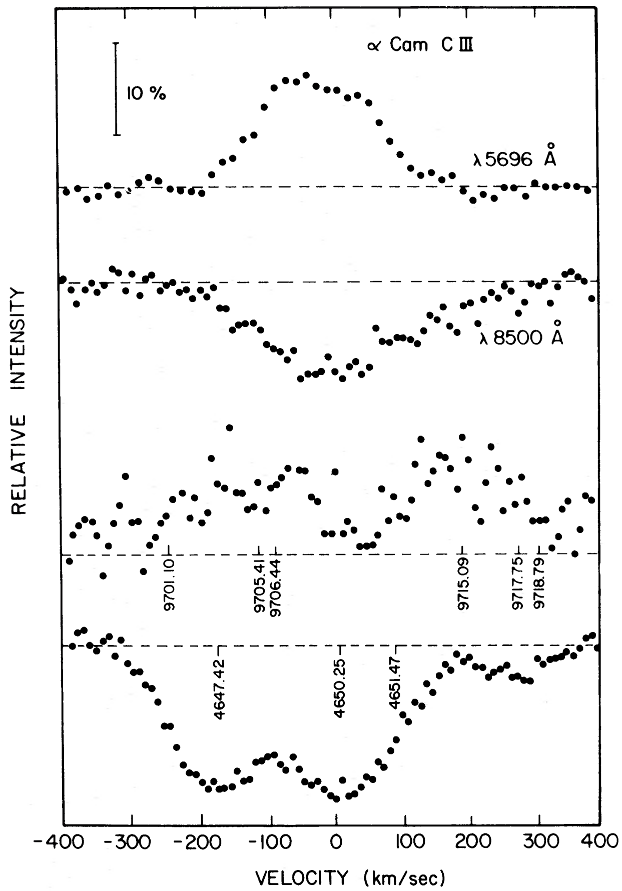

FIG. 10.—These observations of α Cam show concisely the observed C III spectrum in luminous O stars. Lines arising from the $3p$–$3d$ transition are in emission for both singlet and triplet series. At the same time, the lower $3s$–$3p$ transitions are strongly in absorption. The $2s3p$ level is drained by transitions to the doubly excited $2p^2$ terms, which lie below $2s3p$ in both series. Thus the atomic physics of the C III ion allows intrinsic emission lines, without an extended atmosphere or nonradiative energy input.

will be drained by two-electron transitions to the $2p^2$ (^1S and ^1D) levels, and he predicts that λ5696 will appear in emission and λ8500 in absorption *both* in main sequence and in higher luminosity stars. The strength predicted for λ5696 agrees well with the values seen in luminosity class V stars. In particular, the transition from emission to absorption in his models is in perfect agreement with the observations. While the models indicate that the emission should be enhanced in stars with lower surface gravity, the intensities actually observed in giants and supergiants substantially exceed the predicted values. The model results are plotted with the McDonald observations in Figure 6.

Similar calculations for the triplet lines λλ4647–4651 and λλ9701–9718 are now in progress (Sakhibullin, Auer, and van der Hucht 1980). While line strengths and profiles are not yet available, solution of the statistical equilibrium equations indicates that λλ9701–9718 will appear in emission in all stars with $T_{\rm eff} > 35{,}000$ K and that λλ4647–4651 will show weak emission only in stars with $T_{\rm eff} > 45{,}000$ K.

Both the observed line strengths and line widths lend strong support to the models developed by Cardona-Nunez and Sakhibullin *et al.* As predicted, λλ9701–9718 is in emission in all stars earlier than O9, including the main-sequence star 68 Cyg. In general, the line profiles are quite similar to those of λ5696 and correlate well with rotational velocity. Although detailed line-profile calculations are required to determine whether rotation is the only source of broadening, we note that Cardona-Nunez (1978) finds that an additional broadening mechanism, possibly either expansion of the atmosphere or (less likely) supersonic turbulence, is required to account for the line widths of λ5696. The same is probably true for the C III multiplet at λλ9701–9718, but the fact that the line widths in general do not exceed ~ 200 km s^{-1} and that the radial velocities are comparable to the stellar velocity (within ~50 km s^{-1} given the uncertainty in effective wavelengths for these blended features) implies that the lines must originate in or near the photosphere and not in a portion of the envelope where the expansion velocity is already high.

The profiles of λ5696 provide further evidence for this claim. In some of the earliest spectrophotometry of this line, Wilson (1958) reported that in several stars the profile consisted of a sharp core superposed on a weaker but rather extensive (±30 Å) "band" emission. This band was interpreted as emission wings which were hypothesized (Underhill 1957; Mihalas, Frost, and Lockwood 1975) to be formed in the rapidly accelerating stellar wind. The photographic data from which these profiles were derived were rather noisy, and later observers (Conti 1974) were unable to corroborate the existence of the broad emission feature. The Reticon observations of λ5696, which are shown in Figures 3 and 4, were obtained primarily to investigate the line profiles with much higher precision data. The signal-to-noise ratio is greater than 300 for all except 9 Sge, and the continuum is extremely well defined. In α Cam, the star for which the most intense wings are claimed, the profile joins the continuum very abruptly at velocities less than 200 km s^{-1} from line center. The broad emission wings are simply not present—at least not in 1979 September. In α Cam there is a very slight asymmetry with the peak intensity of the emission being blueshifted by about 25 km s^{-1} from the line center. In all other stars, however, the profiles are almost perfectly symmetric and join the continuum with no trace of broad wings, either in emission or absorption.

Additional support for the models is provided by the tight correlation in strength between λλ9701–9718 and λ5696. Even though 9 Sge and 68 Cyg, for example, have very different atmospheric parameters, their C III line ratios follow the same relation. The fact that the singlet/triplet ratio is independent of atmospheric structure argues that atomic physics is the primary factor in determining the strengths of the C III lines.

IV. SUMMARY

Observations of C III $\lambda\lambda$9701–9718 can and should be extended to a wider sample of stars, including particularly those with spectral types earlier than O6. However, the present exploratory study has clearly established that this multiplet is in emission in O-type stars of later spectral type and of all luminosity classes. These measurements are in accord with preliminary calculations that predict that emission at this wavelength is produced in the photospheres of O-type stars, although detailed comparison of the observed and calculated line strengths and profiles must await completion of the models. Emission is enhanced in stars that are known from other spectral diagnostics to have extended atmospheres, and this enhancement probably accounts for the fact that emission in supergiants extends to lower temperatures than predicted by the models. However, geometrically extended envelopes, velocity fields, selective excitation, and nonradiative heating are not prerequisites for the appearance of the emission. The multiplet C III $\lambda\lambda$9701–9718 thus joins C III λ5696 and N III $\lambda\lambda$4634–4641 as examples of emission lines that can be formed in a static atmosphere in radiative equilibrium.

The measurements made at Mauna Kea were possible only because of the availability of the Reticon system constructed at the University of British Columbia. We wish, therefore, to express particular thanks to Bruce Campbell and Gordon Walker for their assistance with the observations. The research carried out at Hawaii was supported in part by a grant (AST 77-27404) from the National Science Foundation. The hospitality and financial support of McDonald Observatory made possible the contribution of D.C.E. to this project and is greatly appreciated.

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