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ON THE IONIZATION OF THE INTERARM MEDIUM OF M33

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RESUMEN

Se han observado 17 regiones H II y tres áreas que corresponden al medio interbrazo de M33, en el intervalo de longitudes de onda λλ4000−6700Å con el telescopio de 122 cm del Observatorio de Asiago. En todas las regiones observadas se detectaron las siguientes líneas de emisión: λ6584 [N II], Hα, λ5007 [O III] y Hβ. Las regiones del medio interbrazo se encuentran en el plano a una distancia comprendida entre 400 y 1300 pc del núcleo de la galaxia.

Se presenta evidencia a favor de que las estrellas OB sean responsables de la ionización del medio interbrazo. A partir de las magnitudes y los colores de 34 estrellas localizadas en una pequeña región del disco de M33 se encuentra que cuando menos una fracción considerable de las estrellas OB necesarias para ionizar el medio interbrazo están sumergidas en él. Se encuentra que la contribución a las líneas de emisión del medio interbrazo debida a la luz dispersada por polvo, o a la ionización producida por remanentes de supernova, rayos cósmicos y rayos X no es significativa.

ABSTRACT

Seventeen H II regions and three areas corresponding to the interarm medium of M33 have been observed in the λλ4000−6700Å wavelength range using the image tube spectrograph attached to the Newtonian focus of the Asiago 122 cm reflector. The emission lines [N II] λ6584, Hα, [O III] λ5007 and Hβ were detected in all the observed regions. The observed regions of the interarm medium are located in the plane of the galaxy at a distance from the nucleus $400 < R < 1300$ pc.

Additional evidence in favor of the ionization of the interarm medium being produced mainly by OB stars is presented. From the magnitudes and colors of 34 stars projected into a $2'.4 \times 0'.7$ area of the disk of M33 it is found that at least a considerable fraction of the OB stars needed to ionize the inner interarm medium are located inside it. It is found that the contribution to the emission lines of the interarm medium due to dust scattered light, or to the ionization produced by SN remnants, cosmic rays and X rays, is not appreciable.

Key words: GALAXIES, INDIVIDUAL — INTERSTELLAR MATTER — NEBULAE.

I. INTRODUCTION

The nature of the diffuse emission in the interarm regions of spiral galaxies as compared to classical H II regions has been the subject of several studies in recent years.

Quantitative observations however have been carried out only for M33 which is an ideal object for this kind of study due to its distance, large number of H II regions, and small inclination with respect to the line of sight. A review of the work on this subject is given by Comte and Monnet (1974). The well established observational facts on the interarm medium are the following: the emission measure as derived from the Hα intensity with a $T_e = 10\,000$°K varies from 225 in the brighter southern section of the galaxy to 80 in the northern section (Torres-Peimbert *et al.* 1974), the Hα/[N II] ratio is systematically lower in the interarm medium than in the H II regions at the same distance from the center. Photoelectric spectrophotometric studies of bright H II regions in M33 in the blue ([O II], [O III], Hβ) and red lines (Hα, [N II], [S II] have been published by Searle (1971) and Smith (1975). Searle observed the [O III]/Hβ ratios for 30 regions. Comte (1973) and Comte and Monnet (1974) estimated that [O III]/Hβ ≤ 0.25 in the same interarm position studied by Deharveng and Pellet (1970), which is located in the northern section at a distance of about 1000 pc from the center of the galaxy. This observation was obtained with a Fabry-Pérot étalon.

Our work is aimed to provide a homogeneous set of spectrophotometric observations of the [O III] and Hβ lines both for the interarm medium and for classical H II regions to be able to discriminate between different models of the interarm medium. A similar survey in the red wavelength range has already been published (Benvenuti *et al.* 1973). A preliminary report on some of the interarm medium observations in the green wavelength range presented here was published elsewhere (Benvenuti and D'Odorico 1975).

II. OBSERVATIONS

Ten spectra in the region $\lambda\lambda 4000-6700$Å have been obtained with the nebular image tube spectrograph attached to the Newtonian focus of the Asiago 122 cm reflector. The instrument has been described by Benvenuti *et al.* (1975). The slit has an extension on the sky of about 7′, and therefore several H II and interarm regions are observed with a single exposure. The scale perpendicular to the dispersion is 127 arcsec mm^{-1}, the dispersion 125Å mm^{-1} and the slit width 6 arcsec on the sky. Exposures up to 4 hours were used to detect the interarm emission. The emission lines of [N II] λ6584, Hα, [O III] λ5007 and Hβ were detected in 17 H II regions and 3 interarm positions. A map of the observations is given in Figure 1 (Plate 1). Microphotometric tracings were obtained for each region in form of punched paper tape. The lengths of the exploring slit were selected according to the dimensions of the H II regions. These usually coincide with the dimensions of the H II regions in the Hα photograph of Courtès and Cruvellier (1965). Microphotometric tracings of spot calibration plates taken in the same nights and developed with the galaxy plates were used to obtain the calibration curves. The data were reduced with the HP 2100 computer of the Asiago Observatory, the final result being smoothed intensity tracings of the spectra. To obtain a better signal to noise ratio, interarm spectra of the same regions were summed up.

The emission line ratios were derived from measurements of the areas under the emission lines after correcting for the underlying continuum. The line ratios were not corrected for extinction and absorption because we considered only the ratios of nearby lines. A small correction for the spectral response of the system as determined form the observations of standard stars was applied to the final data. Table 1 summarizes the results. The number of the H II regions, when not NGC objects, are from the Catalogue by Courtès and Cruvellier (1965) with the addition of Boulesteix *et al.* (1974). Column 2 gives the distance from the center in parsecs in the plane of the galaxy. An inclination of 33°, a position angle of the major axis of 20° and a distance of 720 kpc were assumed. Column 3 gives the ratio of the distance from the nucleus of the H II region to the semi-major axis of the galaxy (25′ or 5.2 kpc). The line intensity ratios log [O III] /Hβ and log [N II]/Hα are given in column 4 and 5. The symbols [N II] and [O III] indicate the sum of the two lines of the doublet. When blended with Hα, λ6549 of [N II] was taken equal to 1/3 of λ6584. When not detected λ4959 was assumed to be 0.34 the intensity of λ5007.

The accuracy of the line ratios was estimated from measurements of the [O I] λ6300/λ6363 night sky line ratio, which is 3.1 from the ratio of the transition probabilities. Out of seven spectra we obtained a mean value 3.14 ± 0.13 rms. We have also obtained more than one observation for several regions. The typical dispersion of line intensity ratios determined from different spectra for a given object is of the order of 20%. From these considerations we have estimated that the error in the logarithm of the line ratios is 0.1. When the line ratio of an H II region was derived from a single spectrum of

TABLE 1

LINE INTENSITY RATIOS

Region	Distance R from the nucleus in the plane of the galaxy (pc)	R/R_0 (R_0 = 5.2 kpc)	$\log \frac{I([O\ III])}{I(H\beta)}$	$\log \frac{I([N\ II])}{I(H\alpha)}$
47	174	0.03	−0.02+	−0.33
93	150	0.03	−0.21	−0.46
29	280	0.05	−0.02	−0.41
99	293	0.06	−0.44	−0.43
66	370	0.07	−0.1	−0.42
27	621	0.12	−0.05	−0.43
25	702	0.13	−0.07	−0.30
26	770	0.15	−0.05	−0.48
52	784	0.15	0.21+	−0.52
94	935	0.18	−0.11	−0.54
56	990	0.19	0.25	−0.79
87	1012	0.19	−0.08	−0.58
77	1152	0.22	−0.26	−0.53
85	1278	0.24	−0.44	−0.46
NGC 595	1532	0.29	0.05	−0.65
55	1667	0.32	−0.1 +	−0.40
NGC 604	3090	0.59	0.41	−0.84
NGC 592	3090	0.59	0.4	−0.98
650	4765	0.91	0.3	−0.71
NGC 588	5131	0.98	0.82	−1.12
D1	726	0.14	0.09	−0.16
D2	409	0.08	−0.04+	−0.1
D3	1209	0.23	−0.22+	−0.25

The measurements of log I([O III])/I(Hβ)) for regions 650, 77 and NGC 592 are from Searle (1971).
+: measurements of lower accuracy.

poor quality, the uncertainty is larger and the measured value is marked with an asterisk in Table 1.

Some regions observed photoelectrically by Searle (1971) or Smith (1975) have been recorded also in our spectra. The differences in the measured line ratios with these authors are of the same magnitude as the dispersion of values observed in different sections of the brightest H II regions (see Smith 1975) and never systematic. Our measurements correspond to rectangular areas cut across the H II regions; the differences with other authors are partly due to the different types of apertures used in the observations. In two cases only the discrepancy is high: in #56 we measure for log [O III]/Hβ, 0.25 versus −0.3 by Searle (1971) and in #93 we measure −0.21 versus −0.92 by Smith (1975). The latter value, if correct, would assign to this region by far the lowest excitation in M33. Once these two limiting cases are excluded, the mean of |(BDP-Smith)| for five regions for the log [N II]/Hα is 0.07. We obtain 0.13 as the mean of the absolute differences in the log [O III]/Hβ for five regions in common with Searle (1971).

The results of the line intensity ratios are summarized in three diagrams. Figures 2 and 3 are plots of log [O III]/Hβ and log [N II]/Hα for the H II regions and the interarm positions as a function of the parameter $\rho = R/R_0$. As already found by Searle (1971) the first ratio increases, the second decreases toward the outer regions of the galaxy. This effect has been thoroughly discussed in the past and interpreted in terms both of variation of the physical conditions and of the chemical composition of the emitting gas. We note that in the disk the [N II]/Hα ratio is systematically higher than in H II regions at the same distance from the center while the [O III]/Hβ ratio has similar values (position D1 having the more accurate measurement of the ratio in the disk). Figure 4 is a plot of log [O III]/Hβ versus log [N II]/Hα. The two ratios are correlated and the H II regions fall in a sequence while the disk positions do not belong to it. In this diagram we have plotted also the interarm value measured by Deharveng and Pellet (1970) for the [N II]/Hα ratio and by Comte and Monnet (1974) for the [O III]/Hβ ratio.

III. DISCUSSION

The observed emission line ratios can be used to discriminate between the different sources of line emission and mechanisms of ionization that have been proposed for the interarm medium.

First we will consider the possibility that the observed interarm emission is due to dust scattered light from the H II regions in the spiral arms. Then we will discuss ionization by non-thermal processes such as hard-UV photons, energetic particles and shock waves from supernova explosions and finally we will study the ionization by OB stars *in situ* and/or by UV photons from OB stars in the spiral arms.

a) *Dust Scattered Light*

Grasdalen and Cohen (1973) have found that the integrated spectra of spiral galaxy disks show Hα in

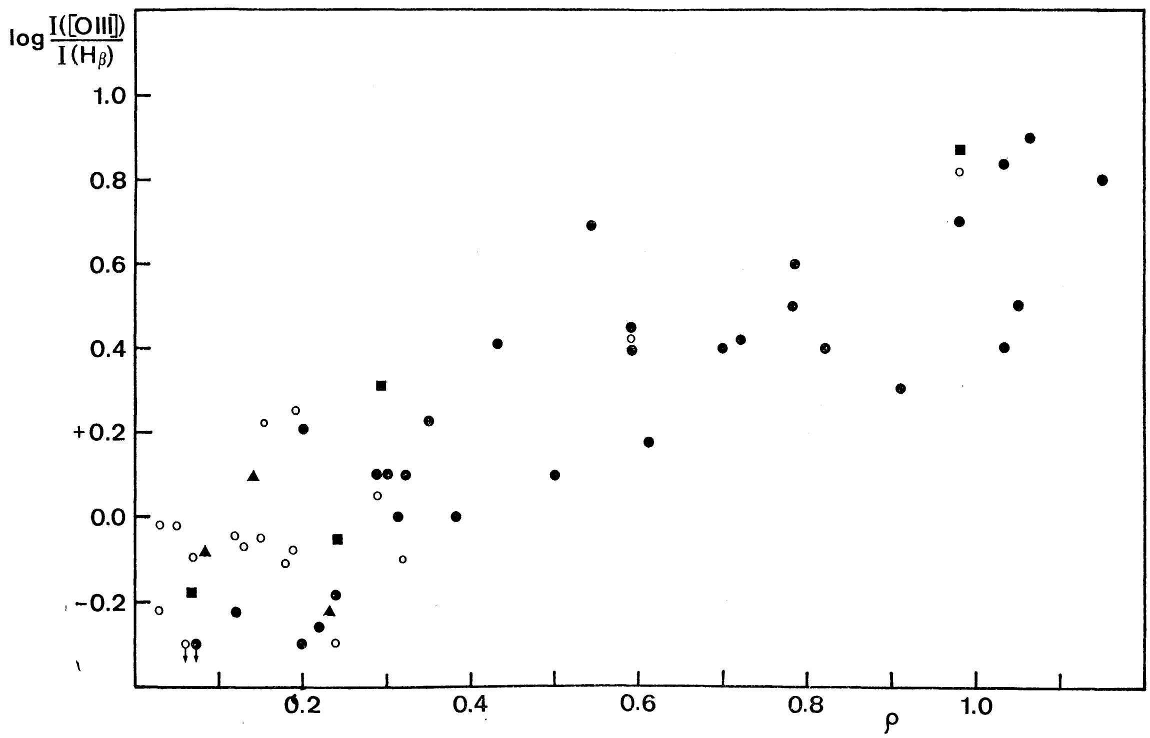

FIG. 2. Variation of the log [0 III]/Hβ ratio with distance R from the center in the plane of the galaxy ($\rho = R/R_0$ with R_0 the semi-major diameter of the galaxy). Filled circles: H II regions observed by Searle (1971). Filled squares: H II regions observed by Smith (1975). Filled triangles: interarm positions (this paper). Open circles: H II regions (this paper).

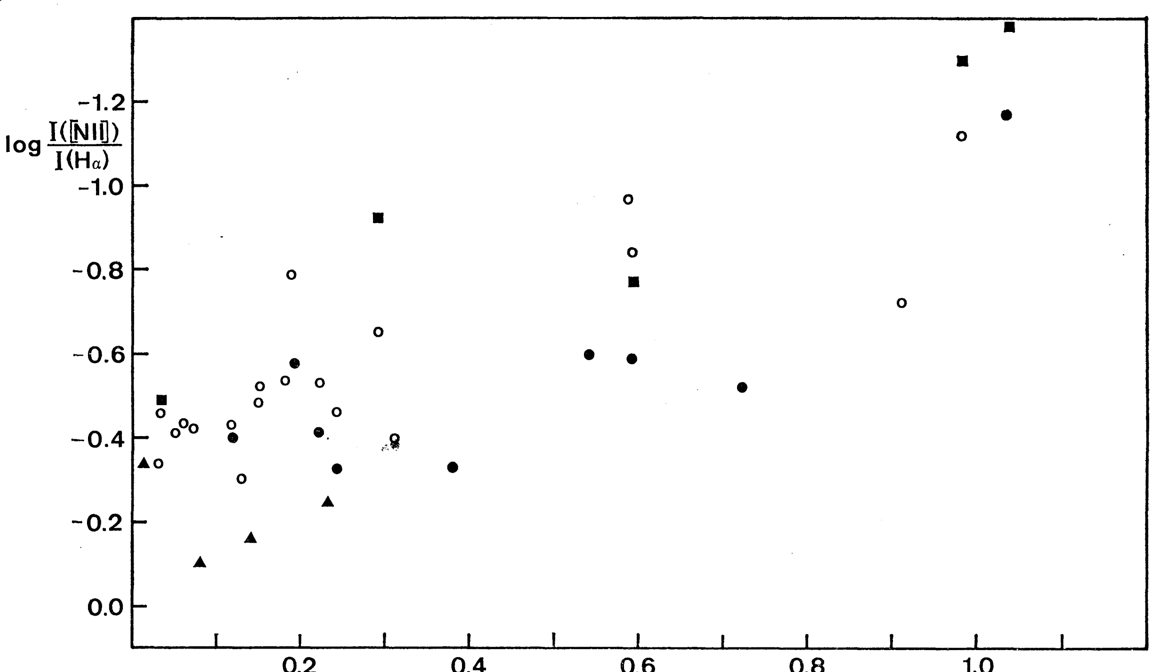

FIG. 3. Variation of the log [N II]/Hα ratio with the distance R from the center in the plane of the galaxy ($\rho = R/R_0$ with R_0 the semi-major diameter of the galaxy). Symbols as in Figure 2.

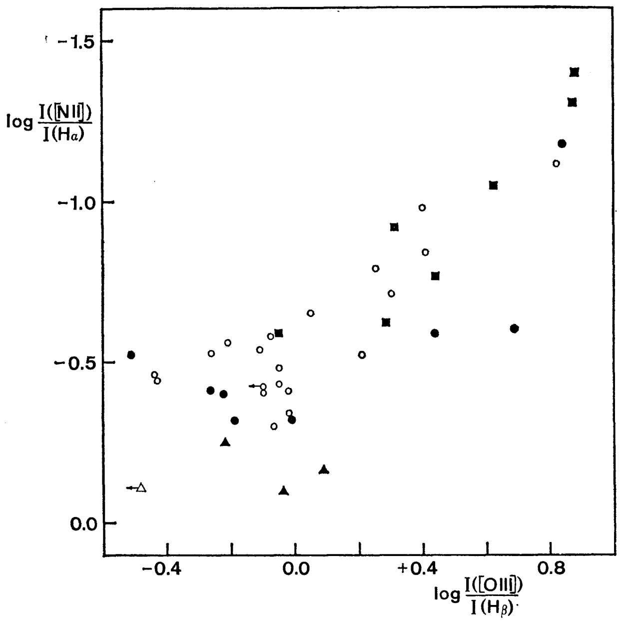

FIG. 4. Plot of log [N II]/Hα versus log [O III]/Hβ for H II regions and interarm positions. Symbols as in Figure 2. The open triangle indicates the measurement of the interarm region by Comte and Monnet (1974).

emission. Based on these observations they suggest that the faint diffuse nebulae at high galactic latitudes observed by Johnson (1972) are reflection nebulae. Since dust is projected in the interarm medium of M33 it is possible that a fraction of the observed emission is due to dust scattering of the light coming from normal H II regions.

The observed emission line ratio Hα/[N II] is systematically lower in the interarm medium than in the nearby H II regions, while no significant difference is found for the [O III]/Hβ ratio. This fact cannot be explained either by gray reflection or by selective dust scattering of the H II regions light, because the albedo of the dust is nearly constant in the 5000−6500Å spectral range (Witt and Lillie 1971) and implies that a significant contribution of dust scattered light to the observed interarm emission can be ruled out.

b) *Hard-UV Photons and Cosmic Rays*

The optical line spectrum of a moderately ionized region heated by UV fluxes and energetic protons has been computed by Bergeron and Souffrin (1971). They adopted solar abundances for the gas and three models of monochromatic heating: hard UV radiation of frequencies $5\nu_H$ and $15\nu_H$, and MeV protons. The optical line intensities of H, He, O, N and Ne have been derived as function of the degree of ionization $N(H^0)/N_e$.

A mean value of $N(H^0)/N_e$ can be obtained from the relation

$$< N(H^0)/N_e > = \frac{\int N(H^0)\,dr}{(L \int N_e^2\,dr)^{1/2}}, \qquad (1)$$

where L is the thickness of the gas associated with the interarm medium; in what follows a value of L = 200 pc will be adopted. Rogstad *et al.* (1976) have observed M33 at 21 cm with a circular beam 2′ in diameter at half power and with a velocity resolution of 10 km s^{-1}; from their observations there is no clear minima in the interarm regions, moreover they can fit their observations with a model for the projected neutral hydrogen density that shows a contrast between the arm and interarm regions of only 3 to 2. From Rogstad *et al*, it is obtained that $\int N(H^0)\,dr = 355$ cm^{-3} pc for the general area of the interarm regions observed by us and from $\int N_e^2\,dr = 172$ cm^{-6} pc (see §IIId) and equation (1) we obtained $< N(H^0)/N_e > = 1.9$. For this degree of ionization the values predicted by the model of Bergeron and Souffrin (1971) for log [O III]/Hβ are 1.7 and 1.2 for $5\nu_H$ and $15\nu_H$ photons respectively (where the ratio I(Hα)/I(Hβ) = 2.87 from Pengelly (1964), for $T_e = 10^4$, has been adopted). For the case of MeV protons Bergeron and Souffrin predict log [O III]/Hα = −0.2, where collisional excitation of level three of the hydrogen atom due to MeV particles was taken into account. The dominant contribution to Hα is due to radiative recombination and since the collisional excitation cross section due to high energy particles drops off rapidly with increasing n (Bates and Griffing 1953), the I(Hα)/I(Hβ) ratio is expected to be in the 2.87 to 4.3 range. Therefore for MeV protons log [O III]/Hβ = +0.3. For the same ionization degree the predicted values for log [N II]/Hα are 0.4, 0.0 and +0.1 for the heating particles with energies $5\nu_H$, $15\nu_H$ and MeV, respectively. A comparison with the interarm line ratios in Table 1 indicates that while the observations might be consistent with the theoretical

[N II]/Hα values, the low measured [O III]/Hβ ratios are in contradiction with the hypothesis of a main contribution from hard-UV photons or energetic particles to the ionization of the interarm medium.

As pointed out by Torres-Peimbert *et al.* (1974) the intensity of the [O III] lines predicted from the model of Bergeron and Souffrin (1971) remains large with respect to those of H for a wide range of ionization degree values. In particular for all three heating models log [O III]/H$\beta > 0.10$ for $0.4 < N(H^0)/N_e < 7$. Thus departures of the $N(H^0)/N_e$ ratio from the computed average, that could be due to a non-uniform distribution of the gas or to an incorrect estimate of the disk thickness, do not invalidate the previous conclusion.

c) *Shock Waves from Supernova Explosions*

The hypothesis that the interarm emission is due to gas ionized by shock waves from SN explosions has been put forward in the past for the galactic interstellar medium and in our case is suggested by the low value of the Hα/[N II] ratio. Unfortunately, there is no estimate of the Hα flux for a galactic, evolved supernova remnant. The optical emission from a remnant is also strongly dependent on the conditions of the surrounding medium and it is unlikely that one can derive an average flux to be compared with the emission measure of the interarm medium in M33. In the blue plate of Figure 5 (Plate 2) and in the Hα photographs published by Boulesteix *et al.* (1974) no filamentary or circular structure is seen; however this might be due to the existence of a relatively dark background in the area. The radio data are also not resolutive. The Crab nebula has a flux of 930 f.u. at 1400 MHz and it is at an estimated distance of 2 kpc. In M33 it would be a point source with a flux of 7×10^{-3} f.u. IC 443, one of the brightest SNR in the optical range, emits 130 f.u. at 1400 MHz at an estimated distance of 2 kpc. In M33 with a diameter of 6.5 arcsec it would emit 1×10^{-3} f.u., below the detection limit of 2.5×10^{-3} of the recent survey of Israel and van der Kruit (1974). No sources were detected in the interarm area. We can estimate how many SNR may be present in the region from supernovae and supernova remnant counts. Tammann (1974) predicts that a SN explodes in M33 every 167 years. In our galaxy, the ages of SNR as derived from the expansion velocities, are $< 10^5$ years for all the objects which show significant optical emission (Lozinskaya 1975); thus we expect about 600 SNR which could give a significant contribution to the optical emission in M33 if the evolution scale is similar to that in our galaxy. The distribution of SN within their parent galaxy has been studied by Barbon *et al.* (1975). In M33 there is no steep surface density gradient and it is safe to assume that the SN are uniformly distributed over the disk within the optical radius of 25′. In the test area we predict then 0.5 SN in the last 10^5 years. In a different approach we can consider the number density of SNR in the Sun's vicinity. Ilovaisky and Lequeux (1972) have found that 90 SNR with diameters < 70 pc are present in an area of 125 kpc^2 centered at the Sun. Larger remnants are so decelerated that the optical emission is negligible. It is fair to assume that the SNR remnant density in the vicinity of the Sun is similar or higher than in the central region of M33. Under this assumption we obtain 0.4 or less SNR in the test area, an estimate surprisingly close to that derived from the SN. In both cases the statistical evidence is against the hypothesis of a significant contribution to the emission from SNR.

It is also possible to test the possibility of a SNR contribution to the interarm emission by comparing the observed emission line ratios in the interarm medium with the observed and predicted ratios for galactic SNR. The [O III]/Hβ ratio cannot be used as a discriminating parameter between SNR and H II regions or between SNR of different age because it shows a wide range of values within a single remnant. In IC 443, the bright optical remnant, the [O III]/Hβ ratio takes values between 0.25 and 4 for different regions (Parker 1964, D'Odorico unpublished). The relative line intensity ratios in the red spectral region are summarized by Daltabuit *et al.* (1976). The [N II]/Hα ratio observed in the interarm medium does approximately correspond to that of a remnant with expansion velocity between 50 and 100 km s^{-1}, this estimate does not consider the possibility of a systematic nitrogen abundance difference between the interstellar medium in our galaxy (D'Odorico *et al.* 1976, Benvenuti *et al.* 1976) and in M33 (Comte 1975, and references therein). However the very small velocity dispersion of 5 km s^{-1}

observed by Carranza *et al.* (1968) for the interarm medium indicates that if there are any SNR present their velocity of expansion should be of that order and for this velocity the predicted [N II]/Hα ratio is substantially smaller than observed.

In conclusion the line ratios combined with the very low velocity dispersion observed also rule out the shock wave mechanism as an important energy source for the interarm emission.

d) *Ionization by OB Stars*

Benvenuti *et al.* (1973), based on the [N II]/Hα line intensity ratios, suggested that the ionization of the interarm medium in M33 was due to OB stars. Torres-Peimbert *et al.* (1974) and Comte and Monnet (1974), based on the [O III]/Hβ upper limit reported by Comte (1973), gave arguments that strengthened this possibility. Moreover Comte and Monnet have pointed out that many hot blue stars are seen in the arms outside of the classical H II regions and that Lyman continuum photons escaping from these stars and from density bounded H II regions in the spiral arms might be mainly responsible for the ionization of the interarm medium.

We want to test the hypothesis that main sequence stars *in situ* may be responsible for the ionization of the inner interarm medium. In the blue plate reproduced in Figure 5 (Plate 2) the limiting B magnitude in the interarm regions here studied is 21.5±0.2. There are several stars projected on positions D1, D2 and D3. We have selected as a test area an interarm region between the two southern arms of the galaxy which includes the D1 position, as shown in Figure 5 (Plate 2). The 2′.4 × 0′.7 area at the distance of 720 kpc corresponds to a region 415 × 140 pc in the plane of the galaxy. 34 stars have been identified projected on the test area in the 18.9 − 21.5 magnitude range. The accuracy of the photographic magnitudes based on a magnitude sequence on the same plate is estimated at 0.2 magnitudes for the stars brighter than 20.5. In Table 2 we present the photographic and absolute magnitudes where a distance modulus corrected for galactic absorption of 24.8 mag has been adopted. The M_B values have not been corrected for interstellar absorption originating in M33.

It should be estimated whether these stars belong to M33 or to our galaxy. From stellar counts the relative number ratios of foreground stars in the observed magnitude range N(21): N(20): N(19) (see Table 3) and in our test area are very similar suggesting that a substantial number of stars in the test area are galactic stars. We have three arguments against this possibility: *a*) On statistical grounds 8.5 stars in the $18.5 < M_B < 21.5$ range are expected to be foreground stars in the test area (see Table 3), where the m_{pg} stars counts presented by Allen (1973) together with the relation $m_B = m_{pg} + 0.11$ were used. *b*) By comparing B and V plates the stellar colors are estimated to be $(B-V) < 0.5$; these colors are in agreement with the large ratio (~ 8) of blue to red supergiants found by Walker (1964) at similar distances from the nucleus of M33. If these objects were closer than 10 kpc their absolute magnitude

TABLE 2

STARS PROJECTED ON THE INTERARM TEST AREA

m_B	Number	M_B	Spectral Type	L_H star^{-1} (10^{49} s^{-1})	L_H (10^{49} s^{-1})
18.9	2	−5.9	O5.5	2.4	4.8
19.2	1	−5.6	O6	1.5	1.5
19.5	4	−5.3	O6.5	0.90	3.6
20.0	1	−4.8	O8	0.34	0.34
20.1	1	−4.7	O8.5	0.25	0.25
20.2	1	−4.6	O9	0.18	0.18
20.3	2	−4.5	O9.5	0.10	0.20
20.5	4	−4.3			
20.8:	2	−4.0			
21.0:	6	−3.8			
21.2:	2	−3.6			
21.5:	8	−3.3			

TABLE 3

TEST AREA STATISTICS

m_B	N(m_B)		
	Observed	Foreground*	Main Sequence†
≤ 17.5	0	0.9	0
17.5−18.5	0	0.9	0
18.5−19.5	7	1.7	3
19.5−20.5	9	2.6	12
20.5−21.5	18	4.2	19

* Expected number of foreground stars according to Allen (1973).

† Expected Star distribution of main sequence stars in M33 normalized to the observed number of 34.

would have to be fainter than +3.9 which is very unlikely taking into account their colors. *c*) From the work by Torres-Peimbert *et al.* (1974) and Cruz-González *et al.* (1974) we have estimated the expected relative numbers of main sequence stars corresponding to the distance of M33 and the observed magnitude range (see Table 3); this estimate is very crude, nevertheless the main sequence ratios are similar to the observed ones. Based on these arguments we conclude that most of the stars in the test area are members of M33.

From their absolute magnitudes and since red supergiants are excluded from the colors, the stars have to be main sequence stars or AB giants and supergiants. From stellar evolution models of massive stars (c.f., Simpson 1971) and observations of young stellar clusters (c.f., Wildey 1963) it is expected that about half of the brightest stars will be main sequence stars and half B and A supergiants. In what follows we will assume that all the stars in the test area brighter than $M_B = -4.4$ are main sequence stars. In Table 2 we present their spectral types and their Lyman continuum photon flux, L_H, in photons per second taken from Cruz-González *et al.* (1974). From Table 2 a total $L_H = 1.09 \times 10^{50}$ s^{-1} is obtained.

We will study now if the L_H value just obtained is sufficient to maintain the test area ionized. Under the assumptions of: a) steady state, b) medium optically thick to Lyman continuum radiation and c) the same electron and proton densities, it follows that the ionization rate, L_H, has to be equal to the recombination rate to all levels but the first, $R_B(H)$, which is given by

$$R_B(H) = A \int N_e N_p \alpha_B(H^o, T)\, dl \qquad (2)$$

where A is our test area, N_e and N_p the electron and proton densities, α_B the effective recombination coefficient to all levels but the first and l the length along the line of sight in cm. From the temperature calibration scale for O stars by Conti (1973) and Morton and Adams (1968) as well as from the heating and cooling curves computed by Searle (1971) we expect a gas temperature of $\simeq$ 7500°K. For this temperature $\alpha_B = 3.27 \times 10^{-13}$ cm^3 s^{-1} (Pengelly 1964, Osterbrock 1974). The fraction on the right hand side of equation (2) which is proportional to the emission measure can be derived from the surface brightness at Hα, S(Hα). From Peimbert *et al.* (1975) we have

$$EM = \int N_e N_p dr = 2.41 \times 10^3\, T_e^{0.92}\, S(H\alpha) \text{ cm}^{-6} \text{ pc} \qquad (3)$$

which for T_e = 7500°K and the measurement of S(Hα) by Benvenuti *et al.* (1973) corrected for night sky emission according to Torres-Peimbert *et al.* (1974) yields EM = 172 cm^{-6} pc. It should be noticed that the temperature dependence of equation (15) by Torres-Peimbert *et al.* is incorrect; however the EM derived by them for T_e = 10 000°K is correct. From the previous discussion equation (2) yields

$$R_B(H) = 9.6 \times 10^{49} \text{ s}^{-1},$$

therefore the L_H value of 1.09×10^{50} s^{-1} derived from Table 2 is adequate to maintain the test volume of the interarm medium ionized.

There are three effects that can change the L_H value: a) a fraction of the most brilliant stars might be A and B supergiants, in which case the L_H value would decrease, b) we have not considered the internal reddening, but as discussed before there is evidence of dust layers over the disk of M33, and a correction of 0.4 magnitudes for internal absorption would double the L_H value, and c) the theoretical L_H flux is also somewhat uncertain since the temperature and radius for a given spectral type are not very well known. In any case it is clear from our result that OB stars *in situ* can ionize a considerable fraction of the inner interarm medium and maybe most of it.

Cruz-González *et al.* (1974) found that the mean distance to the galactic plane for O star runaway candidates is 108 pc, a value twice as large as the mean distance for O stars inside H II regions detectable on the Palomar Sky Survey. Since a typical distance of our test area from the spiral arms is about 150 pc it is likely that a considerable fraction of the O stars in our test area are runaway O stars originating in the spiral arms.

From the computations presented above and in §IIIb it is obtained that for the interarm medium $< N_H > 1.8$ cm^{-3} and $< N_e > 0.9$ cm^{-3}. If the ionization in due to OB stars, it implies that a substantial fraction of the interarm medium is completely ionized. The Strömgren radii for the H II regions surrounding the test area stars is given by

$$r = \left(\frac{L_H}{4/3 \Pi \alpha_B N_H^2} \right)^{1/3} . \qquad (4)$$

For $N_H = 1$ cm^{-3}, O6, O8 and O9.5 stars yield radii of 72, 44 and 29 pc respectively which correspond to 21″, 13″ and 8″.

IV. CONCLUSIONS

From a study of the line emission intensities in the interarm medium of M33 it is found that most of this emission is not due to dust scattered light, nor to the ionization produced by SN remnants, X rays, UV photons or MeV particles.

The line emission intensities are compatible with the possibility of OB stars being responsible for most of the ionization of the inner interarm medium of M33. From the presence of numerous blue luminous stars in the inner interarm medium it is found that OB stars *in situ* might be responsible for most of the ionization. These stars could be runaway stars that originated in the spiral arms. The presence of large quantities of neutral hydrogen and of blue luminous stars in the interarm medium of M33 tend to favor the possibility that the ionization of the interarm medium is due ot OB stars *in situ* rather than to Lyman continuum photons escaping from the spiral arms. However both possibilities are still open.

A considerable fraction of the volume comprising the interarm medium is ionized.

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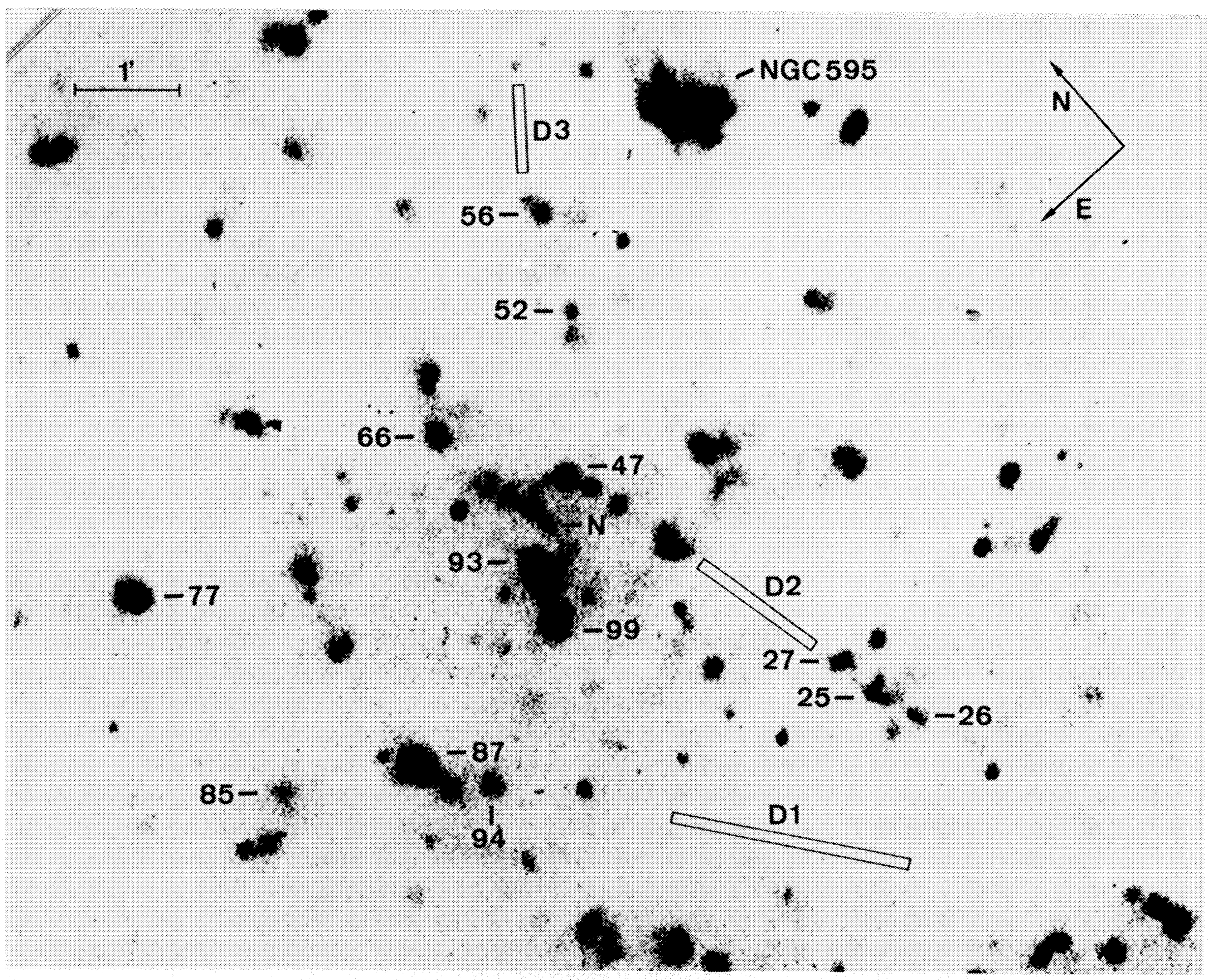

Fig. 1.- A narrow filter, Hα photograph of the central part of M33 kindly made available by G. Courtès. H II regions for which the [O III]/Hβ and [N II]/Hα line intensity ratios have been measured are numbered after Courtès and Cruvellier (1965). Positions where the line ratios were measured in the interarm region are indicated by a D letter.

Benvenuti *et al* (see page 3)

PLATE 2

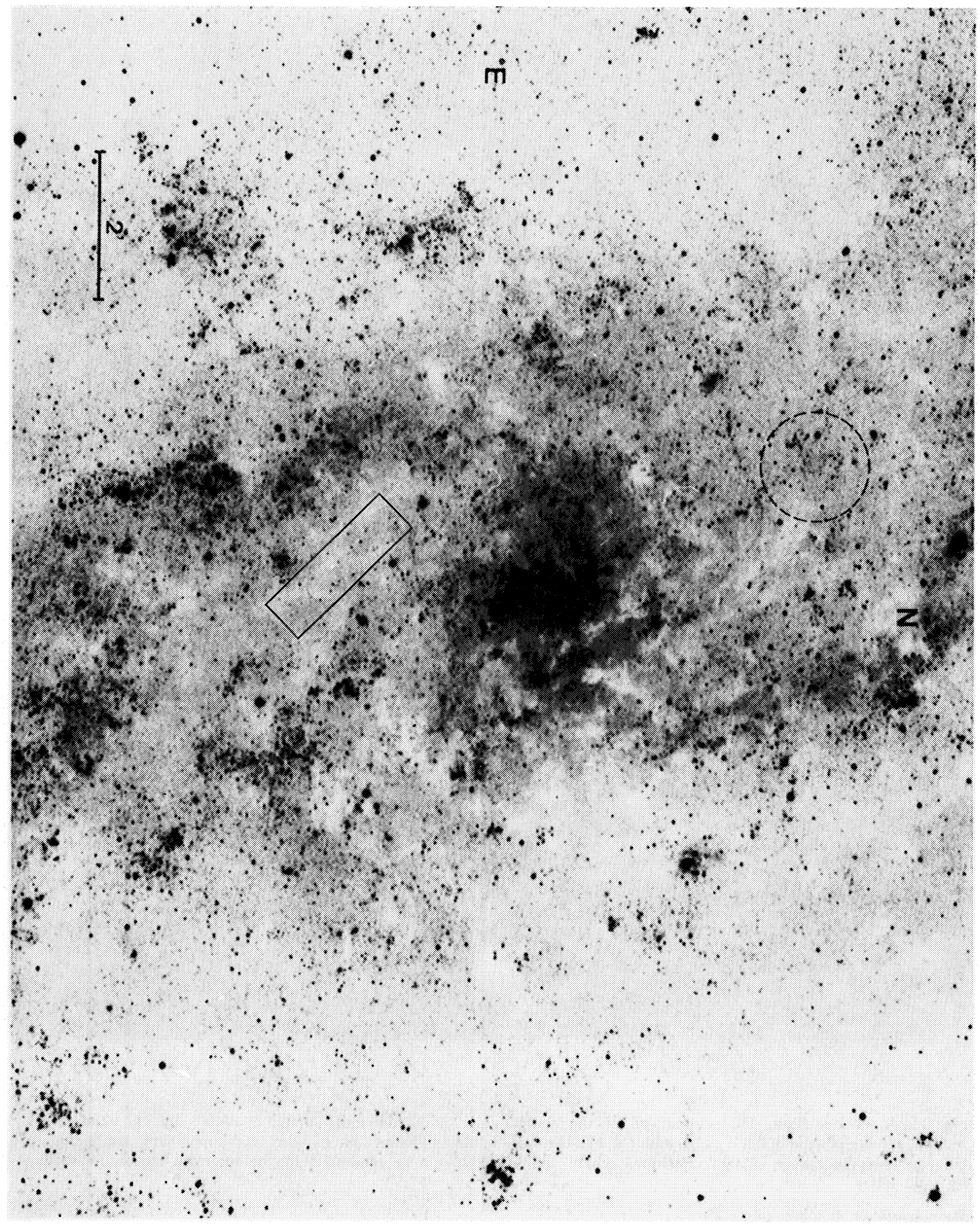

Fig. 5.-Blue photograph of M33 (GG 13 + 103a – 0). 182 cm M. Ekar telescope, 1^h exposure (courtesy of L. Rosino). The rectangle indicates the interarm area discussed in the text. The dashed circle indicates the approximate position of the interarm area studied by Deharveng and Pellet (1970) and by Comte and Monnet (1974).

Benvenuti *et al* (see page 3)