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A study of blue Hα objects in galaxy M 33

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Abstract. Blue stars with Hα excess in the galaxy M 33 are investigated. 549 such objects have recently been listed as candidates for unique objects of SS 433 and LBV types. On the basis of photometry of their Hα images 81 stars, 154 diffuse nebulae, 180 bubble–type nebulae and 117 intermediate objects have been selected. These groups are different in colours, fluxes, surface brightness and sizes in Hα, and their distribution over the galaxy. The maximum in the nebulae Hα size distribution is at FWHM = 10–14 pc. There is evidence that their location in the galaxy and properties are defined by interstellar gas parameters and related to spiral arms. The diffuse nebulae are H II regions with an embedded star. The bubbles are probably envelopes around WR stars or SN remnants. Among the stars we isolate a group of 20 brightest stars, which in their average properties fit well to the parameters of blue super–supergiants or LBVs. The stars of intermediate brightness follow very well to supergiants of average spectral type B1Ia. The interstellar absorption derived from these two groups of stars is $A_V = 0\overset{m}{.}93 \pm 0\overset{m}{.}05$. The faintest stars of the list ($18\overset{m}{.}5 \le V \le 19\overset{m}{.}5$) may be classified as OB main sequence stars with $A_V \approx 1\overset{m}{.}0$, however, a great excess of luminosity, $\Delta M_V = 1^m \div 2^m$, appears as compared to stars of this type. We classify the faintest stars as blue Ib supergiants, their average absorption is $A_V \approx 0\overset{m}{.}6$. In this case these are seen only in the nearest face part of the galaxy disk, but not through the whole depth of it.

Key words: galaxy: stellar content: individual (M 33): stars: blue objects — Hα excess

1. Introduction

Fabrika and Sholukhova (1995) stated the criteria of search for unique objects of SS 433 type in nearby galaxies. The criteria are based on the likeness of candidates for SS 433 which is free from interstellar absorption. The principal one is the existence of an early–type star with a strong and broad emission line Hα. This property is characteristic not only of SS 433 and potential candidates for this kind of objects in nearby galaxies. Other brightest stars — luminous blue variables (LBV) — the most massive and rare stars which are at the stage of transition to WR stars (Garcia–Secura et al., 1996), as well as some types of WR stars, satisfy this criterion too. Detection and study of new LBV and WR stars represent quite an important problem. That is why it seemed natural to extend the work and carry out a systematic search for all stars of the above–mentioned types on the basis of selection of objects by the criterion OB star + Hα emission. In selection of such stars on the basis of analysis of images in Hα the stars, whose Hα emission is formed in a nearby nebula, will also fall within the sample.

In our previous paper (Fabrika et al., 1997, hereafter FSZ) a selection of candidates for the objects of SS 433 type, LBV and WR stars in the galaxy M 33 has been done on the basis of photometry of blue stars (Ivanov et al., 1993) on the Hα images of M 33 (Courtes et al., 1987). Out of 2332 OB stars ($(U - B) < 0^m$, $(B - V) < 0^m$) up to $V = 19\overset{m}{.}5$ contained in the catalogue by Ivanov et al. (1993) we managed to perform Hα photometry of 1619 stars. Using the criterion of excess of the Hα flux over the flux from stars of the same magnitude in V, 549 candidates with emission were separated from them. All these are the brightest stars of the galaxy, in the U, B and V bands they are star–like objects or close to them. The study of these objects on the diagrams "flux and surface brightness — size in Hα" permitted us to isolate several different sequences there and separate (in average) the selected objects according to their Hα morphological types (FSZ). In the present paper we investigate all types of the candidates we have selected in more details.

2. Types of the selected objects

Among blue Hα objects FSZ have isolated about 81 stars (s), 154 diffuse (d) and 180 bubble (b) nebulae, 117 common (c) to all the sequences or intermediate objects and 17 objects, whose sizes are formally zero (zs). The fluxes and sizes of the objects of type c are reliably measured but they are small. They are common to the three isolated sequences (s, d and b) at their junction, which did not permit them to be classified as stars or nebulae. We did not succeed in measuring the size in the zs type objects. All these objects are located on a steep background gradients and frequently are seen as a hump at the periphery of a bright nebula. The FWHM size of such an object was underestimated and turned out to be equal to zero. Objects of this type have considerable Hα fluxes. We have decided to study the objects as a separate group for these are appreciably different from others in colours (see below).

So, as a result of photometry of blue stars on Hα images it was found out that 60 % of the selected emission objects possessed the characteristics of nebulae (nebulae b and d). We can compare new nebulae with the already known ones in the galaxy M 33. The fullest list was compiled by Courtes et al. (1987) that contained 748 nebulae classified according to morphological properties. We used the same photographic images taken by Courtes et al. (1987) with the 6 m telescope in the Hα band with FWHM = 35 Å (the scale of the images 34.5″/mm, spatial resolution ≈ 1″). Courtes et al. (1987) picked out the nebulae by visual inspection of the images, whereas our nebulae were found in computer photometry. In the former case the sample must contain the largest nebulae with dimensions of more than a few arcseconds. In the latter — nebulae no more than a few arcseconds in size so far as the basis of the list is provided by objects (Ivanov et al., 1993) having stellar images in the B and V bands.

In Fig. 1a are presented the distributions of sizes for 748 objects from the sample of Courtes et al. (1987) (shaded) and 334 nebulae of type b and d from Table 1 in FSZ. Both distributions are normalized to the total number of objects in each sample. We restrict ourselves to sizes up to 40″, which is sufficient for our purpose of comparing the distributions. As one would expect, the maxima in the two distributions are markedly different. The distribution of nebulae found with the visual inspection of the images has a wide maximum in the region of 5″ – 12″. It is evident that its location is determined by the selection effect of incomplete inclusion of nebulae smaller than 12″ in size. The maximum of distribution of the nebulae under investigation falls at a size 3″ – 4″, which corresponds to 10–14 pc with a scale of distances in M 33 3.5 pc per 1″. Estimates of the most likely size of H II regions in M 33 are known from 4.5″ (Sabbadin et al., 1980) to 13″ (Boulestex et al., 1974). The most likely size derived depends on a number of factors, mainly on the image scale (see the review and discussion in Sharov, 1988). It is improbable that the true distribution of nebulae sizes in M 33 should terminate at 10 pc. For instance, in our Galaxy H II regions of small size occur fairly often (Wink et al., 1982). Therefore the position of the maximum of the size distribution for the objects of our sample is also explained by the selection effect in isolating nebulae. Losses of our nebulae caused by the selection originate at sizes smaller than 3″ – 4″.

In Fig. 1b is shown the total distribution of sizes of the nebulae from Courtes et al. (1987) and FSZ, which appears quite smooth and continuous. From a comparison of Fig. 1a and 1b it can be concluded that in the region of sizes 5″ – 7″ many nebulae are missing in our sample; the incompleteness of the list here is not less or about 50 %. For nebulae with sizes greater than 7″ (25 pc) the incompleteness of our list sharply increases. This is due to the fact that a single early star is incapable of ionizing larger H II regions. Such regions are ionized by groups of stars or OB associations, which were, naturally, disregarded when compiling the catalogue by Ivanov et al. (1993). As was shown (Ivanov, 1991), the size distribution of OB associations in M 33 fits well such distribution of H II regions from the list of Courtes et al. (1987).

By using Fig. 2 it is possible to investigate in more detail the distribution of our objects' sizes (FWHM). In Fig. 2 the solid line shows the distribution of stars, the distribution of bubbles is displayed with the long dashes and that of diffuse nebulae with the short dashes. The three distributions are normalized to the number of objects in each of the three samples s, b and d, respectively. The distribution of stars extends as far as 6″, and it reflects only the fact that photographic data were used (FSZ). Nevertheless it is well seen that the three distributions are considerably different. This suggests that the objects in each sample are physically different. If the centres of the distributions of the stars and nebulae b are close (3.5″ and 3.7″, respectively), then the median size of the nebulae d is larger, about 4″. In Fig. 2b and 2c are shown separately the size distributions of the nebulae b and d. It is seen that the nebulae d are, on the average, more large–sized, their distribution is asymmetric and extends as far as 11″ (39 pc). The distribution of bubbles is well more symmetric, their sizes are in the region 2.5″ – 5.5″ (9 – 20 pc). Their likely size is 13 pc.

In the list of Courtes et al. (1987) are presented 23 bubbles whose sizes range from 70 to 250 pc. The sizes of FSZ nebulae of the same type b differ greatly. The largest b nebula in the sample of FSZ is 11″, the smallest bubble in Courtes et al. (1987) has a size of 14″. In the region 2.5″ – 5.5″ their density is 54 per 1″ interval, in 6″ – 8″ we find a density of 2.3 nebulae per 1″ (Fig. 2b), in 8″ – 11″ it is as low as 1 per 1″, whereas in the interval 20″ – 70″ the nebulae of Courtes et al. (1987) are distributed with a den-

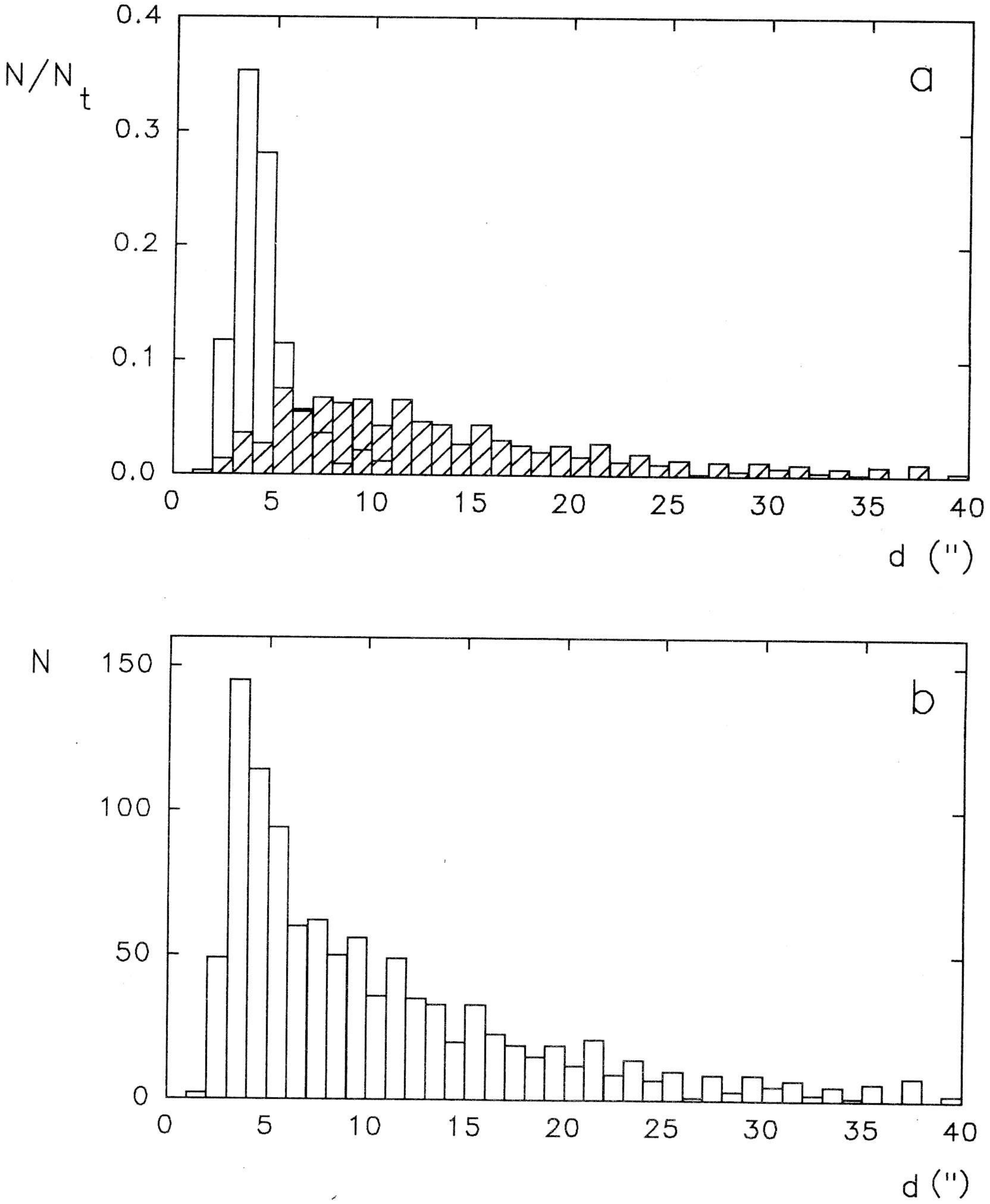

Figure 1: *Size distributions of 748 objects from Courtes et al. (1987) (shaded) and 334 nebulae investigated of b and d type (FSZ). a – both distributions are normalized to the total number of nebulae in the lists, b – the summary distribution.*

sity of 0.4/1″. The distribution of large bubbles has a maximum in the interval of sizes 30″ – 40″, where their density is 0.7/1″, and a minimum in the region 10″ – 20″, where even jointly over two samples the density amounts only to 0.3/1″. It is clear that the total distribution of bubbles is double-peaked. The deficit of medium-sized nebulae may be due to the above mentioned selection effects. Now, when analyzing physical properties, we come to a conclusion that in the case of b type nebulae the central star is a minor contributor to the total flux of a nebula. This may be an additional cause of the shortage of large (> 5″) bubble nebulae as they are likely to have been left out when compiling the catalogue of blue stars (Ivanov et al., 1993). Based on the character of distributions of the b nebulae from these two samples it can be suggested that our bubbles of small sizes (Fig. 2b) and the bubbles of Courtes et al. (1987) are of different physical nature, whereas our nebulae of b type with sizes > 6″ may belong to the same population as the b nebulae from Courtes et al. (1987).

Up to the sizes 20″ – 30″ the sample of Cour-

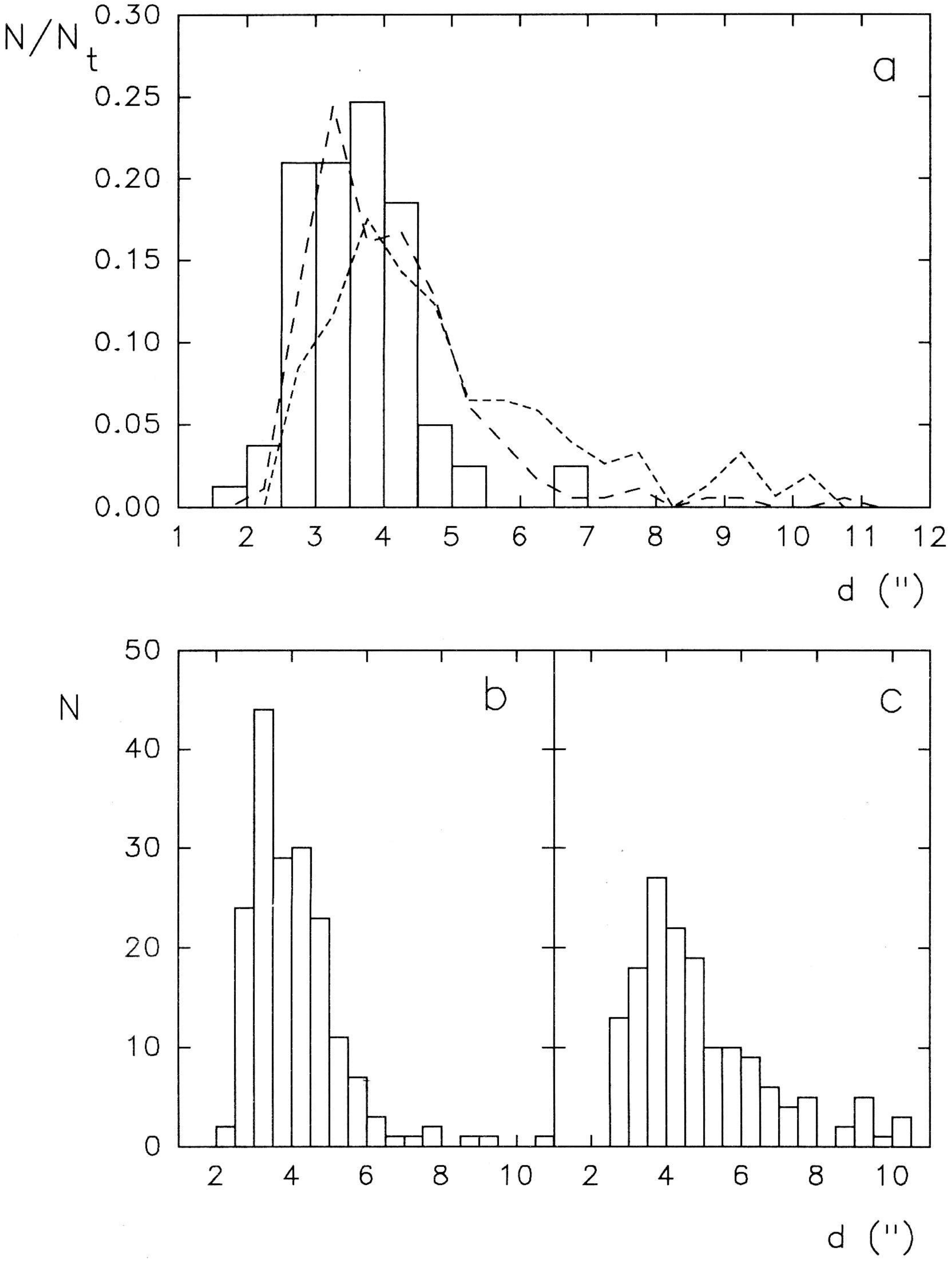

Figure 2: *Size (FWHI) distributions of the objects studied: a – stars (solid line), nebulae – bubbles (long dashes) and diffuse nebulae (short dashes), b,c – bubbles and diffuse nebulae, respectively*

tes et al. (1987) chiefly contains diffuse and compact objects, and the shaded histogram in Fig. 1a actually represents the distribution of objects only of these types. The distribution of objects from both lists looks compatible and supplementing each other in Fig. 1. We can suggest that, as different from bubbles, diffuse nebulae of the two lists are likely to belong to the same population.

In Fig. 3 are displayed the distribution of the selected objects according to the galactocentric distance R_{gc}, that is the number of objects within the interval of distances from the galactic centre. The corresponding distribution of the number of objects per unit area would be similar but would have quite a strong peak at small R_{gc}, which would make it difficult to analyze. From the coordinates the objects were depro-

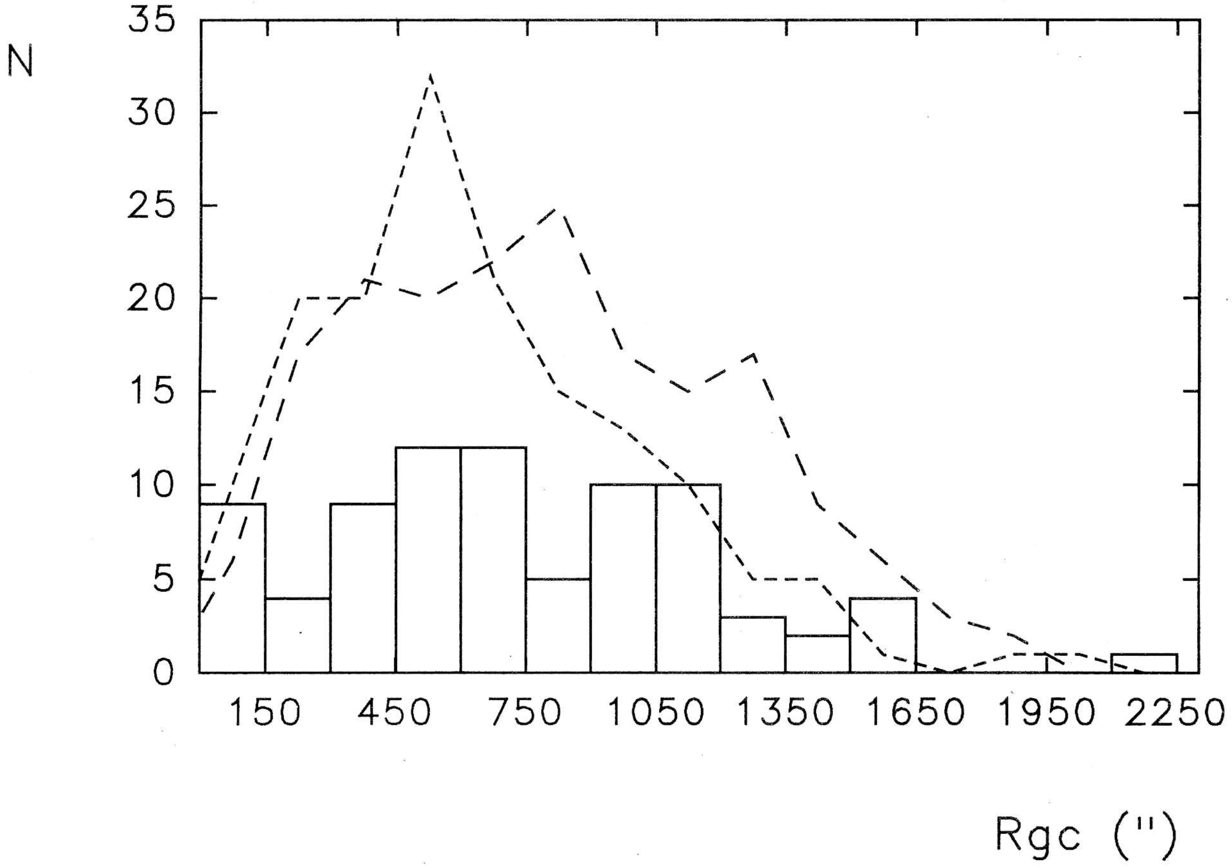

Figure 3: *Distribution of objects in the intervals of galactocentric distance. Designations are the same as in Fig.2a.*

jected from the picture plane onto the galactic plane. It was adopted according to Vaucouleurs (1959) that the inclination angle of the galactic axis to the line of sight $i = 55°$ and the position angle of the major axis $P.A. = 23°$. The solid lines show the distribution of stars, long-dash line — nebulae of type b, short-dash line — diffuse nebulae. From the figure it follows also that the three types of objects belong to different populations. It is important to note here that in the central regions of the galaxy the actual density must be higher. The selection effect is due to the difficulty of identification against the strong Hα background of the central part (the first 1–2 bins in Fig. 3). However, objects of all types considered are small, that is why the consequence of the selection effect is approximately the same for all of them. The distribution of emission stars along the radius of the galaxy is relatively uniform. Individual minima, if even they are real, are insignificant in our data and may be random. The density of stars per interval of distances from the centre falls by a factor of 2 at the distance $R_{1/2} \approx 4.2$ kpc. The distribution of diffuse nebulae is quite different: on the average these are closer to the centre, $R_{1/2} \approx 2.4$ kpc, and show a clear maximum at 1.8 kpc. This maximum is significant; under the assumption of Poisson distribution of objects in the nearest bins its significance level amounts to $2.5\,\sigma$. The objects of type c, whose distribution is not presented in the figure, most of all resemble diffuse nebulae in distribution. The nebulae of type b exhibit the widest distribution with $R_{1/2} \approx 4.7$ kpc. It has two maxima at 2.9 and 4.5 kpc. The maxima are formally insignificant, however, the distribution itself of the b type nebulae is considerably more irregular than that of the diffuse ones with an approximately the same number of objects. It is not improbable that these maxima display that predominantly spiral arms fall within the defined intervals of galactocentric distances, or possibly they are due to ring structures in the galaxy.

There is another remarkable detail in Fig. 3. The maxima in the distribution of stars and diffuse nebulae fall within the regions $400'' - 600''$ and $1000'' - 1200''$ (1.4–2.1 and 3.5–4.2 kpc, respectively) and coincide with the minima in the distribution of the b type nebulae. This matter is dealt with below.

Thus, it can be concluded that the three types of the isolated by FSZ emission objects belong to different physical populations. They are distinguished by a number of characteristics. The diffuse and large-sized bubbles in our sample are likely to be members of the same populations as the nebulae selected in Courtes et al. (1987) but are smaller in size. The bulk of bubbles represent a separate group of objects.

3. The nebulae

A considerable number of the selected emission objects are nebulae of types d and b, that is why in this section we will cover in some detail their investigation, namely discuss their colour characteristics. The contribution of the star that excites a nebula to the radiation in the U, B and V bands from the selected nebulae does not seem possible to be estimated as yet. As distinct from the continuous spectrum of stars, where there is a direct relationship between colours and temperature of a star, the colour of a nebula will depend on a number of factors and, mainly, on the degree of gas excitation. The colour depends on the temperature of the ionizing star, electron density, dilution factor (size of a nebula), optical depth. Besides, the colour may vary in a complex manner depending on the reddening. The intensity of hydrogen Balmer lines does not depend strongly on the temperature of a nebula. The forbidden lines [O III] λ 4959, 5007 are the most intensive lines in the spectra of nebulae and a good indicator of electron temperature of gas (Allen, 1977). They are approximately equal contributors in the B and V bands. Other strong lines do not fall within the V band. In the B band are the intensive lines of a hot gas: [Ar IV] λ 4712, [Ne IV] λ 4725, He II λ 4686, [O III] λ 4663 and [Ne III] λ 3967, 3969. The last two lines make an about the same contribution in the U band. In the U band is the line [O II] λ 3727. With growing electron temperature of the gas of a nebula or its excitation degree the flux in the B band will dominate, accordingly the value of U–B will increase while B–V will decrease. In Table 1 we present the mean photometric values of all the emission objects selected in FSZ: stars (s), diffuse nebulae (d), bubbles (b), common (c) and objects of formally zero size (zs). In the columns are given the types of the objects, their number, magnitude V, U–B, B–V (Ivanov et al., 1993) and V–Hα colours, surface brightness (Hα flux per square arcsecond) as well as the parameter S which was used by FSZ to isolate emission objects. This parameter is equal to the value of excess of the Hα flux over the flux of non-emission stars (of the same brightness in V) expressed in terms of standard deviations of the non-emission stars sequence. In particular, it is seen from the table that in U–B and B–V the diffuse objects differ greatly from the bubbles. This is also displayed in Fig. 7 (see below). ¿From the colours the diffuse nebulae are cool, their behaviour in Fig. 7 resembles the behaviour of the stars but they have a smaller U–B. This may be due to the emission Balmer jump and the strong hydrogen lines in their spectra. The latter is suggested also by the large value of S in the diffuse nebulae (Table 1). In contrast, the colour of the bubbles indicates that the degree of excitation in them is high. Besides, the objects of type b are, on the average, considerably fainter than the diffuse nebulae. The low luminosities, the high temperatures of the gas and the morphology in Hα (the bubbles) point to the idea that WR stars are likely the source of ionization in them, while in the excitation of gas collisional processes are dominating.

Fig. 4 shows the relationship between the standard colours and V–Hα index. The stellar magnitude in Hα is not calibrated and has been derived from the relative flux in this band, m(Hα)= −2.5 lg F(Hα)+24.5. It should be borne in mind that the F(Hα) flux for extended objects depends directly on a nebula size, but this is not the case for stars as point sources. The flux is linearly related to the intensity of the Hα line (see discussion in FSZ). In Fig. 4, as in the rest of the figures that follow, the stars are designated by dots (approximations — solid lines), rhombs are for the diffuse nebulae (short–dashed line), the b type nebulae — long–dashed line. The stars in Fig. 4 behave as one may expect: with increasing blue excess the intensity of the Hα line grows. Here and further in the analysis of the relationships we use the linear function y = Cx + C_1 and give only the value of C and its mean-square deviation. For the stars $C(U-B, V-H\alpha) = -0.085 \pm 0.035$ and $C(B-V, V-H\alpha) = -0.083 \pm 0.029$. The relationships of the nebulae of b and d types differ considerably from those of the stars in this figures, which confirms that these are the objects of different nature. Of all the nebulae only in the diffuse ones a significant dependence, $C(U-B, V-H\alpha) = -0.109 \pm 0.019$, is observed, which is likely to be due to the growing size of the H II region with increasing temperature of the exciting star. The rest of the relations in Fig. 4 are insignificant. It is not improbable that the bubbles get cooler as the size increases (or their F(Hα) flux increases) since U–B decreases, while B–V grows. The latter is consistent with Fig. 5 from which it can be seen that with growing size of the bubbles (only approximation is shown) their temperature drops. However the significance of the relationships for the nebulae of type b allows this effect just to be suspected. It is quite noteworthy that for the diffuse nebulae this figure supports the assumption that the size of such a nebula, i.e. H II region, is determined by the temperature of the star and $C(U-B, d) = -0.097 \pm 0.015$. The colours of the diffuse nebulae are in agreement with those calculated for optically thick slab of hydrogen gas with temperature $T \approx 10^4$ K (Kolesov, 1996). Comparing the data in Fig. 5 with the calculations one can conclude that with growing size of the diffuse nebulae their temperature (or optical thickness) drops. We present in Fig. 6 the relation-

Table 1: *Parameters and their r.m.s. of the emission objects*

Type	n	m_V	U − B	B − V	V − Hα	SB	S
s	81	18.23	− 0.78	0.08	2.26	277	19.7
		0.10	0.04	0.03	0.11	9	2.0
d	154	18.35	− 0.85	0.08	2.52	180	28.0
		0.07	0.03	0.02	0.11	5	2.9
b	180	18.83	− 0.68	0.04	1.65	75	6.9
		0.03	0.02	0.02	0.05	2	0.6
c	117	18.85	− 0.82	0.05	1.60	625	4.2
		0.04	0.03	0.02	0.05	218	0.2
zs	17	18.55	− 0.98	0.01	3.14		93
		0.20	0.07	0.09	0.36		34

ships between the surface brightness in the Hα line, $SB = F(\mathrm{H}\alpha)/d^2$ and the galactocentric distance of an object. Besides the apparent separation of the nebulae into two groups in surface brightness (this was discussed in more detail in FSZ), the surface brightness in the bubbles is seen to decrease with distance from the centre, $\mathrm{C}\,(SB, R_{gc}) = -0.024 \pm 0.004$. The surface brightness increase of the diffuse nebulae is also noticeable, but this effect is not significant. The nebulae of d type in this figure show a considerable scatter. Nevertheless, one can see that the diffuse nebulae whose surface brightness is not high ($SB \lesssim 150$) do not show SB to depend on the distance from the centre, while in brighter objects the surface brightness is likely to grow with distance. In other words, the brightest diffuse objects exhibit the dependence of SB on R_{gc}.

It is evident from geometrical considerations that with increasing size the surface brightness of the diffuse nebulae rises, whereas in the bubbles it diminishes (or remains approximately constant). The increase in SB of the bright diffuse nebulae with distance from the centre of the galaxy is quite consistent with the results of Searle (1971), Smith (1975), Shields, Searle (1978), where the strengthening of the field of ionizing radiation along the radius of M 33 is discussed. This effect was discovered on the basis of the analysis of the line intensity ratios [O III]/Hβ and Hα/[S II] along the radius. The relationships of the nebulae of type d in Fig. 4–6 confirm the assumption that the average temperature of hot stars grows with distance from the galactic nucleus. These relationships may be also explained by the chemical composition gradient, the more so that such a gradient has been determined in M 33 (Kwitter, Aller, 1981). Another interpretation of all the data on the diffuse nebulae, as the decrease of the mean electron density of interstellar gas along the radius, is hardly probable.

The Hα flux in a diffuse nebula depends on the central star temperature, while the size of nebula — on the electron density. We define for a diffuse nebula (FSZ) $W'_\lambda = F(\mathrm{H}\alpha)/F_\lambda$, where H$\alpha$ line flux is assumed to originate in nebula, while the underlying continuum flux per 1 Å is of stellar origin. In such a case the value W'_λ is a direct function of the ratio of the star's luminosity beyond the Lyman limit to the luminosity in the V band, i.e. the star's temperature. The mean W'_λ of the Hα line of the diffuse nebulae in the sample of FSZ is $< W'_\lambda > = 560 \pm 80$ Å. ¿From the calculations of Churchwell and Walmsley (1973) this corresponds to effective spectral class of ionizing stars O9.5. The size of the nebula or the Stromgren radius is defined, in turn, by the luminosity and temperature of the star, as well as by the density of the surrounding gas. Taking the mean electron density $N_e = 1\,\mathrm{cm}^{-3}$ on the basis of the calculations in Prentice and Haar (1969) for B0 stars, the sizes of their H II regions are found to range from a few pc to tens of pc depending on luminosity class of the star. These values agree with typical sizes of the d type nebulae in our list.

The bubbles show an inverse relationship between SB and R_{gc}. Such a behaviour of the surface brightness of the bubbles is due to the drop of pressure of interstellar gas caused by the decrease of gravitational potential with increasing distance from the nucleus. The size of a bubble is defined by its internal energy and by the pressure of the surrounding gas. In the case of envelopes around WR stars, the total energy of a bubble is the energy of gas ejected during the time of WR stage. Accordingly, in the case of SN remnant this is the kinetic energy of ejecta. With a possible considerable dispersion of those values the decrease in pressure with distance throughout the galaxy ac-

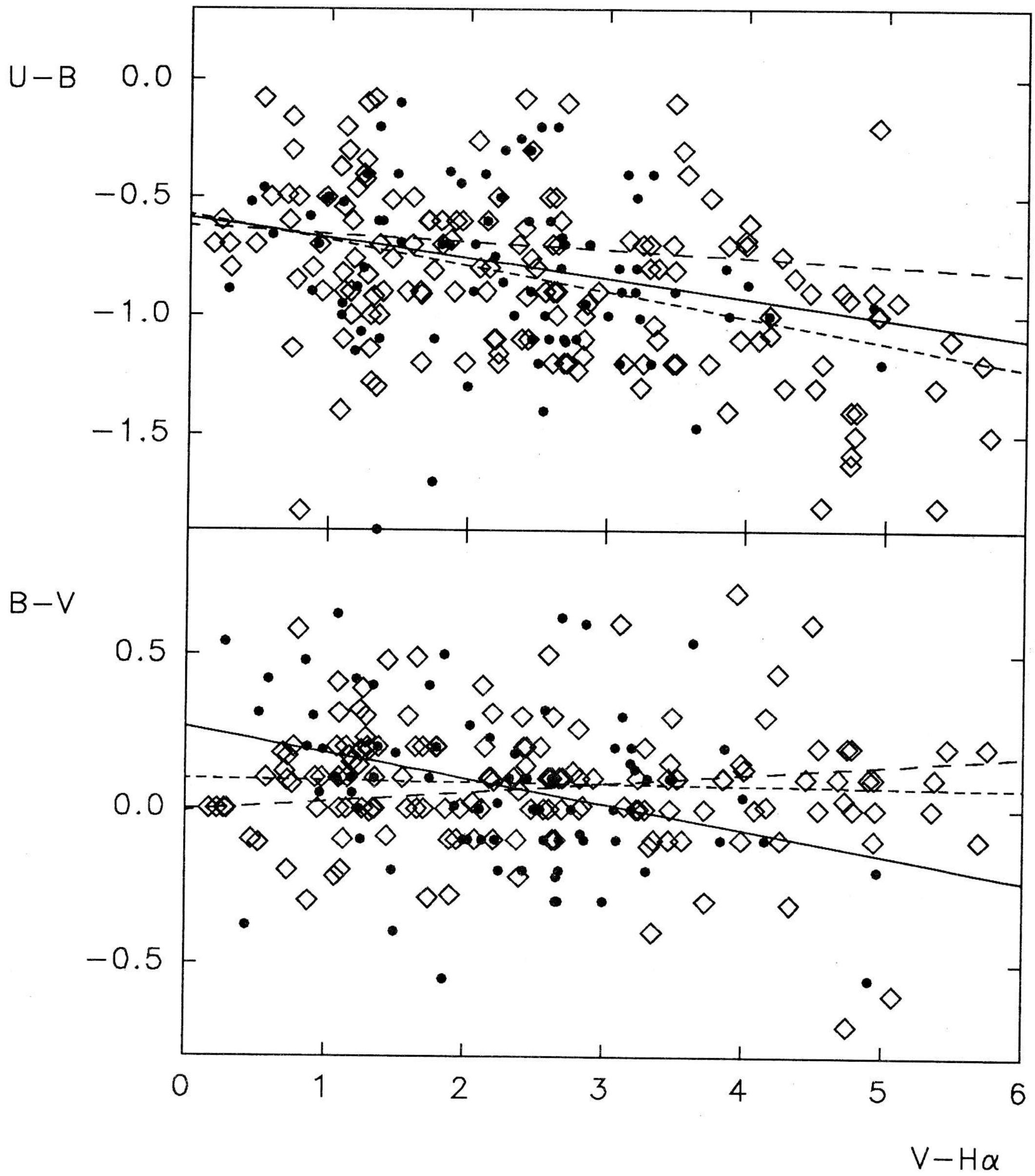

Figure 4: *Colours as a function of V-Hα. Here, as in the following figures, the stars are marked with dots (approximations - solid lines), diffuse nebulae - rhombs (short dashes). The data on b type nebulae are not presented not to overload the figure.*

counts for the relationship in Fig. 6. This effect was noticed earlier by Boulestex et al. (1974). They found that sizes of large, 30″÷60″, bubbles grow with radial distance.

One can readily see (Fig. 6) that with an average fall of SB along the radius of the galaxy the relation itself is not monotonic. There are two pronounced peaks near 400″ – 600″ and 1000″ – 1200″. In these distance intervals the surface brightness of the bubbles rises as if the mean density of the interstellar medium is maximum here. In order to emphasize this effect, we present the mean values and their errors in bins of 100″ denoted by the filled symbols. The significance of the deviations from the linear trend is considerable and amounts to no less than 3–4 σ in separate bins. These features are consistent with those discussed above when analyzing Fig. 3, namely: there are more emission stars and diffuse nebulae in spiral arms but the number of bubbles is smaller. It can be seen in Fig. 6 that the latter have an enhanced surface brightness in these particular distance intervals, which may be connected with the increase in interstellar gas pressure. Humphreys and Sandage (1980) isolated up to 10 arms in the M 33 disk. In some intervals along the galaxy radius the density of the spiral arms turns out to be higher than in the adjacent ones.

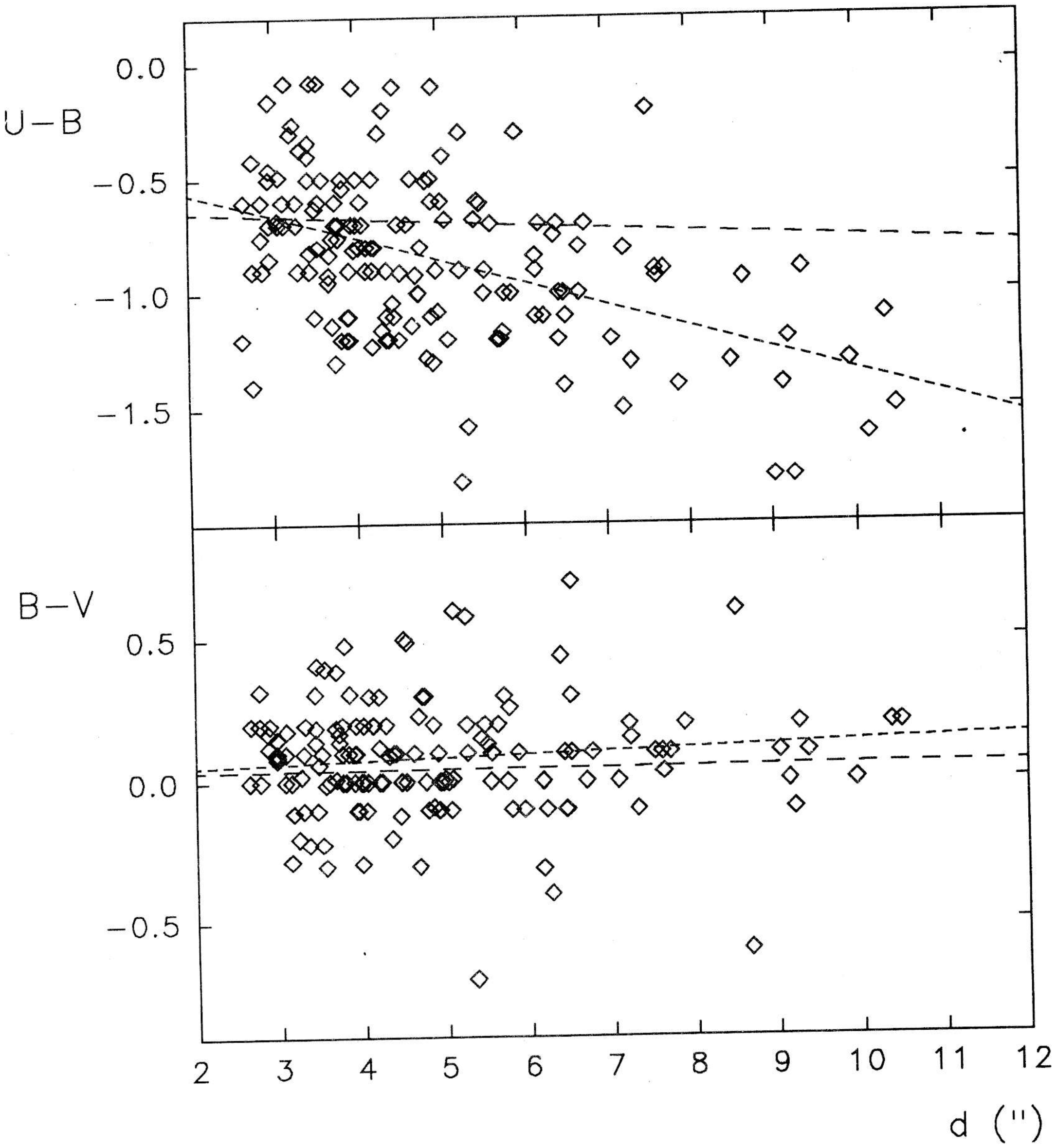

Figure 5: *Colours as a function of nebulae sizes. The designations are the same as in Fig. 4.*

This is quite possible because of the non-uniform location of arms as well as their different curvature. In this case one may observe the effects of the type detected in Fig. 3, 6. ¿From the other hand the existence of ring structures in M 33 may well be assumed. There is a great deal of evidence (e.g. Mezger, 1970) that such structures do exist in the Galaxy.

The sizes of our bubbles are basically in the region 7–20 pc (2″ − 6″) as it follows from Fig. 2b, their distribution extends to 40 pc. It is noteworthy that the known galactic ring structures around WR and Of stars are about of the same size (Lozinskaya, 1992) and distributed in the interval 3 ÷ 30 pc. The sizes of galactic SN remnants have a somewhat greater dispersion — from 7 to 50 pc.

Thus, a number of characteristics: colours, surface brightness, distribution over sizes and radius in the galaxy suggest that b and d nebulae are physically different objects. For instance, in V − Hα they differ by 8σ (Table 1). The distribution of these objects in the galaxy is not uniform. There is evidence that the location and properties of nebulae depend on the interstellar gas density distribution, i.e. are related to spiral arms.

The diffuse nebulae are H II regions with an exciting star. These are chiefly situated in the central part of the galaxy, in the regions of enhanced gas density. The sizes of these nebulae in Hα are very sensitive to the temperature of the central star. We believe that the brightness and colours of these objects are defined by the star. On the two-colour diagram (Fig. 7) they follow to the sequence of stars. Hydro-

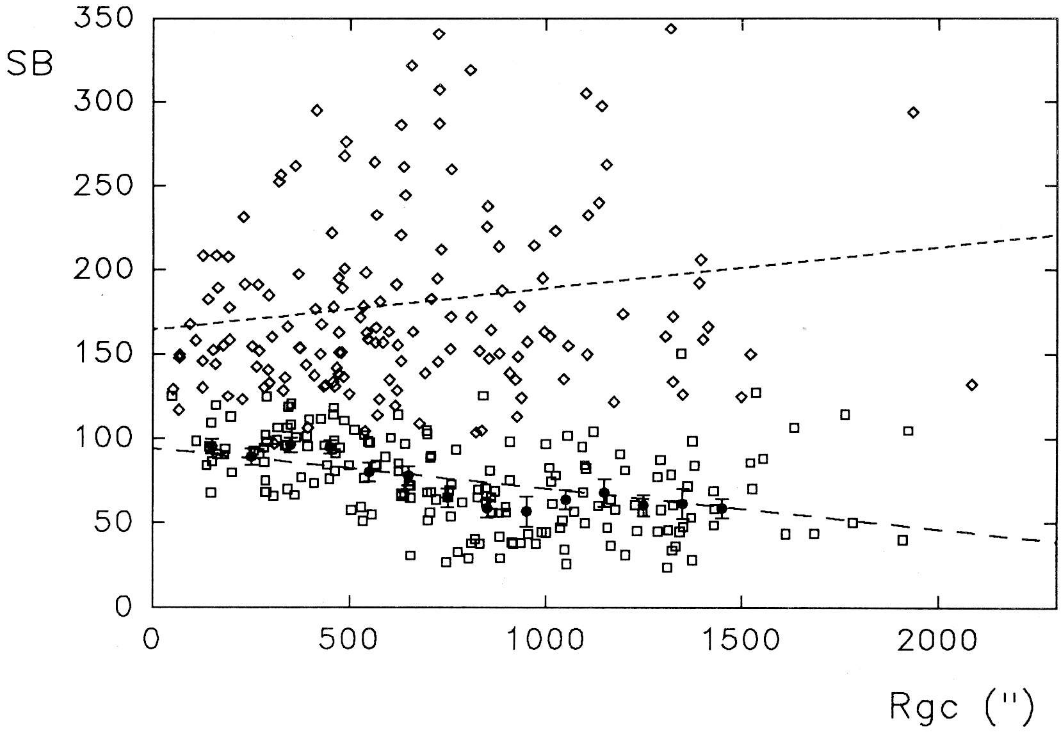

Figure 6: *Dependences of the surface brightness in Hα lines upon the galactocentric distance of the nebulae. The designations are the same as in Fig. 4. For bubbles (squares) the average values and their errors in the intervals over 100″ are shown also.*

gen emission (Hα in the main) is likely to predominate in their spectra, while nebular lines are weak. Otherwise these objects would not be point–like ones on the U, B, V plates and would not be entered in the list of blue stars (Ivanov et al., 1993). These inferences are corroborated by the two investigated objects. The object N 712 in FSZ (Hα 19 as designated by Fabrika and Sholukhova (1995)) is a d–type nebula 7″ in size. It proved to be an eclipsing binary system with orbital period of 33.108 days and eclipse amplitude about $0^m.6$ (Sharov et al., 1997). The light curve is remarkable in many respects, being variable with a period (precession?) of 589.9 days. In 1992 at our request B. Margon (1992) and S.I. Neizvestny obtained spectra of this star. In the spectra are visible a blue continuum and strong hydrogen emission lines no broader than 400 km/s. Nebular lines were not detected in the spectrum. A similar situation occurred with the object N 33 in FSZ (Hα 7 from Fabrika and Sholukhova (1995)). This is also a diffuse nebula 3″ in size. From the data of photographic photometry of A.S. Sharov (1992) the star is variable with an amplitude of about 1^m and has narrow hydrogen emission lines in the spectrum (Margon, 1992).

Nebulae of type b are high excitation ones. The location of these objects on the diagram in Fig. 7 suggests that they are clearly different in degree of excitation and that the central star is a minor contributor to the spectrum. If the heating of such nebulae is radiative, the star must then have a relatively small size and a sufficiently high temperature. It is unlikely, however, that the size of these nebulae is defined by the central star's temperature and luminosity at all. From their morphology, colour, sizes, low luminosity and the behaviour of surface brightness we can refer them to envelopes around WR stars and SN remnants. Estimates show (Lozinskaya, 1992) that no less than 80 % of WR stars in the Galaxy have H II regions around them, no less than 40 % having ring nebulae. If these are bubbles that surround WR and Of stars, then in heating and excitation mechanisms they are similar to planetary nebulae. In this case we can conclude that the star itself is not seen in the visible region of the spectrum and the observed emission is produced by the nebulae. In the case of extremely hot central stars of planetary nebulae, the star is fainter than the nebulae by $\Delta B = 6^m$, and at a temperature of the star of about $3 \cdot 10^4$ K the star is fainter by $\Delta B = 0^m.4$ (Allen, 1977). It can also be concluded that on U, B and V plates these objects must look like diffuse ones. That is why the largest of such objects are likely to be missing in the catalogue (Ivanov et al., 1993). It may be for the same reason b nebulae have smaller sizes than d ones (Fig. 2a). It can be stated that they may not be ordinary planetary nebulae (the brightest of which have $M_B = -2^m$) since

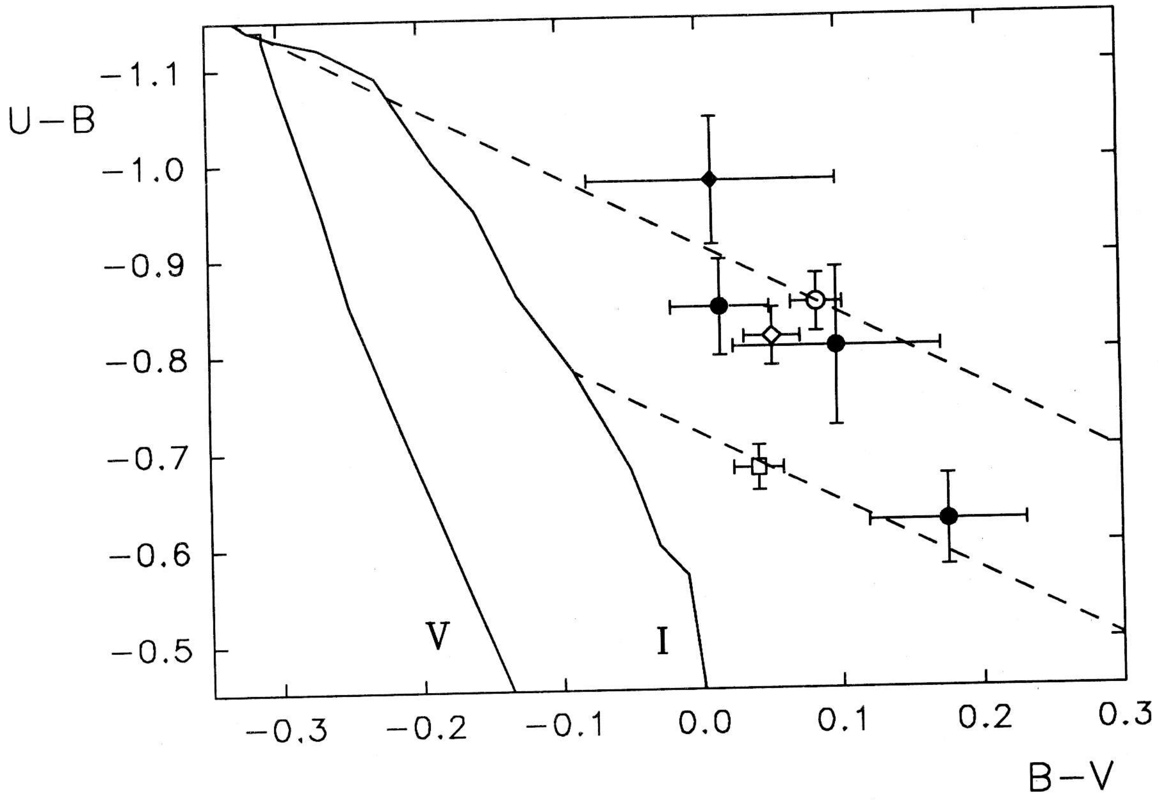

Figure 7: *Two-colour diagram for stars (full circles), from the bottom upwards for bright, mean and weak groups, respectively; diffuse nebulae (circles), bubbles (squares), common intermediate objects (rhombs) and zs type objects (filled rhombs). Consequences of* I *and* V *luminosities and their corresponding reddening lines are marked.*

the latter are of too low luminosity. Besides, the sizes of b nebulae are at least by an order of magnitude greater than those of the hugest planetary ones.

In the group of common (intermediate) objects all types are present, however, compact and diffuse nebulae are apt to be the most numerous. It is very remarkable that the zs-type objects that have been classified as a separate group only by morphology on the Hα image (FSZ) have the bluest colour U–B, the reddest colour B–V and the most powerful Hα emission (see Table 1). May be these are compact H II regions with a high gas density, where hydrogen emission lines of a nebula being a powerful contributor to the spectrum.

4. The stars

Among emission stars selected in FSZ there are objects with V= $15\overset{\rm m}{.}5$ – $19\overset{\rm m}{.}5$. At a distance modulus for M 33 $24\overset{\rm m}{.}3$ it is obvious that all of them are early massive stars of different luminosity classes. Because of the great dispersion of luminosities, it was a good plan to divide all the stars into three groups: bright ($V< 17\overset{\rm m}{.}5$), medium ($17\overset{\rm m}{.}5< V <18\overset{\rm m}{.}5$) and faint ($18\overset{\rm m}{.}5< V <19\overset{\rm m}{.}5$). In Table 2 we present the number of stars in the groups and the mean observed colours with their errors. On the two-colour diagram displayed in Fig. 7 filled circles indicate the groups. In the same figure are shown the nebulae that we discussed in the previous section. The error bars are r.m.s. of the mean values. All stellar magnitudes presented by Ivanov et al. (1993) have been calibrated by photoelectric standards and have no noticeable systematic errors. The average scatter when determining the magnitudes and reducing from various systems is equal to $\sigma(\mathrm{U}) = 0\overset{\rm m}{.}22$, $\sigma(\mathrm{B}) = 0\overset{\rm m}{.}29$ and $\sigma(\mathrm{V}) = 0\overset{\rm m}{.}20$, the error being larger for the objects in compact groups. For isolated objects the error does not exceed $0\overset{\rm m}{.}1$. If the colour errors are found from these values, then (being normalized to the root of the number of objects in each group) they would very well fit to the r.m.s. given in Tables 1 and 2. That is why in Fig. 7 (and further in Fig. 8) we present the errors from the tables. In the figure are shown two sequences for stars of luminosity classes I and V as well as two reddening lines (dashed) for B0I and OV stars, respectively (Strajzhis, 1977). The slopes of the reddening lines differ insignificantly. For each of the three groups and for each of the two sequences of luminosity I and V we have determined the corrected

Table 2: *Parameters of the stars*

V	n	U − B	B − V	E(U − B), I	E(B − V), I	A_V, I	$(U-B)_0$, I	$(B-V)_0$, I	M_V
		r.m.s.	r.m.s.	V	V	V	V	V	
< 17.5	20	− 0.62	0.18	0.20	0.29	0.96	− 0.82	− 0.11	− 8.3
		0.05	0.06	0.33	0.45	1.48	− 0.95	− 0.27	
17.5 — 18.5	21	− 0.80	0.10	0.22	0.28	0.91	− 1.02	− 0.18	− 7.3
		0.08	0.07	0.30	0.41	1.35	− 1.10	− 0.31	
18.5 — 19.5	40	− 0.85	0.01	0.15	0.19	0.62	− 1.00	− 0.18	− 5.9
		0.05	0.04	0.24	0.32	1.04	− 1.09	− 0.30	− 6.3

for the reddening colours $(U-B)_0$ and $(B-V)_0$, the colour excesses E(U–B) and E(B–V) and the light absorption values $A_V = R \cdot E(B-V)$. The values R (Strajzhis, 1977) have been used for sequences I and V separately, but they are also very close, R≈ 3.29. In Table 2 we present the values obtained for both sequences. For each group of stars the top line in the table conforms to the assumption that their luminosity class is I, the bottom one — V. The division of stars into three brightness groups is conventional and needed for a safer determination of their characteristics. Nevertheless, the difference in colour of the groups (Table 2) is apparent and justifies the division itself. From analysis of the colours and their errors it is seen that the medium group of stars is less homogeneous.

We have assumed that bright and medium stars should be referred to luminosity class I, faint ones to V. This has been done not only from brightness considerations. It is with this division that we obtain throughout the three groups very close values of interstellar absorption with the mean value $A_V = 0^{\rm m}.97$ ($0^{\rm m}.93$ over two bright groups). Accordingly for all three groups close values of E(B–V) are derived. Thus, among bright early stars with Hα emission in M 33 the interstellar absorption is $A_V \approx 1^{\rm m}.0$. Below we provide evidence that the bright and medium groups should be only used for the absorption to be determined most reliably. We conclude then that the mean value of interstellar absorption is $A_V = 0^{\rm m}.93 \pm 0^{\rm m}.05$. This estimate of A_V is consistent with results of other authors. Humphreys (1980) gives $A_V = 0^{\rm m}.8 \pm 0^{\rm m}.07$ for blue supergiants in M 33. From CCD photometry of OB stars Wilson (1990) has found the mean value $< E(B-V) > = 0^{\rm m}.3$ ($A_V = 0^{\rm m}.9 \div 1^{\rm m}.0$). The interstellar absorption in our Galaxy in this direction is $0^{\rm m}.2 \div 0^{\rm m}.3$ (Sharov, 1988; van den Bergh, 1991).

Now we can proceed to spectral classification of the selected emission stars. All of them are star-like sources in Hα. This line is the most powerful one in H II spectra, one may suggest that if even H II region does exist near these stars, it is unlikely that its lines contribute essentially to the U, B and V bands. On the colour–luminosity diagram (Fig. 8) the filled circles show the stars of the three groups at $A_V = 1^{\rm m}.0$ — if the bright and medium stars are supergiants (I), while faint ones are main sequence stars (V). The open circles indicate the position of the faint group stars under the assumption that they are also of luminosity class I, however their mean interstellar absorption $A_V = 0^{\rm m}.6$ (see below). The bars correspond both to the colour errors (as in Fig. 7) and the intervals of stellar magnitudes in M_V. The curves for different classes of luminosity are plotted from the compilations of Strajzhis (1977, 1982a). The uppermost curve for super-supergiant stars is constructed from the data of Lang (1992). The group of the brightest stars does not conform to any of the classical stellar sequences (Strajzhis, 1977, 1982b). The close luminosity class is Ia, in colours they fit on the average to B0Ia–B4Ia. However, the stars of this group are essentially brighter ($\Delta M_V = 1^{\rm m}.1$) than Ia stars. We draw the conclusion that the bright group stars belong to the class of super–supergiants (LBV stars are found among them) since from their characteristics they fit well this kind of objects (Humphreys, Davidson, 1994). It can be seen in Fig. 8 that they fully satisfy this sequence (at $A_V = 1^{\rm m}.0$, $m - M = 24^{\rm m}.3$). Their mean luminosity $M_V = -8^{\rm m}.3$. The mass of such stars is over 60 $M_\odot$.

The stars of the intermediate group both in colours and in luminosities conform, on the average, very well to B1Ia supergiants. This conclusion is illustrated in Fig. 8. The mean luminosity of this type of stars $M_V = -7^{\rm m}.3$. Masses of such stars are about 40–45 $M_\odot$. Any other classes of luminosity can safely be excluded for these stars.

We assumed that the luminosity class of the faint group stars is V from the criterion of equality of interstellar absorption values ($A_V \approx 1^{\rm m}.0$) for all three groups. In that case their average spectral class is B0V, however, a great excess of luminosity, $\Delta M_V = 2^{\rm m}.3$, appears as compared to stars of this type. One could assume these stars to be of luminosity class III.

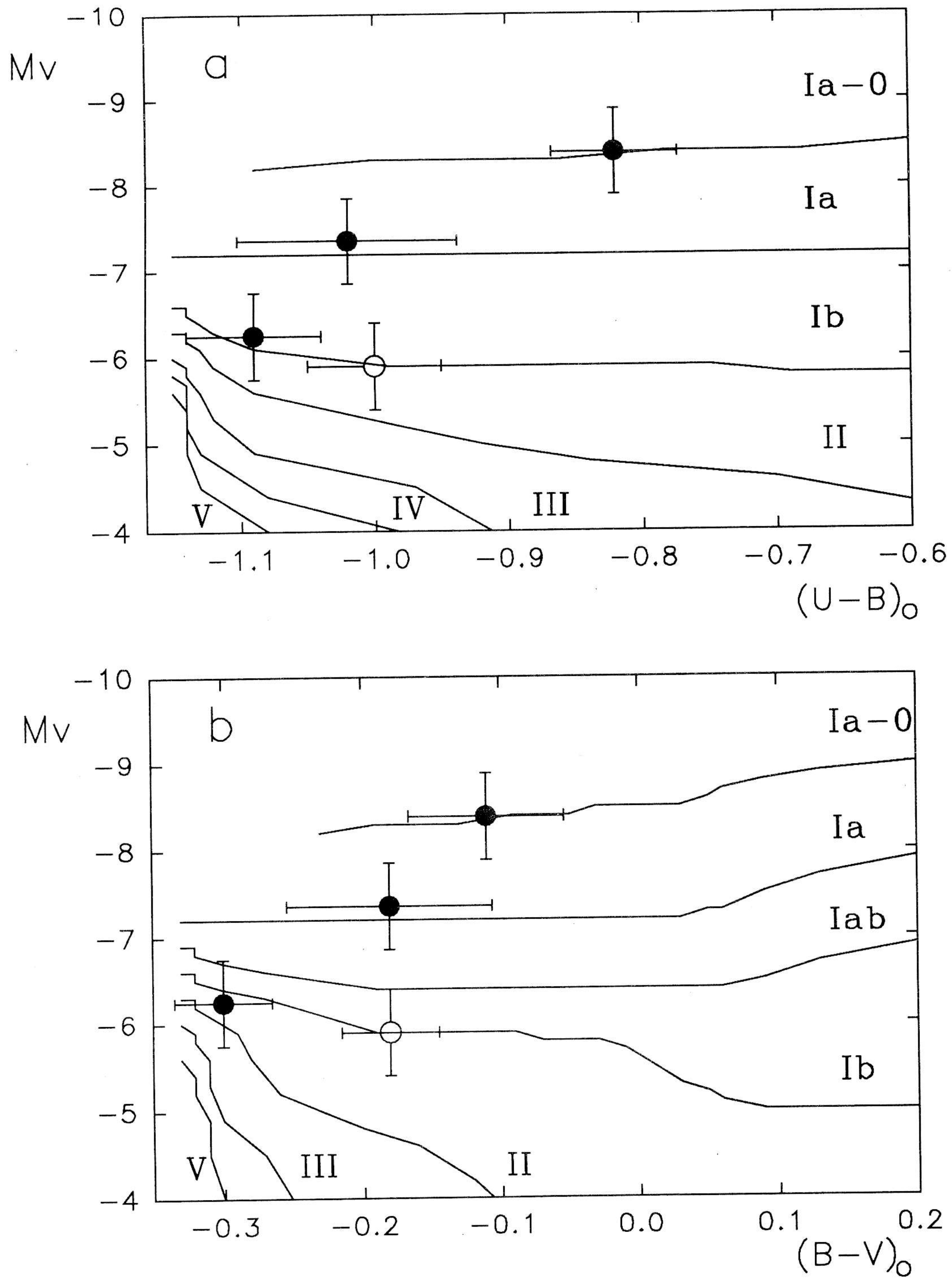

Figure 8: *Colour-luminosity diagram for the bright, mean and weak groups of stars. Filled circles show I luminosity class for stars of the first two groups, and V – for stars of the weak group ($A_V = 1\overset{\rm m}{.}0$). An open circle marks the position of weak group stars, if their luminosity class is I, and the average interstellar absorption $A_V = 0\overset{\rm m}{.}6$.*

It is quite close to class V in colours, in this case their mean spectral class is B0III. For luminosity classes V and III masses of the faint stars are about 20–25 $M_\odot$. However, even if these stars are giants, their luminosity excess ($\Delta M_V = 1\overset{\rm m}{.}4$) remains unexplained all the same. Even if they belong to extremely hot stars of luminosity V and III, the excesses remain and are equal to $0\overset{\rm m}{.}7$ and $0\overset{\rm m}{.}3$, respectively. We believe that this discrepancy is significant enough for the interpretation of faint stars as those of the main sequence be suspected as wrong. Since the limiting magnitude of the stars (Ivanov et al., 1993) is $V = 19\overset{\mathrm{m}}{.}5$, it is apparent that at $A_V = 1\overset{\mathrm{m}}{.}0$ only the stars with $M_V \leq -5\overset{\mathrm{m}}{.}8$ will be accessible to us. This practically rules out the appearance of noticeable portion of the main sequence stars among the faint group stars.

An attractive interpretation becomes possible if one assumes that the faint stars are supergiants. This possibility was pointed out by A.I. Zakharov. In this case we obtain for them $A_V \approx 0\overset{\mathrm{m}}{.}6$ (Table 2) and their mean luminosity $M_V = -5\overset{\mathrm{m}}{.}9$. These stars are markedly fainter than Iab supergiants but they fit very well the Ib sequence (open circle in Fig. 8). From the luminosity criterion they are B1Ib–B5Ib stars, whereas from both colour and luminosity their average spectral class satisfies completely B1Ib. Masses of such stars are about 20–25 $M_{\odot}$. Obviously, the group of faint stars is not homogeneous, and we discuss their average properties. Both supergiants and the hottest main sequence stars may enter this group.

The mean interstellar absorption of bright supergiants in the list, $A_V \approx 0\overset{\mathrm{m}}{.}93$, corresponds to an optical depth of 0.86 (Strajzhis, 1977). For the faint group stars, if they are Ib supergiants, these values are 1.5 times as small. This implies the faint stars are not observable throughout the whole disk of M 33 but only over the near face part of its surface. To be more precise, the stars of this group are located, on the average, in the near half, which takes up 60 % of the galaxy disk's cross–section on the line of sight. Hence, the incompleteness of our faint star group (supergiants with Hα emission) is no less than 40 %, i.e. M 33 must contain over 70 such stars. This is a lower estimate, actually the incompleteness has to be greater. The incompleteness is, naturally, caused by the limiting magnitude $V = 19\overset{\mathrm{m}}{.}5$ in the sample (Ivanov et al., 1993) and by the problems in photometrying faint stars on Hα images (see discussion in FSZ).

Thus, the blue Hα emission stars in our list are supergiants of luminosity classes Ia–Ib. We also conclude that the group of 20 brightest stars is well consistent, on the average, with the characteristics of super–supergiants or LBV type objects. The expected number of such objects in M 33 is about that value from (Fabrika, Sholukhova, 1995). The mean interstellar absorption estimated from the brightest supergiants which are visible across the entire galaxy disk depth is $A_V \approx 0\overset{\mathrm{m}}{.}93$. The interstellar light absorption of the faintest Ib supergiants is $A_V = 0\overset{\mathrm{m}}{.}6$. These objects are visible only in the nearest half of the disk but not across the whole cross–section. They are basically restricted in number by the limiting stellar magnitude in the original sample. We have performed the division of stars into types and their classification mainly over three groups of luminosity. It is natural that there exists a continuous sequence along which star characteristics change depending on their mass, original chemical composition and age.

5. Conclusion

In this paper we have studied blue objects with Hα excess in the galaxy M 33 which were selected previously as candidates for unique SS 433 and LBV type stars. All of them are the brightest stars of the galaxy, in the U, B and V they are star–like objects (Ivanov et al., 1993), on the Hα images far from all candidates appeared to be star-like. In FSZ the objects of the sample were divided into diffuse nebulae, bubble–type nebulae, stars as well as common (intermediate) objects. The objects of these groups differ in a wide variety of characteristics: luminosity, colours, fluxes in Hα, sizes, and distribution along the galaxy radius. There is evidence that the location and the properties of the nebulae depend on the density and pressure of interstellar gas and are related with spiral arms.

The diffuse nebulae are Hα regions with an exciting star. Hydrogen emission is likely to be dominant in their spectra and nebula lines are weak, but the colours are defined by the star. The bubbles are probably composed of high excitation gas, nebula lines must predominate in their spectra. The contribution of the central star to the total flux of these objects may be insignificant. By their properties we identify these objects with envelopes round WR stars and with supernova remnants. The group of common objects comprises objects of all types, but, basically, these are stars and compact diffuse nebulae. The diffuse and large bubble–type nebulae in our list are likely to belong to the same assemblies of nebulae listed by Courtes et al. (1987), but they are small–sized, mainly 7–20 pc.

Among the selected emission stars we isolate a group of 20 brightest stars which, in their average characteristics, conform to the blue super–supergiants or LBV type objects. The stars of intermediate luminosity comply with the bright supergiants of average spectral class B1Ia. The interstellar absorption for these two types of stars is $A_V = 0\overset{\mathrm{m}}{.}93 \pm 0\overset{\mathrm{m}}{.}05$. The faintest stars are in main blue Ib supergiants. The mean absorption of these stars $A_V = 0\overset{\mathrm{m}}{.}6$, they are not observable across the whole disk but only in its nearest to the observer part. The number of the latter stars is restricted by the limiting stellar magnitude on the list of Ivanov et al. (1993).

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