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GENERAL PROPERTIES OF HII REGIONS IN GALAXIES

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GENERAL PROPERTIES OF HII REGIONS IN GALAXIES

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1. General

A cloud of ionized hydrogen, the luminescence of the gas in which is primarily due to recombination of electrons and ions, is called a HII zone. The surface brightness (both the optical and the radio emission from the HII zone) is proportional to the degree of emission (ME), which is the square of the electron concentration, integrated over the line of sight: $ME = \int n_e n_p \, dl$. Ionization of the hydrogen in a HII zone is due to ultraviolet radiation beyond the Lyman continuum (L_c). With I_ν as the intensity of emission of a star, for the total number of L_c quanta emitted by the star, we have the expression /5*

$$4\pi r_*^2 \int_{\nu_1}^{\infty} \pi I_\nu \frac{d\nu}{h\nu},$$

where ν_1 is the frequency of the Lyman series limit (λ = 912A). By equating to the number of recombinations, we obtain:

$$r_o^3 n_e^2 \sum_2^{\infty} C_i = 3 r_*^2 \int_{\nu_1}^{\infty} \pi I_\nu \frac{d\nu}{h\nu}$$

Since the emission intensity I_ν is given by the Planck formula, with temperature T, we find that

$$u \equiv r_o n_e^{2/3} = \left[\frac{3 r_*^2 f(T_*)}{4K}\right]^{1/3},$$

where r_o is the radius of the zone, u is the excitation parameter, f(T) is function T_*, the gas temperature T_e and the atomic constants. Stars of spectral classes O5-B5 ionize most strongly. The excitation parameters of these stars and their temperatures are presented in Table 1.

TABLE 1

Spectrum	O5	O6	O7	O8	O9	B0	B1
T°(K)	179000	63000	50000	40000	32000	25000	23000
u ($pc \cdot cm^{-2}$)	140	110	87	56	46	26	17

* Numbers in the margin indicate pagination in the foreign text.

TABLE 1 (CONT.)

Spectrum	B2	B3	B4	B5
$T^{\circ}(K)$	20000	18600	17000	15500
u (pc cm^{-2})	11	7.2	5.2	3.7

Usually, HII zones are not excited by one star, but by several stars of different spectral classes, and the greatest contribution to ionization is made by type O stars. For a typical HII zone, according to [1], the following parameters can be introduced: diameter = 5-40 pc; $T = 10{,}000^{\circ}K$; $n_e = 10\ cm^{-3}$; $n_e/n_h = 1$; $M_V = -10^m - -12^m$. /6

HII zones are not uniform. A fine structure can be distinguished in them. According to Metzger [2], the majority of HII zones with high surface brightness consist of compact condensations with linear dimensions of less than 1pc, which are submerged in extended HII zones of low concentration. The average concentration in the condensations is high, reaching 10^2-10^4 cm^{-3}, but they contain a total of a few $M_{\odot}$ or several tens of $M_{\odot}$ of ionized hydrogen. These compact condensations probably are early evolutionary stages of subgroups in O associations, in which the exciting stars are hidden in a dense dust cloud around the star, in the majority of cases. In the Orion nebula, as well as in other HII zones, there are still smaller scale inhomogeneities of ionized gas, from $1.5 \cdot 10^{-2}$ to $5 \cdot 10^{-2}$ pc, $n_e = 5 \cdot 10^7$ cm^{-3} in size. This is on the order of the dimensions of a protostar.

Similar formations radiate intensely in the infrared range. Therefore, compact sources of infrared radiation, observed in both galactic and extragalactic HII zones, are interpreted as protostars. The lifetime of HII zones can be estimated from the lifetime of main sequence stars of types O5-B0. It is 10^5-10^7 years. Similar estimates can be reached from kinematic considerations [3]. After 10^7 years, the gas /7 will be swept out of the HII zone, and a "pure" open cluster or O association remains.

The short lifetime, the connection with hot young stars and the presence of compact protostars in HII zones indicate an intensive star formation process in them, which is occurring now. These are star formation "boilers."

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A larger scale structure can be distinguished in HII zones, besides the compact formations.

There may be several nuclei (concentrations) within one shell, together with the forming HII complexes. Similar complexes are seen easily in other galaxies, and they can reach very large sizes, up to 3 kiloparsecs.

Some parameters of the nuclei and shells of the gigantic HII complexes in the Large Magellanic Cloud, M 33 and M 101 are presented in Table 2.

TABLE 2

Zone name		ME ($10^3 cm^{-2} pc$)	Diam. (pc)	Conc. (cm^{-3})	Mass ($10^6 M_\odot$)
NGC 5455	nucl	87	245	I6.5	4.7
	shell	0.6	I095	0.7	I9
NGC 546I	nucl	2I3	205	33.3	5.5
	shell	2.4	I665	I.2	I06
NGC 547I	nucl	3·I32	3·I20	3·32.7	3·I.2
	shell	4.4	8I0	2.3	24
NGC 5447	nucl	52	205	I6	2.6
	shell	4.3	I220	2	70
NGC 5462					
	nucl	2·4I	2·I60	2·I5.8	2·I.3
	shell	I.7	2235	0.9	I90
Center M IOI	nucl	2·I26	2·I00	2·35.I	2·0.7
	shell	0.7	975	0.9	I6
NGC 604	nucl	9.2	42	47	0.I2
	shell	0.05	334	I.2	I.6
NGC 595	nucl	6.2	3I	44.6	0.05
	shell	0.02	27I	0.8	0.6
30 Dor	nucl	2I.5	64	53.I	0.52
	shell	0.065	7I8	I.I	I3.9

The largest number of hot young stars is in the spiral arms of galaxies. Just like the hot stars, HII clouds are concentrated in the spiral arms. Gigantic HII zones are particularly strongly concentrated in spiral arms. Metzger, in studying the HII zone structure of our galaxy [5], concluded that the spirals are traced only by the gigantic HII zones (see Fig. 2). Bright HII zones outline the spiral arms in other galaxies very well, for example, in M 51 [6], or in other spiral galaxies with distinctly expressed spirals (this is seen well in the atlases of Hodge [7, 8]). Where the arms are wide and open, there are HII zones everywhere. According to Hodge, in normal spiral galaxies, HII zones fall within a ring, the parameters of which depend on the dimensions, properties and type of galaxy (see Fig. 3). However, it must be noted that the number of zones in the central part of galaxies can be underestimated significantly, because of the high surface brightness of galaxies near the center, as well as the presence of diffuse emissions in the H_α lines. In irregular galaxies, diffuse emission in the H_α lines frequently is observed, which covers the entire galaxy. HII zones are located in them without apparent order. NGC 6822 and some other irregular galaxies can serve as examples of such galaxies [9]. /8

In [10], Hodge examined the distribution of HII zones in peculiar galaxies, as well as their anomalous distribution in normal galaxies. He considered a number of anomalies in the distribution of HII zones. /9

In considering HII zones in binary and interacting galaxies, Hodge did not find any primary location of HII zones with respect to the neighboring galaxy (of 13 galaxies studied, the largest HII zones of 6 were located on the side nearest the neighboring galaxy, in the most remote part of 4 and, in the remaining 3, their distribution made no difference, with respect to the direction to the neighboring interacting galaxy [11]).

If the dimensions of HII zones at different distances from the galactic center are considered, no relationship can be found. Only for HII zones of special circular shape, Boulesteix [12] found a similar relationship (Fig. 4). These HII zones have a high surface brightness and dimensions of from 50 to 200 pc.

In classifying HII zones by type, Monnet [13] distinguishes four types of HII zones:

1. small HII zones, ionized by the radiation of one or more stars;

2. HII zones in the nuclear regions of galaxies, characterized by rapid movements and abnormal spectral line relationships;

3. gigantic HII zones in the spiral arms of galaxies, ionized by the emissions of small HII zones;

4. diffuse zones covering a considerable portion of a galaxy.

2. Relation to Star Formation

a. We consider the relation of HII zones to star formation in /10 galaxies. The rate of star formation in galaxies is proportional to the gas density to the n power: $\frac{dM_*}{dt} = f(t) = \rho^n_{gas}$. In the simplest case, the μ ratio of the mass of the gas to the total mass of the galaxy can be used as the ρ_{gas} characteristic. With s as the ratio of the total mass of all forming stars in the galaxy to the mass of the galaxy and with the consideration that fraction r of the mass of the stars formed has again shifted to the interstellar medium, we obtain

$$(1-r)\cdot s + \mu = 1 \quad ;$$

in our galaxy at the present time,

$$s = (1-\mu)/(1-r) = 1,3$$

for μ = 0.09 and r = 0.3, according to Metzger [5]. Our assumption leads to the following equation:

$$\frac{ds}{dt} = \frac{1}{M_t}\frac{dM_*}{dt} = \frac{1}{(1-r)\tau}\mu^n ,$$

i.e.,

$$\mu = \begin{cases} \exp\left(-t/\tau\right) & n = 1 \\ \left(t/\tau + 1\right)^{1-n} & n \neq 1 \end{cases}$$

With the number of Lyman continuum quanta, from HII zone observations, and the number of these quanta per unit mass known (with the mass function of the stars considered as in the vicinity of the sun), Metzger found that

$$\frac{dM_{\star}}{dt} = \frac{\sum L_c^{\text{quanta}}}{T} \cdot \frac{\langle M \rangle}{\langle L_c \rangle} = 4.2 M_{\odot} \text{ per year},$$

where T is the lifetime of a radio HII zone. Thus, by substitution of /11
the numerical values, it turns out that, in our galaxy, $4.2M_{\odot}$ per year forms. Theory gives $4.6M_{\odot}$ per year for n = 1, and $1.8M_{\odot}$ per year for n = 2.

Since μ decreases with time, the rate of star formation slows down with time. Since the parameter which determines the rate of star formation is not μ, but ρ, in galaxies with different matter densities, the rate of star formation will slow down at different speeds.

According to van den Bergh, different types of galaxies have the following characteristic densities:

E	$100 \cdot 10^{-24}$ g/cm^3
Sc	$10 \cdot 10^{-24}$ g/cm^3
Ir	$1 \cdot 10^{-24}$ g/cm^3

Therefore, the rate of star formation in them changes (according to van den Bergh), as is represented in Fig. 6 [14].

In complete correspondence with this, the greatest ionization is observed in Ir galaxies, and it decreases gradually from Sc to Sa galaxies (Fig. 5 from [15]).

b. Hodge also has found a relationship of the surface density of HII zones σ_{HII} to the surface density of HI zones σ_{HI} for galaxies (Fig. 7 from [15]).

A similar relationship is observed for individual galaxies:

M3I $\quad \sigma_{HII} \sim \sigma_{HI}^{2.1\pm0.2}$ [I6]

M33 $\quad \sigma_{HII} \sim \sigma_{HI}^{2.1\pm0.2}$ [I7]

Large Magellanic Cloud $\quad \sigma_{HII} \sim \sigma_{HI}^{1.9\pm0.3}$ [I8]

Small Magellanic Cloud $\quad \sigma_{HII} \sim \sigma_{HI}^{1.8\pm0.1}$ [I6]

our galaxy $\quad \sigma_{HII} \sim \sigma_{HI}^{2}$ [I9] .

That is, the rate of star formation is approximately proportional /12 to the square of the gas density.

If a graph of the relationship, number of zones in the galaxy (from Hodge [20]) to the surface density of hydrogen (from Balkowski [21]) is plotted, for galaxies of different types, a more complex picture is obtained (Fig. 8).

According to a study of Madove [17], in M33, a different σ_{HII} vs. σ_{HI} is observed, for the inner part of the galaxy, σ_{HII} $\sigma_{HI}^{0.91\pm0.14}$, and the other part of the galaxy, σ_{HII} $\sigma_{HI}^{2.57\pm0.24}$. This is explained by varying thickness of the gas disk in different parts of the galaxy. Toward the periphery, the thickness of the gas disk increases. With the same surface density, the bulk density is different. The complex nature of Fig. 8 can be explained, if it is assumed that the thickness of the gas disk has strong variations from galaxy to galaxy.

The HII and HI distribution in the galaxies can be traced. Such graphs for our galaxy and M33 are presented in Fig. 9. It is evident that HI extends very much further than HII from the center of the galaxy. The star formation rate depends primarily on the local gas density, which is determined by the conditions of development of large gas complexes. According to the hypothesis of Quirk [22], star formation in galaxies has led to the equality of the average density ρ and critical density ρ_c, beginning with which, the rotation of the disk stops preventing the growth of gravitational perturbations and gas condensation:

$$\rho = \rho_c = f^0 K^2/\pi G ,$$

here K is the epicyclic frequency, which is connected to the angular velocity of rotation of the galactic disk by the relationship: /13

$$K^2 = 4\Omega^2 \left(1 + \frac{R}{2\Omega}\frac{d\Omega}{dR}\right),$$

and f is a coefficient close to 1.1 [23]. Where $\rho = \rho_c$, star formation proves to be retarded and, according to Quirk, it occurs due to the loss of gas with proevolved stars or the fall of gas into the galaxy from outside. According to Quirk, the HI distribution is in good agreement with that obtained theoretically, on the assumption that

$$\rho \approx \rho_c .$$

In a number of galaxies, a hydrogen deficit in the inner regions of the galaxy also is observed. Pikelner expressed the hypothesis [24] that, due to star formation, which is most active in regions of high gas density, the value of ρ tends to remain constant, while the thickness of the gas disk decreases toward the center of the galaxy (because of the growth in density of the star disk). This results in a decrease of σ_{HI} toward the center of the galaxy.

In galaxies where there is an active nucleus or a diffuse HII zone, a substantial portion of the hydrogen is ionized, which results in a decrease of σ_{HI}. Rogstad [25] estimated the HI deficit near the center of M 101 at $3.5 \cdot 10^{20}$ atom/cm^2, and Monnet [13] found $3 \cdot 10^{20}$ atom/cm^2 for the density of the diffuse nuclear HII zone.

c. Metzger [5], in studying the distribution of star formation rate over our galaxy, concluded that 71% of the stars form in the spiral arms, 17% between the spiral arms and 12% in the central 200 parsecs. That is, the star formation rate in the center of our galaxy is 60 times higher than in the peripheral regions. Since the star formation rate in the central part of the galaxy is higher than in other regions of it, /14 a larger quantity of heavy elements should form there, and the interstellar medium should be enriched in heavy elements and helium.

A chemical composition gradient is observed in a large number of galaxies, and it shows that the heavy element content is higher in the nuclear regions than in the periphery of galaxies.

Data on the chemical composition of the interstellar medium can be extracted from study of HII zone spectra. The ratio of the 0111 and H_β lines changes with change in distance from the center of the galaxy. The log $0111/H_\beta$ gradient for M 33, M 101 and M 51, from [26], is presented in Fig. 10. Searle [27] also found a OII/NII gradient (Fig. 11), and Comte also found a NII/SII gradient. These studies were conducted in the M 33 and M 101 galaxies. The following values were obtained for the gradients:

	M 33 MIN^{-1}	M 101 MIN^{-1}
grad N/S	$-0.5 \cdot 10^{-5}$	$-5.7 \cdot 10^{-5}$
grad $\frac{NII}{OII}$	$-8.8 \cdot 10^{-4}$	$-60 \cdot 10^{-4}$

Similar gradients also are observed in M 51 and M 81 [28]:

		N/S
M 5I	$r \leqslant 1.25''$	1.53
	$r \leqslant 3.5''$	1.07
M 8I	$r \leqslant 1.25''$	1.42
	$r \leqslant 3.5''$	0.98

In the sun, this ratio is 0.59 and, in the Orion nebula, 0.13. The chemical composition gradient should be associated with various degrees

of excitation of the HII zones, since, according to the theory of Kahn [29], $M_{cr} \sim z^{-1/2}$, where M_{cr} is the greatest mass of a star which can form. He obtained this relationship from consideration of the gravitational compression of stars, with dust taken into account. Thus, lower ionization and a lower HII zone temperature should be observed in the nu- /15
clear regions of galaxies. This is observed, both in our galaxy [30], and in other galaxies [31].

The helium concentration gradient also is observed.

The Burbridges [32] present H_α/NII ratios for a large number of galaxies. According to their study, in irregular galaxies, excitation of the HII zones is higher than in other galaxies. This is in good agreement with the hypothesis that there now is a particularly high star formation rate and, possibly, a lower heavy element content there [14].

The strongest variation of H_α/NII and the strongest HII zones in the central part of the galaxy are observed in SB galaxies, as well as in individual type Sc/Sbc galaxies. In general, type Sc, Sbc and Sb galaxies show a smaller amount of ionized gas in the nuclear region. The H_α/NII ratio in the nuclear regions is 0.1-1.0, while it is close to 3 in the peripheral portion of the galaxy. Such changes in the H_α/NII ratio may be caused by both an excess of nitrogen in the galactic nucleus and another HII zone excitation mechanism in the nuclear regions of galaxies (for example, electron collisions, but not photoionization, which gives a lower H_α/NII ratio, or corpuscular emission of the stars).

According to [31], the excitation and chemical composition gradient differ in different types of galaxies. In early spiral galaxies, the excitation is lower and the chemical composition gradient is less than in late spirals:

		$\lg \frac{[OIII]}{H_\beta}$	$10^4 \cdot \frac{O}{H}$	$\frac{N}{O}$
Sbc	nucleus	-1	90	0.5
	outer part	-0.25	10	0.15
Scd	nucleus	-0.7	15	0.15
	outer part	+1.0	1.5	0.04
Ir		+1.0	4	0.04

It is evident from this that OIII is seen easily, only in sufficiently /16
strongly excited HII zones, in slightly excited only once ionized oxygen.

3. Relation of HII Parameters to Other Characteristics of Galaxies

a. The dimensions of emission regions in galactic nuclei fluctuate within broad limits, from 40 to 2,000 parsecs.

As has been stated, the formation of hot young stars in the nuclear regions is found primarily in Sb and Sab galaxies. Up to 30% of all galaxies of these types have hot nuclear regions [33]. There are both continuous emission regions and "hot spots," surrounding the nucleus, in the nuclear regions of galaxies made up of stars of late spectral classes. According to a study of Pastoriza [34], the dimensions of the "hot spots" are 100-1,000 pc.

Powerful emission regions also are observed in the nuclei of Seyfert galaxies. Extremely large dispersion of velocities is observed in them, as well as different I-V and V-I color ratios [14]. The size of the nuclear regions of Seyfert galaxies is 40-700 pc [35]. It is likely that these objects are related to quasars, and not to conventional HII zones excited by hot stars [14]. High energy particles, responsible for both strong nonthermal emission and, possibly, for ionization and excitation, play a large part in them.

HII zones are indicators of the star formation rate. Consequently, the rate of star formation and its relation to the integral properties of galaxies can be decided from the HII zone population of the galaxies.

b. The HII zone population of a galaxy can be characterized by three methods:

1. total number of HII zones in the galaxy; /17

2. dimensions of largest HII zones in the galaxy;

3. total emission of the galaxy in the emission line.

To some extent, all these quantities reflect the total amount of ionized hydrogen, and this means, the number of Lyman continuum quanta necessary for its ionization.

A major study of the number of HII zones in the galaxies was performed by Hodge [20]. He found a dependence of the number of HII zones on the luminosity of the galaxy (Fig. 12a). This dependence is completely natural, and it is a dependence on the size of the galaxy (mass, radius, number of stars).

If the number of HII zones (according to Hodge) vs. type of galaxy is examined (Fig. 12b), it is evident that the number of HII zones is greatest in Sbc galaxies, and there are fewer in Sb galaxies than in the corresponding Sa galaxies.

Characterization of the star formation rate by the number of HII zones has a number of shortcomings:

1. in the closest galaxies, small HII zones can be observed, while we see only gigantic HII zones in the more remote galaxies;

2. in different galaxies, the HII zone sizes differ significantly, and the degree of ionization in the galaxy also depends on the sizes of the HII zones in a given galaxy.

c. It is interesting to consider HII zone dimensions vs. the type and integral properties of the galaxies. The total excitation parameter u_t for an entire galaxy can be presented in the form

$$u_t = \int_{\ell_1}^{\ell_2} \psi(\ell)\, u(\ell)\, d\ell,$$

where ℓ_1 is the minimum size of the HII zones, approximately equal to a /18 few parsecs, ℓ_2 is the maximum size of the HII zones in a given galaxy, $\psi(\ell)$ is the HII zone size distribution function (see Fig. 13 a, b, c, d), $u(\ell)$ is the dependence of the excitation parameter of an individual HII zone on its dimensions (see Fig. 14). Thus, the quantity which determines the total excitation parameter of a galaxy is the size of the largest HII zones in this galaxy. To characterize the dimensions of the largest HII zones in a given galaxy, the average size of the three largest HII zones in this galaxy can be used. The largest HII zones have large dimensions (on the order of several hundred parsecs), and they are confidently measured in quite remote galaxies.

HII zone dimension data (average sizes of the three largest HII zones in the galaxy (d_3) in parsecs) were taken from the measurements of Sersic [3]. Data on galactic properties were taken from Balkowski [21] and Bottinelli and Gouguenheim [36]. The distances to the galaxies were assumed to be the same as those of Balkowski. The resulting relationships are presented in Fig. 15.

Type dependence clearly shows that Sb galaxies have larger HII zones.

The dependence on L, M_h, M_t and R is a dependence on size of the galaxy (just as for the number of HII zones). Similarly, the super-associations required for excitation of gigantic HII zones are observed, as a rule, in giant galaxies. Similar dependence on M_{pq} of the galaxies were obtained by Sandage and Tamman ($\log d_3 = -0.14M_{pq}-0.2$ [37]), and on M_H, by Sersic [39] ($\log d_3 = 0.16M_H+1.13$), but they considered less statistical material and were limited only to Sc, Sd and Ir galaxies.

The separation of type Sa-Sb galaxies on the graphs evidently is /19
explained by the presence of a large spherical subsystem in these galaxies, and the dimensions of the HII zones should be determined primarily by the parameters of the galactic disk, since the gas and young hot stars are concentrated in it. Van den Bergh [14] introduced the ratio of the bulge size to the disk size, which is at a maximum for Sa galaxies and decreases from Sb to Sc galaxies, as a characteristic of the type of galaxy. To reduce the integral properties of the galaxies to the disk parameters, they must be decreased for Sa and Sb galaxies. Then, galaxies of these types will not be isolated from the general relationship for spiral and irregular galaxies. The separation of the Sa-Sb galaxies on the d_3 vs. M_H graph possibly indicates a thicker low density gas disk, or there are dynamic obstacles to the formation of

gigantic HII complexes in these galaxies. The smaller dispersion of values around a straight line in the case of d_3 vs. R is explained by smaller errors in determination of the galactic radius, the same dependence of d_3 and R on distance to the galaxy and by the fact that R primarily characterizes the disk and not the spherical component of the galaxy.

d. The differential rotation of galaxies, which depends on the angular velocity of rotation of the galaxy, prevents the formation of large gas complexes and slows down star formation in the galaxies by preventing the condensation of stars from the gas. This is in good agreement with the resulting dependence of d_3 on Vm/R, which characterizes the angular velocity of rotation of the galaxy.

Mouschovias, Shu and Woodward [39], in studying the Parker instability in galaxies, found that the spiral arms should break down into gas complexes several hundred parsecs in size, with a mass on the order of 10^6 solar masses, which give, after condensation into stars, superasso- /20 ciations and gigantic HII zones, in which their largest dimensions are reached in galaxies with small differential rotation. This is observed.

Since the star formation rate depends on the bulk density of the gas, it should be higher in the spiral arms, the density waves, and the higher, the stronger the contraction in the spirals. Van der Kruit [40] found that the magnitude of the contraction in the spirals is inversely proportional to the Rm/Ro ratio, where Rm is the radius where the maximum rotation rate of the galaxy is achieved, and Ro is the radius to the most remote HII zone from the center of the galaxy. This explains the dependence of d_3 on Rm/Ro.

An interesting relationship is obtained from the bulk density of matter in the galaxy (like the gas) (Fig. 15). The bulk density was calculated by the formula $\rho = \sigma/aq_0$, where a is the photometric radius of the galaxy and q_0 is a parameter which takes account of contraction of the galaxy.

The total emission from galaxies in the H_α line was measured by Cohen [41]. According to his measurements, 2/3 of the total emission comes from the galactic dish and 1/3 from the bulge. The change of W_{H_α} is connected with variations of the proportions of O and B stars in the galaxy. Quantity W_{H_α} shows the dependence on color of the galaxy B-V

$$W_{H_\alpha} \approx 160\,(1-B-V)\cdot \AA$$

If HII zone size vs. luminosity of the galactic core is studied, relationships are obtained, as presented in Fig. 17, a. to absolute star magnitude of the nucleus in the visible wavelengths (from B.A. Vorontsov-Vel'yaminov [42]) and b. to the luminosity of the nucleus in the radio range (from van der Kruit [40]). It is evident from the resulting relationships that, in galaxies with a bright nucleus, the HII zones are larger, and this means, the star formation process is faster. /21

e. In considering the locations of the largest HII zones in Sb and Sc galaxies (from the Hodge atlases [7, 8]), it can be noted that, in Sb galaxies, the largest HII zones (like the larger number of them) is found in the branches near the ends of the bar. In Sc galaxies, they frequently are located at the ends of the spirals. The spiral arm appears to end with a large HII zone.

Superassociations, studied by R.K. Shakhbazyan [43], also have a tendency to be located at the ends of the spirals.

In 13 of the 22 galaxies considered, superassociations exceed 1,000 parsecs in size (with H = 50 km/sec·Mpc), and M_{pg} is up to -17.6^m.

In some galaxies, giant HII zones reach very large dimensions of up to 3 kiloparsecs or more.

The existence of very large HII zones and the location of the largest HII zones near the ends of the spiral arms permit consideration that the satellites at the ends of the spirals are related to the giant HII zones.

Arp [44] considers that the satellites at the ends of the spirals are:

a. large HII zones, if the luminosity and dimensions of the satellites are not too great;

b. associations of HII zones, if the satellites are larger;

c. the largest satellites are galaxies.

In other arms of galaxies which have satellites at the ends of the spirals, there are large HII zones.

Near E and So galaxies which do not have large HII zones, blue clusters are found, which have an emission spectrum [45]. In some cases they have connectors with the galaxy. Their diameter is 2-3 kiloparsecs, $M_{pg} = -16^m$ to -17^m. Consequently, they can be related to giant HII zones. /22

Among the Markaryan and Aro galaxies and the compact Zwicky galaxies, there are objects, which can be called "intergalactic HII zones" (for example, galaxies IZ_W 18 and IIZ_W40, studied by Searle and Sargent [3]). They can be (according to van den Bergh [14]):

a. very young galaxies, less than 10^8 years old;

b. galaxies, the stars of which have an abnormal luminosity function (here, there is an abnormally large number of bright, massive stars); in the past, star formation in them was slow;

c. galaxies, in which "star formation bursts" are observed.

4. Conclusion

The general properties of HII zones in galaxies of different types were considered in this survey. A relation is sought from available observation data, between various characteristics of galaxies and the basic parameters of the HII zones. The dependence on average size of the three brightest HII zones was examined in the greatest detail. Some characteristics of these relationships are noted in type Sb and Sab galaxies which, most likely, are related to the characteristics of distribution of the gaseous component in these systems. The question of the relation of the HII zone parameters to the kinematic characteristics of the galaxies is discussed.

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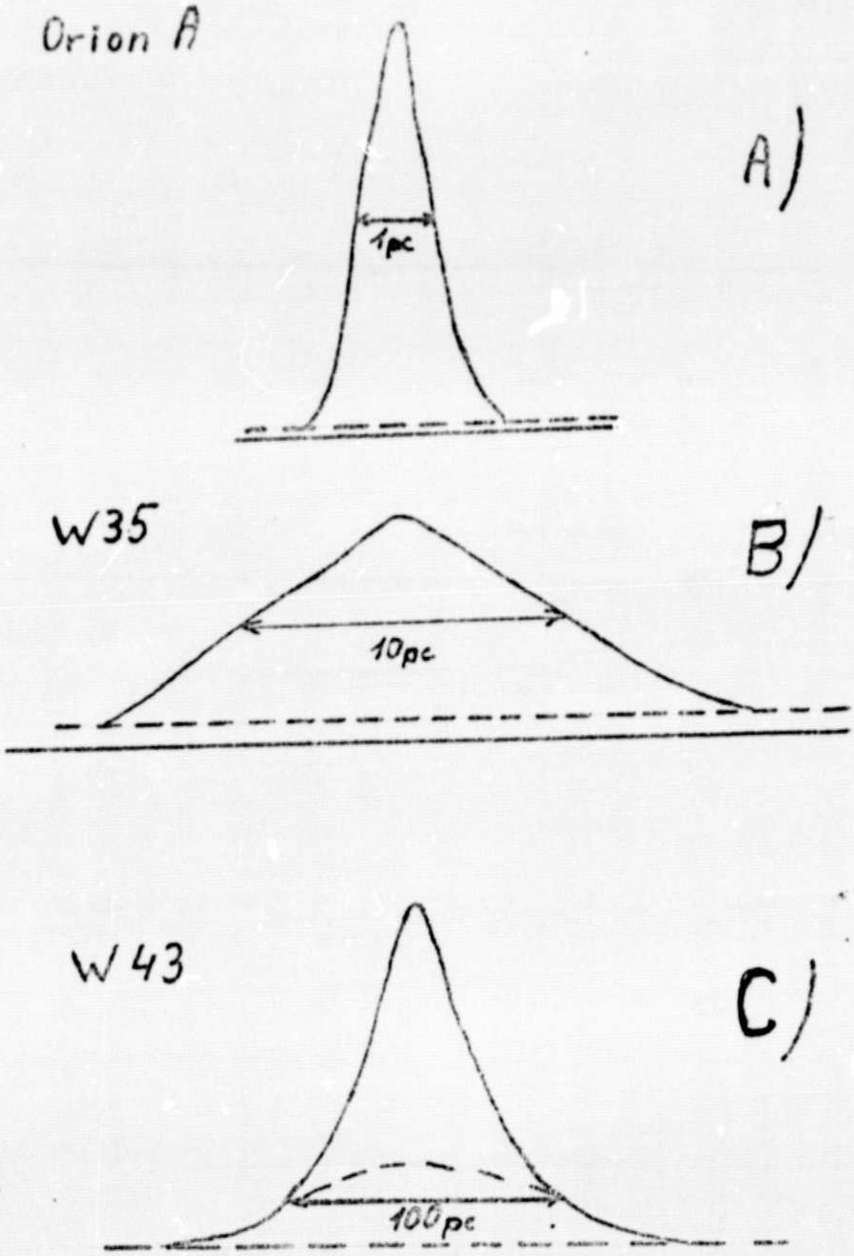


Fig. 1. Brightness distribution in HII zones 4 : A. small HII zone, strong concentration toward center; B. larger HII zone, lower concentration toward center; C. giant HII zone, nucleus and halo visible.

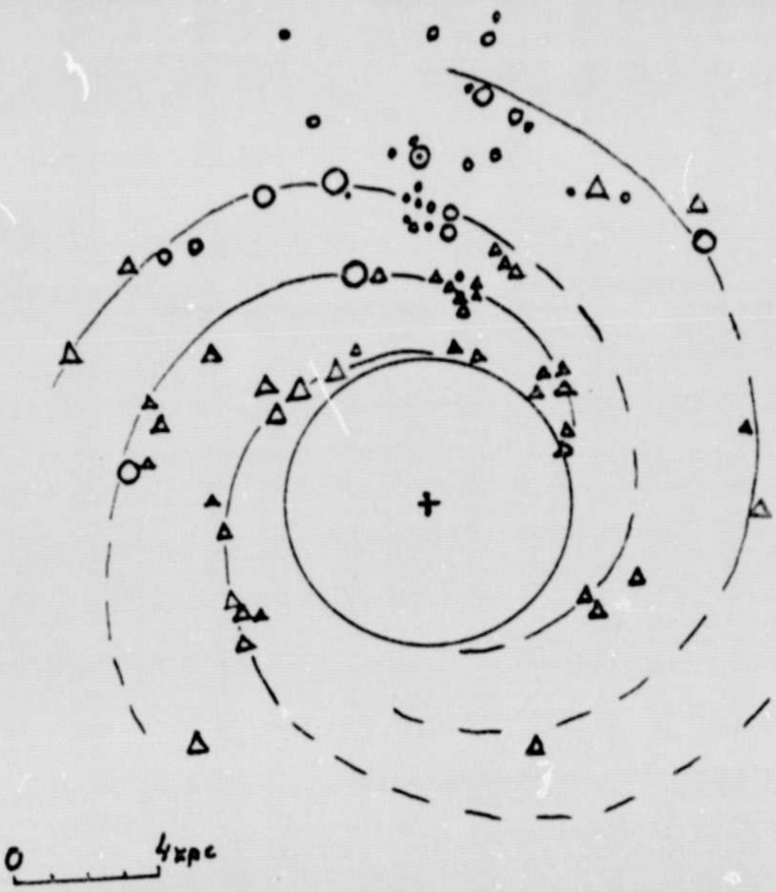


Fig. 2. Spiral structure of our galaxy from HII · zones (from Metzger [5]); symbol sizes correspond to the following values of ionization parameter: u>200 pc·cm^{-2}; u = 100-200 pc·cm^{-2}; u = 70-110 pc·cm^{-2};

⊙ - sun; + - galactic center;

○ - optical HII zones;

△ - radio HII zones;

symbol size corresponds to u

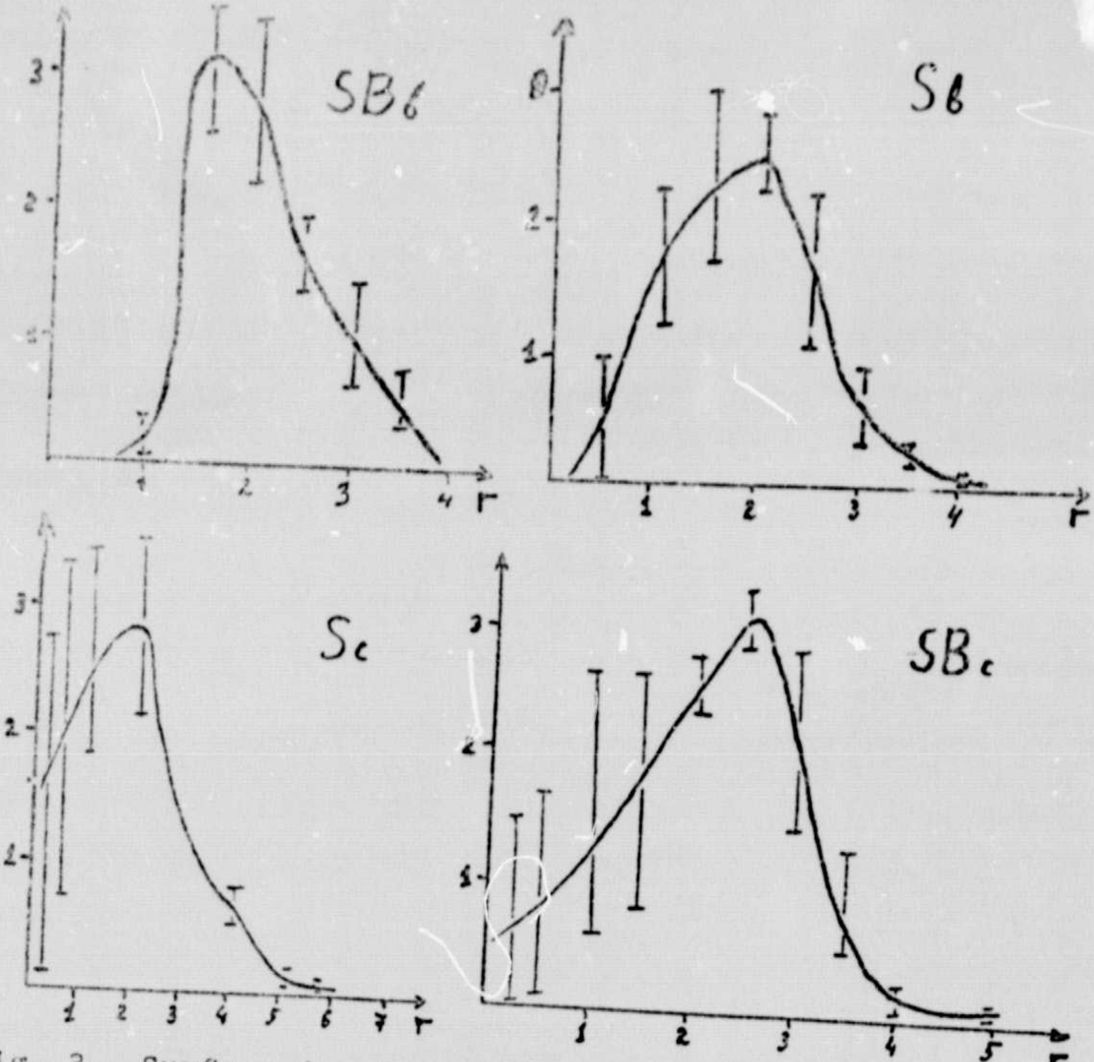


Fig. 3. Surface density distribution (number of HII zones per kpc^2) of HII zones along radius of different types of galaxy (from Hodge).

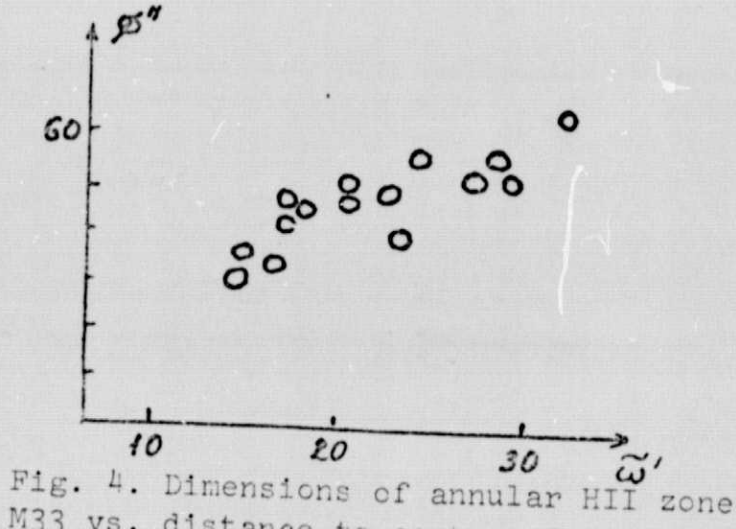
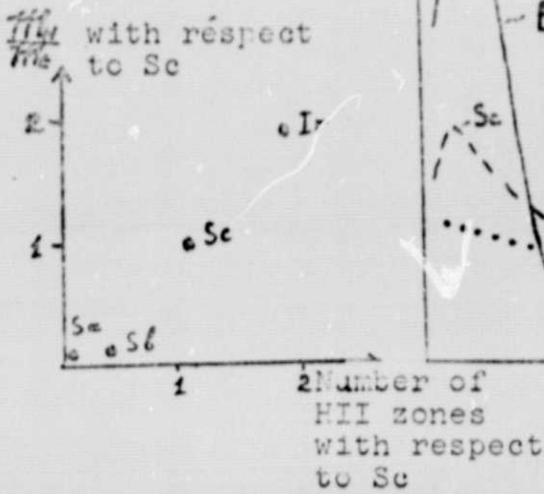


Fig. 4. Dimensions of annular HII zones in M33 vs. distance to center of galaxy [12].



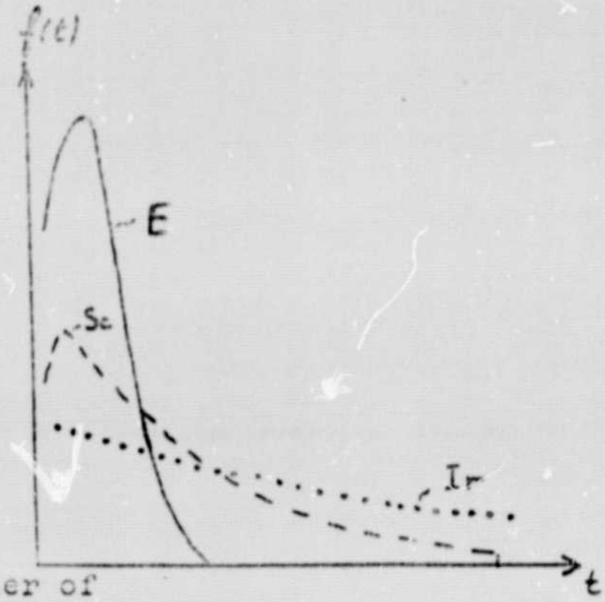


Fig. 5. Number of HII zones in galaxy vs. its hydrogen content [15] (standardized to Sc galaxies).

Fig. 6. Change in star formation rate in galaxies of various types [14].

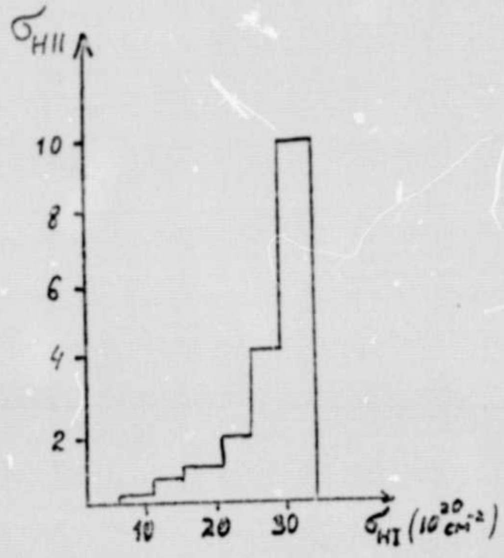


Fig. 7. Surface density of HII zones vs. surface density of neutral hydrogen for Sc galaxies [15].

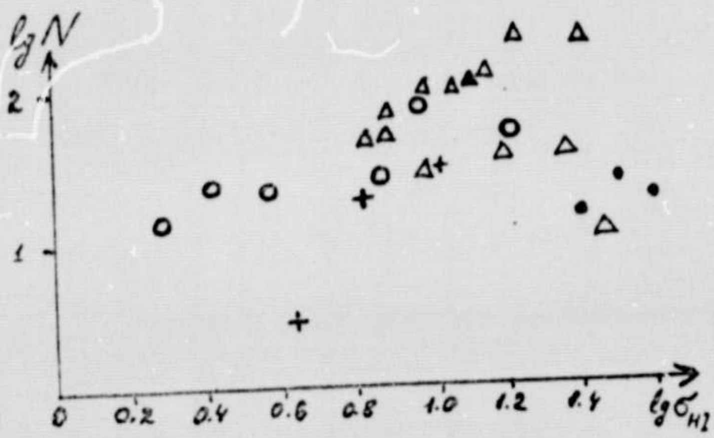


Fig. 8. Number of HII zones in galaxy vs. surface density of hydrogen for galaxies of various types.

o – SB

Δ – Sc + Sd

+ – Sa + Sb

• – Ir

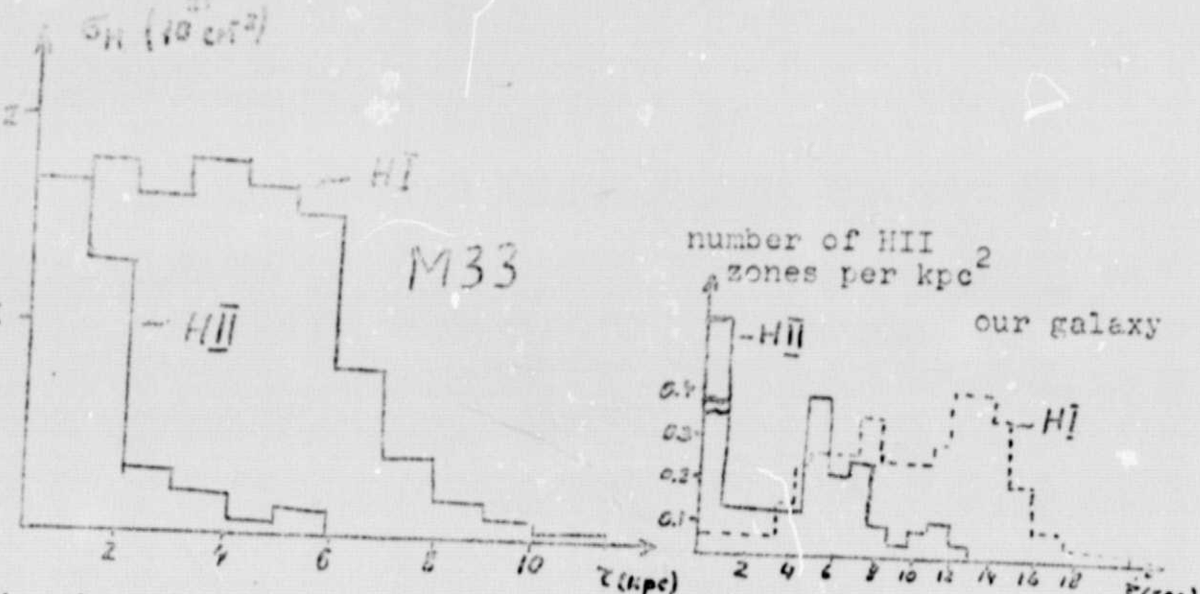


Fig. 9. HII and HI surface density distribution vs. distance to center of galaxy for M33 and our galaxy ([12, 5]).

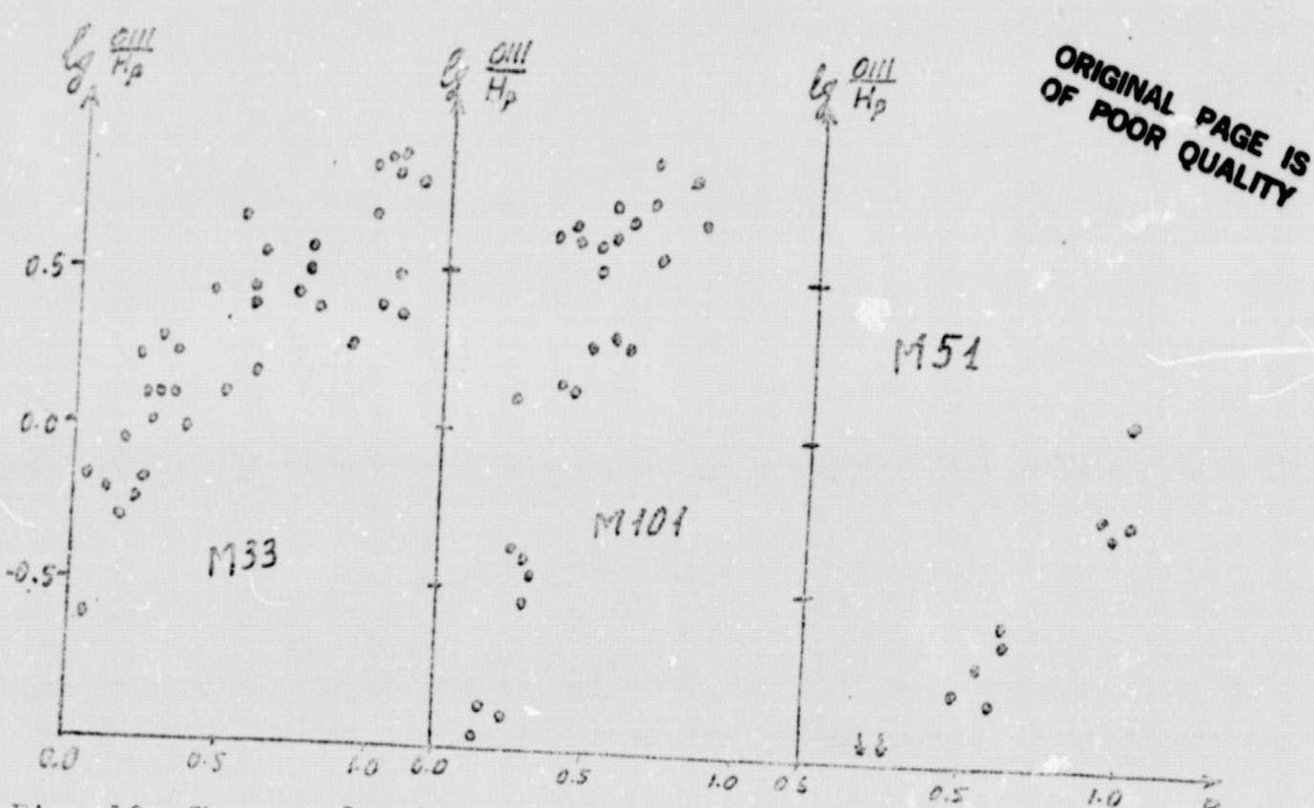


Fig. 10. Change of emission line intensity [OIII] relative to H_β in HII zones vs. distance to center of galaxy [26] (in galactic radius units).

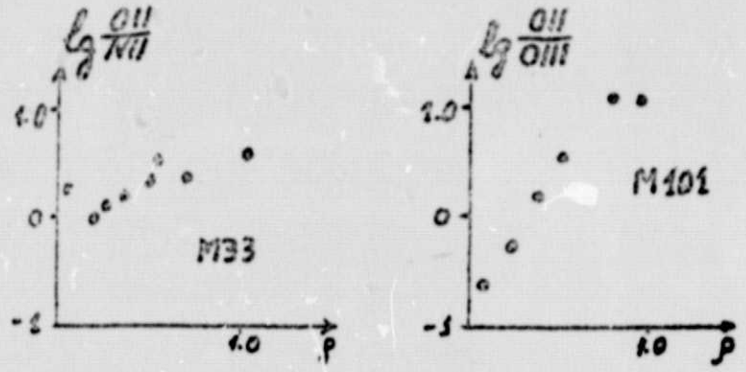


Fig. 11. Change of emission line intensity ratio vs. distance to center of galaxy [27] (in galactic radius units).

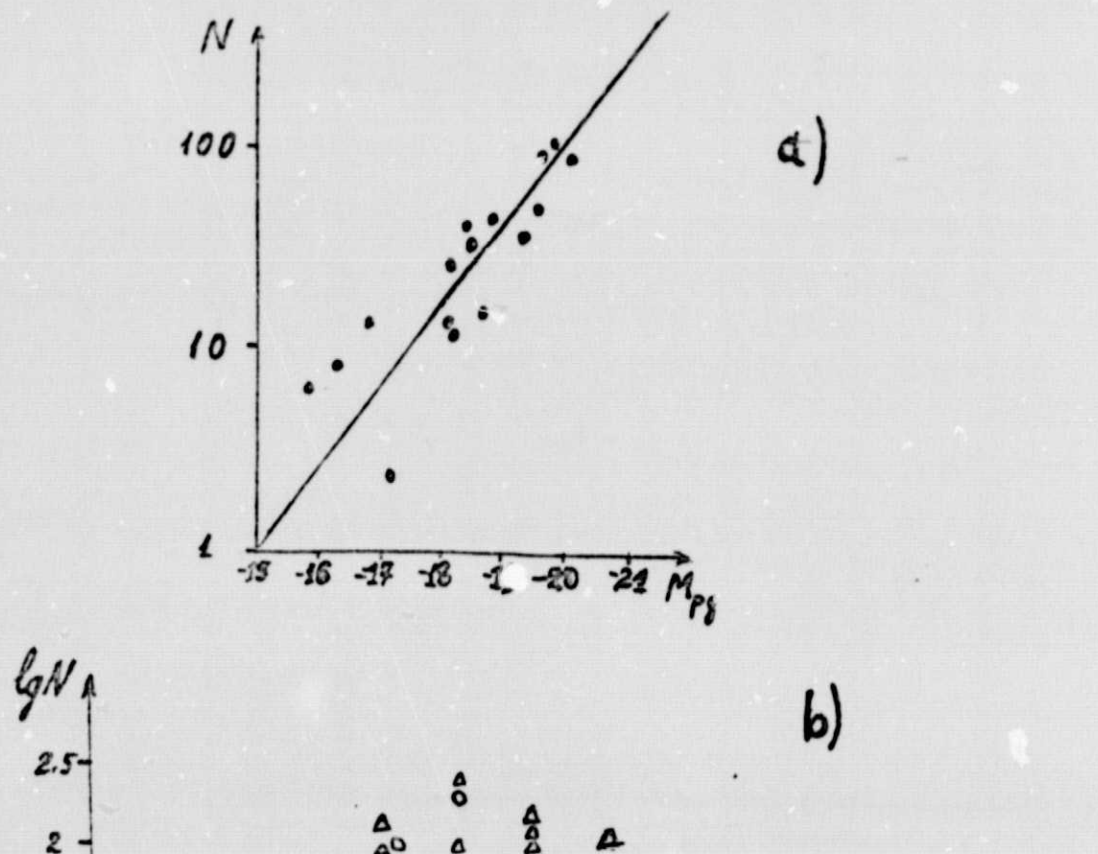


Fig. 12. Number of HII zones in galaxies vs. a) absolute star magnitude of galaxy [15], b) morphological type of galaxy.

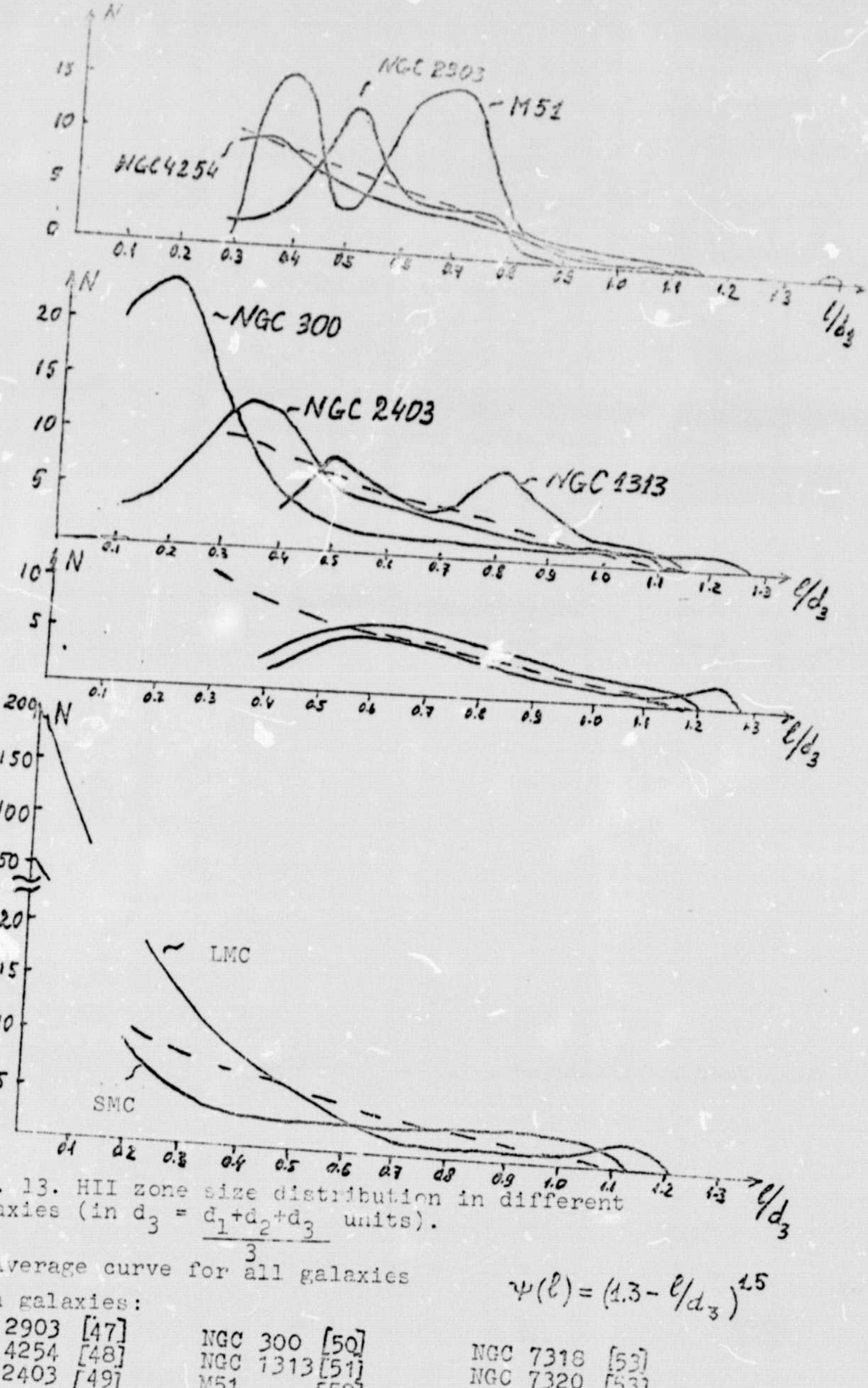


Fig. 13. HII zone size distribution in different galaxies (in $d_3 = \frac{d_1+d_2+d_3}{3}$ units).

- - - Average curve for all galaxies

$$\psi(l) = (1.3 - l/d_3)^{1.5}$$

Data on galaxies:

NGC 2903 [47]
NGC 4254 [48]
NGC 2403 [49]
NGC 300 [50]
NGC 1313 [51]
M51 [52]
NGC 7318 [53]
NGC 7320 [53]
SMC, LMC [54]

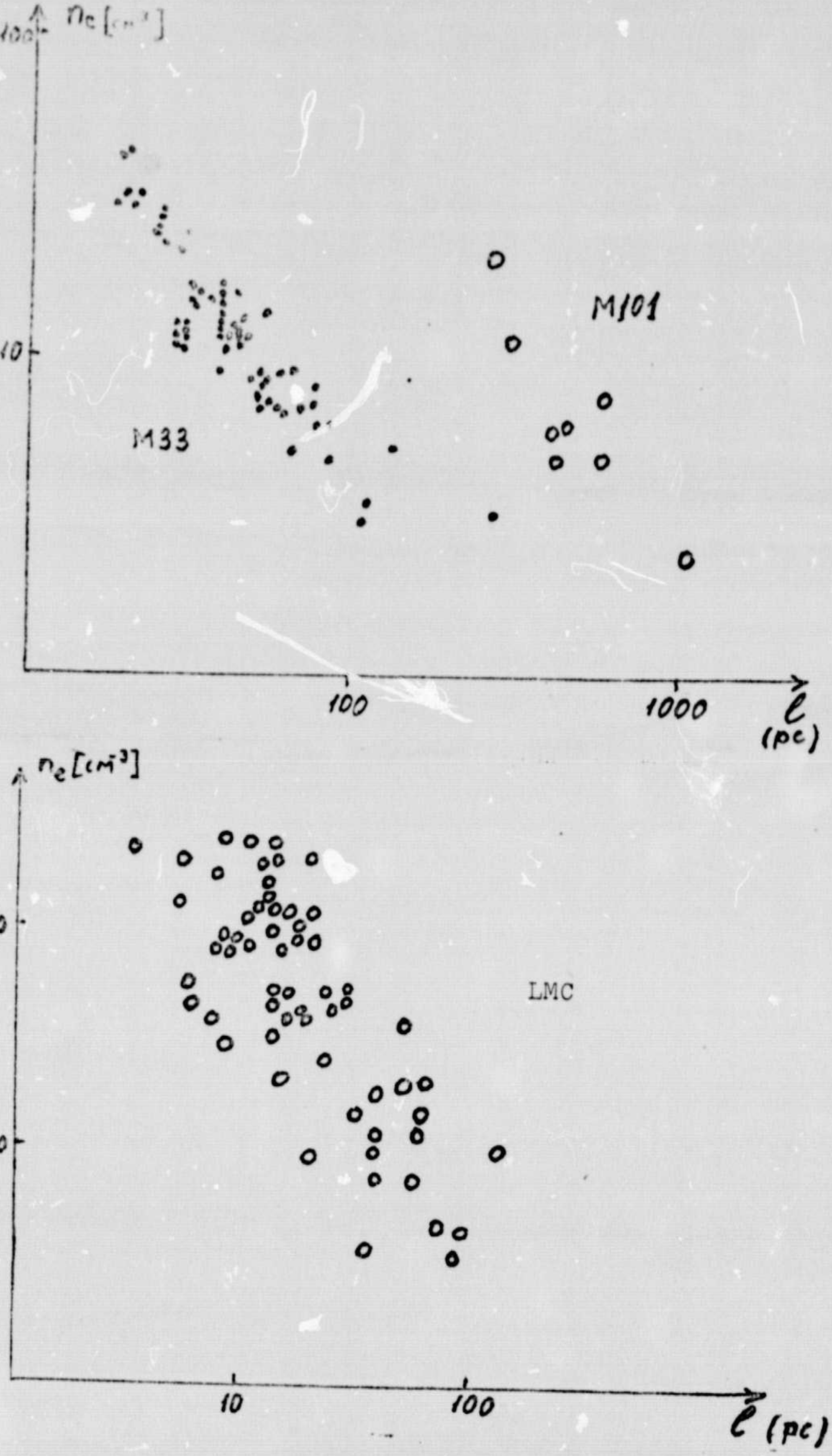


Fig. 14. Electron density in HII zones vs. data on M33 [55], MIOI [56], LMC [4]

$n_e \sim l^{-\kappa}$

κ = I.45 LMC [4] – for our galaxy κ = 0.75,
κ = I.23 M33 [27] – for M33 κ = I.50,
$u = l^{0.8-1.0}$.

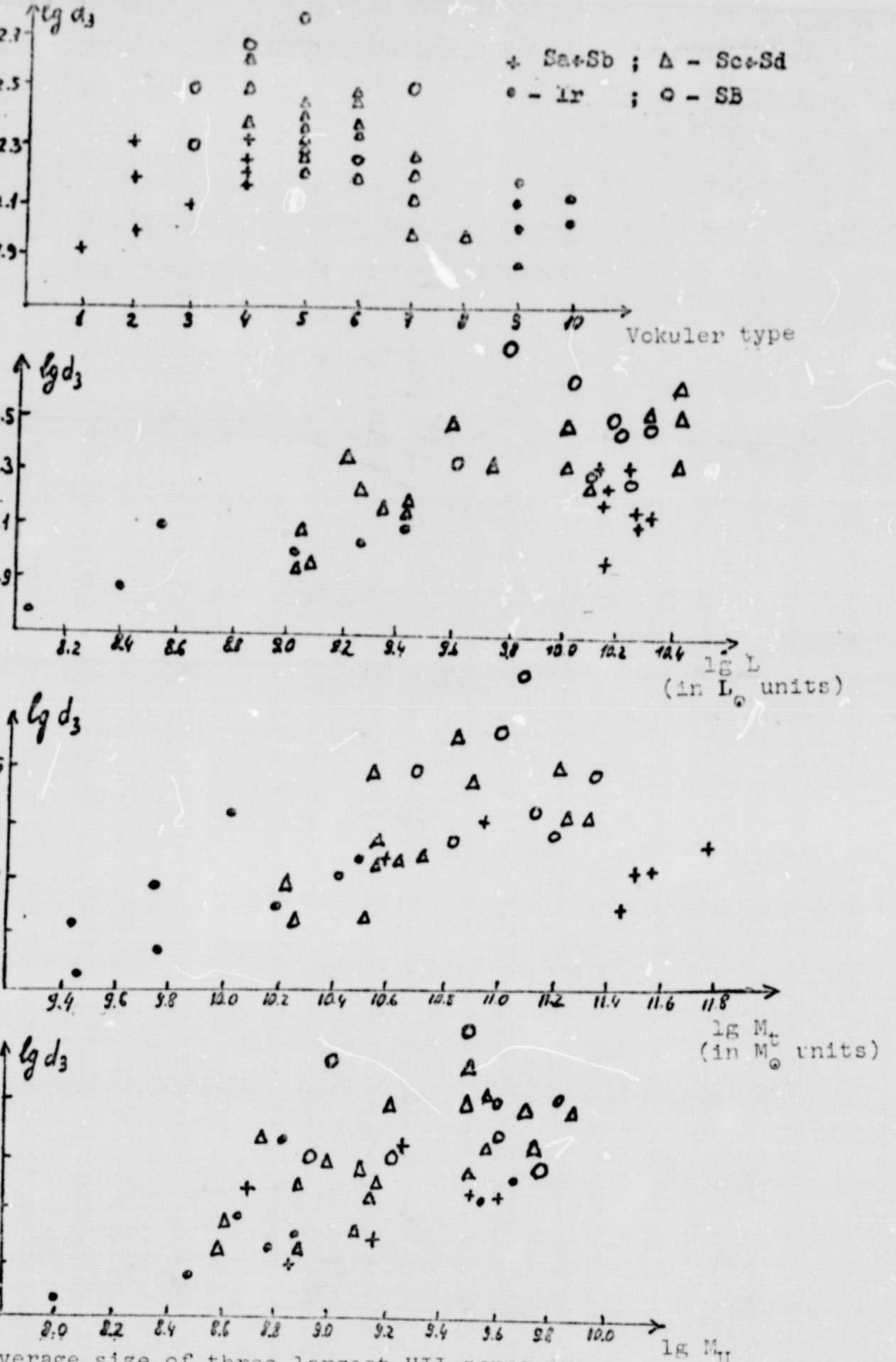
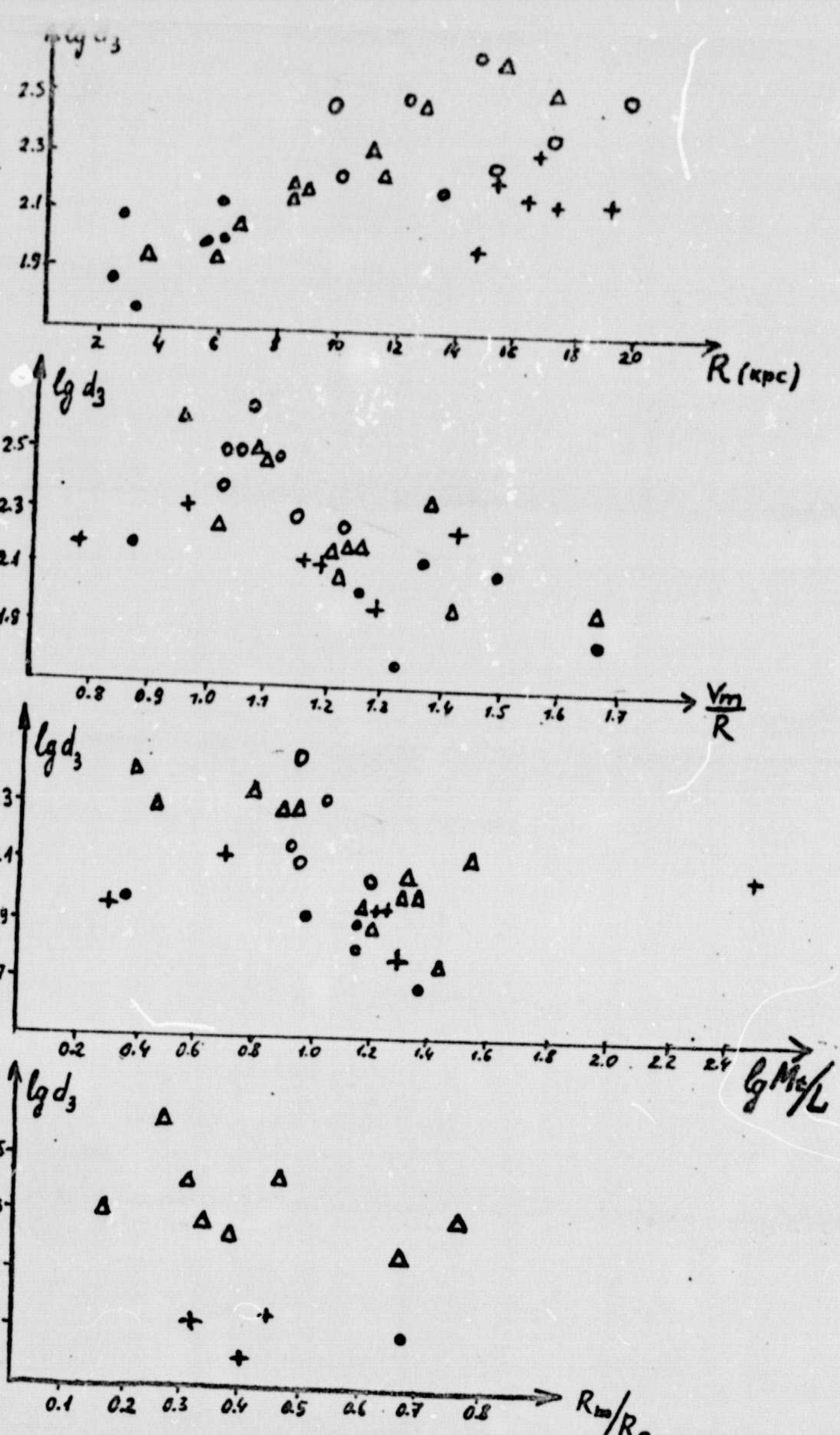


Fig. 15. Average size of three largest HII zones in galaxy (d_3) vs.: a. morphological type of galaxy; b. absolute luminosity of galaxy; c. total mass of galaxy;



d. mass of hydrogen in galaxy; e. radius of galaxy; f. ratio of maximum rotation rate of galaxy Vm (km/sec) to radius of galaxy in kpc; g. ratio of total mass to luminosity of galaxy; h. Rm/Ro ratio, where Rm is the radius where maximum rotation rate is achieved and Ro is the radius where the most remote HII zones from center is located; (b, c, d in solar units).

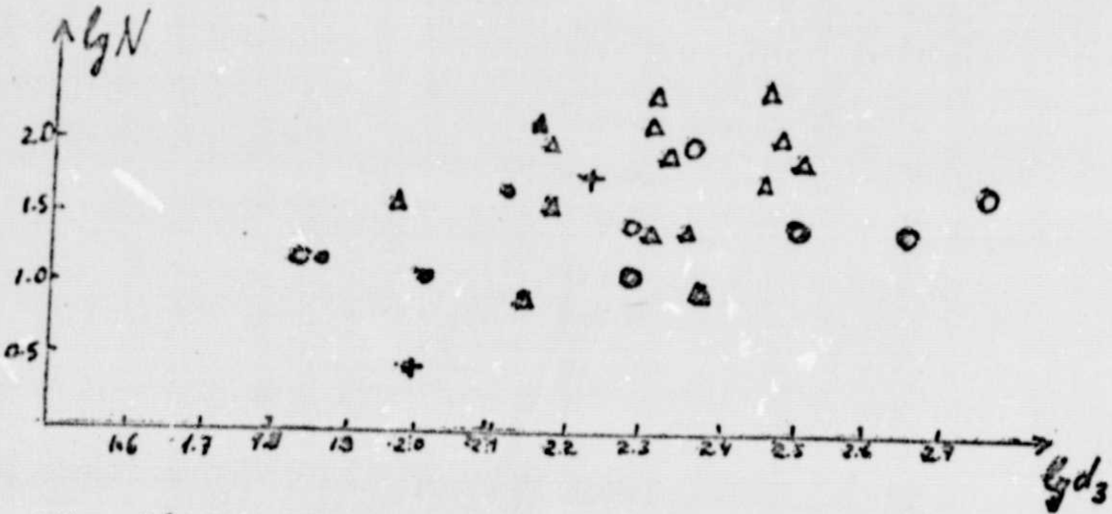


Fig. 16. Relationship between number of HII zones in galaxy and average size of three largest HII zones in it.

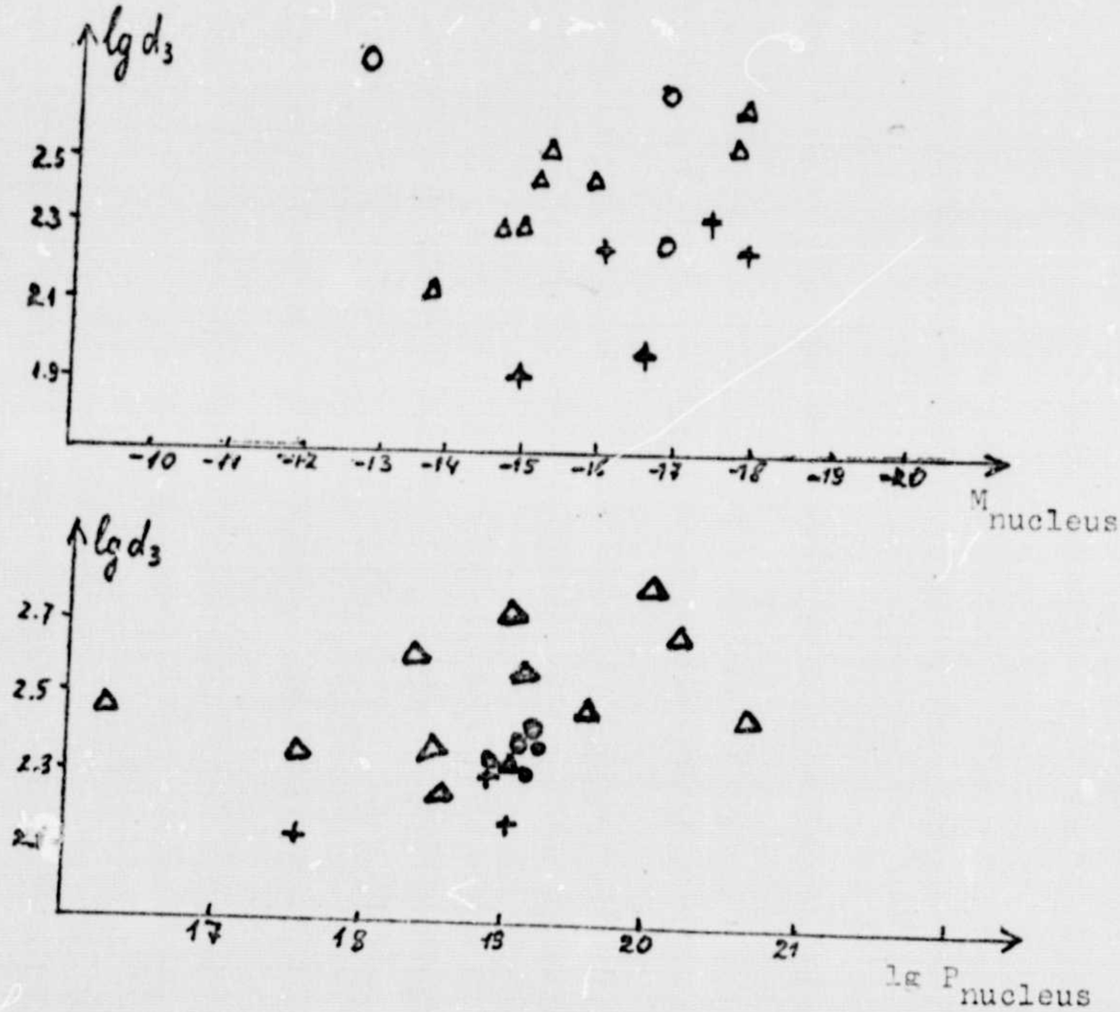


Fig. 17. Average size of 3 largest HII zones vs.: a. absolute star magnitude of galactic nucleus; b. absolute luminosity of nucleus in 1415 MHz range (in W/Hz·ster).

(1415 MHz)