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NUCLEAR H II REGIONS IN GALAXIES WITH EMISSION LINES

G. T. Petrov, I. M. Yankoulova, V. K. Golev

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The beginning of a systematic study of galactic spectra may be said to date back to 1925, when Slifer investigated the spectra of 41 galaxies. A catalog containing the radial velocities of 800 galaxies was published in 1956 [1]. Spectrophotometric investigations are proceeding along two lines: the stellar composition of the galaxies is re-established by absorption characteristics, while the physical conditions, chemical composition and the dynamics of the gas component are estimated by the emission spectra.

The emission spectra of the galaxies were investigated in our previous paper. As is known, a diffuse emission from the entire disc, as well as an emission of the H II regions from the spiral sleeve and of other regions, can be observed in the galaxies. In turn, the emission of nuclear regions is a consequence of (*a*) nuclei with characteristics of the type Sy 1, (*b*) nuclei of type Sy 2, (*c*) lines or Seyfert nuclei of type 3, and (*d*) nuclear H II regions. The boundary between the Seyfert galaxies and less active galaxies was determined, according to [2], by: (0 III)/Hß$\geq$3, $FWHM_{(0\,III)}>300$ km/sec. At that, as noted in [3], the ionization mechanism is the most important parameter. The width of the lines is a secondary indication. What the nuclear sources, listed in (*a*), (*b*) and (*c*), have in common is that they cannot be explained by the ionization of gas from hot stars.

Let us now consider the properties of the nuclear H II regions. Original observation material, supplemented by lit. data, has been used for the purpose. The data on the relative intensities of the lines $I_\lambda/H_{H\alpha}$ comprise 114 galaxies. The data on the fluxes F_λ, luminosities L_λ, the effective volume occupied by the gas V_{eff}, the mass of gas m_{gas} electron density n_e and the number of ionizing stars of class 07 V reter to 85 of them. The study covered 14 galaxies with a high surface brightness (Akn), 31 galaxies with a u. v. continuum (Mrk) and 40 nearly galaxies (NGC) which do not belong to other groups. Our data include 50 of the investigated galaxies.

The following parameters are relevant when the physical condition in the nuclear H II region are studied: fluxes and luminosities in the line H_α (in some cases the fluxes in the line H_β were determined and then the relation $F_{H\alpha}=2.88\times F_{H\beta}$ was used), the effective volume V_{eff} and the effective radius taken from the emitted gas respectively, the electron density n_e and the power of the ionization source, in this case represented as the number of stars of the 07 V class whose u. v. radiation suffices to maintain the gas in an ionization-recombination equilibrium. The electron temperature T_e in all these

Table 1

Physical conditions for Arakelian, Markarian and nearby galaxies

Galaxy class		lg F_{H_α} [erg/cm².sec]	lg L_{H_α} [erg/sec]	lg V_{eff} [cm³]	lg $\mathfrak{M}_{gas}$ [g]	n_e [cm³]	n* — No of Stars of Class 07 V	Note
Nearby galaxies	from-to	—14.10÷—12.15	37.45÷40.92	55.54÷61.63	34.72÷39.55	100÷3800	50÷2650	
	X	—13.09	39.23	57.99	37.00	1100	464	
	σ	0.48	0.70	1.31	1.01	970	532	
	n	40	40	40	40	40	40	
Arakelian	from-to	—14.222÷—12.80	39.60÷40.78	57.38÷62.53	37.18÷39.75	100÷8900	520÷9600	* without Akn 144
	X	—13.54	40.10	59.15	37.18	1440	3060	
	σ	0.44	0.31	1.99	1.00	2530	3165	
	n	14	12	11	11	10*	11	
Markarian	from-to	—15.10÷—12.03	38.82÷41.61	57.11÷61.46	35.70÷39.98	50÷6160	80÷47900	
	X	—13.37	40.24	59.10	38.02	1130	6565	
	σ	0.62	0.73	1,21	0.98	1410	10360	
	n	31	31	31	31	31	31	

Table 2

Physical conditions for different groups of Markarian galaxies

Group		lg F_{H_α}[erg/cm²sec]	lg L_{H_α} [erg/sec]	lg V_{eff}[cm³]	lg $\mathfrak{M}$ gas[g]	n_e[cm^{-3}]	n^* — No. of stars of class 07 V	Note
Mrk a	from-to	—14.02÷—12.66	38.82÷40.38	57.12÷61.36	35.70÷39.28	50÷6160	80÷ 2850	$n^* < 3000$
	X	—13.57	39.74	58.65	37.52	1070	1050	
	σ	0.66	0.46	10.05	0.76	1360	930	
	n	18	18	18	18	18	18	
Mrk b	from-to	—13.46÷—12.55	40.46÷40.92	57.88÷60.64	37.07÷39.09	230÷5130	3370÷ 9650	$3000 \geq n^* >$ >10000
	X	—13.20	40 73	59.30	38.34	1600	6720	
	σ	0.36	0.16	1,11	0.76	1750	2320	
	n	5	8	8	8	8	8	
Mrk c	from-to	—13.26÷—12.03	40.98÷41.61	59.27÷61.46	38.57÷39.98	200÷1190	11100÷47900	$10000 < n^*$
	X	—12.86	41.30	60.40	39.29	590	26145	
	σ	0.44	0.22	0.78	0.49	340	12670	
	n	5	5	5	5	5	5	

regions varies relatively slightly, from 6000 to 15000 °K. The data on the different types of objects are shown in Table 1, which also includes the intervals of variation of the respective magnitudes per group, the mean magnitudes $\langle X \rangle$, their dispersions σ and the number of investigated galaxies. The results boil down to:

1) The fluxes $F_{H\alpha}$ decrease on the average from the NGC via the Arakelian to the Markarian galaxies. This is a natural reflection of the fact that the first group comprises nearby galaxies.

The luminosities $L_{H\alpha}$ on the average increase in the same sequence.

3) The mass of emitted gas $\mathfrak{M}_{gas}$ on the average changes from $5\times10^3 M_\odot$ for the nearby galaxies and $75\times10^3 M_\odot$ for the Arakelian galaxies to $52\times10^3 M_\odot$ for the Markarian galaxies.

4) The emitting gas occupies correspondingly a volume with an effective radius of ca. 10 p. c. for the nearby galaxies and ca. 20 p. c. for the other groups.

5) The electron density determined by the doublet of the ionization sulfur [SII] λλ 6717, 6731, according to [4], correspondingly varies from ≤ 100 to 4000 cm^{-3} for the nearby galaxies, 100 to 9000cm^{-3} for the Markarian galaxies. The only exception is the Arakelian 144 galaxy, whose electron density is $\sim$32000 cm^{-3}.

6) The ionization source is qualitatively estimated with the necessary number of stars of the 07 V class, whose u. v. radiation would suffice to maintain the gas in an ionization-recombination equilibrium. Each of these stars has a mass of ca. 30 $M_\odot$. The estimate is formal in a certain sense, because there are indications that the gas may be heated by stars of the horizontal branch of the Herzsprung-Russel diagram with masses lower by one order [5]. Ergo, $\sim$500 such stars (maximum 3000) are on the average necessary and sufficient for the nearby galaxies, $\sim$3000 (max 10000) for the Arakelian galaxies and 6500 for the Markarian galaxies, the upper limit being about 50000. The last figure is impressive, considering that a star of the 07 V class is statistically encountered on the average in 10^6-10^7 dwarf stars, i. e. a mass of the order of 10^{12}-10^{13} $M_\odot$ is enclosed in the nucleus of such a galaxy. It follows that the Markarian galaxies are the most active. This is borne out by the percentage of Seyfert galaxies among the last two groups: 1 % of the Arakelian galaxies and over 10 % of the Markarian galaxies (let us recall that only non-Seyfert galaxies are examined here).

7) As regards the homogeneity of the group of Markarian galaxies, our data reveal that it is not a homogeneous group. If we divide them conventionally by the power of the ionization source into three groups — $n_* < 3000$, $3000 > n_* > 10000$ and $10000 < n_*$, in such a way that the first are close in parameters to the 'nearby' galaxies, and the second are close to the Arakelian galaxies, there remains the last group for which there is no analog. The data on the subgroup (Table 2) indicate that here the gas mass changes by one order: 10^4, 10^5 and 10^6 $M_\odot$. The natural inference is that at least the galaxies of the third subgroup may be heated by another mechanism. In the nucleus of the Mrk 171 galaxy (which refers to the second subgroup) the gas may also be heated, as we showed in [6], by shock waves. It should be noted that no correlation was found between the division of the subgroups and the spectral characteristics of the nucleus adduced by Markarian et al.

The relative intensities of the emission lines were then considered, viz., the ratios I_λ 6584 [NII]/$I_{H\alpha}$ and $I_{\lambda\lambda}$(6717+6731) [SII]/$I_{H\alpha}$. Analogous data on other classes of emission objects — normal HII regions, planetary nebulae, Sey-

Table 3

Mean ratios $I_{\lambda\lambda}$ 6584/IH_α and $I_{\lambda\lambda}$ (6717+6731) HI_α for different classes of emission objects

Class	nearby	Akn	Mrk	Mrk *a*	Mrk *b*	Mrk *c*	PIN	*H* II *a*	*H* II *b*	SyG1 CG 1+	SyG2 CG 2+
[NII] $\frac{6584}{H_\alpha}$	1.13	0.55	0.57	0.57	0.73	0.37	0.07	0.42	0.31	0.06	0.80
[SII] $\frac{6724}{H_\alpha}$	0.62	0.38	0.36	0.33	0.52	0.32	0.02	0.32	2.36	0.04	0.48
No. per class	41	27	46	34	7	5	19	11	7	34	40

fert type 1 and 2 galaxies, as well as radio galaxies with broad and narrow lines — are given for the sake of comparison (results in Table 3). At that, the lower the excitation is, the greater in value the examined ratios are. As the data reveal, the lowest excited are the nuclei of the 'nearby' galaxies. The conditions in the nuclear HII regions of the Arakelian and Markarian galaxie are close to those in the normal HII regions. The high ratios I_λ 6584/IH_α and $I_{\lambda\lambda}$(6717+6731)/$I_{H\alpha}$ of the Seyfert type 2 galaxies and the radio galaxies with narrow lines refer to the zones (OII), which are characterized by relatively low densities and temperatures.

This observation gradation may be explained as follows: (1) Sulfur and nitrogen ions are known to emit only in low-density regions $n_e \sim 10^3$-10^4 cm^{-3}, while H_α emits in the entire volume. The low ratios for Sy 1 and BLRG are then a reflection of a relatively wide density region with n_e up to 10^9 cm^{-3} which is not observed in the other objects. For Arakelian and Markarian galaxies one should then expect zone (OIII), with a relatively low density $(SII)_e \sim 10^4$-10^5 cm^{-3}. (2) It is possible that at least lines λλ 6717, 6731 of the ionized sulfur may emerge in the hot regions HI, if there is a mechanism heating them up to several thousand degrees (e. g., shock waves, stellar wind and the like).

Finally, let us consider certain interesting objects and results.

a) The Arn 144 galaxy has the highest hitherto known ratio $I_{\lambda\lambda}$ (6717 +6731) (SII)/$I_{H\alpha}$ = 3.60. At that, the electron density determined by this doublet is 32000 cm^{-3}.

b) The Mrk 442 galaxy likewise shows a very high ratio of the sulfur lines and $H_\alpha \geq 2$.

c) In the NGC 5005 galaxy strong differences are observed between lit. [2,7] and our data: the fluxes in the H_α line differ by two orders, while the differences in the ratios of the foremost lines come up to two times. Similar differences are also observed in the NGC 5194 galaxy. A more detailed investigation is called for here.

Department of Astronomy
Bulgarian Academy of Sciences

Chair of Astronomy
Faculty of Physics
Sofia University

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