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Spectrophotometry of the nucleus of the galaxy Arakelyan 144

V. A. Mineva, G. T. Petrov, V. K. Golev, and Z. I. Tsvetanov

Astronomy Section, Bulgarian Academy of Sciences, Sofia
and Astronomy Department, Sofia University

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Spectra of the galaxy Arakelyan 144 obtained with the 6-m telescope have been subjected to spectrophotometric analysis. Very strong forbidden lines of S^+ are present: $I(\lambda\lambda\ 6716, 6731\ [\mathrm{S\ II}])/I(\mathrm{H}\alpha) = 3.50$. The ratio $I(\lambda\ 5007\ [\mathrm{O\ III}])/I(\mathrm{H}\beta) \approx 1$. The S^+ lines imply a very high electron density for the gas: $\log n_e = 4.56$. The Hβ flux density and luminosity are $F(\mathrm{H}\beta) = 3.16\times 10^{-15}$ erg cm^{-2} sec^{-1}, $L(\mathrm{H}\beta) = 4.8\times 10^{39}$ erg/sec; the mass of the gas is $\approx 1000\ M_{\odot}$. The ultraviolet emission of about 2000 type of 07 V stars would suffice to maintain the gas in ionization–recombination equilibrium. The relative abundance of S^+ ions is an order of magnitude higher than average for the various types of emission-line objects, but the N^+ abundance is typical for galaxies of all types other than Seyfert 1.

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In 1975 Arakelyan[1] singled out a group of galaxies with high surface brightness; although not very numerous they include several unique objects. Most of these galaxies exhibit emission lines (90% of them, according to a private communication from Arakelyan). Some of the may be a among the brightest galaxies in the universe. There are a few x-ray sources among the Arakelyan galaxies (an example is Ark 120). The galaxies of high surface brightness display enhanced 408-MHz radio emission.[2] Six of the objects, or about 1% of the entire class, are at the same time Seyfert galaxies.

Little spectrophotometry has been done on the Arakelyan galaxies. Several of them, all Seyferts, have been investigated by Osterbrock and Phillips[3] and by one of the authors.[4] Another of us has determined equivalent widths and relative intensities for 12 non-Seyfert Arakelyan galaxies.[5] In view of the peculiar nature of the objects listed by Arakelyan, further spectrophotometric studies of them are worthwhile.

TABLE I.' Emission Lines in Nucleus of Arakelyan 144

Ion	λ	W_λ	$I_\lambda/I_{\mathrm{H}\alpha}$
	4861	2.2	0.36
O^{++}	5007	1.9	0.32
N^+	6548	1.6	0.26
H	6563	6.2	1.00
N^+	6584	4.0	0.61
S^+	6717	6.0	1.00
S^+	6731	16.0	2.56

[SII]λ6717/[SII]λ6731=0.40
[NII]λ6584/[NII] (λ6717+λ6731) =0.25

The galaxy Ark 144 ($\alpha = 7^{\mathrm{h}}52^{\mathrm{m}}.9$, $\delta = +61°47'$, 1950.0) is numbered 10-12-23 in the Morphological Catalog.[6] With diameters D = 0'.3, d = 0'.25 and a magnitude $m_{pg} = 15^{\mathrm{m}}.2$, the galaxy has a surface brightness in Arakelyan's system $\tilde{B} = 21^{\mathrm{m}}.5/(1'')^2$. Arakelyan describes it as very compact, blue, with a faint, asymmetric envelope. Dibai et al.[7] have measured a redshift z = 0.028 for Ark 144. They furthermore mention the presence of emission lines in its spectrum: strong Hα emission and medium-intensity forbidden lines of the N^+ and S^+ ions.

The aim of our present investigation was to carry out a more detailed spectrophotometric analysis of Ark 144. Spectra of the galaxy were obtained in February 1981 with the 6-m telescope of the Special Astrophysical Observatory, USSR Academy of Sciences. The UAGS spectrograph was equipped with the three-stage UM-92 image tube. Two spectrograms, in the red and the blue (centered on Hα and Hβ), were recorded at 100-Å/mm dispersion with 10-min exposures on A-600 emulsion. The spectral resolving power of the system was 4-5 Å. Tracings of the spectra were then made with the G III microphotometer of the Astronomy Section, Bulgarian Academy of Sciences. Table I gives the results of our analysis of the tracings: equivalent widths and relative intensities for all the emission lines reliably identified in the spectrum. A tracing of the red portion of the spectrum, in density units, is shown in Fig. 1.

To analyze the spectra we have employed Dibai and Pronik's technique for investigating emission-line objects.[8] In addition to these authors, Osmer et al.,[9] have proposed a unified method for studying objects of the same

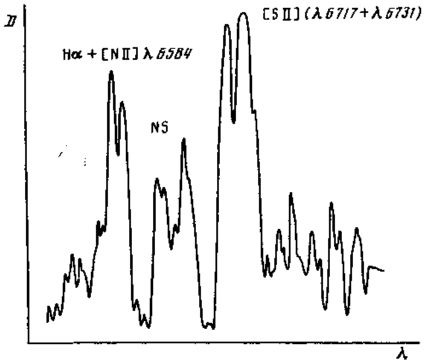

FIG. 1. Density tracing of the spectrum of the nucleus of the galaxy Arakelyan 144 (red region).

kind, but mainly because of less accurate approximations the results obtained by the latter procedure differ by a factor of about 2.

In order to establish the flux density in the Hβ line, along with the equivalent line width one must know the magnitude of the nucleus of the galaxy. The Zwicky catalog gives an integrated magnitude $m_{pg} = 15.2$ for Ark 144. No determination of morphological type has been made in the customary system. According to the description by Arakelyan[1] and in the MCG,[6] the galaxy may be classified as S0. Using the 2-m telescope of the Bulgarian National Astronomical Observatory we have taken a direct photograph of Ark 144 in the B wavelength band (scale 12".8/mm, image size 2"), from which it appears that the galaxy belongs to type Sa or SBa. For Sa or SBa galaxies, the data given by Gorbachev[10] and in the "Soobshcheniya" of the Byurakan Observatory (Vol. 47, p. 43, 1975) yield the following correlation between the magnitude m_n of the nucleus and the integrated magnitude m:

$$m_n = 0.64m + 6.38$$

(correlation coefficient r = 0.68). For Ark 144 this relation gives $m_n = 16^m.1$; the corresponding flux density in the Hβ line is $F_{H\beta} = 3.16 \cdot 10^{-15}$ erg · cm^{-2} · sec^{-1}.

Knowing the intensity ratio λλ4959, 5007 [O III]/λλ 6548, 6584 [N II], we can apply the method of Alloin et al.[11] to determine the electron temperature: $T_e = 6500$°K for Ark 144. However, these authors themselves remark that in cases where no appreciable λ4363 [O III] is observed, the value found for T_e will be underestimated by several thousand degrees compared with the actual temperature. We therefore have adopted for further calculation the customary value in such cases, $T_e = 10{,}000$°K.

The electron density of radiating gas is often determined from the forbidden-line intensity ratio λ6717 [S II]/λ6731 [S II]. On the basis of new data on the collision strengths for transitions within the ground configuration of the S^+ ion, Nosov[12] has derived a more accurate relation between log n_e and the λ6717/λ6731 ratio. For the intensity ratio of 0.40 observed in Ark 144, his relation gives a quite high density: $\log n_e = 4.56$, $n_e = 3.6 \cdot 10^4$ cm^{-3}. At such densities, however, log n_e may be in error by more than 1.00, so the value obtained here for n_e is not very reliable.

Using the above values, $\log n_e = 4.56$ and $\log T_e = 4.00$, we arrive at the following estimates for the parameters of the emission region in the nucleus of Ark 144:

Distance modulus	$35^m.25$
Magnitude of nucleus:	
m_n	$16^m.1$
M_n	$-19^m.1$
Flux density in Hβ line, erg · cm^{-2} · sec^{-1}	$3.16 \cdot 10^{-15}$
Luminosity in Hβ line, erg/sec	$4.8 \cdot 10^{39}$
Effective radius, cm	$3.35 \cdot 10^{18}$
Mass of radiating gas, $M_\odot$	1000
Total gas luminosity in lines, erg/sec	$3.0 \cdot 10^{41}$
Kinetic energy of gas (v ≈ 250 km/sec), erg	$6.2 \cdot 10^{50}$
Number of ionizing stars (type O7 V)	1700
Relative abundance of ions (log H = 12.00):	
log N^+	7.50
log S^+	7.68
log O^{++}	7.95.

The estimates given here for the relative abundance of the N^+, S^+, O^{++} ions have been obtained by Peimbert's method.[13]

Thus the galaxy Ark 144 is an interesting object in many respects. Above all, the lines of the S^+ ion are very strong: the ratio λ6584 [N II]/λλ 6717, 6731 [S II] = 0.25 is perhaps comparable with the analogous ratio for certain H II regions in the Galaxy. Probably the ratio λλ 6717, 6731 [S II]/Hα = 3.50 is the highest value yet known. For emission-line objects this ratio[14] averages less than 0.5, and it is often less than 0.1.

The relative abundance of S^+ ions in Ark 144 is an order of magnitude higher than the average for the various types of emission-line objects (planetary and diffuse nebulae, Markaryan galaxies, Seyfert galaxies, radio galaxies). On the other hand, Ark 144 has a relative abundance of N^+ ions which is typical of all types of galaxies except Seyferts 1. The gas has a very high electron density (on the average for most objects, $\log n_e = 3.0$ in the O^+ zone), equal to that in the O^{++} zones in Seyfert 2 galaxies. But the luminosity in the Hβ line is one or two orders lower than the average for Seyfert galaxies, while the kinetic energy of the gas is comparable with the energy for Seyferts 2 and is an order of magnitude lower than for Seyferts 1. The number of type O7 V stars whose emission would suffice to maintain the gas in ionization–recombination equilibrium is about 2000. Thus the radiation of hot young stars is a likely heat source for the gas.

Our results indicate that peculiar physical conditions exist in Ark 144, and further, more comprehensive study of this interesting galaxy is much needed.

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The nature of the galactic H I supershells

I. V. Gosachinskiĭ

Special Astrophysical Observatory, USSR Academy of Sciences, Nizhniĭ Arkhyz

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The majority of the shell and supershell formations typical of the galactic distribution of neutral hydrogen probably do not result from the impact of supernova remnants or stellar wind on the interstellar medium, but reflect normal, stratified spiral structure.

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There is a variety of evidence to show that certain galactic objects are interacting with the ambient interstellar gas. Ionized hydrogen zones, supernova remnants, and stellar associations are surrounded by expanding envelopes of neutral hydrogen which unquestionably are physically related to those objects. Heiles[1] has recently listed a large number of H I shells. The objects he cites are of great interest for two reasons. First, only a very few of them have any apparent relationship to other galactic objects. Second, if as Heiles suggests the shells actually represent expanding envelopes produced by supernova explosions, then the outbursts must have been remarkably energetic; up to 10^{54} erg each. Heiles proposes that each such envelope may have resulted from multiple supernova events.

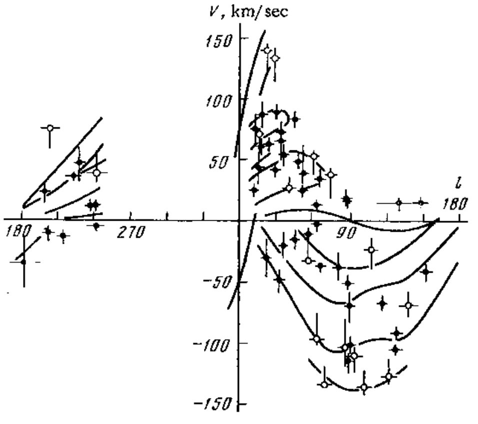

FIG. 1. The relationship between the Heiles H I shells and the galactic spiral arms. Horizontal and vertical bars indicate the extent of the shells in longitude and the radial-velocity range. Circles represent expanding shells.

Bruhweiler et al.[2] maintain that these "supershells" would have developed through joint action of stellar wind emanating from the OB stars of a rich stellar association, and subsequent multiple supernova outbursts. In this letter we wish to describe certain properties of the H I supershells which conflict with that interpretation, and we offer an alternative explanation for the nature of the objects investigated by Heiles.

All 47 of Heiles's objects[1] are plotted in Fig. 1 in a diagram of radial velocity against longitude. The circles represent shells in which radial motion of the H I has been detected. At each point the cross indicates the extent of the shell in longitude and the observed range in radial velocity. Heavy curves delineate the H I spiral arms as outlined by Kardashëv et al.[3] Sixteen additional objects have been excluded from further analysis because their radial velocities, according to Heiles,[1] are formally precluded by the model of steady galactic rotation, and their distances are indeterminate. We would point out, however, that according to Fig. 1 there actually are only six such objects; the other ones closely fit the H I spiral arms, which in some cases themselves deviate from the formal model. It is clear from Fig. 1 that H I shells occur in all the spiral arms, even those distant from Fig. 1 that H I shells occur in all the spiral arms, even those distant from the sun, suggesting that the sample may be reasonably complete and that we are entitled to consider