# The nucleus of the galaxy NGC 5929: preliminary spectrophotometry

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Spectra of the nucleus of the galaxy NGC 5929 obtained with the 1.25-m and 6-m telescopes show emission lines with separate components in the wings. The physical parameters of the nucleus are estimated (assuming a temperature $T_e = 10^4$ °K for the radiating gas): electron density $n_e \approx 400$ cm$^{-3}$, flux density $F_{H\beta} \approx 2.49 \times 10^{-14}$ erg cm$^{-2}$ sec$^{-1}$, luminosity $L_{H\beta} \approx 3.85 \times 10^{39}$ erg/sec. The relative abundance of several ions is evaluated. Lyman continuum emission by hot young stars may be responsible for ionizing the gas in the nucleus. About 1000 type O5 V stars would be needed to maintain the gas in ionization–recombination equilibrium. For the emission-line spectrum to result from shock heating of the gas is inconsistent with the observational evidence.

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Spectrophotometrists are showing an increasing interest in the study of non-Seyfert galaxies with emission lines. Detailed spectrophotometric analysis of the nuclei of such galaxies is of great value and can contribute significantly to solving the problem of activity in galaxy nuclei generally. One galaxy of this sort is NGC 5929. In the Revised NGC it is described by the code[1] EL,BM,SLDIFHALO; that is, elongated, brighter toward the middle, with a slightly diffuse halo. It is paired with NGC 5930, the two components being separated by 0'.5. The pair is included as No. 90 in Arp's atlas of peculiar galaxies,[2] together with a photograph. In Zwicky's catalog[3] the galaxies are classed as compact objects (I Zw 112), and Karachentsev lists the pair as No. 466 in his catalog of isolated double galaxies.[4]

Page[5] has determined a combined mass $M = 1.25 \cdot 10^{10}\ M_\odot$ for the pair, and a radial velocity $V_0 = 2696$ km/sec for NGC 5929. He also mentions that hydrogen and nitrogen emission lines occur in the spectrum of both galaxies. With an angular size of 0'.7 × 0'.7 and $m_{pg} = 13^m.0$, NGC 5929 has a surface brightness of $22^m.6/(1'')^2$, so that according to Arakelyan's criterion it is a galaxy of low surface brightness, a circumstance which impedes detailed study.

NGC 5929 was placed on our program of spectrophotometry of non-Seyfert, emission-line galaxies, described in a previous letter.[7] For the present analysis a total of four spectra were available to us: two taken (by Petrov) with the 125-cm Éngel'gardt reflector of the Shternberg Astronomical Institute's Southern Station in the Crimea, using the A spectrograph with a single-stage image tube near the Hα line; and the other two taken with short exposure at the prime focus of the 6-m telescope of the Special Astrophysical Observatory, USSR Academy of Sciences, using the UAGS universal spectrograph and a three-stage image tube in the vicinity of the Hα and Hβ lines. Tracings of the last two spectra on a density scale are displayed in Fig. 1.

All the spectra were recorded at ≈ 100 Å/mm dispersion; since the image-tube screen has a resolution of ≈ 20–25 mm$^{-1}$, the corresponding resolution in wavelength is ≈ 4–5 Å. The Crimean spectra were reduced on the direct-intensity recording photometer of the Crimean Astrophysical Observatory, USSR Academy of Sciences, while the other two were scanned with the high-speed G III microphotometer of the Astronomy Section, Bulgarian Academy of Sciences, by standard techniques. The spectral sensitivity of the instrumentation was established relative to the spectrum of the standard star BD + 25°3941 listed by Stone.[8] Photometric calibration was performed with an ISP-51 laboratory spectrograph and a multistep wedge.

The following lines have been identified on these spectra (see Fig. 1): Hα, Hβ, λλ 6300, 6363 [O I], λλ 4959, 5007 [O III], λλ 6717, 6731 [S II], λλ 6548, 6584 [N II], and probably λ 6312 [S III]. The λ 5199 [N I] line is faintly visible, as well as the Fraunhofer absorption feature b, representing the neutral magnesium line λ 5175 Mg I. The width of the emission lines exceeds the instrumental broadening (compare the night-sky lines marked NS in Fig. 1). In the blue and red wings of each line one can see components shifted 5-6 Å away from the center. Other authors who have studied the galaxy NGC 5929 make no mention of such components, namely Page,[5] who obtained spectra of ≈ 400 Å/mm dispersion in order to measure the radial velocity, and Turner,[9] who reduced

TABLE I. Spectrophotometric Parameters

| Parameter | $H^+$ | | $O^0$ | | $S^+$ | | $N^+$ | | $O^{++}$ | |
|---|---|---|---|---|---|---|---|---|---|---|
| | λ4861 | λ6563 | λ6300 | λ6363 | λ6717 | λ6731 | λ6548 | λ6584 | λ4959 | λ5007 |
| $W_\lambda$ | 6.0 | 17 | 6.5 | 2.5 | 8.5 | 7.5 | 8.0 | 18 | 9.0 | 20 |
| $I_\lambda/I_{H\beta}$ | 1 | 5,45 | 2.0: | 0.6: | 3.47 | 2.66 | 1.95 | 3.75 | 1.59 | 3.64 |
| $I^0_\lambda/I^0_{H\beta}$ | 1 | 2.88 | 1.0: | 0.3: | 1.80 | 1.41 | 1.07 | 2.02 | 1.50 | 3.32 |
| $\lg X_i/H^+ + 12.00$ | — | | 7.59 | | 7.15 | | 7.23 | | 8.50 | |

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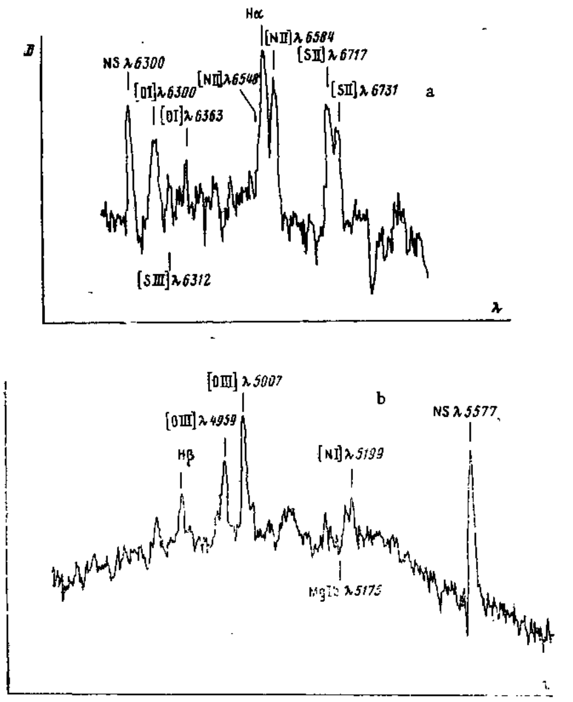


FIG. 1. Tracings of spectra of the NGC 5929 nucleus in density units in the vicinity of: a) the Hα line; b) the Hβ line. The spectrograms were recorded at ≈100 Å/mm dispersion at the prime focus of the 6-m telescope.

his spectra of ≈ 140 Å/mm dispersion automatically by a special program that also served to determine the radial velocity.

At our request A. R. Petrosyan kindly obtained a direct photograph of the nucleus of NGC 5929 at the prime focus of the 2.6-m telescope of the Byurakan Astrophysical Observatory, Armenian Academy of Sciences. The nucleus appears to be devoid of structure. A spectrum of the other member of the pair, NGC 5930, obtained at the same resolution in wavelength, does not show components in the wings of the lines. The components we have found in the line profiles of the NGC 5929 nucleus can be interpreted as evidence for radial motion of gaseous masses at speeds of 200–300 km/sec. Thus the NGC 5929 nucleus is evidently experiencing a mild form of activity, quite different from the activity in Seyfert nuclei.

Table I gives our measured values of several spectrophotometric quantities: the equivalent width of each line, the relative intensity $I_\lambda/I_{H\beta}$, and the same ratio corrected for interstellar absorption, $I^0_\lambda/I^0_{H\beta}$. The reddening correction is based on the relation $\log I^0_\lambda = \log I_\lambda + c_\beta f(\lambda)$, where $c_\beta$ denotes the absorption at Hβ determined from the Balmer decrement and $f(\lambda)$ represents the Peimberts' interstellar extinction function.

Physical interpretation. We turn now to a determination of the physical conditions in the NGC 5929 nucleus. From the dependence[11] of the intensity ratio $I_{\lambda 6717}/I_{\lambda 6731}$ for the [S II] doublet lines upon the quantity $X = 10^2 n_e T_e^{-1/2}$, one can estimate the electron density $n_e$, taking as usual $T_e = 10^4$ °K. In our case

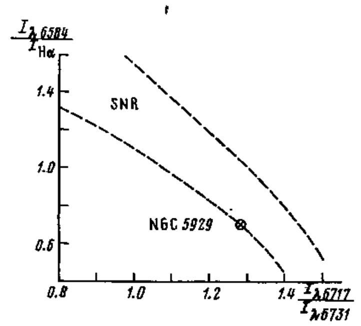


FIG. 2. The position of the NGC 5929 nucleus in the $[I_{\lambda 6584}/I_{H}, I_{\lambda 6717}\cdot(I_{\lambda 6731})^{-1}]$ diagram. The dashed curves outline the domain occupied by supernova remnants in the Galaxy.[13]

$I_{\lambda 6717}/I_{\lambda 6731} = 1.28$, which corresponds, for this temperature, to $n_e = 400$ cm$^{-3}$.

We can now calculate the volume emission coefficient in the Hβ line:

$$4\pi j_{H\beta} = h\nu_{H\beta}\alpha_{42}^{\mathrm{eff}}(T_e)\, n_e n_p \ \mathrm{erg\cdot cm^{-3}\cdot sec^{-1}}$$

where

$$\alpha_{42}^{\mathrm{eff}}(T_e) = 4.19\cdot 10^{-16}\cdot(4^2)\, b_4 \frac{e^{\chi_4/kT_e}}{T_e^{3/2}}\cdot A_{42}$$

and

$$A_{42} = 8.37\cdot 10^6 \ \mathrm{sec^{-1}}.$$

For the galaxy NGC 5929 this coefficient is equal to $2.0\cdot 10^{-20}$ erg · cm$^{-3}$ · sec$^{-1}$.

Applying the method proposed by Dibai and Pronik,[12] we can estimate the flux density and luminosity in the Hβ line as well as the effective volume and mass of the radiating gas. Taking the magnitude of the nucleus to be ≈ $15^m$ and an equivalent width $W_{H\beta} = 6$ Å, we find that the Hβ flux density outside the earth's atmosphere is $F_{H\beta} = 2.49\cdot 10^{-14}$ erg · cm$^{-2}$ · sec$^{-1}$. Since the distance of the galaxy is 36 Mpc (if H = 75 km · sec$^{-1}$ · Mpc$^{-1}$), the luminosity of the NGC 5929 nucleus in the Hβ line is $L_{H\beta} = 3.85\cdot 10^{39}$ erg/sec. The radiating gas accordingly occupies an effective volume of $1.76\cdot 10^{57}$ cm$^3$, and the amount of gas within that volume is 5850 $M_\odot$.

From the combined intensity of the forbidden lines we can evaluate the energy needed to maintain the gas in ionization–recombination equilibrium:

$$E_{\mathrm{eq}} = 11.2\,\frac{L_{H\beta}}{h\nu_{H\beta}}(\bar{\varepsilon} + 13.6\,\mathrm{eV}) \ \mathrm{erg/sec}$$

where $\bar{\varepsilon}$ denotes the mean energy that the free electrons acquire through ionization. For the NGC 5929 nucleus $E_{\mathrm{eq}} = 4.27\cdot 10^{41}$ erg/sec. The number of type O5 V stars whose Lyman continuum radiation could provide energy at such a rate is about 1000. Our own Galaxy contains one O5 V star for every $10^7$ stars of the general field,[12] so we may expect the mass of the NGC 5929 nucleus to be of order $10^{10}$ $M_\odot$. As the galaxy is of morphological type S0, the bulk of its mass resides in its nucleus. Our mass estimate is of the same order as that obtained by Page[5] in a different way, lending support to our assessment of physical conditions in the nucleus of NGC 5929. The most likely mechanism for ionizing the gas in this nucleus therefore might well be the Lyman continuum emission of hot young stars located there.

Let us now attempt to interpret the observed spectrum in terms of the model of gas heated by a shock wave. Alloin et al.[13] have calculated the dependence of the relative [N II] intensity $I_{\lambda 6584}/I_{H\alpha}$ upon the [S II] intensity ratio $I_{\lambda 6717}/I_{\lambda 6731}$ for the case of supernova remnants. This relation is illustrated in Fig. 2; the dashed curves bound the region of the diagram occupied by supernova remnants, and the cross marks the position of the NGC 5929 nucleus, at $I_{\lambda 6584}/I_{H\alpha} = 0.70$ and $I_{\lambda 6717}/I_{\lambda 6731} = 1.28$. We see that the nucleus is located at the edge of the supernova-remnant domain, a circumstance which suggests that the moving "clouds" of gas we observe might perhaps reflect some sort of eruptive process in the nucleus, analogous to outbursts of supernovae.

Furthermore, the emission lines have the same intensity in the NGC 5929 nucleus as in the supernova remnants Vela X and N 49. According to calculations by Osterbrock and Dufour,[14] these line intensities correspond to shock heating of the gas. Let us estimate the energy of excitation of the gas by such a shock, following Dibai and Pronik's approach.[12] The motion of 5850 $M_\odot$ of gas at a velocity of $\approx$ 200–300 km/sec would supply a kinetic energy $E_k = Mv^2/2 \approx 5.26 \cdot 10^{51}$ erg. Knowing the distance of the galaxy and the angular size of the emission region in the nucleus ($\approx 8''.6$, as indicated by a scan along the $H\alpha$ line, perpendicular to the dispersion), we find that the linear diameter of this region is $\approx$ 1500 pc. Then the "age" of the eruptive formation should be $t \approx 2.5 \cdot 10^6$ yr. The recombination energy loss during this interval would be $E_e = E_n t \approx 3.3 \cdot 10^{55}$ erg. Thus $E_k \ll E_e$, and the kinetic energy of the moving gas which is excited by the shock wave would definitely be inadequate to account for the observed flux in the emission lines.

This last fact also argues for a thermal mechanism to sustain the gas in ionization—recombination equilibrium. But the nature of the eruptive process responsible for producing the components in the nuclear emission-line profiles remains unclear, and further, more detailed spectrophotometric analysis of NGC 5929 is needed.

Finally, if we make use of the procedure suggested by Peimbert[15] we can estimate the relative abundance of the $O^0$, $S^+$, and $O^{++}$ ions for $T_e = 10^4$ °K and the standard abundance log n(H) = 12.00:

$$O^0/H^+ = 3.89 \cdot 10^{-5}, \quad S^+/H^+ = 1.41 \cdot 10^{-5},$$
$$N^+/H^+ = 1.70 \cdot 10^{-5}, \quad O^{++}/H^+ = 3.16 \cdot 10^{-4}.$$

These values for the relative number of ions are given in the last line of Table I, in units of $\log (X_i/H^+) + 12.00$.

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