THE COMPLEX NATURE OF THE SEYFERT GALAXY NGC 7592

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1. Morphology

NGC 7592 $\equiv$ VV 731 $\equiv$ MCG–01–59–017 is a system of close interacting galaxies. Two main galactic bodies are present in the CCD R-band image taken at the 1.8m, F/9 telescope of the Asiago Observatory and shown in Figure 1:

- a north-western (NW) component ($\equiv$VV 731B), whose starlike nucleus (A) shows a Seyfert-type spectrum (Archipova et al., 1981). A is surrounded by a nearly spheroidal envelope, with an extension in the west at $P.A. = 290°$ detected up to a distance from A of ≈ 9 arcsec, which corresponds to $\approx 2.5h^{-1}kpc$ of projected linear distance (1 arcsec $\approx .35$ $h^{-1}kpc$ at the redshift $z = 0.0244$; $H_0 = 100$ h km $s^{-1}Mpc^{-1}$). This extension seems to bend in the northern direction and to join a bright wing, detected up to ≈ 22 arcsec from A, which turns to east and resembles a spiral arm or a tidal tail.

- The envelope around A is connected (over ~ 20 arcsec $\approx 7h^{-1}kpc$) to a second galactic body (SE) located in the south-east of it. Its nucleus (B), identified by Markarian and Lipovetskii (1976) as the nucleus of Mkn 928, is located at $d_{AB} \sim 11$ arcsec($\sim 4h^{-1}kpc$) from A at $P.A. = 100°$. The morphology of this component is highly peculiar. In the central region, B is linked to two fainter knots which extend up to $d'' \sim 4$ arcsec at $P.A. = 90°$. This structure gives to the region surrounding B an elongated and distorted shape. Moreover, a bar-like structure is detected on either sides of B. The north-eastern side of the bar ($P.A. = 40°$) joins a slightly distorted loop of condensations, which can be traced from $P.A. = 335°$ (at a distance from B ≈ 6 arcsec ≈ 2.1 $h^{-1}kpc$) to $P.A. = 100°$ and from $P.A. = 200°$ to $P.A. = 240°$, but not in corrispondence of the contact region between the two galaxies. This structure seems to be drained and distorted in the direction of a third condensation C at $d_{BC} \approx 11.7$ arcsec (≈ 4.1 $h^{-1}kpc$) from B at $P.A. = 212°$. A faint plume bent in a direction opposite to that expected for spiral arms of the SE galaxy appears to extend from the west side of C.

2. Spectroscopy

Long slit spectra of NGC 7592 were taken on Sep. 26–30, 1989 at the 1.52 cm ESO telescope, equipped with a Boller and Chivens spectrograph and an RCA High Resolution CCD camera. The covered spectral ranges are 3700–7300 Å with resolution ≈ 3.7 Å, and 4500–5500 Å and 6300–7300 Å with resolution ≈ 1.8 Å. NGC 7592 was observed at two position angles: $P.A. = 212°$ (along B and C), and $P.A. = 100°$ (along B and A), with a slit width of ≈ 2 arcsec ≈ 700 $h^{-1}pc$.

2.1 Physical conditions

The Hα, Hβ, [OIII]$\lambda\lambda$4959,5007, [NII]$\lambda\lambda$6548,6583, [SII]$\lambda\lambda$6717,6731, and [OII] λ3727 emission lines have been found to be spatially extended. The strongest ones, Hα and [OII]λ3727, are detected over ≈ 30 arcsec ≈ 10.5 $h^{-1}kpc$ at $P.A. = 100°$ and ≈ 28 arcsec ≈ 9.8 $h^{-1}kpc$. The size of the emitting regions is comparable with the size of the galaxies belonging to the system NGC 7592 measured on its broad band image. A more refined analysis of the cross dispersion profile of Hα permits to isolate 6 different emitting regions
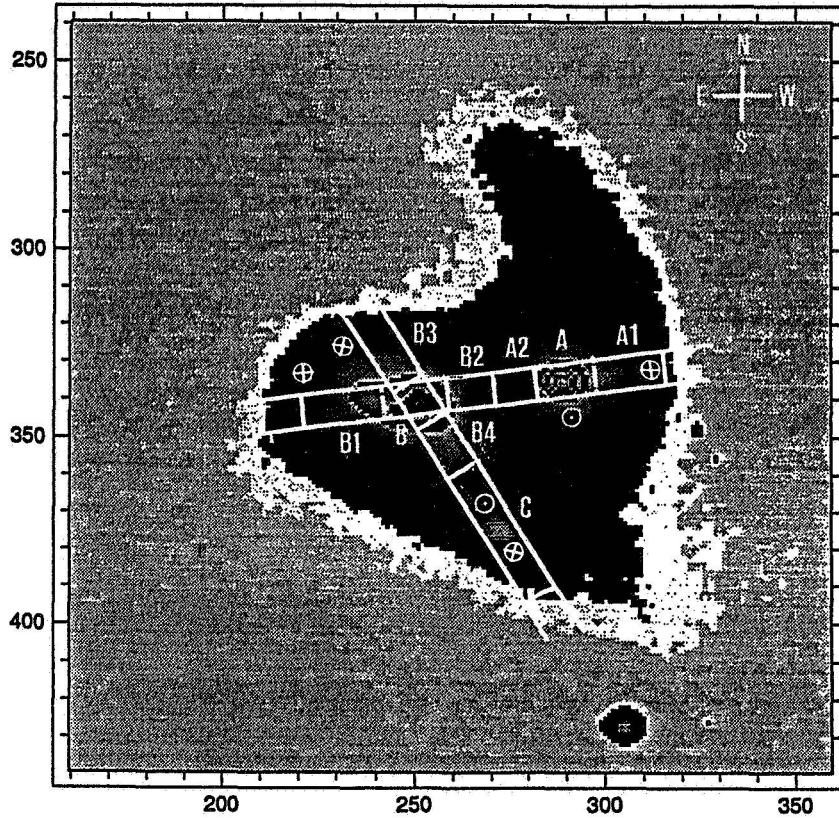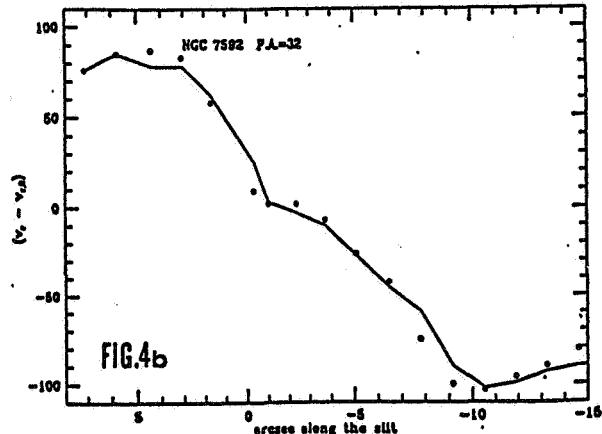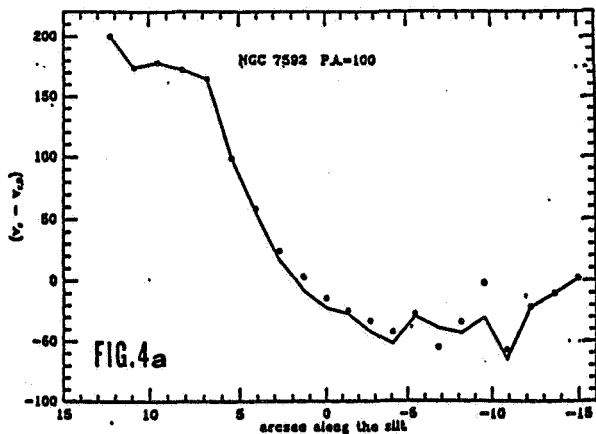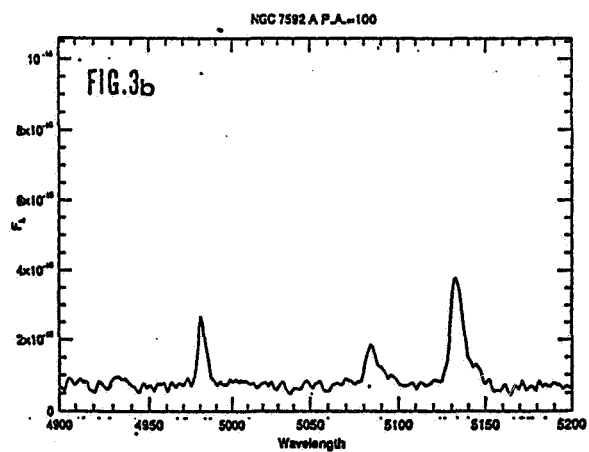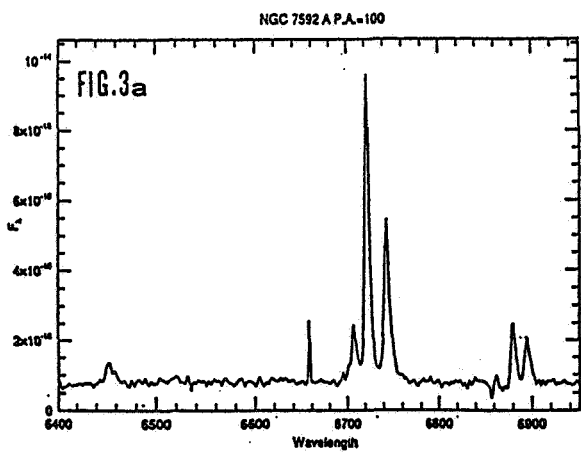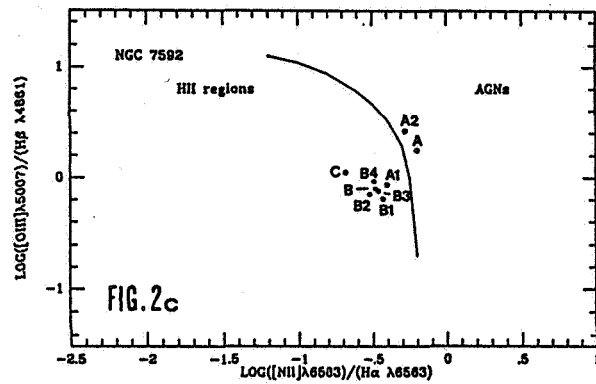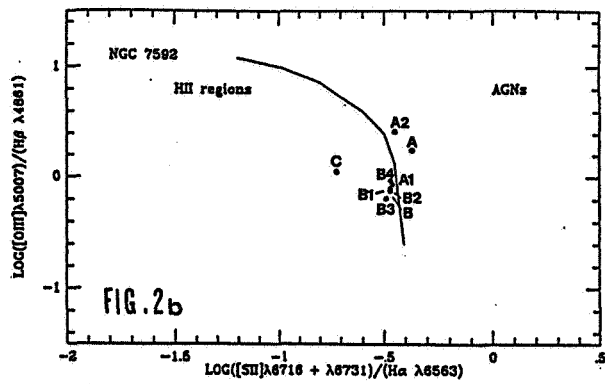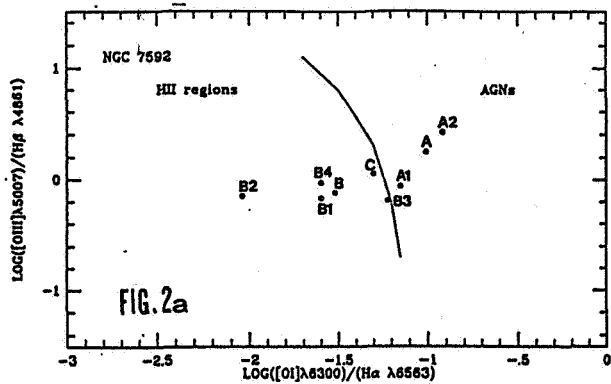
FIG. 1

(A1,A,A2,B2,B,B1) along $P.A. = 100°$ and 4 regions (C,B4,B,B3) along $P.A. = 212°$. The slit positions and the regions analyzed are marked in Figure 1.

The diagnostic diagrams proposed by Veilleux and Osterbrock (1987) were used to analyze whether the ionization of the line emitting gas is produced by a thermal (HII regions) or by a non-thermal continuum (AGN), Figures 2a,2b,2c. The Seyfert nucleus A of the NW component and A2, a region very close to A on its eastern side, are photoionized by a non-thermal source. All the other emitting regions are in the area typical of HII regions. This finding has been also tested using the diagnostic diagram based on the line ratios [OII]λ3727/[OIII]λ5007 and [OIII]λ5007/Hβ (Baldwin *et al.*, 1981), which further allows to distinguish between gas photoionized by thermal sources and shock-heated gas. We found that A and A2 are the only regions not located in the HII area.

The spectrum of the Seyfert nucleus A shows a faint broad component of Hα, already suspected by Archipova *et al.* (1981), whose $FWZI$ measured in the high resolution spectra is 3200 km/s (Figure 3a). An upper limit to its flux is $5 \times 10^{-14} erg\ cm^{-2}s^{-1}$, being $H\alpha_{BC}/H\alpha_{NC} \approx 0.7$. Since no broad component is present in Hβ, A can be classified as a Seyfert 1.9 nucleus. The FWZI of the [OIII]$\lambda\lambda$4959,5007 lines is $\sim 1500 km\ s^{-1}$, namely about twice the FWZI of Hβ, $\sim 800\ km\ s^{-1}$. This is due to the presence of a semi-broad component of the [OIII]$\lambda\lambda$4959,5007 lines displaced toward the red (Figure 3b). The semi-broad component indicates that there is a region whose density is larger than the density of the Narrow Line Region of A, $n_{e,A} \geq 2 \times 10^2 cm^{-3}$ (estimated employing the [SII]λ6731/λ6716 ratio, after correcting for the B-band absorption) and smaller than the density typical of the Broad Line Region $n_e > 10^9 cm^{-3}$. The active nucleus ionizes the interstellar gas between A and B (see also the results on the kinematics), and provides the main ionization source up to a distance of 5.1 $arcsec \approx 1.8\ h^{-1}kpc$ (region A2). It is noteworthy that outside of A and

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FIG.2a

NGC 7592

HII regions

AGNs

A2
A
C
B4 A1
B2 B B3
B1

LOG([OIII]λ5007)/(Hβ λ4861)

LOG([OI]λ6300)/(Hα λ6563)

FIG.2b

NGC 7592

HII regions

AGNs

A2
A
C
B4 A1
B1 B2
B3 B

LOG([OIII]λ5007)/(Hβ λ4861)

LOG([SII]λ6716 + λ6731)/(Hα λ6563)

FIG.2c

NGC 7592

HII regions

AGNs

A2
A
C B4 A1
B B3
B2 B1

LOG([OIII]λ5007)/(Hβ λ4861)

LOG([NII]λ6583)/(Hα λ6563)

NGC 7592 A P.A.=100

FIG.3a

F_λ

Wavelength

NGC 7592 A P.A.=100

FIG.3b

F_λ

Wavelength

FIG.4a

NGC 7592 P.A.=100

$(v_r - v_{cn})$

arcsec along the slit

FIG.4b

NGC 7592 P.A.=32

$(v_r - v_{cn})$

arcsec along the slit

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A2 the line emission is due to photoionization by a thermal continuum provided by O and B stars, and that the Hα luminosity of A, $L(H\alpha)_A \approx 4.8 \times 10^{40} \ h^{-1} erg \ s^{-1}$ is less than that of B and C, being $L(H\alpha)_B \approx 6.1 \times 10^{40} \ h^{-1} erg \ s^{-1}$ and $L(H\alpha)_C \approx 5.4 \times 10^{40} \ h^{-1} erg \ s^{-1}$. A comparison with the Hα luminosity function for starburst galactic nuclei published by Kennicutt et al. (1989) shows that the Hα luminosities of B and C are typical of this class of objects and that they are too high for disk HII regions. The Hα luminosities of the regions A1, B1, B2, B3, B4 range from $\approx 2 \times 10^{40} erg \ s^{-1}$ to $\approx 3 \times 10^{40} erg \ s^{-1}$ and are located on the high luminosity tail of the luminosity function of disk HII regions of Kennicutt et al.(1989).

2.2 Kinematics

The velocity curves at P.A. = 100° and at P.A. = 212° are shown in Figure 4a and 4b respectively. The heliocentric radial velocity $(V_{r,B} = 7320 \pm 10 \ km \ s^{-1})$ and the position of B have been taken as zero points of the coordinates. The velocity curve at P.A. = 212° is described by a straight line from ≈ -7 arcsec to $\approx +3$ arcsec. This region corresponds to the bar-like structure revealed by the R image. The velocity curve considerably flattens beyond both edges of the linear part, and a shallow decrease begins in corrispondence of C $(d" \sim 12 \ arcsec)$, which has an heliocentric radial velocity $V_{r,C} = 7230 \pm 10 \ km \ s^{-1}$. At P.A. = 100°, on the eastern side of B a steep velocity gradient is present up to ≈ 7 arcsec, and it is followed by a flatter part, which can be traced up to ≈ 12 arcsec. As a whole, the velocity curve resembles that of a normal spiral galaxy.

On the western side of B, the gas motions are peculiar. A contour plot of the spectral region around Hβ and Hα (Figures 5a and 5b) shows that the gas turns to higher radial velocities $(v_r$ increases from $\approx 7300 \ km \ s^{-1}$ to $\approx 7490 \ km \ s^{-1})$ up to the position of A. In correspondence of A the profiles of the lines Hα, Hβ and the [NII]λλ6548,6583 are double and show:

1. a strong *blue* component, at heliocentric radial velocity $v_{r,A} = 7280 \ km \ s^{-1}$, which is due to the Narrow Line Region of the Seyfert nucleus. $v_{r,A}$ has been assumed as the systemic velocity of the Seyfert nucleus;

2. a fainter *red* component, related to the extended emitting regions connecting B with A. Its peak velocity is $v_r \approx 7445 \ km \ s^{-1}$. This component may give a contribution up to $\approx 30 \ \%$ to the total Hα flux (the value given above may therefore be overestimated by the same fraction).

On the western side of A (A1) the velocity curve turns swiftly toward higher radial velocities.

3. Discussion

The problem of the nature of C is addressed at first. C shows an heliocentric radial velocity very similar to that of A and B. Moreover, the arm departing from C is most probably a tidal tail, because its extension is large and its orientation is peculiar. The high Hα luminosity of C is typical of a starburst nucleus. These facts argue in favour of C being the nucleus of a third galactic component (southern component S) physically interacting with the SE component of NGC 7592. The directions of the velocity vectors in various regions of NGC 7592 are marked in Figure 1. It is noteworthy that the SE component rotates clockwise, if the radial velocity difference Δv_r from its nucleus B is due to rotation. Under the same assumption for the $\Delta v_r = v_r - v_{r,A}$, the NW component seems to rotate counterclockwise. Thus, the gas in the regions where the two galactic bodies are in contact moves in the same way, suggesting that a prograde encounter is occurring. It is known (e.g. Toomre and Toomre, 1972) that prograde encounters have the most disruptive effects on the interacting galaxies, leading to the formation of tidal tails. The interpretation of the wing of the NW component in terms of a tidal tail thus appears very likely. Figure 1 shows that a similar situation holds for the interaction between SE and S too, where S rotates counterclockwise. The interpretation of the arm departing from C as a tidal tail is supported also in this case. The difference in radial

NGC 7592 P.A.=100

NGC 7592 P.A.=100

Hβ

Hα

FIG.5a

FIG.5b
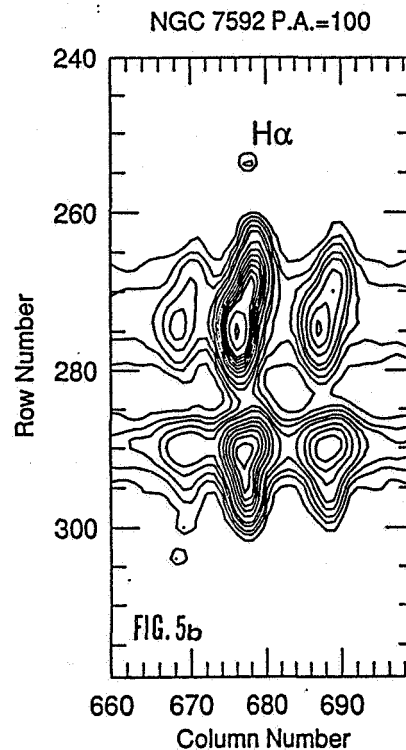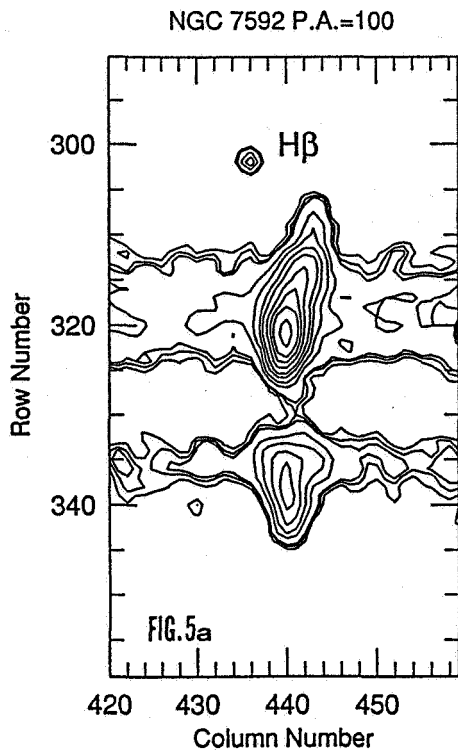
velocity between A and B ($\Delta v_r \approx -40$ km s^{-1}) and the morphology of NGC 7592 suggest that the NW component is beyond the SE one and is approaching it. The most heavily reddened regions ($E(B-V) \approx 0.7$, derived from the Hα/Hβ ratio) are B2 and B4, namely the regions between A and B. Moreover, the small difference in radial velocity between A,B,C suggests that the three galaxies form a bound system, and their kinematics hints that they are most probably in the early stage of a merging phenomenon. In addition, the emitting gas connected to the *red* component of Hα on A appears to regress from the observer. An appealing hypothesis would be to consider the line emitting gas as infalling toward A, perhaps ultimately accreting onto the central core of the active nucleus.

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