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NUCLEAR OUTFLOW FROM THE EDGE-ON GALAXY NGC 3628

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ABSTRACT

We present new evidence for collimated outflow from a starburst nucleus in the edge-on galaxy NGC 3628. A plume of X-ray emission along the minor axis of this galaxy is suggested by the distribution of counts in the softer energy channels of the *Einstein Observatory* IPC. Plumes of Hα emission are visible in a CCD image of the southern minor axis region, at a position angle consistent with that of the X-ray plume, while extended, possibly filamentary, Hα emission is visible in the north. Optical spectroscopy along the northern minor axis clearly detects line emission, with line ratios of Hα, [N II], and [S II] changing from those characteristic of normal H II regions near the nucleus, to a low-ionization state, consistent with shock heating, farther out. All this evidence, and the IR and radio continuum properties of this galaxy, make NGC 3628 another member of the growing class of galaxies with starburst nuclear activity and outflowing winds, to which NGC 253 and M82 already belong.

Subject headings: galaxies: individual (NGC 3628) — galaxies: internal motions — galaxies: nuclei — galaxies: X-rays

I. INTRODUCTION

NGC 3628 is an edge-on Sbc galaxy with a prominent dust lane (see Schmelz, Baan, and Haschick 1987*a* for a summary of galaxy parameters). It is an interacting member of the Leo Triplet and has a prominent nuclear radio continuum source similar to that of NGC 253 (Condon *et al.* 1982). Complex kinematics near the nuclear regions have been reported, as a result of high-resolution observations in the H I and OH lines (Schmelz, Baan, and Haschick 1987*a*, *b*). These data suggest the presence of a rotating circumnuclear disk and of a second structure, which was interpreted as either outflow, or an expanding spiral arm, or a second expanding elliptical disk. NGC 3628 was observed in X-rays with the *Einstein Observatory* IPC (see Giacconi *et al.* 1979 for a description of the satellite) by Bregman and Glassgold (1982), who were seeking evidence for X-ray emitting galactic coronae. Although they did not detect an extended halo, they reported the detection of two X-ray sources in this galaxy, one of which is positionally coincident with the nucleus.

Here we present new X-ray and optical evidence that establishes the presence of a nuclear outflow in NGC 3628, prompted by a reanalysis of the X-ray data in different energy bands. This suggested the presence of a soft plume elongated along the minor axis, as previously observed in the starburst galaxies NGC 253 and M82 (Fabbiano and Trinchieri 1984; Watson, Stanger, and Griffiths 1984; Fabbiano 1988*a*) and led us to obtain images in the Hα and [N II] lines and optical spectra. These results are described and discussed in this paper.

II. X-RAY DATA ANALYSIS

A reanalysis of the Rev-1B reprocessed (Harnden *et al.* 1984) IPC data of NGC 3628 revealed differences in the appearance of the nuclear source in the standard soft (0.2–0.8 keV) and hard (0.8–3.5 keV) bands. While in the hard image a pointlike source was clearly present, possibly embedded in more diffuse emission perpendicular to the galaxy plane, the soft image only showed a fairly weak source, elongated perpendicular to the plane of this edge-on galaxy. This feature is reminiscent of the plumes/halos of X-ray emission detected in the starburst nuclei on NGC 253 and M82 (Fabbiano and Trinchieri 1984; Watson, Stanger and Griffiths 1984; Fabbiano 1988*a*) and prompted a more careful reanalysis of the data to ascertain its reality. Looking at the different IPC energy channels, we found that virtually no extended emission is present in the 1.7–4.5 keV, "hard" band (PI bins 8–11), while the nuclear source looks definitely elongated in the 0.2–1.4 keV, "soft" band (PI bins 2–6). The isointensity contour maps from the IPC data in these two energy bands are shown in Figure 1, overlayed on a reproduction of the POSS E plate.

In Figure 2 we show the radial profiles for the "hard" source (which is azimuthally symmetric), and the two radial profiles for the "soft" source, derived from the parts of the image between position angles 150°–240° and 330°–60° (the minor axis direction), and those between the complementary position angles (the major axis direction). The data were binned into 30″ wide radial bins centered on the centroid of the "hard" source (R.A. = $11^h17^m40^s.2$; decl. = +13°51′42″). The field background was estimated locally from a source-free region between 420″ and 600″ for the "hard" source, and from between 390″ and 600″ for the "soft" source, and then subtracted. In the major axis "soft" profile, the X-ray surface brightness reaches the background level at ~200″, but then the profile rises again because of the two emission regions visible on either side of the nucleus in Figure 1. We do not show this outer profile in Figure 2, since here we are only interested in the nuclear source.

To compare these radial profiles with the expected radial distribution from a point source, we fitted them with Gaussian functions of variable σ_G. We find that the "hard" source is well fitted by a Gaussian of $\sigma_G = 35''$, which is a good representation of the IPC point response function for this energy range and spectral channels (see Mauche and Gorenstein 1986). The best-fit Gaussian to the major axis profile of the "soft" source is consistent with the IPC point response function, but the minor axis profile appears more extended. For this profile we

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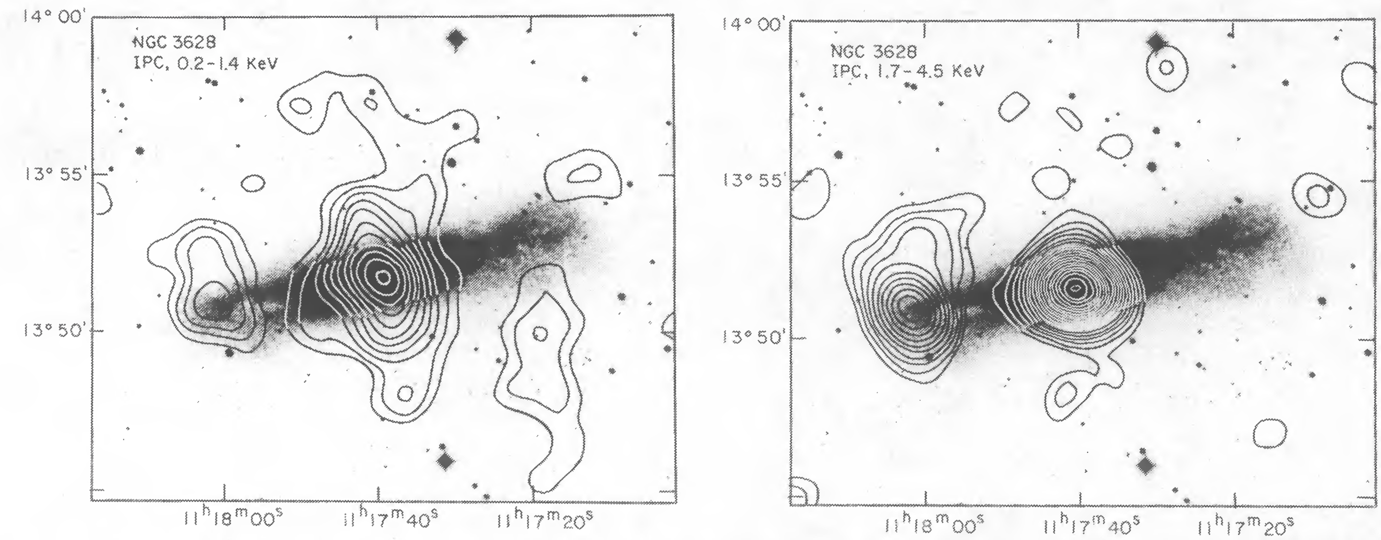

FIG. 1.—The "soft" and "hard" X-ray contour maps of NGC 3628 (see text), overlaid on a reproduction of the POSS E plate. The X-ray data were averaged over 16″ × 16″ regions and smoothed with a Gaussian with $\sigma_G = 35''$. The first contour shown is in both cases at a significance level of 2 σ over the field background. Subsequent contours follow at 1 σ increments over the previous ones. In this paper we discuss only the central X-ray source.

obtain a best-fit $\sigma_G = 90''$, with a 99% confidence lower limit of 70″, while the expected IPC point response function has σ_G in the 50″–65″ range. However, neither of these "soft" profiles is well fitted by Gaussians. In the "soft" image, within 240″ from the nucleus, there is an excess of 61 ± 21 source counts in the minor axis sectors relative to the major axis ones. This excess is significant at the 2.9 σ level. There is also emission between 240″ and 360″ in the minor axis sectors that appears connected with the central source (see Fig. 1). Adding this region to the minor axis sectors, after field background subtraction, the excess counts would be 94 ± 25.

Although the appearance of the "soft" source is not that of a point source at the nucleus, this source is elongated in one of the IPC cross-wire directions, and its position is near a "hot wire," which could cause a spurious enhancement of the surface brightness. This effect would be more pronounced at the soft energies. However, the ridge of the surface brightness distribution is displayed by 2–3 instrument pixels from the "hot wire," and some of the features (e.g., the extension at the NW) are definitely unconnected with this wire. This indicates that the elongation of the "soft" source cannot be totally attributed to an instrumental feature. Nonetheless, a definitive study of this feature will require future X-ray observations.

We have attempted a spectral fit of the photons within a 3′ circle centered on the centroid of the nuclear source, by using both a power law with a low-energy cutoff model and a thermal bremsstrahlung (exponential plus gaunt) with a low-energy cutoff model. These counts are dominated by the point-like "hard" source, although a contribution from the extended component at the low energies cannot be excluded. Even so, both fits require absorption columns in excess of the galactic line of sight N_H, consistent with an absorbed nuclear source (Fig. 3). Neither fit can discriminate between different power laws or effective temperatures for the pointlike nuclear source.

The net detected counts in the "soft" source within 360″ are 246 ± 27. With an exposure time of 12,680 s, and assuming a line of sight $N_H = 2 \times 10^{20}$ cm^{-2} (Stark *et al.* 1984) and a thermal bremsstrahlung emission spectrum with $kT = 1 - 0.1$ keV, this corresponds to a 0.15–1.5 keV emitted flux of ~5.2–12 × 10^{-13} ergs cm^{-2} s^{-1} and to a luminosity of ~1.3–

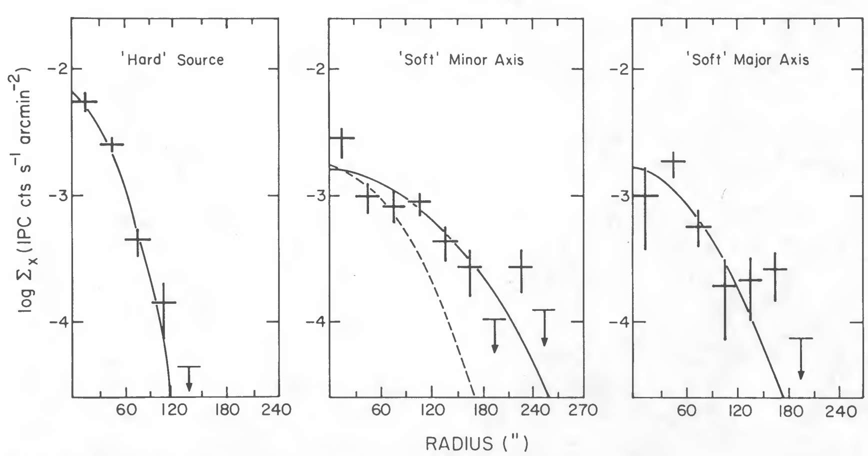

FIG. 2.—Radial profiles of the X-ray surface brightness of the nuclear source. The solid curves represent Gaussians with the best-fit σ_G (see text). The dashed curve in the "soft" minor axis plot is the best-fit Gaussian of the "soft" major axis profile.

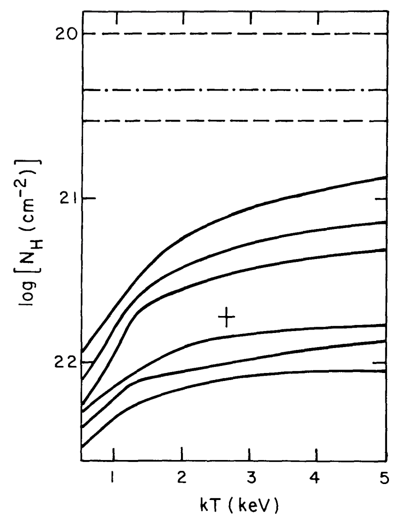

FIG. 3.—99%, 90%, and 68% confidence contours for a two-parameter spectral fit of the nuclear source to an absorbed exponential plus gaunt spectrum. Spectral channels 2–10 were used for the fit. A minimum $\chi^2 = 3.5$ was obtained with five degrees of freedom, for $kT = 2.7$ keV and $N_H = 5.9 \times 10^{21}$ cm^{-2} (*the cross*). The dash-dotted line represents the galactic line of sight N_H, and the dashed lines are the 90% bounds on this N_H (using Elvis *et al.* 1986).

3×10^{40} ergs s^{-1}, for a distance of 14.4 Mpc to NGC 3628. The net counts of the "hard" nuclear source within 3′ from the centroid are 153 ± 14. The corresponding emitted (0.2–4.0 keV) flux and luminosity for a thermal bremsstrahlung emission with $kT \sim 5$ keV are $\sim 4.8 \times 10^{-13}$ ergs cm^{-2} s^{-1} and $\sim 1.2 \times 10^{40}$ ergs s^{-1}, respectively. However, the intrinsic luminosity could be larger, because of intrinsic absorption. If one adopts $N_H = 6 \times 10^{21}$ cm^{-2}, as suggested by the spectral fit of the nuclear source (see above), the intrinsic flux and luminosities of the pointlike nuclear component would be 1.1×10^{-12} ergs cm^{-2} s^{-1} and 2.7×10^{40} ergs s^{-1}.

III. OPTICAL CCD OBSERVATIONS AND ANALYSIS

One of us (T.H.) has taken direct images of NGC 3628 with the prime focus CCD (TI2 chip) on the 4 m telescope at the Kitt Peak National Observatory (KPNO) on 1988 May 15. The TI2 was used in a 800 × 800 pixel mode (no on-chip pixel summation), with a pixel size of 0″.30 and a 4′.0 field of view. Two image pairs were taken, the first pair centered 15″ NW of the nucleus and the second 85″ SSW of the nucleus. Each pair consisted of a narrow-band image taken through a ~ 70 Å FWHM filter centered on redshifted Hα + [N II] $\lambda\lambda$6548, 6584 and a broad-band image taken with the "nearly Mould" *R* filter. The integration times were 1576 and 256 s at the north position for the narrow-band and broad-band images, respectively. The corresponding exposure times were 768 and 256 s at the south position.

A bias frame was subtracted from each image, and the bias-subtracted image was then divided by a normalized image of a dome-screen illuminated by a quartz lamp. The flat-fielded images were then sky-subtracted, and the broad- and narrow-band images were scaled by the ratios of the products of exposure times and filter throughputs. After careful alignment, the broad-band images were subtracted from the narrow-band images yielding continuum free images in the light of the Hα + [N II] lines. The broad-band images were scaled so that stars (pure continuum sources) disappeared in the subtracted frame. This is equivalent to a deconvolution of the filter with the spectral energy distribution of the stars. The resulting images were flux calibrated using observations of KPNO IIDS standard stars obtained through the narrow-band filters at the beginning and end of the night.

The Hα + [N II] images reveal several morphological components in the ionized gas (Figs. 4*a* and 4*b* [Pl. 8–9]). There is weak (1.3×10^{-13} ergs cm^{-2} s^{-1}) emission in and around the nucleus ($r < 750$ pc, for an assumed distance of 14.4 Mpc). The brightest emission in NGC 3628 comes from a complex of knots, presumably giant H II regions. This complex lies along the major axis of the galaxy, is about 30″ × 120″ (2.1 × 8.4 kpc) in size, and is centered about 15″ south of the continuum peak in the galaxy. In addition to this bright complex, there is also faint diffuse emission from the disk of the galaxy (size $\sim 4' \times 1'$). The total Hα + [N II] flux from the disk, including the nucleus and the complex of bright knots, is about 1.9×10^{-12} ergs cm^{-2} s^{-1} ($L = 4.7 \times 10^{40}$ ergs s^{-1}).

The most interesting morphological features are those located well outside the plane of the galaxy in the region of the extended "soft" X-ray nuclear source. The most prominent such feature is a plume extending about 130″ (9 kpc) to the SW in position angle $\sim 210°$. The plume is not perfectly radial in orientation, and it meets the disk, in projection, about 20″ (1.4 kpc) west of the nucleus. The surface brightness of this feature is typically 3×10^{-17} ergs cm^{-2} s^{-1} arcsec^{-2}, and its total flux is about 5.6×10^{-14} ergs cm^{-2} s^{-1} ($L = 1.4 \times 10^{39}$ ergs s^{-1}). A second fainter plume may be present $\sim 1'$ to the east and roughly parallel to the first plume, but a deeper image is needed to verify this. The emission along the minor axis to the north (Fig. 4*b*) is less spectacular: faint emission with a surface brightness of $\sim 3 \times 10^{-17}$ ergs cm^{-2} s^{-1} arcsec^{-2} extends out to a radius of about 1′. Some substructure ("filaments") may be present in this region, but the present data are too noisy to be certain.

CCD images were also obtained by WCK at the KPNO 2.1 m using the same chip as the 4 m observations, covering the northern part of the bulge (a square of 159″ side) in the *R* band and with a 70 Å wide filter centered at 6563 Å. Exposures were 10 and 20 minutes, respectively. These observations were done on 1988 June 15–16. The data frames were shifted to register star images and iteratively scaled for subtraction to yield a pure emission-line frame. This image shows the complexes of H II region near the nucleus and diffuse "fans" of emission extending northward of the galaxy plane, rather than the higher contrast plume seen to the south. This is the material sampled spectroscopically. The two sets of images agree as to what is there north of the plane.

IV. SPECTROSCOPY

A spectrum along the minor axis of NGC 3628, at position angle 15°, through the prominent H II region amid the dust lane, was obtained by WCK with the Cryogenic Camera at the KPNO 4 m on 1988 June 9–10. A total of 30 m exposure was obtained, using a 2″.5 slit at a spectral resolution of 13 Å FWHM. Feige 34 was observed as a flux standard.

The line-by-line measurements of the spectrum are shown in Figure 5, where the errors in each location can be estimated from the line-to-line scatter (the spatial resolution is about 2″.5, so adjacent points do not sample fully independent regions). The continuum intensity along the slit is shown as a guide to the relative positions of changes in spectrum characteristics and to their location on direct images. All Hα intensity measures have been corrected for underlying absorption using the

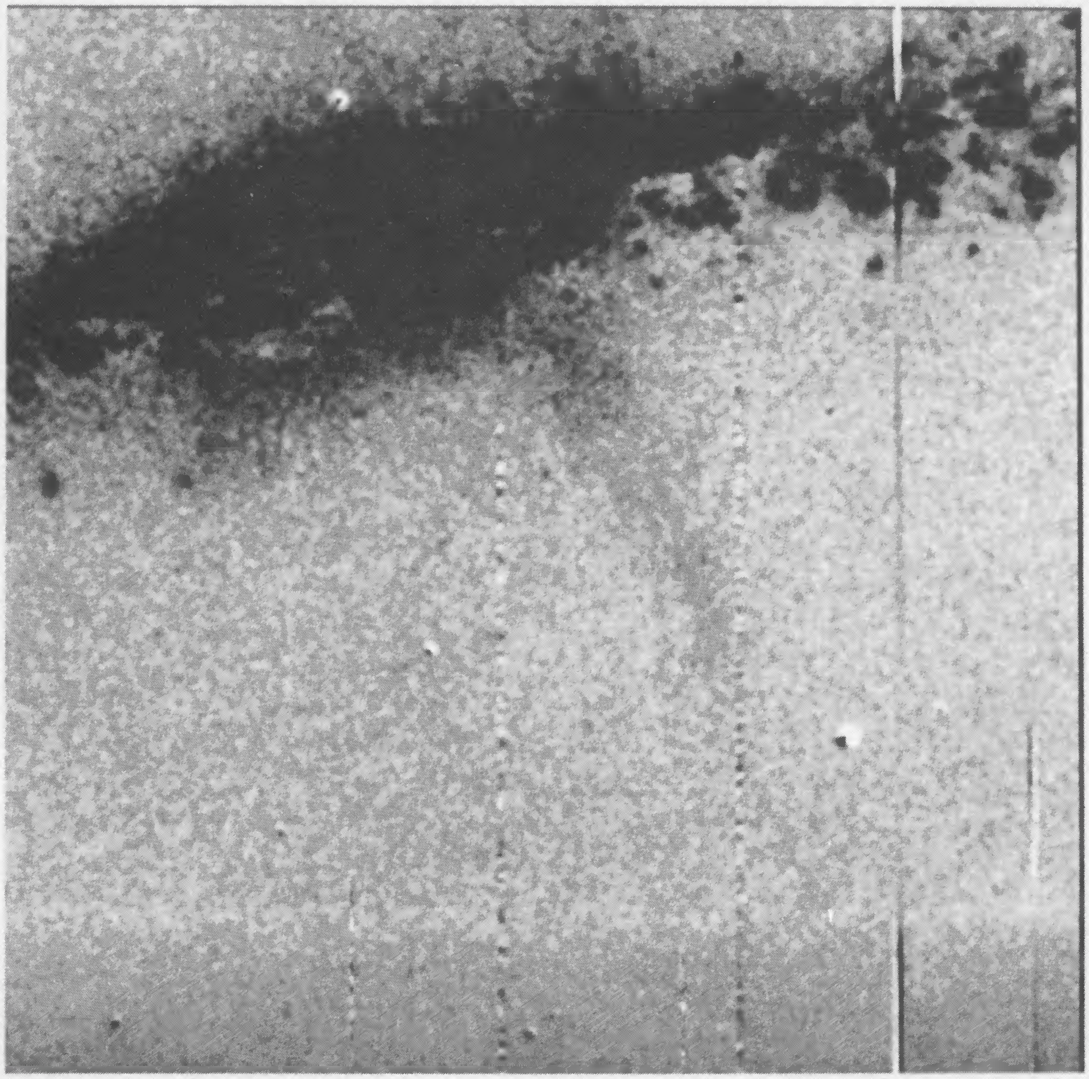

FIG. 4a

FIG. 4.—(*a*) CCD image of NGC 3628, showing the central H II regions and the southern Hα plume. (*b*) CCD frame showing the northern filaments. Both frames are 796 × 796 pixels, with a pixel ∼0″.3.

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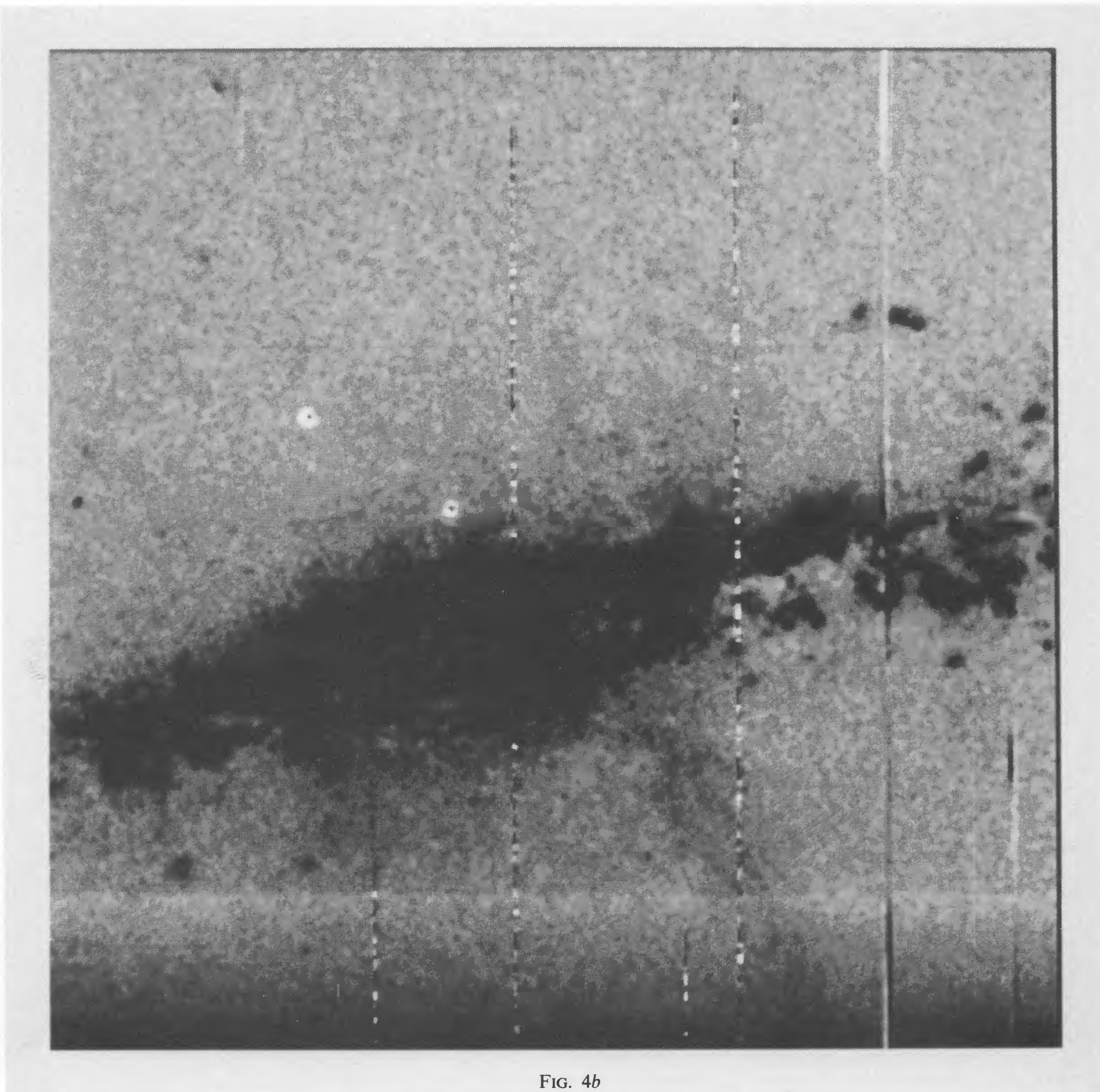

FIG. 4*b*

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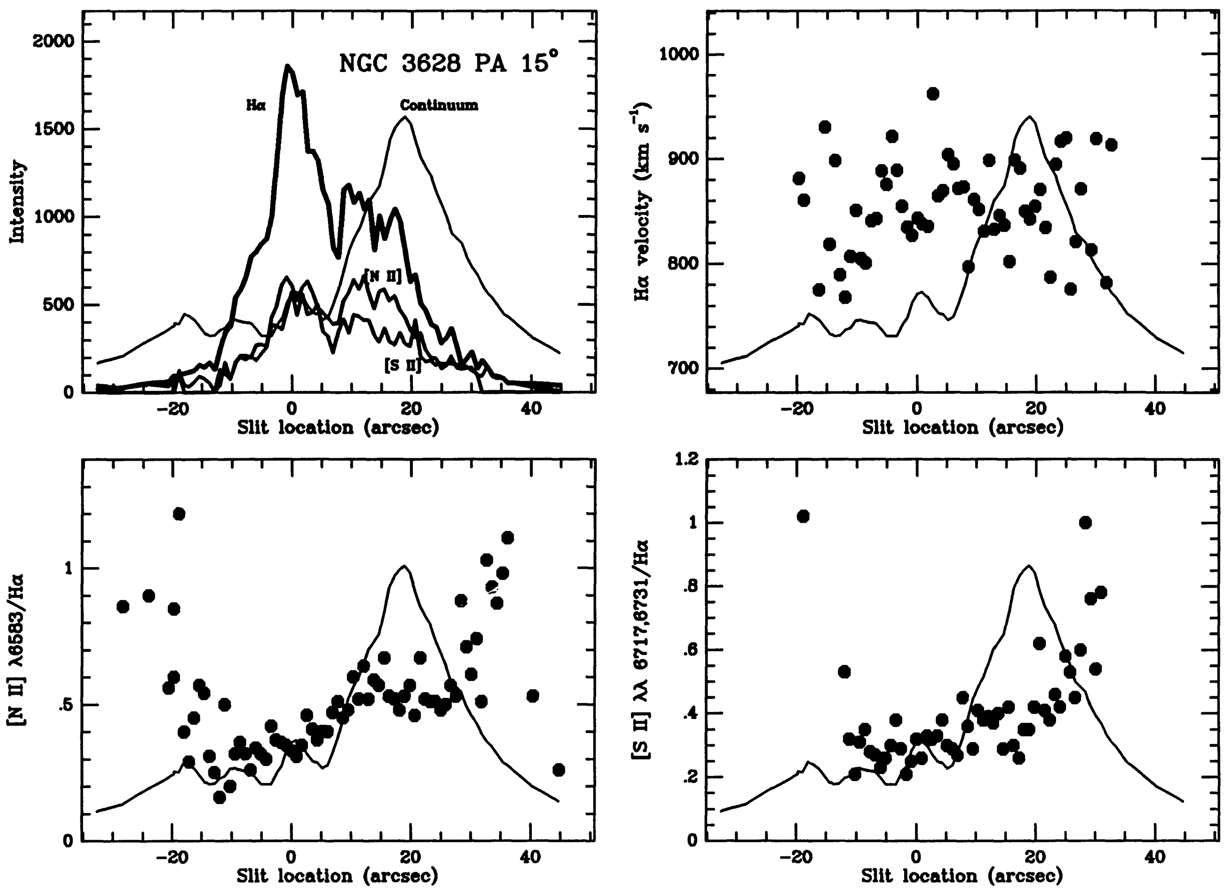

FIG. 5.—Emission-line properties of NGC 3628 along the minor axis (position angle 15°). Positive values of slit location are to the north, with zero set at the prominent H II region centered in the dust lane. (*Upper left*) Intensity profiles along the slit in Hα, [N II] λ6583, [S II] λλ6717, 6731, and the continuum at Hα. Where necessary, lines have been deblended using a Gaussian representation of the instrumental response. Units for the emission lines are 10^{-18} ergs cm^{-2} s^{-1} arcsec^{-2} for the lines and 10^{-19} ergs cm^{-2} s^{-1} Å^{-1} arcsec^{-2} for the continuum, so the continuum and emission-line indicators cross at an equivalent width of 10 Å. The continuum distribution is repeated on the other panels for orientation. (*Upper right*) Radial velocity centroid of Hα. Since the error of an individual measurement is of the order 50 km s^{-1}, no gradients at this level were detected. (*Lower left*) Distribution of [N II] λ6583/Hα along the slit. The ratio climbs from low values, characteristic of normal H II regions as seen along the dust lane, to higher values indicating other modes of ionization where light from the bulge becomes visible around the dust lane on both sides. (*Lower right*) Similar behavior as seen in the [S II] λλ6717, 6731/Hα ratio.

1.8 Å equivalent width appropriate for an old bulge population; the errors introduced from this should be smaller than measurement limits throughout, unless there is an unusually young extended bulge population in NGC 3628. No gradients in emission-line radial velocity are seen at the 50 km s^{-1} level (see Fig. 5), in accordance with motions predominantly in the plane of the sky for an edge-on system.

Within the central-most 40″ (2.8 kpc), the [N II] and [S II] lines are only 20%–50% as strong as Hα (see Figs. 5 and 6). These line ratios are commonly seen in moderately metal-rich, normal giant H II regions in the disks of spiral galaxies (see McCall, Rybski, and Shields 1985; Kennicutt, Keel, and Blaha 1989). Thus this gas is apparently photoionized by young stars, possibly related to the central starburst. At larger radii, both to the north and to the south, the [N II] and [S II] lines strengthen markedly relative to Hα. Such line ratios ([N II] and [S II] = 50%–100% of Hα) are typical of gas that is shock-heated (see Table 1 and Baldwin, Phillips, and Terlevich 1981). Thus the optical spectra are at least consistent with the wind model (e.g., Chevalier and Clegg 1985), which predicts that the gas visible optically is shock-heated by the ram pressure of the wind. Strong [O I] λ6300 emission would also be expected from such material, but at the small redshift of NGC 3628 it falls on the wings of night-sky emission from the same transition; no [O I] was detected in our spectrum, but the limits are seldom of help. For example, in the northern bulge area 15″–25″ from the center position, λ6300 has no more than 25% the intensity of Hα. The emission south of the nucleus is much

TABLE 1

OPTICAL EMISSION-LINE RATIOS

Source of Emission	[N II]/Hα	[S II]/Hα
NGC 3628 center[a]	0.4 ± 0.1	0.3 ± 0.1
NGC 3628 center[b]	0.8 ± 0.2	0.7 ± 0.3
H II Regions[c]	0.02–0.4	0.02–0.3
Shocked Gas[d]	0.4–2	0.4–2

[a] Typical values for the region from 10″ S to 20″ N of the peak in the Hα surface brightness (see Fig. 4).

[b] Typical values for regions greater than 10″ S or greater than 20″ N of the peak in the Hα surface brightness.

[c] Values of line ratios for normal giant H II regions in the disks of galaxies (Kennicutt, Keel, and Blaha 1989).

[d] Values for gas in old supernova remnants and Herbig-Haro objects (gas believed to be heated by shock waves). See Heckman, Armus, and Miley 1989.

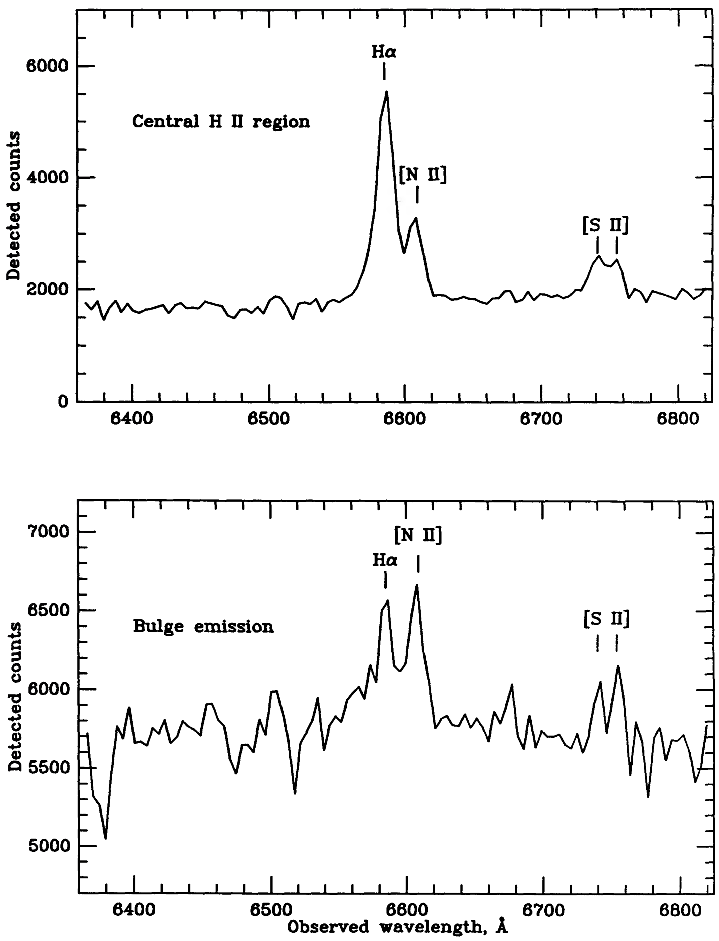

FIG. 6.—Spectra of NGC 3628 showing the H II region projected near the center of the dust lane (*upper*), and light from the bulge 20″–30″ north of this (*lower*), showing both [N II] and [S II] lines relatively strong relative to Hα. The features at 6363 and 6680 Å are night-sky residuals; the large angular size of NGC 3628 rendered very accurate sky subtraction difficult.

weaker than that to the north at this position angle, since the existence of the southern plume of emission was not known to WCK at the time this spectrum was taken, and he did not orient the slit to coincide with brightest emission-line regions.

The signal-to-noise ratio in the density-sensitive [S II] doublet is too low outside the prominent H II regions to tell whether a density dropoff similar to that seen in M82 (McCarthy, Heckman, and van Breugel 1987) is indicated here.

V. DISCUSSION

The data presented in this paper, together with the far-infrared (Rice *et al.* 1988) and radio (continuum and line; Condon *et al.* 1982; Schmelz, Baan, and Haschick 1987*a*, *b*) properties of NGC 3628, make this galaxy a very strong candidate for a nuclear starburst galaxy with wind outflow. The nucleus is prominent both in the far-infrared and in the radio continuum, as is typical of starburst regions, and the "hard" X-ray image shows an unresolved luminous source. The luminosity of this source ($\sim 3 \times 10^{40}$ ergs s^{-1}) is well above that expected from a single accretion binary and is comparable to that observed in other starburst nuclei (see Fabbiano 1989, and references therein). Similar luminosities have also been detected from low-activity nonthermal nuclei (e.g., M81, Elvis and Van Speybroeck 1982; Fabbiano 1988*b*, 1989), which are typically unresolved in high-resolution HRI *Einstein* images. The lack of a comparable high-resolution X-ray image in this case cannot be used to rule out this possibility. An optical spectrum of the nucleus cannot be obtained because of the dust lane. However, given the general properties of this region, it is reasonable to assume that we are in the presence of a starburst nuclear source. Moreover, the far-infrared and radio continuum emission (see Table 2) are in the range of those observed in other starburst galaxies. They are also consistent with the correlation found between these two quantities in the sample of galaxies observed with *IRAS* (e.g., Helou, Soifer, and Rowan-Robinson 1985). If the X-ray nuclear region is of size similar to that of the radio continuum core ($\sim 10''$; Condon *et al.* 1982), it would appear unresolved in the IPC.

The origin of the X-ray emission of a starburst nucleus has been discussed in many papers (see Fabbiano 1989, and refer-

TABLE 2

THREE STARBURST GALAXIES WITH NUCLEAR OUTFLOWS

Galaxy	B_0^{Ta} (mag)	D (Mpc)	$L_{H\alpha+[H II]}$(wind) (ergs s^{-1})	$L_{IR}^{(Tot)}$ ($L_\odot$)	L_x(wind) (ergs s^{-1})	L_x(nucleus) (ergs s^{-1})	$P_{21\,cm}$[b] (ergs s^{-1} Hz^{-1})
NGC 253	7.40	3.40	3×10^{39}[c,d]; 7×10^{40}[d,e]	2.5×10^{10}[f]	$(0.6–1) \times 10^{39}$[g] $\sim 2 \times 10^{39}$[h]	3×10^{39}[i]	3.3×10^{28}
M82	8.72	3.25	4×10^{40}[j]	3.9×10^{10}[f]	2×10^{40}[k]; 2.8×10^{39}[l]	7.4×10^{39}[m]	6.6×10^{28}
NGC 3628	9.47	14.4	$\sim 2 \times 10^{39}$[c]	3.7×10^{10}[f]	$(1.3–3) \times 10^{40}$	$\sim 3 \times 10^{40}$	4.8×10^{28}

[a] de Vaucouleurs, de Vaucouleurs, and Corwin 1976.
[b] From flux densities in Condon *et al.* 1982.
[c] No extinction correction.
[d] McCarthy, Heckman and van Breugel (1987).
[e] Correcting with nuclear extinction.
[f] Total infrared luminosity from Rice *et al.* 1988, adjusted to our adopted distances.
[g] From the high-resolution HRI data; the range of values reflects different emission temperatures, ranging from 0.6 keV to a few keV (Fabbiano and Trinchieri 1984).
[h] From the IPC data, at larger radii (Fabbiano 1988*a*).
[i] Fabbiano and Trinchieri 1984.
[j] Extinction-corrected luminosity of gas at $r \geq 300$ pc from the nucleus (Heckman, Armus, and Miley 1989).
[k] From the HRI data, within 30″ to 300″ from the nucleus (Watson, Stanger and Griffiths 1984).
[l] From the IPC data, within 210″ to 540″ from the nucleus (Fabbiano 1988*a*).
[m] Watson, Stanger, and Griffiths 1984.

ences therein). In particular, the integrated contributions of the thermal emission of supernova remnants and the emissions of massive young binary X-ray sources together with the coronal emission of very massive young stars are all possible candidates. Inverse Compton emission due to the interaction of the electrons giving rise to the radio synchrotron emission with the infrared photon field could contribute substantially to the X-ray emission of the nuclear region (e.g., Rieke *et al.* 1980). The data do not allow us at present to discriminate between these possibilities. An explanation of the X-ray emission as an extension of the radio synchrotron emission is instead unlikely (see Fabbiano, Feigelson, and Zamorani 1982).

The evidence for nuclear outflow in NGC 3628 presented here consists of an X-ray plume, Hα plumes and filaments, and optical line ratios indicative of shocks. Of these, the most uncertain at present is the X-ray evidence, since instrumental effects in the IPC could partially affect our results. Future X-ray observations will be needed for confirming the reality of the X-ray plume and for studying in detail its spatial and spectral characteristics. However, we used this X-ray evidence for predicting the presence of Hα filaments (in analogy with NGC 253 and M82), which were then detected. The most prominent filament in the south follows the outside of the X-ray "plume," reminiscent of what was observed in NGC 253 (McCarthy, Heckman, and van Breugel 1987). The most direct evidence from the spectral data that we are seeing an outflow is the high [N II]/Hα and [S II]/Hα ratios far from the core, as found in M82 (McCarthy, Heckman, and van Breugel 1987). Observations in the OH and H I lines give information on the region that is obscured optically (Baan, Haschick, and Henkel 1989, and references therein). These results are consistent with the presence of a nuclear outflow in NGC 3628. The two other already established members of the class of galaxies with starburst nuclei and nuclear outflows are NGC 253 and M82; a summary of the properties of these two galaxies and those of NGC 3628 is given in Table 2. NGC 253, M82, and NGC 3628 all have similar infrared and radio core luminosities. They also have Hα and wind X-ray emission in the 10^{39}–10^{40} ergs s^{-1} range, if the soft X-ray emission of NGC 3628 can all be attributed to a wind component.

Assuming that all of the "soft" X-ray source is due to an outflow component, and that this gas occupies a conical volume on the two sides of the minor axis, with 4′ height and 2′ maximum radius, one can derive the following gas parameters: particle density $n_e = 1.9 \times 10^{-3}\ \eta^{-1/2}$ cm^{-3}, gas mass $m_{gas} = 1.3 \times 10^8\ \eta^{1/2}\ M_\odot$, and cooling time $\tau_c = 1.9 \times 10^9\ \eta^{1/2}$ yr, where η is the volume filling factor. If the nuclear starburst has been active for 10^8 yr (as calculated for the starbursts in M82 and NGC 253 by Rieke *et al.* 1980), the mass-loss rate could be as high as 1 $M_\odot$ yr^{-1}. This estimated mass flow rate agrees well with the predictions of the supernova-driven model developed by Chevalier and Clegg (1985) for starburst galaxies. The above estimates, however, are extremely uncertain, because of the compounded uncertainties on the distance, the emission volume and filling factor, and the X-ray flux of such a component. For these reasons, our estimate of the X-ray emitting gas mass and of the mass outflow rate can at best be used to set upper limits to the real value.

VI. CONCLUSIONS

In conclusion, we believe that there is strong indication that NGC 3628 belongs to the class of starburst galaxies with nuclear outflow, of which M82 and NGC 253 are the prototypes. However, further studies both at the optical and mostly at the X-ray wavelengths will be needed to constrain the characteristics of this outflow. New X-ray observations will be soon possible with the German satellite *ROSAT*, and they will be essential for confirming the presence of the soft plume of X-ray emission suggested by the *Einstein* image. Future spectral X-ray measurements will also be needed to establish if the outflow X-ray emission is due to the very hot wind escaping the nuclear region, or to the interaction of this wind with circumnuclear clouds (Heckman, Armus, and Miley 1989). Finally, infrared spectroscopy of the nucleus in the Brγ region will be needed to explore further the similarity with M82 and NGC 253.

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