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# DISCOVERY OF NEBULOSITY ASSOCIATED WITH THE QUASAR 3C 273

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## ABSTRACT

The image (excluding the jet) of 3C 273 has been resolved with structure extending ~15″ from the quasar to a surface brightness level, $\mu_R \approx 25$ mag arcsec$^{-2}$. The integrated magnitude of the underlying nebulosity, $R \approx 16$, corresponds to $M_R \approx -25$, and the isophotal angular diameter to $D \approx 90$ kpc.

Two narrow emission lines (FWHM $\lesssim$ 15 Å) observed in the nebulosity ~5″ to the north of the quasar at the redshifted positions of [O II] 3727 Å and [Ne III] 3869 Å establish a physical association of the resolved nebulosity with 3C 273. Evidence for the [O III] 5007 Å emission line in the nebulosity is also presented. Comparison of photometric and spectroscopic data indicate that the dominant emission in the nebulosity to the north of the quasar is continuum radiation. A plausible source of the continuous radiation is integrated starlight from an underlying galaxy associated with 3C 273.

*Subject headings:* galaxies: individual — quasars

## I. INTRODUCTION

Some quasars are observed to have diffuse images resembling very distant galaxies (cf. Gunn 1971; Kristian 1973). Notable among resolved quasars are 3C 48 and 4C 37.43 (both with $z \approx 0.37$) for which spectroscopic observations establish beyond doubt a physical association of the quasar with faint, extended emission regions (Wampler *et al.* 1975; Stockton 1976). Several additional quasars have been resolved and shown to have underlying physically associated galaxies (cf. Stockton, Wyckoff, and Wehinger 1979; Morton, Williams, and Green 1978; Green, Williams, and Morton 1978; Wyckoff *et al.* 1980).

The brightest known ($V = 12.8$ mag) and one of the lowest-redshift ($z = 0.158$, Schmidt 1963) quasars, 3C 273, has a prominent optical jet, but the quasar image itself has never been resolved. In this *Letter* we report the discovery of diffuse nebulosity physically associated with 3C 273.

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## II. OBSERVATIONS

A photograph (IIIa-F emulsion +OG570 filter) of 3C 273 obtained at the prime focus (scale 19″ mm$^{-1}$) of the ESO 3.6 m telescope was reduced to a logarithmic intensity map (Fig. 1) after subtracting a surface average of the plate background from a rastered area (~400 arcsec$^2$) centered on the quasar. (Further reduction details are given in Wehinger, Gehren, and Wyckoff 1980). In addition to the jet southwest of the quasar, Figure 1 shows a diffuse asymmetrical extension in the outer isophotes to the northeast of the quasar. This asymmetry is not seen in isophotes of stars of the same magnitude on the same plate. The nebulosities detected around 3C 48 and 4C 37.43 are also asymmetrical with respect to the quasar (Wampler *et al.* 1975; Stockton 1976).

After digital removal of the jet from the isophotal map of 3C 273, image profiles were produced of the quasar and of two comparison stars of approximately the same magnitude lying within a projected angular distance of ~1′ of the quasar. The image profiles displayed in Figure 2 represent circular averages of surface brightness calculated as a function of radial distance from the quasar (and stellar) image centers.

The point spread function (PSF) is defined by the average profile of the two field stars. The broader profile for 3C 273 compared to the PSF indicates that the quasar image is resolved with a radial size scale ~15″ at a surface brightness level, $\mu_R \approx 25$ mag arcsec$^{-2}$. The *difference profile* (in the sense 3C 273-PSF) in Figure 2 represents the average radial surface-brightness distribution of the underlying, resolved structure.

The Image Photon Counting System (IPCS) has been used with the 3.9 m Anglo-Australian and the 3.6 m European Southern Observatory telescopes to obtain spectra of the extended structure to the north of 3C 273. Relevant observational data are summarized in Table 1 and (the ESO) slit aperture illustrated in Figure 1. The AAT IPCS circular apertures (not shown in Fig. 1) had inside edges separated by 20″ (east-west) and sampled the nebulosity 5″.0 and 7″.5 northeast of the quasar with a chopping time between sky and object of ~20 minutes. Equal sky and nebulosity integration times were obtained for both the ESO and AAT IPCS spectra. The ESO IPCS spectra were reduced using the Tololo-Vienna Interactive Image Processing System (Albrecht 1979) and the Harris-Datacraft computer of the Cerro Tololo Inter-American Observatory. The two-dimensional frames were corrected for flat field; the spectra were extracted, converted to a linear wavelength scale, reduced to absolute flux, and coadded. The AAT data were reduced in a similar manner using the Scanner Data Reduction System (Straede 1978). We note that no corrections for scattered light from the quasar have been applied to the spectroscopic data.

Figure 3 shows the 3900–4700 Å region of the ESO IPCS spectrum of 3C 273 and of the nebulosity 4″.5 to the north of the quasar. Table 2 summarizes the measurements of features visible in the nebulosity spectrum and absent or weaker in the quasar spectrum. As is evident from Figure 3 and Table 2, there are two narrow emission lines with observed positions at 4318 and 4478 Å which, at the redshift of 3C 273 ($z = 0.158$), correspond to two of the most prominent emission lines also observed in the nebulosity associated with the

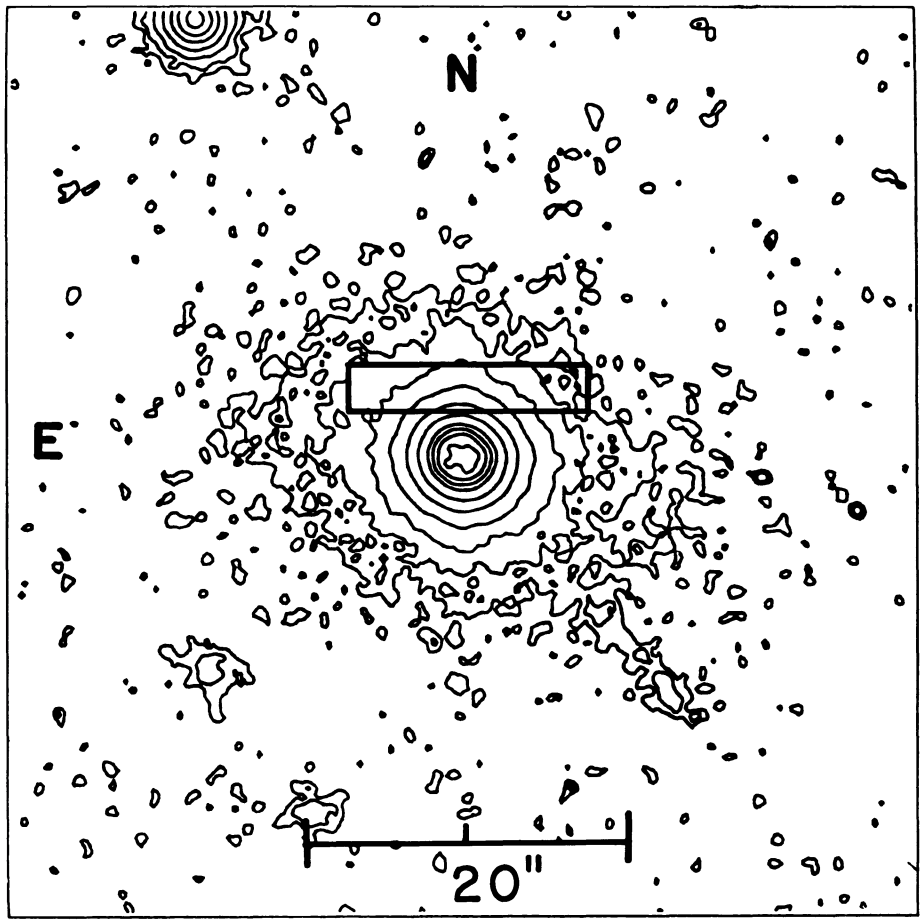


FIG. 1.—Logarithmic isophotal map (5700–6900 Å) of 3C 273. The lowest contour level is 5% the night sky ($\mu_R \approx 25$ mag arcsec$^{-2}$). The intervals between contour levels $\Delta \log I = 0.36$. The jet extends ~22″ to the southwest of the quasar. Outer isophotes to the northeast show a marked asymmetry. The rectangular entrance aperture of the ESO IPCS slit is shown 4″.5 to the north of the quasar. The sky was monitored with an equivalent aperture centered alternately (chopping cycle time ~16 minutes) at positions 15″ east and west of position shown.

quasar 4C 37.43 (Stockton 1976), namely, [O II] and [Ne III]. We note that the [O II] line is *absent* from the spectrum of 3C 273; and the [Ne III] line is much weaker or absent from the quasar spectrum. The AAT spectra of the nebulosity also indicate the presence of a narrow emission feature at the rest position ~3727 Å. The other prominent line observed in spectra of quasar nebulosities is [O III] 5007 Å (Wampler *et al.* 1975; Stockton 1976). This line is probably also present in our spectra of the nebulosity, though it is blended with the quasar 5007 Å line. Table 3 gives the observed [O III]/Hβ line intensity ratios measured in the quasar and the nebulosity, for both the AAT and ESO spectra. From the line ratios in Table 3, it is clear that the [O III]/Hβ ratio is 40–50% larger in the nebulosity to the north of 3C 273 than in the quasar.

Thus the spectra establish a physical association of an extended gaseous region with 3C 273.

## III. DISCUSSION

The photographic data (Figs. 1 and 2) and the spectra (Fig. 3, Tables 2 and 3) establish conclusively the existence of extended nebulosity associated with 3C 273. The emission lines present in the spectrum of the nebulosity indicate the presence of a low-density hot gas at a projected distance ~4″.5 (~15 kpc) from the quasar. ($H_0 = 75$ km s$^{-1}$ Mpc$^{-1}$, $q_0 = +1$, assumed hereafter.)

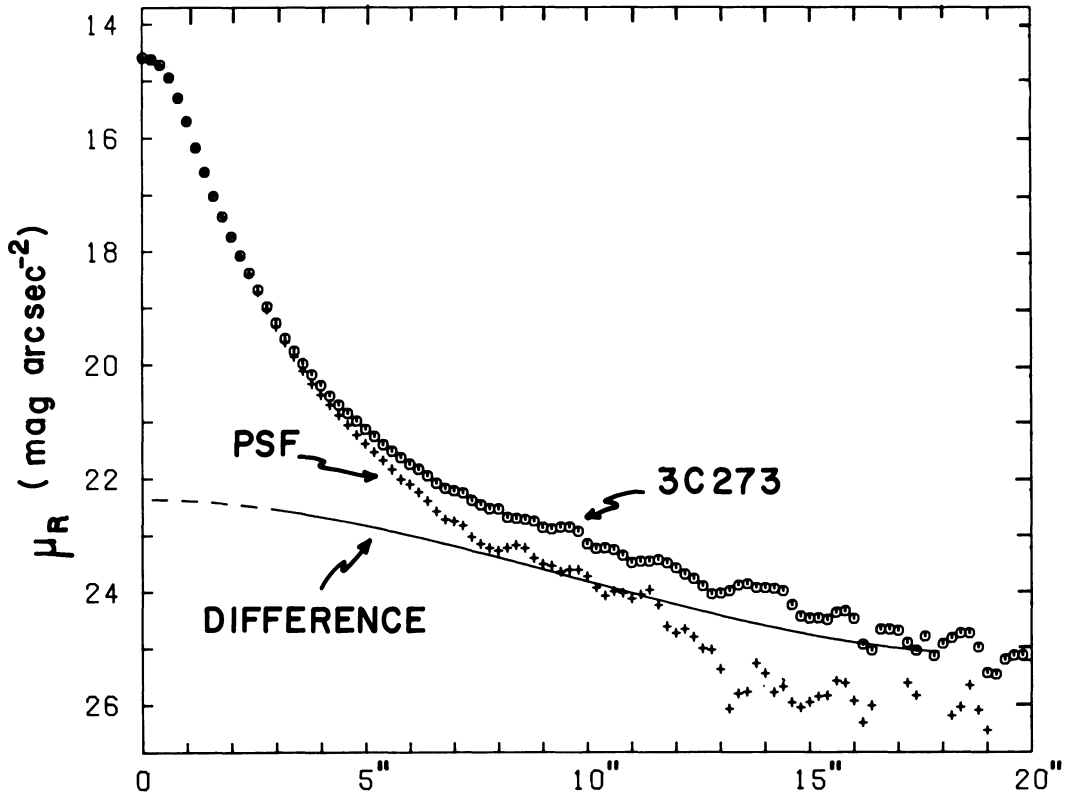


FIG. 2.—Image profiles (average surface brightness vs. radial distance from image center) of 3C 273 (jet removed) and the point-spread function (PSF). Surface brightness calibrated assuming quasar $V = 12.8$ and $V - R = 0$. Seeing diameter (PSF FWHM) = 1″.6. Broader profile for 3C 273 indicates quasar image resolved. *Solid line:* fifth-order polynomial fit to the difference profile (3C 273–PSF) of resolved structure. *Dashed line:* extrapolation for $0 \leq r \leq 3$ arc seconds.

TABLE 1

SUMMARY OF IPCS OBSERVATIONS

| Telescope | Date | Integration (*h*) | Spectral Range (Å) | Entrance Aperture (″) | Offset from 3C 273 Δα (″) | Offset from 3C 273 Δδ (″) | Resolution[a] |
|---|---|---|---|---|---|---|---|
| AAO..... | 1980 Feb. 14 | 1.7 | 3500–7100 | 3 | +6.7<br>+3.5 | +3.4<br>+3.5 | 4.5/2.7 |
| ESO..... | 1980 Mar. 14 | 1.8 | 3500–7000 | 3×12 | 0 | +4.5 | 2.3/2.1 |

[a] Ratio of spectral resolution to spatial resolution in angstroms per channel and arc seconds per pixel, respectively.

The relative contributions of continuum and emission-line radiation to the observed nebulosity can be estimated from the present data. The photographic bandpass was 5700–6900 Å. The spectra of the nebulosity ~15 kpc north of the quasar indicate that [O III] 5007 Å (5798 Å observed) is the strongest emission line in the spectral range. If the nebulosity is entirely line emission due to [O III] 5007 Å, then, assuming [O II]/[O III] ≈ 0.3 (average of 3C 48 and 4C 37.43 nebulosity line ratios), we would expect the surface brightness 4″.5 north of the quasar to measure, $S(5007\ \text{Å}) \approx 6.0 \times 10^{-17}$ ergs cm$^{-2}$ s$^{-1}$ arcsec$^{-2}$. From the isophotal map (Fig. 1), we estimate the average surface brightness of the nebulosity in the IPCS aperture to be $\mu_R = 23.0 \pm 0.5$ mag arcsec$^{-2}$ which corresponds to $S(5700\text{–}6900\ \text{Å}) \approx 2.1\ (-0.8, +1.2) \times 10^{-15}$ ergs cm$^{-2}$ s$^{-1}$ arcsec$^{-2}$. Thus the estimated [O III] 5007 Å surface brightness fails by approximately a factor of 30 to account entirely for the nebulosity. This implies that the dominant radiation (5700–6900 Å) in the nebulosity to the north of 3C 273 is continuum.

It is noteworthy that the average surface brightness of the nebulosity, $\mu_R \approx 23$ mag arcsec$^{-2}$, and the angular extent (diameter ≈ 90 kpc) are characteristic of a

TABLE 2

OBSERVED[a] EMISSION-LINE FLUXES AND LUMINOSITIES FOR NEBULOSITY NORTH (4″.5) OF 3C 273

| LINE | LAB. λ (Å) | OBS. λ (Å) | $z$ | FWHM Δλ (Å) | $W_\lambda$ (Å) | FLUX ($10^{-15}$ ergs cm$^{-2}$ s$^{-1}$) | $L$(rest)[b] ($10^{41}$ ergs s$^{-1}$) | FLUX ($10^{-15}$ ergs cm$^{-2}$ s$^{-1}$) 3C 48[c] | FLUX ($10^{-15}$ ergs cm$^{-2}$ s$^{-1}$) 4C 37.43[d] | $L$(rest)[b] ($10^{41}$ ergs s$^{-1}$) 3C 48[c] | $L$(rest)[b] ($10^{41}$ ergs s$^{-1}$) 4C 37.43[d] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| [O II]..... | 3727.0 | 4317.9 | 0.1585±0.0005 | <15 | 2.4 | 0.65 | 0.25 | 0.44 | 1.30 | 0.8 | 2.4 |
| [Ne III]... | 3868.7 | 4478.4: | 0.1576±0.0005 | <15 | 1.2: | 0.35: | 0.14: | ... | 0.39 | ... | 0.7 |
| [O III].... | 5006.8 | 5790.0*bl*: | ... | ... | ... | ... | ... | 1.04 | 8.43 | 1.9 | 15.2 |

[a] Uncorrected for scattered light.

[b] $H_0 = 75$ km s$^{-1}$ Mpc$^{-1}$, $q_0 = +1$.

[c] Wampler *et al.* 1975.

[d] Stockton 1976.

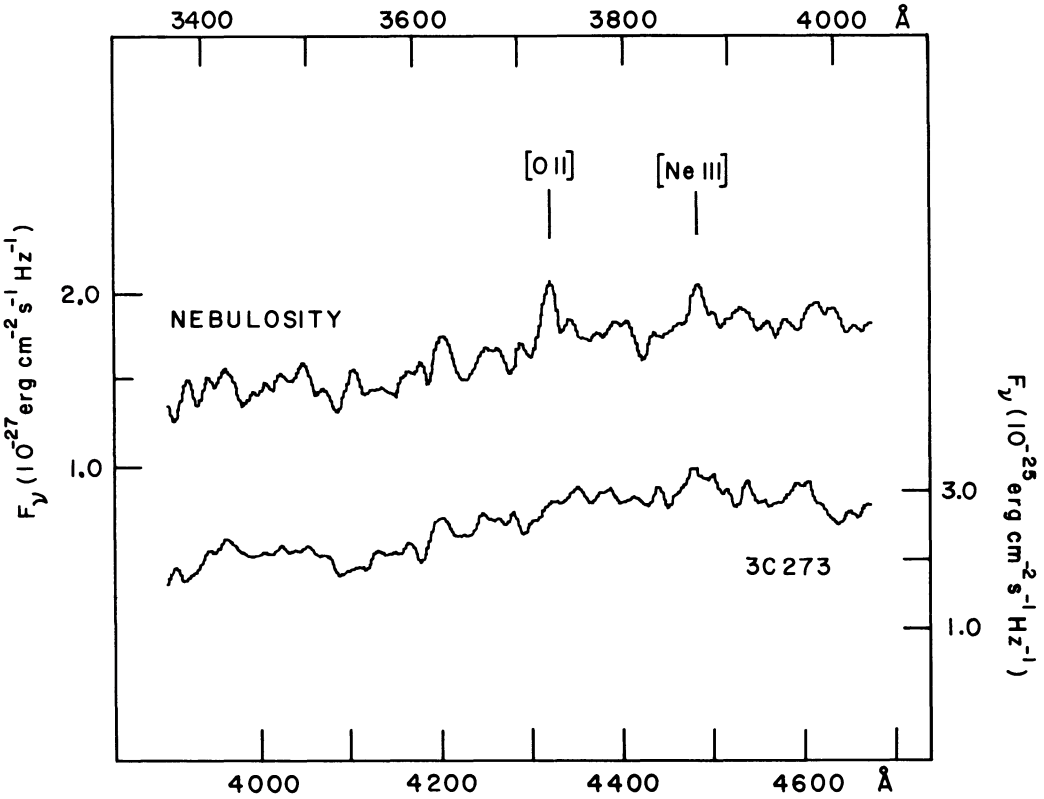


FIG. 3.—IPCS spectra of the nebulosity 4″.5 north of 3C 273 and centered on the quasar. Narrow emission-line features in the nebulosity and not in quasar are identified. Wavelength scales: (*bottom*) observed frame; (*top*) rest frame.

galaxy with $z = 0.158$. Moreover, the integrated magnitude of the nebulosity surrounding the quasar is measured to be $R \approx 16$, or $M_R \approx -25$, which, if dominantly galactic in nature, corresponds to a luminous galaxy (Kristian, Sandage, and Westphal 1978). The difference in magnitude between the quasar and the surrounding nebulosity is $\sim$3.5 mag, a value found for previously resolved quasars shown to be seated in galaxies (cf. Stockton, Wyckoff, and Wehinger 1979; Wyckoff *et al.* 1980). Although the nature and amount of the continuum contribution to the observed nebulosity have not yet been determined, the surface brightness, integrated magnitude, and size make plausible an interpretation of the extended nebulosity as a galactic component associated with 3C 273.

TABLE 3

OBSERVED EMISSION-LINE INTENSITY RATIOS[a]

| | $\frac{I[\text{O III}]\ 5007\ \text{Å}}{I(\text{H}\beta)\ 4861\ \text{Å}}$ | |
|---|---|---|
| TELESCOPE | 3C 273 | Nebulosity |
| AAT..... | 0.49 | 0.68 |
| ESO..... | 0.41 | 0.61 |

[a] Uncorrected for scattered light.

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